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ARTI REFRIGERANT DATABASE:
ARCHIVAL AND HISTORICAL CITATIONS

September 1999

prepared by

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INTRODUCTION

This report provides citations and summaries from the *ARTI Refrigerant Database* from the *Archival and Historical Citations* file. It is one of a series prepared to provide a record of the database entries in printed form.

Purpose

The Refrigerant Database is an information system on alternative refrigerants, associated lubricants, and their use in air conditioning and refrigeration. It consolidates and facilitates access to property, compatibility, environmental, safety, application and other information. It provides corresponding information on older refrigerants, to assist manufacturers and those using alternative refrigerants, to make comparisons and determine differences. The underlying purpose is to accelerate phase out of chemical compounds of environmental concern.

Contents

The database provides bibliographic citations and abstracts for publications that may be useful in research and design of air-conditioning and refrigeration equipment. The complete documents are not included, though some may be added at a later date.

The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-414A, R-414B, R-415A, R-416A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available even though standard designations may not have been assigned yet. It addresses lubricants including alkylbenzene, polyalkylene glycol, polyolester, and other synthetics as well as mineral oils. It also references documents addressing compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits.

Incomplete citations or abstracts are provided for some documents. They are included to accelerate availability of the information and will be completed or replaced in future updates.

Limitations

The Refrigerant Database is intended as a means to assist users in locating sources of information on alternative refrigerants. But, the database is:

- neither a comprehensive nor authoritative reference source,
- not a substitute for independent data collection by users,
- not a substitute for examination of the data, information on how they were arrived at, assumptions, and caveats in the cited documents, and
- not an endorsement of suitability or accuracy of referenced publications.

Materials compatibility, properties, safety considerations, and other characteristics affecting suitability or desirability may be influenced by a number of factors. Among them are specific application conditions, preparation such as drying before use, additives including fillers, impurities, catalytic interactions with other materials used, and changes in compounding between one source or batch and another. Similarly, new findings or corrections may supersede previously published data. The database is an aid in locating data that may be pertinent; it is not and should not be viewed as the source of data for research, design, analysis, or other purposes.

Database Form

The database is available in both computerized ("electronic") and report ("manual" or "listing") versions.

Computerized Version

The computerized version includes both data summaries and bibliographic citations organized into a number of segments ("files"). These segments can be searched individually or together, in any combination.

The computerized database provides 606 specially-prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. The refrigerant profiles cover designations, common uses, chemical and trade names, other identifiers, molecular mass, critical properties (pressure, temperature, specific volume, and density at the critical point), physical and thermophysical properties for selected conditions, safety classifications, toxicity and flammability data, exposure limits, atmospheric lifetime, ozone depletion potential, global warming potential, halogen global warming potential, commercialization, phaseout, and other data.

The computerized version also provides more than 6,100 citations. They are organized into a primary file that includes recently added and key references, a supplement on copper in air

Distribution of the Refrigerant Database

	computerized (diskette)	report (listing)	documents (copies)
data summaries			
• refrigerant profiles	yes	no	[a]
• compatibility	yes	no	[a]
• toxicity	yes	no	[a]
bibliographic citations and synopses (detailed abstracts)			
• recently added and key	yes	yes	[a]
• copper supplement [b]	yes	[b]	[a]
• archival and historical	yes	no	[a]
search and retrieval software	yes [c]	no	no
additions and changes flagged	no	yes	no
distributed on cost-recovery basis			
• subscription (periodic updates)	yes	yes	no
• as ordered	no	yes	yes [d]

[a] Data summaries, citations, and synopses may be printed with the computerized version.

[b] The Copper Development Association (CDA) sponsored supplement provides additional citations and synopses, most of which address compatibility with or use of copper in air-conditioning and refrigeration systems. The supplement is included and searchable with the computerized version, but published as a separate report.

[c] Use of the search and retrieval software is subject to acceptance of the license agreement for it; both accompany the computerized version.

[d] Distribution is limited to documents in the public domain or for which authorization has been obtained. Others may be ordered from their publishers, which are identified in the bibliographic citations.

conditioning and refrigeration, and an archival group covering historical and superseded documents.

The search and retrieval software provided with the computerized version enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify use. They include optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. The program also allows printing of selected portions of the database. Printing the entire database would yield more than 8,000 pages, so a printed version is available for those who prefer to use the database manually.

Report Version

A listing of the recent and key citations is provided in report form. The citations are grouped under the primary or first subject addressed; they are not cross-referenced under other topics. The computerized version, therefore, is better suited to search for information by subject.

Citations and summaries from the supplement on copper in air conditioning and refrigeration are published separately. They also are arranged by subject.

Archival and historic citations are included in a third report. They are presented in reverse chronological order, beginning with the most recent. These citations remain accessible through the computerized version.

Documents

The database also includes a collection of published and unpublished documents, copies of which can be ordered individually. Approximately one third of the documents cited in the database are included in this collection. They include documents that are not protected by copyright or proprietary restrictions. They also include documents for which the authors or copyright owners granted permission for reproduction and distribution. The remainder can be obtained from their publishers, libraries, and other sources (see page 6).

Ordering Information

The computerized version of the database and the report version for recently added and key references can be ordered along with a subscription for updates. The report versions of the copper supplement and the archival citations report are available as separate documents distributed through the database.

An order form for the Refrigerant Database, which indicates the pricing, accepted methods of payment, and applicable terms and conditions, may be downloaded from the Internet from *http://www.arti-21cr.org/db/qa.html*. Alternatively, a copy may be obtained by mail or fax by calling +1-703/524-8800 or faxing +1-703/522-2349. Questions should be sent by email to *database@spectrum-internet.com.* Please note that the same form may be used to obtain the computerized database and remaining scheduled updates, the report version and remaining scheduled updates for primary and key references, and database documents by completing the corresponding portions of the form.

Additions

Future updates and expansions to the database are planned. Please help in making it more useful, and facilitating use of alternative refrigerants, by submitting the following:

- corrections to errors identified in the database,
- copies of helpful papers - whether your own or written by others - for citation, and
- suggestions for improving the database.

Authors or those holding rights to published or unpublished works pertinent to the database are invited - and encouraged - to authorize their reproduction and unrestricted distribution through the database. Product literature normally is not included, but studies providing relevant information, whether on proprietary or generic substances, will be considered.

Please send your inputs to:

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Thank you for your help with and use of the database. Its objective is to accelerate phase out of chemical compounds of environmental concern by sharing the information needed to do so.

Obtaining Documents

Documents indicated as *available from JMC* in their citations are available through the database. An order form, which indicates the pricing, accepted methods of payment, and applicable terms and conditions, may be downloaded from the Internet from *http://www.arti-21cr.org/db/qa.html*. Alternatively, a copy may be obtained by mail or fax by calling +1-703/524-8800 or faxing +1-703/522-2349. Questions should be sent by e-mail to *database@spectrum-internet.com*.

Other documents should be ordered from their publishers or alternative sources as identified in the database. Many of these documents also may be obtained from libraries. An effort will be made to secure permission for JMC to distribute additional documents, to facilitate access to them, but compliance with copyright provisions precludes doing so until appropriate arrangements are made. Reports from national laboratories and the Gas Research Institute may be ordered from the NTIS; most other publications from the U.S. Government may be obtained from the GPO. Addresses for several alternative sources follow:

ACGIH	American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Suite 600, Cincinnati, OH 45240 USA; phone +1-513/742-2020, fax +1-513/742-3355, e-mail acgih_pubs@pol.com.org
AIHA	American Industrial Hygiene Association, 2700 Prosperity Avenue, Suite 250, Fairfax, VA 22031 USA; phone +1-703/849-8888, fax +1-703/207-3561; http://www.aiha.org
ARI	Air-Conditioning and Refrigeration Institute, 4301 North Fairfax Drive, Suite 425, Arlington, VA 22203 USA; phone +1-703/524-8800, fax +1-703/528-3816; http://www.ari.org
ASHRAE	Publication Sales, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1791 Tullie Circle NE, Atlanta, GA 30329 USA; phone +1-404/636-8400, fax +1-404/321-5478, e-mail orders@ashrae.org
CAS	Chemical Abstracts Service, Document Delivery Department, Post Office Box 3012, Columbus, OH 43210-0012 USA; phone + 1-614/447-3670 x2956 (from USA 800/848-6538), fax + 1-614/447-3648
EHIS	Environmental Health Information Service, OCR Subscription Services Incorporated, Post Office Box 12510, Research Triangle Park, NC 27709-2510 USA; phone +1-919/541-3841, fax +1-919/541-0273, e-mail: ehis@niehsnih.gov
EPRI	EPRI Distribution Center, 207 Coggins Drive, Post Office Box 23205, Pleasant Hill, CA 94523 USA; phone+ 1-510/934-4212
GPO	Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 USA; phone + 1-202/512-1800
IIR / IIF	Institut International du Froid, 177, Boulevard Malesherbes, F-75017 Paris, France; phone +33-1 / 42.27.32.35, fax +33-1 / 47.63.17.98, e-mail iifiir@ibm.net
JAR	Japanese Association of Refrigeration, Nippon Reito Kyokai, 4th Floor, San-ei Building, 8 San-ei-cho, Shinjuku-ku, Tokyo 160, Japan; phone +81-3/3359-5231, fax +81-3/3359-5233
JMC	James M. Calm, Engineering Consultant, 10887 Woodleaf Lane, Great Falls, VA 22066-3003 USA, fax+ 1-703/450-4313, e-mail database@spectrum-internet.com
JSRAE	Japan Society of Refrigerating and Air Conditioning Engineers, Sanei Building, 8 Sanei-cho, Shinjuku-ku, Tokyo 160-0008, Japan; phone +81-3/3359-5231, fax +81-3/3359-5233
LHL	Linda Hall Library of Science, Engineering, and Technology, 5109 Cherry Street, Kansas City, MO 64110-2498 USA; phone + 1-816/363-4600, fax + 1-816/926-8785, e-mail requests@lhl.lib.mo.us
NTIS	National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161 USA; phone +1-703/487-4780
SAE	Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096-0001 USA

REFRIGERANT DATABASE - CITATIONS AND ABSTRACTS

1999

December 1999

November 1999

October 1999

September 1999

August 1999

July 1999

June1999

May 1999

Aril 1999

March 1999

February 1999

January 1999

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-100, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1999 (462 pages with 1 table, available from JMC as RDB9134)

This document provides bibliographic citations for 3227 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-414A, R-414B, R-415A, R-416A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 5800 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes 592 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews

please see page 6 for ordering information

for refrigerants. More than 8,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

1999 (month not indicated)

1998

December 1998

November 1998

October 1998

J. M. Calm (Engineering Consultant), **Property, Safety, and Environmental Data for Alternative Refrigerants,** *The Earth Technologies Forum* (proceedings, Washington, DC, 26-28 October 1998), Alliance for Responsible Atmospheric Policy, Arlington, VA, 192-205, October 1998; republished as report DOE/CE/23810-101, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1998 (14/18 pages with 2 tables, available from JMC as RDB8B16)

This paper presents tabular summaries of selected physical, safety, and environmental (atmospheric lifetime, ozone depletion potential, ODP, global warming potential, GWP) data for alternative and candidate refrigerants along with comparative information for those that have been or are being replaced. The alternatives include both those in commercial production or development and a number that are still being evaluated, such as hydrofluoroethers and fluorinated amines. The two tables, one sorted by designation and the other by normal boiling point (NBP), provide data in both metric (SI) and inch-pound (IP) units for a total of 186 compounds and blends. The paper also describes a large database, consisting of refrigerant profiles, compatibility and toxicity data summaries, and bibliographic references. This database offers a means to locate thermodynamic and transport property, compatibility, performance, safety (flammability and toxicity), environmental, and other data on alternative refrigerants. It also addresses associated lubricants, retrofit procedures and experience, as well as test and analysis methods to qualify refrigerants and refrigerant-lubricant combinations. The paper describes the refrigerant profiles, which encompass more than 200 parameters, depending on the information available for individual refrigerants, for nearly 500 single compound refrigerants and blends.

September 1998

August 1998

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-96A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, August 1998 (472 pages with 1 table, available from JMC as RDB8850)

This document provides bibliographic citations for 3324 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-414A, R-414B, R -415A, R-416A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 4800 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes 580 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 8,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

July 1998

June 1998

May 1998

April 1998

March 1998

J. M. Calm (Engineering Consultant), **Refrigerant Database,** report DOE/CE/23810-91A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 March 1998 (472 pages with 1 table, available from JMC as RDB8345)

This document provides bibliographic citations for 3270 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-414A, R-414B, R-415A, R-416A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 4800 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes more than 550 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 6,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

February 1998

L. Zipfel (Solvay Fluor und Derivate GmbH, Germany), W. Krücke (Solvay, Germany), P. Dournel (Solvay Research and Technology, Belgium), K. Börner (Solvay, Germany), and P. Barthélemy (Solvay, Germany), **HFC-365mfc, HFC-246fa, and**

please see page 6 for ordering information

New Blends Promising HFC Blowing Agent Options, paper 5, *Blowing Agent Systems: Formulations and Processing* (seminar proceedings), Rapra Technology Limited, Shropshire, UK, 19 February 1998 (7 pages with 4 figures and 5 tables, RDB8808)

status of and data for R-245fa, R-365mfc, and azeotropes of R-365mfc with R-134a, R-227ea, n-pentane, isopentane, and cyclopentane, namely R-134a/365mfc (13/87), R-227ea/365mfc (7/93), R-601/365mfc (41.6/58.4), R-601a/365mfc (54.3/-45.7), and R-cyclopentane/365mfc (27.5/72.5), respectively; R-245fa and R-365mfc also are candidate refrigerants; comparative physical properties, thermal conductivity, safety and handling, characteristics as blowing agents

Heat Transfer and Pressure Drop in the Dry-Out Region of In-Tube Evaporation with Refrigerant-Lubricant Mixtures, research project 800-RP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1993 - February 1998 (ASH0800)

This research examined heat transfer in the final stage of in-tube evaporation, where the annular liquid film thins and dries out. The work was initiated to formulate a generalized heat transfer coefficient in this dry-out region, where significant area is required to achieve desired levels of superheating. Unusual behavior or refrigerant-lubricant mixtures also may occur in this region. Measurements of heat transfer and pressure drop were expected in both smooth and enhanced tubes with R-22 and R-134a, or an appropriate alternative, as a function of lubricant content. Tests were planned for mixtures containing 0, 1, 2, 3, and 5% lubricant, for conditions determined through a literature search and examination of the energy transfer process in qualities exceeding 90%. The contractor for the project was the École Polytechnique Fédérale de Lausanne (ÉPFL), Ecublens, Switzerland, led by J. R. Thome; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

January 1998

1998 (month not indicated)

1998 Threshold Limit Values for Chemical Substances in the Work Environment, *1998 TLVs® and BEIs®: Threshold Limit Values for Chemical Substances and Physical Agents; Biological Exposure Indices,* American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1-89 and notes, 1998 (89 of 192 pages with 5 tables and 4 appendices; 1 page errata; available from ACGIH for $22.50, RDB8810)

This book provides data for use as guidelines or recommendations in the control of potential health hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). The document indicates the molecular weights and bases or critical effects underlying the adopted TLV concentrations. Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document flags TLVs and other data for compounds included in the Notice of Intended Changes (NIC), to flag data for which future revision has been proposed. It also provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter. The refrigerants addressed include R-11, R-12, R-13B1, R-20, R-21, R-22, R-30, R-40, R-113, R-114, R-115, R-160, R-160B1, R-170 (ethane), R-290 (propane), R-600 (butane), R-601 (pentane), R-610, R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-1150, R-1270, R-7146 (sulfur hexafluoride), and others. A TLV concentrations has been added for R-290 (propane), previously deemed a simple asphyxiant. Changes are proposed for R-1130a, R-1132a, R-1140, R-1140B1, R-1141, and others. R-20B1, R-20B3, R-30, R-30B1, R-150, R-160B1, R-746, R-748, R-764, R-1216, and others are identified as chemical substances under study.

Test Method for Inorganic Acid Removal Capacity of Desiccants Used in Liquid Line Filter Driers, proposed research project 793-RP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1994 - February 1996, extended to 1998 (ASH0793)

This research will develop a method of testing desiccants, at liquid-line conditions, for inorganic acid removal capacity from circulating refrigerant. It then will demonstrate the consistency of the method with different desiccants and refrigerants. UOP molecular sieve 4AX-H6 (8x12), Rhône-Poulenc activated alumina grade A (3-5 mm), and Davison Chemical silica gel grade 407 (8-20 mesh) will be tested. It also will determine the solubility of hydrochloric acid (HCl) in R-12 and R-22 at specified temperatures. The work is needed to assist component manufacturers in design of filter driers with maximum performance. The need is heightened by increased refrigerant recycling and recovery. The contractor for the project is Imagination Resources, Incorporated (IRI), led by R. C. Cavestri; it is sponsored by Technical Committee 3.3, *Contaminant Control in Refrigeration Systems.*

1997

December 1997

J. M. Calm (Engineering Consultant), **Refrigerant Database,** report DOE/CE/23810-90A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 December 1997 (474 pages with 1 table, available from JMC as RDB7C10)

This document provides bibliographic citations for more than 3300 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-414A, R-414B, R-415A, R-416A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 4800 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes more than 500 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 6,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

November 1997

J. J. Byrne, M. W. Abel, and A. M. Gbur (Integral Sciences, Incorporated, ISI), **Methods Development for Organic Contaminant Determination in Fluorocarbon Refrigerant Azeotropes and Blends**, replaced version of report DOE/CE/23810-85, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 30 November 1997 (158 pages with 34 figures and 35 tables, RDB7C07)

Report presents new gas chromatography (GC) methods to determine the organic purity of zeotropic and azeotropic refrigerants. Appendices patterned after those in ARI Standard 700 Appendix 95 identify columns, chromatographic conditions, and methods to determine both the composition and purity of covered blends. They address those in the 401, 402, 404, 405, 406, 407, 408, 409, 410, 411, 412, 500, 502, 503, 507, 508, and 509 refrigerant series following the designations assigned in ANSI/ASHRAE Standard 34. They include R-401A, R-401B, R-401C, R-402A, R-402B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-500, R-502, R-503, R-507A, R-508A, and R-509A. The new methods are applicable to both new and reclaimed refrigerants. The report identifies procedural improvements, clarifications, limitations, and recommendations for future additions. [This report was replaced with a

please see page 6 for ordering information

corrected version and is no longer available; see RDB8505 for replacement.]

X. Ma, G. Du, and J. Shang (Hangzhou First Chemical Company Limited, China), **Evaluation of First-12 in Replacing CFC-12 in Refrigerator-Freezers,** *Proceedings of the International Conference on Ozone Protection Technologies* (Baltimore, MD, 12-13 November 1997), Alliance for Responsible Atmospheric Policy, Arlington, VA, 92-95, November 1997 (4 pages with 6 figures and 1 table, RDB8331)

near-azeotropic blend of R-22/152a as a replacement for R-12 in refrigerator-freezers: claims 5-10% improvement in efficiency and 20-30% reduction in charge amount

October 1997

J. G. Crawford (The Trane Company), **Heat Pump Technology on the Horizon**, *Refrigerants for the 21st Century* (proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 6-7 October 1997), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 104-110, 1997 (7 pages with 3 tables, RDB7B12)

reviews factors driving the forecast of technologies for heat pumps: the factors specifically addressed are the functions of a heat pump, diversity of demand, energy sources, thermal source and sink, heat pumping process, compression mechanisms, thermal distribution subsystem, efficiency trajectory, frosting, and refrigerant selection; concludes that vapor-compression systems will remain dominant due to intrinsic efficiency advantages, but that absorption cycle use and water-source will increase for some applications; screw and scroll compressor penetration will increase while rolling-piston rotary compressors may lose market share; R-22 will remain the dominant refrigerant for several years and then be replaced by hydrofluorocarbon (HFC) blends as R-22 is phased out; an appendix examines the suitability of evaporative cooling as a not-in-kind (NIK) with a conclusion that comfort cannot be maintained for many common conditions; a second appendix examines use of absorption chillers to replace electric-driven vapor-compression systems; it finds that absorption may be economically attractive, but will not reduce global warming

H. König (Solvay Fluor und Derivate GmbH, Germany), **Technical and Cost Comparisons of Refrigeration Cycles (R22 - R407C - R410A - Propane)**, *R22 Substitution - Reality or Wishful Thinking* (ASERCOM Symposium, IKK, Essen, 8 October 1997), reprints available from Solvay Fluor und Derivate GmbH, Hannover, Germany, October 1997 (19 pages with 5 figures and 3 tables, RDB8C05)

discusses theoretical and experimental differences between R-290 (propane), R-407C, and R-410A as replacements for R-22; compares their thermodynamic performance in optimized cycles and capacities in typical cycles; tabulates the phaseout schedule for R-22 in Europe by country; compares the costs of equipment designed for the three replacements; concludes that no alternative offers the technical advantages of R-22; projects that both R-407C and R-410A will be used as replacements and that R-410A will be the primary candidate

H. König (Solvay Fluor und Derivate GmbH, Germany), **Comparison of R410A, R407C and Propane in Heat Pump Applications,** *Heat Pump Systems, Energy Efficiency and Global Warming* (proceedings of the IIR conference, Linz, Austria, 28 September - 1 October 1997), publication 1997/4, International Institute of Refrigeration (IIR), Paris, France, 94-104, 1997 (11 pages with 3 figures, RDB8C06)

discusses theoretical and experimental differences between R-290 (propane), R-407C, and R-410A as replacements for R-22; compares their thermodynamic performance in optimized cycles and capacities in typical cycles; concludes that no alternative offers the technical advantages of R-22; projects that both R-407C and R-410A will be used as replacements and that R-410A will be the primary candidate

Emissions of Greenhouse Gases in the United States, 1996, report DOE/EIA-0573(96), Energy Information Administration, U.S. Department of Energy, Washington, DC, October 1997 (158 pages with 18 figures and 60 tables, available from GPO as document 061-003-01008-3, limited copies available from JMC as RDB8501)

estimated emissions in the USA of carbon dioxide (R-744), methane (R-50), nitrous oxide (R-744A), halocarbons, sulfur hexafluoride (R-7146), criteria pollutants (carbon monoxide, nitrogen oxides, and nonmethane volatile organic compounds, VOCs), and other greenhouse gases: the halocarbons addressed include R-10 (carbon tetrachloride), R-11, R-12, R-12B1 (halon 1211), R-13B1 (halon 1301), R-14, R-20 (chloroform), R-22, R-23, R-30 (methylene chloride), R-113, R-114, R-115, R-116, R-123, R-124, R-125, R-134a, R-140a (methyl chloroform), R-141b, R-142b, R-143a, R-152a, R-227ea, and R-31-10; the halocarbon data are presented individually and collectively for the bromofluorocarbon (BFC, halon), chlorofluorocarbon (CFC), hydrochlorofluorocarbons (HCFC), hydrofluorocarbons (HFC), perfluorocarbon (PFC) groups; depending on the substance, data cover the period from 1989 through 1996; estimated emissions are from all uses - refrigerant components are a small fraction of the total; report identifies the data sources, conversion methods, and limitations

September 1997

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-89A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 September 1997 (482 pages with 1 table, available from JMC as RDB7950)

This document provides bibliographic citations for more than 3400 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-414A, R-414B, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 4800 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes more than 500 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 6,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

August 1997

July 1997

M. N. Sarevski, **Influence of the New Refrigerant Thermodynamic Properties on Some Refrigerating Turbocompressor Characteristics**, *Fuel and Energy Abstracts*, 38(4):260, July 1997 (1 page, rdb8C31)

consideration of properties in centrifugal compressor design

June 1997

May 1997

J. M. Calm (Engineering Consultant), **Copper in Air Conditioning and Refrigeration - Supplement to the ARTI Refrigerant Database**, report JMC/-ARTI/CDA-9705D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, and the Copper Development Association (CDA), New York, NY, May 1997 (88 pages with no figures or tables, available from JMC as RDB7522)

This document provides bibliographic citations for more than 450 publications that may be useful in research, design, and application of air-conditioning and refrigeration (ACR) equipment. Summaries or brief descriptors of the content, materials addressed, and key conclusions are provided for the majority. This supplement to the ARTI Refrigerant Database increases the information provided, by focusing on the suitability of and application data for copper and copper alloys with refrigerants. The

please see page 6 for ordering information

key concentration areas are application data, compatibility, and heat transfer (including surface enhancement). An introduction outlines the reasons copper is the preferred fabrication material in many ACR components. It cites the metal's superior heat transfer properties, corrosion resistance, ease of fabrication and joining, strength, and machinability. It also notes the latitude afforded by copper, brass, bronze, and other alloys in manufacturing processes such as casting, forging, machining, drawing, sintering, and forming. A concluding section provides descriptions of both the Refrigerant Database and the Copper Data Center (CDC) database.

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-86A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, May 1997 (452 pages with 1 table, available from JMC as RDB7561)

This document provides bibliographic citations for more than 3200 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-414A, R-414B, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 4600 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes approximately 500 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 6,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

T. B. Coplen (U.S. Geological Survey, USGS), **Atomic Weights of the Elements 1995**, *Journal of Physical and Chemical Reference Data*, 26(5):-1231-1253, May 1997 (23 pages, RDB7B48)

definitive atomic weights used to calculate the molecular mass of refrigerants

April 1997

March 1997

February 1997

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-83A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, February 1997 (452 pages with 1 table, available from JMC as RDB72A9)

This document provides bibliographic citations for more than 3200 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A,

R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-414A, R-414B, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 4400 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes 479 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 5,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

Addenda to Number Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34a-o, 34q-z, 34ab, and 34ae (Addenda to ANSI/ASHRAE 34-1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1997 (18 pages with 3 tables, available from ASHRAE, RDB8602) [first distributed June 1998]

This cumulative addendum combines addenda a through o, q through z, 34ab, and 34ae as well as errata sheet number 1 to ANSI/ASHRAE Standard 34-1992. The errata correct a conversion error in the metric units for flammability classifications. The addenda provide a designation distinction for zeotropic blends having the same components in different proportions, expand the applicability of dual classifications (as formulated and worst case of fractionation) to azeotropes, and add new definitions. The last address acute toxicity, azeotropic temperature, cardiac sensitization, ceiling (as in exposure limits), chronic toxicity, committee (in the context of the standard), critical point, heat of combustion, LC_{50} (median lethal concentration), maximum temperature glide, ppm, permissible exposure level (PEL), short-term exposure limit (STEL), and Workplace Environmental Exposure Limit (WEEL). The addenda clarify that concentrations identified as "ppm" for safety classifications are "ppm by volume", expand the purpose, and provide detailed instructions for designation and classification applications. They also modify the designation system for miscellaneous organic compounds as well as inorganic compounds, provide uniform systems to number the carbon atoms in molecules and determine designations for fluoroethers, differentiate among azeotropic blends having the same components, and add a new reference. Composite tables remove the "provisional" notation previously appended to some safety classifications, correct a number of chemical names for consistency with the International Union of Pure and Applied Chemistry (IUPAC) conventions, correct informational (not part of the standard) data on refrigerants, and add safety classifications for R-23, R-32, R-116, R-124, R-125, R-143a, and R-218. The addenda also add designations, tolerances, and safety classifications for R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-507A, R-508A, R-508B, and R-509A. A subsequent addendum revises the tolerances for R-407A and R-407B. The addenda detail the submission requirements - including both content and copy quantities - to apply for designations and classifications of additional refrigerants. A foreword and table identify the changes by specific addendum.

Addenda to Number Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34a-o, 34q-z, and 34ab (Addenda to ANSI/ASHRAE 34-1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1997 (18 pages with 3 tables, available from ASHRAE, RDB7250) [distributed February 1997]

This cumulative addendum combines addenda a through o, addenda q through z, addenda 34ab, and errata sheet number 1 to ANSI/ASHRAE Standard 34-1992. The errata correct a conversion error in the metric units for flammability classifications. The addenda provide a designation distinction for zeotropic blends having the same components in different pro-

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portions, expand the applicability of dual classifications (as formulated and worst case of fractionation) to azeotropes, and add new definitions. The last address acute toxicity, azeotropic temperature, cardiac sensitization, ceiling (as in exposure limits), chronic toxicity, committee (in the context of the standard), critical point, heat of combustion, LC_{50} (median lethal concentration), maximum temperature glide, ppm, permissible exposure level (PEL), short-term exposure limit (STEL), and Workplace Environmental Exposure Limit (WEEL). The addenda clarify that concentrations identified as "ppm" for safety classifications are "ppm by volume", expand the purpose, and provide detailed instructions for designation and classification applications. They also modify the designation system for miscellaneous organic compounds as well as inorganic compounds, provide uniform systems to number the carbon atoms in molecules and determine designations for fluoroethers, differentiate among azeotropic blends having the same components, and add a new reference. Composite tables remove the "provisional" notation previously appended to some safety classifications, correct a number of chemical names for consistency with the International Union of Pure and Applied Chemistry (IUPAC) conventions, correct informational (not part of the standard) data on refrigerants, and add safety classifications for R-23, R-32, R-116, R-124, R-125, R-143a, and R-218. The addenda also add designations, tolerances, and safety classifications for R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-507A, R-508A, R-508B, and R-509A. A subsequent addendum revises the tolerances for R-407A and R-407B. The addenda detail the submission requirements to apply for designations and classifications of additional refrigerants. A foreword and table identify the changes by specific addendum.

January 1997

D. Y. Goswami, D. O. Shah, C. K. Jotshi, S. S. Bhagwat, M. Leung, and A. S. Gregory (University of Florida), **Foaming Characteristics of Refrigerant/Lubricant Mixtures**, seminar presentation (ASHRAE Winter Meeting, Philadelphia, PA, 25-29 January 1997), report DOE/CE/23810-82B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 29 January 1997 (38 pages with 29 charts, available from JMC as RDB7402)

A summary and presentation charts summarize the objectives, interim findings, and plans for an ongoing study of the foaming absorption and desorption rates for hydrofluorocarbon (HFC) refrigerants and polyolester (POE) lubricants and to define the characteristics of the foam formed following a pressure drop. The stated objectives are to define those characteristics, to determine the rate at which an HFC leaves solution with the POE after the pressure drop, and to determine the rate at which the POE reabsorbs the HFC refrigerant. The tests address and R-32, R-125, R-134a, R-143a, R-404A, R-407C, and R-410A with two ISO 68 POEs (Witco Suniso(R) SL68 and ICI Emkarate™ RL68H). Comparative tests are included for R-12 and R-22 with a naphthenic mineral oil (MO, Witco Suniso(R) 3GS and 4GS). The charts describe the apparatus and measurements; they also present the data obtained and interpretations for them. They note that R-32 and R-134a favored foaming while R-125, R-143a, and most of the blends did not, that pressure-release foaming yielded very little stability for the HFC-POE pairs, and that foaming only was observed for fast pressure drops, not for slow ones. The document concludes with plans for future work.

E. A. Groll (Purdue University), **Modeling of Absorption/Compression Cycles Using Working Pair Carbon Dioxide/Acetone**, paper PH-97-12-1, *Transactions* (Winter Meeting, Philadelphia, PA, 26-29 January 1997), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 103(1):863-872, 1997 (10 pages with 9 figures, RDB7C23)

R-744/acetone

Experimental Determination of Shell-Side Condenser Bundle Heat Transfer Design Factors for Refrigerants R-123 and R-134a, research project 676-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1991 - January 1997 (ASH0676)

This research determined the heat transfer coefficients (HTC) for R-123 and R-134a in condensers for the refrigerant-side (outside) of tubes. Limited, comparative measurements also were made for R-11 and R-12. Four or more different geometries for tube bundles, with at least two finned and two enhanced tubes types, were examined. Correlations or charts were developed for use in heat exchanger design. The contractor for the project was Iowa State University of Science and Technology led by M. B. Pate; it was sponsored by ASHRAE Technical Committee 8.5, *Liquid-to-Refrigerant Heat Exchangers.*

Fundamental Study of Refrigerant Line Transients, research project 736-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1993 - January 1997, extended to 1998 (ASH0736)

This research project examined causes and consequences of pressure transients, induced by condensation during hot-gas defrost, in refrigerant piping. The underlying goal was to develop means to prevent their occurrence, either by appropriate design or operation. The problem induces hydraulic shock and vapor-propelled liquid slugging. The work involved a literature search, documentation of critical flow regimes, and analysis of both condensation-induced hydraulic shock and vapor-propelled liquid slugs. The contractor was the University of Illinois, led by A. M. Jacobi; it was sponsored by ASHRAE Technical Committees 10.3, *Refrigerant Piping* and 10.1, *Engineered Refrigeration Systems*.

1997 (month not indicated)

H. Z. Abou-Ziyan, M. F. Ahmed, M. N. Metwally, and H. M. Abd El-Mameed, **Solar Assisted R22 and R134a Heat Pump Systems for Low-Temperature Applications,** *Applied Thermal Engineering*, 17(5):455-469, 1997 (15 pages, rdb8512)

regression fits of published properties for R-22, R-134a, and R-404A; comparative performance of R-134a and R-404A in a cascaded solar-assisted heat pump system

L. A. Weber and D. R. Defibaugh (National Institute of Standards and Technology, NIST), **Derivation of the Bubble Pressure Surface, P(x,T), of a Binary Mixture by Ebulliometry: The System $C_3H_3F_5$ + $C_4H_2F_8$**, *Journal of Chemical and Engineering Data*, 4(6):1187-1190, 1997 (4 pages with 3 figures and 4 tables, RDB8210)

R-245ca, R-338mcc (identified in the paper as R-338mccq), the azeotropic blend R-245ca/338mcc, calculated dew and bubble curves for 27-102 °C (80-215 °F) and pressures of 98-970 kPa (14-141 psia), thermodynamic properties, thermophysical data; the azeotropic composition of R-245ca/338mcc ranges from 56/44 to 79/21 for the temperature and pressure ranges indicated

L. Zipfel, W. Krücke, K. Börner, P. Barthélemy (Solvay Fluor und Derivate GmbH, Germany), and P. Dournel (Solvay Research and Technology, Belgium), **HFC-365mfc and HFC-245fa Progress in Application of New HFC Blowing Agents**, *Proceedings of the Polyurethanes World Congress 1997* (Amsterdam, the Netherlands), 176-184 plus 1 page errata, 1997 (10 pages with 10 figures and 7 tables, RDB8809)

status of and data for R-245fa and R-365mfc; comparative physical properties, thermal conductivity, fire resistance, toxicity, handling, characteristics as blowing agents, and experiences in trial uses

1997 Threshold Limit Values for Chemical Substances in the Work Environment, *1997 TLVs(R) and BEIs(R): Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1-53 and notes, 1997 (53 of 160 pages with 5 tables and 4 appendices, available from ACGIH for $15.00, RDB7A50)

This book provides data for use as guidelines or recommendations in the control of potential hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document flags TLVs and other data for compounds included in the Notice of Intended Changes (NIC), to flag data for which future revision has been proposed. It also provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter. The refrigerants addressed include R-11, R-12, R-13B1, R-20, R-21, R-22, R-30, R-40, R-113, R-114, R-115, R-160, R-160B1, R-170 (ethane), R-290 (propane), R-600 (butane), R-601 (pentane), R-610, R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-1150, R-1270, R-7146 (sulfur hexafluoride), and others. The TLV concentrations are changed for acetone, R-40B1 (methyl bromide), R-748 (ozone), and others in this revision; changes are proposed for R-112, R-1130a, and others. R-290 (propane), R-601 (n-pentane), mineral oil mist, and others remain in the NIC list as does R-748 with a revised TLV proposal. R-20B1, R-20B3, R-30, R-30B1, R-150, R-160B1, R-746, R-764, R-114, and others are identified as chemical substances under study.

Production, Sales and Atmospheric Release of Fluorocarbons through 1995, Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Washington, DC, 1997 (108 pages with 2

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figures and 41 tables, limited copies available from JMC as RDB7363)

R-11, R-12, R-22, R-113, R-114, R-115, R-134a, R-141b, R-142b, production and emission data

1996

December 1996

A. Sekiya (National Institute of Materials and Chemical Research, NIMC, Japan) and S. Misaki (Research Institute of Innovative Technology for the Earth, RITE, Japan), **A Continuing Search for New Refrigerants**, *ChemTech*, 26(12):44-48, December 1996 (5 pages with 2 figures and 7 tables, RDB8317)

properties of fluoroether (FE) and hydrofluoroether (HFE) candidates for refrigerant use; basic physical properties (normal boiling point, viscosity, density, surface tension, and thermal conductivity) and qualitative stability indications for R-E236fa1, R-E245fa1, R-E263fb1 (shown as R-E236ea1 in the paper), R-E338mcf2, two fluorinated amines ($CH^3CH^2N(CF^3)^2$ and $CH^2FCH^2N(CF^3)^2$), and two fluoro-oxysilanes ($CF^3CF^2CH^2OSi(CH^3)^3$, and $(CF^3)^2CHOSi(CH^3)^3$); tabular comparison of the normal boiling point and critical temperature, pressure, and specific volume of R-114, R-E134, R-E227ca1, R-E236fa1, R-E263fb2, R-E31-10mcc1, and R-E31-10mcc2; atmospheric lifetime and halocarbon global warming potential (HGWP) of R-11, R-E236ea1, R-E245fa1, R-E254cb1, R-E365mcf2, and four fluorinated amines; summary properties of the three hydrofluoroethers (HFEs) deemed to be the most promising, namely R-E245cb1, R-E347mcc3, and R-E347mmy1; thermophysical data; overview of the project for "Development of Advanced Refrigerants for Compression Heat Pumps" undertaken by the Research Institute of Innovative Technology for the Earth (RITE)

November 1996

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-79A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, November 1996 (432 pages with 1 table, available from JMC as RDB6B41)

This document provides bibliographic citations for more than 3200 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 4200 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes 474 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 5,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated *thesaurus* of synonyms and related terms, chain searches to broaden or narrow prior searches, a *wildcard* capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

October 1996

H. König (Solvay Fluor und Derivate GmbH, Germany), **Ersatz von R22: Weltweite Tendenzen** [Replacements for R-22: Worldwide Directions], *KK Die Kälte- und Klimatechnik*, Germany, 49(10):-758-762, October 1996 (5 pages in German, rdb-8C07)

replacements for R-22

S. Misaki (Research Institute of Innovative Technology for the Earth, RITE, Japan) and A. Sekiya (National Institute of Materials and Chemical Research, NIMC, Japan), **Update on Fluorinated Ethers as Alternatives to CFC Refrigerants,** *Proceedings of the International Conference on Ozone Protection Technologies* (Washington, DC, 21-23 October 1996), Alliance for Responsible CFC Policy, Arlington, VA, 65-70, October 1996 (6 pages with 8 tables, RDB7108)

R-E245cb1 [$CH_3OCF_2CF_3$], R-E347mmy1 [CH_3-$OCF(CF_3)_2$ or $CF_3CF(OCH_3)CF_3$], R-E347mcc3 [$CH_3OCF_2CF_2CF_3$]; physical properties, synthesis, thermal stability with lubricants and metals (aluminum, copper, and steel), critical properties (temperature and pressure), toxicity, flash point, atmospheric lifetime, GWP, HGWP, cycle performance

September 1996

R. S. Agarwal (Indian Institute of Technology, India), **Isobutane as Refrigerant for Domestic Refrigeration in Developing Countries**, *Proceedings of the IIR Conference on Applications for Natural Refrigerants* (Århus, Denmark, 3-6 September 1996), International Institute of Refrigeration (IIR), Paris, France, September 1996 (rdb9308)

use of hydrocarbons as refrigerants, R-600 (n-butane), R-600a (isobutane)

M. C. Bogdan, D. J. Williams, P. B. Logsdon, and R. C. Parker (AlliedSignal Incorporated), **Status Report on the Development of HFC-245fa as a Blowing Agent**, *Polyurethanes Expo '96* (proceedings of the 39th Annual Technical and Marketing Conference, September 1996), Society of the Plastics Industry (SPI), Washington, DC, 1996 (10 pages with 13 figures and 17 tables, RDB6B40)

R-245fa, physical properties, flammability, environmental data, toxicity (4-hr LC_{50} rat >200,000 ppm, LC_{50} mouse > 101,300 ppm, LD_{50} >2,000 mg/kg, cardiac sensitization >20,000 ppm, weak activity in human lymphocyte at 300,000 ppm v/v, not active in mouse micronucleus study at 100,000 ppm, Ames assay negative), thermal and hydrolytic stability, compatibility (compatible with Buna-N, EPDM, neoprene, polyethylene, polypropylene, polytetrafluoroethylene (PTFE); not compatible with epichlorohydrin, HNBR, nitrile (marginal), Viton; based on shrinkage <5% and swelling <20% after 2-week immersion at room temperature), foaming characteristics, foam aging effects

August 1996

Addenda to Number Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34a-o and 34q-x (Addenda to ANSI/ASHRAE 34-1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1996 (20 pages with 3 tables, available from ASHRAE for $8 members and $12 nonmembers plus handling fee, RDB6801) [distributed August 1996]

This cumulative addendum combines addenda a through o, addenda q through x, and errata sheet number 1 to ANSI/ASHRAE Standard 34-1992. The errata correct a conversion error in the metric units for flammability classifications. The addenda provide a designation distinction for zeotropic blends having the same components in different proportions, expand the applicability of dual classifications (as formulated and worst case of fractionation) to azeotropes, and add new definitions. The last address acute toxicity, azeotropic temperature, cardiac sensitization, ceiling (as in exposure limits), chronic toxicity, committee (in the context of the standard), LC_{50} (median lethal concentration), maximum temperature glide, ppm, permissible exposure level (PEL), short-term exposure limit (STEL), and Workplace Environmental Exposure Limit (WEEL). The addenda clarify that concentrations identified as "ppm" for safety classifications are "ppm by volume", expand the purpose, and provide detailed instructions for designation and classification applications. They also modify the designation system for miscellaneous organic compounds as well as inorganic compounds, provide uniform systems to number the carbon atoms in molecules and determine designations for fluoroethers, differentiate among azeotropic blends having the same components, and add a new reference. Composite tables remove the "provisional" notation previously appended to some safety classifications, correct a number of chemical names for consistency with the International Union of Pure and Applied Chemistry (IUPAC) conventions, correct informational (not part of the standard) data on refrigerants, and add safety classifications for R-23, R-32, R-116, R-124, R-125, R-143a, and R-218. The addenda also add designations, tolerances, and safety classifications for R-401A, R-401B, R-401C, R-402A, R-

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402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-507A, R-508A, R-508B, and R-509A. The addenda detail the submission requirements to apply for designations and classifications of additional refrigerants. A foreword and table identify the changes by specific addendum.

July 1996

J. M. Calm (Engineering Consultant), **Copper in Air Conditioning and Refrigeration - Supplement to the ARTI Refrigerant Database**, report JMC/-ARTI/CDA-9607D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, and the Copper Development Association (CDA), New York, NY, July 1996 (60 pages, available from JMC as RDB6720)

This document provides bibliographic citations for 316 publications that may be useful in research, design, and application of air-conditioning and refrigeration (ACR) equipment. Synopses or brief descriptors of the content, materials addressed, and key conclusions are provided for the majority. This supplement to the ARTI Refrigerant Database increases the information provided, by focusing on the suitability of and application data for copper and copper alloys with refrigerants. The key concentration areas are application data, compatibility, and heat transfer (including surface enhancement). An introduction outlines the reasons copper is the preferred fabrication material in many ACR components. It cites the metal's superior heat transfer properties, corrosion resistance, ease of fabrication and joining, strength, and machinability. It also notes the latitude afforded by copper, brass, bronze, and other alloys in manufacturing processes such as casting, forging, machining, drawing, sintering, and forming. A concluding section provides descriptions of both the Refrigerant Database and the Copper Data Center (CDC) database.

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-77B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1996 (426 pages with 1 table, available from JMC as RDB6772)

This document provides bibliographic citations for more than 3200 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes approximately 4000 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes more than 450 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 4,500 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

D. R. Defibaugh, K. A. Gillis, M. R. Moldover, J. W. Schmidt, and L. A. Weber (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of CF_3-CHF-CHF_2, 1,1,1,2,3,3-Hexafluoropropane,** *Fluid Phase Equilibria*, 122(1-2):-131-155, 31 July 1996 (25 pages with 8 figures and 6 tables, RDB8253)

reports thermodynamic properties of R-236ea based on measurements of the vapor pressure, density of the compressed liquid, refractive index of saturated liquid and vapor, critical temperature, speed of sound in the vapor phase, and surface tension determined from the capillary rise; also reports the ideal-gas heat capacity, saturated liquid and vapor densities, surface tension, and estimates of the critical pressure and density based on the measured data; provides coefficients for the Carnahan-Starling-DeSantis (CSD) equation of state (EOS)

W. Goetzler and L. Bendixen (Arthur D. Little, Incorporated, ADL), **Risk Assessment of HFC-32/-HFC-134a (30/70) in Mini-Split Residential Air Conditioners**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 27-32, July 1996 (6 pages with 3 figures, RDB6753)

concludes that the risks due to fires resulting from use of R-32/134a (30/70) in mini-split air conditioners in Japanese residences would be extremely low; risks from servicing and other handling are higher but can be controlled

G. G. Haselden (University of Leeds, UK), **Wide-Boiling Refrigerant Mixtures - Technical and Commercial Challenges**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 193-198, July 1996 (6 pages with 1 figure and 2 tables, RDB6839)

energy saving by use of blends with high temperature glide; flow circuit incorporating a liquid injection system coupled with a modulating float valve; evaluations by analytical methods and confirming tests for R-407C, R-32/125/134a (31/32/37), R-125/152a/600a (50/25/25), R-32/227 (probably R-32/227ea) (35/65)

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-77A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1996 (36 pages with 4 figures and 11 tables, available from JMC as RDB6C02)

This interim report summarizes progress in measuring primary thermodynamic data for seven binary and one ternary blends as potential replacements for R-22 or R-502. They include R-32/125/134a, R-32/143a, R-32/290, R-125/134a, R-125/143a, R-125/290, R-143a/134a, and R-290/134a. Measurements also are being made for R-41 and R-41/744 as potential replacements for R-13. The work consists of simultaneous measurements of the coexisting liquid and vapor densities, compositions, and bubble point pressures over a wide range of temperatures and compositions. These data will be used to determine the mixing parameters, including any temperature and/or composition dependence, for the Carnahan-Starling-DeSantis (CSD) equation of state and an extended corresponding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and virial coefficients; and the critical point parameters. The report describes measurement of vapor-liquid equilibrium (VLE) properties for R-32/125/134a, R-125/134a, R-125/143a, and R-143a/134a. It also summarizes bubble point pressure and near saturation density measurements of R-32/125/134a, R-125/143a, and R-143a/134a as well as initiation of isochoric heat capacity measurements of R-143a/125. It further describes similar measurements and triple-point temperature and heat of fusion measurements for R-41. Figures compare the new data and those published in prior, independent studies to calculated data from the ECS model in REFPROP for R-32/125/134a. Others show the liquid phase isochoric and saturated liquid phase heat capacities of R-41. Tables present the VLE and near-saturation data for R-143a/134a. Additional tables show VLE, bubble point pressure, and near saturation data for R-32/125/134a. A final set of tables present near saturation as well as experimental liquid, gas, and two-phase heat capacities of R-41. All of the tables are repeated in metric (SI) and inch-pound (IP) units of measure.

X. Liu (Carrier Corporation), **LMTD Applications in Two-Phase Heat Transfer and Two-Phase Heat Exchangers**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 145-150, July 1996 (6 pages with 1 table, RDB6828)

M. O. McLinden and S. A. Klein (National Institute of Standards and Technology, NIST), **A Next Generation Refrigerant Properties Database**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 409-414, July 1996 (6 pages with 2 figures and 2 tables, RDB6C16)

description of REFPROP Version 6; explains uses of the modified Benedict-Webb-Rubin (MBWR) and Helmholtz equations of state (EOSs) along with an extended corresponding states (ECS) model to calculate the thermodynamic properties of single-compound refrigerants; tabulates the EOS, source, and limits of application for R-11, R-12, R-22, R-32, R-113, R-

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123, R-124, R-125, R-134a, R-143a, R-152a, R-170, R-290, R-600, R-600a, R-717, and R-744; lists the ECS reference fluids for R-13, R-14, R-23, R-114, R-115, R-116, R-134, R-141b, R-142b, R-170, R-227ea, R-236fa, R-245ca, R-C270, R-C318, and R-1270; describes "mixture Helmholtz models" based on application of mixing rules to the Helmholtz EOS and transformations of the MBWR EOS and ECS models; presents the pure fluid and mixture models for transport properties; describes the FORTRAN subroutines suite for property calculations and user interface written in Pascal

D. M. Robinson and E. A. Groll (Purdue University), **Using Carbon Dioxide in a Transcritical Vapor Compression Cycle**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 329-336, July 1996 (8 pages with 6 figures, RDB6923)

literature review of R-744 in refrigeration, suitable applications, and research needs; thermodynamic modeling

E. G. Zaulichnyi and A. P. Iakoushev (National Academy of Sciences of Belarus, Minsk, Belarus), **Universal Effective Cooling and Heating Systems on the Compressed Air**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 541-547, July 1996 (7 pages with 4 figures, RDB6C34)

R-729 (air), *vortical gas-energy dividing tube* (VGEDT) [a vortex tube refrigeration process], experimental data, industrial tests

X. Zeng, G. Peterson, L. Ye, and W. Harvey (Smart Power Systems), **A Performance Analysis of Low Pressure HFC Refrigerants in Vapor-Compression Refrigeration Cycles**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 337-342, July 1996 (6 pages with 8 figures and 1 table, RDB6924)

evaluation of two undisclosed, low-pressure refrigerants identified as HFC-LVP and HFOC-LVP (the latter probably a hydrofluoroether, HFE); comparison to R-134a for air conditioning using a small centrifugal compressor; efficiency comparisons to R-113, R-123, and R-134a; concludes that a performance increase of 5-15% over R-134a is possible

V. V. Zhidkov (NORD Association, Ukraine), V. P. Zhelezny, and A. G. Butler (Odessa State Academy of Refrigeration, Ukraine), **Ecological and Energetical Aspects of Changing-Over Refrigerant Equipment of Joint-Stock Company NORD to Alternative Refrigerants**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 507-512, July 1996 (6 pages with 1 figure and 3 tables, RDB6C33)

comparative performance of R-134a, R-401A, R-600a, R-134a/152a, R-152a/600a, and R-290/-600a; cooling capacity, coefficient of performance, total equivalent warming impact (TEWI)

Genetron(R) AZ-20 (R-410A) Product Brochure, bulletin G-525-012, AlliedSignal Incorporated, Morristown, NJ, July 1996 (16 pages with 4 figures and 7 tables, RDB6B27)

This bulletin supplies information on R-410A, a patented blend of R-32 and R-125 - R-32/125 (50/50) -that behaves like an azeotrope. It was designed to replace R-22 in a variety of new equipment including unitary air-conditioners, chillers, and commercial refrigeration. The document outlines potential applications and provides physical property data including the chemical name and formula, appearance, molecular weight, normal boiling point, corresponding heat of vaporization and vapor density, critical parameters (temperature, pressure, specific volume, and density), and flammability. It also indicates the liquid density, vapor pressure, and the vapor and liquid heat capacity, thermal conductivity, and viscosity at 25 °C (77 °F). The bulletin then presents product specifications and provides both a pressure-temperature table and pressure-enthalpy (Mollier) diagrams. It reviews servicing considerations presents a tabular summary of the stability of R-410A with polyolester lubricants and metals (aluminum, copper, and steel). The text refers inquiries on desiccants to drier manufacturers, but provides a solubility plot for water in R-410A and lists suitability indications for 27 elastomers and plastics. The bulletin suggests use of polyolester lubricants, but indicates that compressor and lubricant manufacturers should be contacted for specific recommendations. It then reviews safety information, addressing general toxicity, inhalation effects, skin and eye contact, responses to leaks, flammability, combustibility, and thermal stability. The bulletin offers guidance for storage, handling, leak detection, retrofit, recycling, reclamation, and disposal. It also provides tabular thermodynamic properties (pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -30 to 70 °C (-60 to 160 °F) [tables cover dissimilar ranges for the two sets of units]. Formulae are presented to calculate thermodynamic properties, including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. The data are provided in both inch-pound (IP) and metric (SI) units. AlliedSignal's product name for R-410A is Genetron(R) AZ-20.

June 1996

P. Dinnage (Rhône-Poulenc Chemicals Limited, UK), **R.22 Drop-In Launched**, *Refrigeration and Air Conditioning,* UK, June 1996 (1 page with 3 figures, RDB6708)

R-403A, R-413A, Isceon 59 and 89 (replacements for R-22 and R-13B1, respectively); development and performance trials

May 1996

H. König (Solvay Fluor und Derivate GmbH, Germany), **Auswirkungen der Druckgrenzenerweiterung durch R22-Ersatzkältemittel auf die Komponenten des Kältemittelkreislauf** [Impacts of Increasing Compression Ratios for R-22 Replacement Refrigerants on the Components of Refrigeration Circuits], *Ki Luft- und Kältetechnik*, 32(5):213-216, May 1996 (4 pages in German, RDB8C03)

evaluation of higher compression ratios

April 1996

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-70B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 April 1996 (382 pages with 1 table, available from JMC as RDB6450)

This document provides bibliographic citations for more than 2800 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 3500 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes more than 450 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 4,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-70A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1996 (36 pages with 6 figures and 14 tables, available from JMC as RDB6C01)

This interim report summarizes progress in measuring primary thermodynamic data for seven binary and one ternary blends as potential replacements for R-22 or R-502. They include R-32/125/134a, R-32/143a, R-32/290, R-125/-134a, R-125/143a, R-125/290, R-143a/134a, and R-290/134a. Measurements also are being made for R-41 and R-41/744 as potential replacements for R-13. The work consists of simultaneous measurements of the coexisting liquid and vapor densities, compositions, and bubble point pressures over a wide range of temperatures and compositions. These data will be used to determine the mixing parameters, in-

please see page 6 for ordering information

cluding any temperature and/or composition dependence, for the Carnahan-Starling-DeSantis (CSD) equation of state and an extended corresponding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and virial coefficients; and the critical point parameters. The report describes measurement of coexisting densities, bubble point pressures, and liquid and vapor compositions of R-32/125 and R-32/143a with a new vapor-liquid equilibrium (VLE) apparatus. It also summarizes development of a vapor pressure equation for R-41, determination of saturated liquid densities and critical point parameters (temperature, pressure, and density) for R-41, completion of five pressure-volume-temperature (PVT) isochores for R-41/744, and initiation of VLE and coexisting density measurements on R-143a/134a. Figures compare the new data and those published in prior, independent studies to calculated data from the ECS model in REFPROP for R-32/125 and R-32/143a. Others show the locus of measurements for R-41 and comparisons of the vapor pressure data to those from other studies. Tables present the VLE data for R-32/125 and R-32/134a, near saturation data for R-32/143a, and bubble point pressures and near saturation data for R-32/125/134a. Additional tables show the compressed liquid, VLE vapor pressure, near saturation, critical parameter, calculated vapor pressure, and saturated liquid data R-41. All of the tables are repeated in metric (SI) and inch-pound (IP) units of measure.

C. Womeldorf and W. L. Grosshandler (National Institute of Standards and Technology, NIST), **Lean Flammability Limit as a Fundamental Refrigerant Property (Interim Technical Report - Phase II)**, report DOE/CE/23810-68, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 30 April 1996 (50 pages with 18 figures and 9 tables, available from JMC as RDB7103)

The report presents an investigation of the lean flammability limit (LFL_0 that is independent of the ignition source. It defines the limit as the fuel-air mixture that extinguishes an adiabatic flame when the strain rate (i.e., the normal gradient of velocity) is zero. The report explains that no method currently exists to measure this fundamental limit directly, but that measurements with an opposed-flow burner provide a quantifiable basis for extrapolating to the zero value. The report reviews the background, describes the experimental apparatus and procedures, discusses the fundamental flammability limit, and summarizes the equilibrium chemistry involved. The opposed flow burner and burner flow control system are shown schematically. The report then presents measurements and comparisons to the lower flammability limit (LFL) values measured in other studies, including those following ASTM E681. The LFL_0 R-50 (methane) was measured as 4.9 ±0.1 % v/v in dry air; that for R-32 was found to be 14.0 ±0.8 % v/v in dry air and 14.1 ±0.6 % v/v with 44% relative humidity. No flames occurred with mixtures of R-134a and air at ambient pressure and temperature. Cited advantages of the new method are higher precision and independence from the ignition source.

March 1996

M. S. Kim, G. Morrison, W. J. Mulroy, and D. A. Didion, **A Study to Determine the Existence of an Azeotropic R-22 'Drop-In' Substitute**, report NISTIR 5784, National Institute of Standards and Technology (NIST), Gaithersburg, MD, March 1996 (66 pages with 14 figures and 9 tables; available from JMC as RDB6432)

R-22 alternatives, R-C270/134a, R-134a/600a, R-290/134a

February 1996

January 1996

J. C. Bare (Environmental Protection Agency, EPA), **Identifying and Evaluating Alternatives to CFC-114 for Navy Shipboard Chillers,** *ASHRAE Journal*, 38(1):44-46, January 1996 (3 pages with 2 tables, RDB6103)

R-114, R-236ea, R-236fa

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-66B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 January 1996 (360 pages with 1 table, available from JMC as RDB6134)

This document provides bibliographic citations for more than 2500 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-

401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes approximately 3200 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes more than 400 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 3,800 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-66A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1996 (36 pages with 4 figures and 4 tables, available from JMC as RDB6603)

This interim report summarizes progress in measuring primary thermodynamic data for seven binary and one ternary blends as potential replacements for R-22 or R-502. They include R-32/125/134a, R-32/143a, R-32/290, R-125/134a, R-125/143a, R-125/290, R-143a/134a, and R-290/134a. Measurements also are being made for R-41 and R-41/744 as potential replacements for R-13. The work consists of simultaneous measurements of the coexisting liquid and vapor densities, compositions, and bubble point pressures over a wide range of temperatures and compositions. These data will be used to determine the mixing parameters, including any temperature and/or composition dependence, for the Carnahan-Starling-DeSantis (CSD) equation of state and an extended corresponding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and virial coefficients; and the critical point parameters. The report describes completion of a new vapor-liquid-equilibrium (VLE) apparatus as well a measurement of coexisting densities, bubble point pressures, and liquid and vapor compositions of R-32/134a and R-32/125/134a. It also summarizes isochoric pressure-volume-temperature (PVT) and vapor pressure measurements for R-41 along with development of a new spherical resonator for sound speed measurements. Finally, it describes initiation of isochoric PVT measurements of R-41/744 and VLE and coexisting density measurements of R-32/125. Figures compare the new data and those published in prior, independent studies to calculated data from the ECS model in REFPROP for R-32/134a and R-32/125/134a. Another shows the locus of measurements for R-41. Tables present the compressed gas and liquid-phase PVT data for R-41, in metric (SI) and inch-pound (IP) units of measure. Two final tables present the vapor pressure measurements for the same refrigerant.

B. A. Nagengast (Consulting Engineer), **History of Sealed Refrigeration Systems**, *ASHRAE Journal*, 38(1):S37, S38, S42-S46, and S48, January 1996 (8 pages with 8 figures, RDB6104)

This article reviews the evolution of hermetic refrigeration systems, to address refrigerant leakage, up to the 1940s. It identifies the Audiffren-Singrün refrigerating machine, which used R-764 (sulfur dioxide) as the refrigerant, as the first successful attempt. This device, nicknamed the "dumb-bell", was developed by Marcel Audiffren in France in the early 1890s. It was first manufactured in France from 1903 through the 1940s, by the Établissements Singrün, and in the United States from 1911-1928, by the General Electric Company. A second, externally-driven, sealed system was invented by Heinrich Zoelly in Switzerland and patented in 1918. The device was manufactured by Maschinenfabriken Escher Wyss & Cie, under the name "Autofrigor"; it used R-40 (methyl chloride). A third system was invented by Jay G. DeRemer before 1918. The design was based on the "Archimedes' Screw," using mercury swirled in slugs up an inclined rotating screw, to compress R-600a (isobutane) and later R-40. The oil-free design was manu-

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factured by Savage Arms Company from 1923 through the 1920s. The article describes three historic efforts to develop hermetic, reciprocating piston compressors with internal drives. They included one by Douglas H. Stokes in Australia, before 1916, and a semi-hermetic compressor by Earl Oswald and Clarence Holly in the USA, before 1924. The latter was manufactured by the Utility Compressor Company; it used R-160 (ethyl chloride), and later R-764, with a glycerin lubricant. The third attempt was developed and tested from 1917 through 1924 by the General Electric Company in the USA. Sales of the resultant oscillating cylinder 2 (OC2) compressors began in 1925.

1996-1997 Research Plan, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1 January 1996 (26 pages with 7 tables, RDB6301)

This list of prospective research subjects identifies 334 proposed projects, 56 designated as *priority* status. The projects are grouped into eight project classifications, based on approved funding guidelines. Projects relating to refrigerants fall in several of these categories, primarily including the third and sixth highest areas, *Environmentally-Safe Materials and Refrigeration Systems*. The research areas were proposed by ASHRAE Technical Committees, Task Groups, and other committees; they were prioritized by ASHRAE's Research and Technical Committee. The highest priority group (*three stars*) includes research of *HFC Refrigerant-Lubricant Modeling for Gas Solubility and Lubricant Viscosity,* identified as a *high-risk* project. The next classification includes *Thermophysical Properties of R-23, Comprehensive Thermodynamic Property Data for Refrigerant Blends,* and *Develop Solubility and Viscosity Data for Various Oil-Refrigerant Mixtures at High Discharge Temperatures and Pressures.* The *one-star* priority group includes *Transport Property Data for Refrigerant Blends, Flammability Properties of Alternative Refrigerants, A Uniform Equation of State for Alternatives to the CFC Refrigerants*, and *Chloride, Fluoride, and Acidity Measurements of CFC, HCFC, and HFC Refrigerants.* It also includes *Evaporation of Ammonia Outside Smooth and Enhanced Tubes with Miscible and Immiscible Oils* and *Measurement of Solubility, Viscosity, and Density of R-32/125 (R-410 Series) Refrigerant-Lubricant Mixtures.* Among nonpriority projects are: *Investigation of Major Sources of Refrigerant Emissions and Feasible Methods for Reducing These Emissions, Assessment of Vibration Insulation Material Compatibility with R-22, Alternative Refrigerants, and Ethylene Glycol Mixtures The Effects of Inundation and Miscible Oil Upon Enhanced Condensation Heat Transfer of Alternative Refrigerants for HVAC Applications, Performance of a Suction-Line Capillary-Tube Heat Exchanger, Performance of an Adiabatic Capillary Tube with Zeotroplc Mixtures, Thermophysical Properties of R-245ca, Measurement of R-22 and Alternative Refrigerant Leakage Rates from Open-Shaft Compressors, Double-Walled Heat Exchangers for Class 2 Refrigerants, Heat and Mass Transfer Additives in Aqua Ammonia Systems, Boiling and Two-Phase Flow of Ammonia and Ammonia-Oil Mixtures in a Corrugated Passage Simulating a Plate Heat Exchanger, Performance Comparison of Different Refrigerants in Flat-Plate, Microchannel Evaporators, Effect of Motion of an Ammonia Air Mixture in an Enclosed Space on Explosivity, Separating Velocities for Ammonia in Horizontal and Vertical Vessels, Laboratory Verification of Modeling Transients in Refrigerant Lines, Refrigerant Piping Pressure Drop Computer Program, and Optimizing Refrigeration for High* T_c *Superconducting Applications and Systems.* This plan summarizes anticipated funding and procedures for implementing the research identified; it replaces versions published for preceding years [see RDB5134].

1996 (month not indicated)

S. Bonekamp and K. Bier, **Influence of Ultrasound on Pool Boiling Heat Transfer to Mixtures of R23 and R134a,** *Pool Boiling 2* (proceedings of the Eurotherm Conference, seminar 48), 227-238, 1996; republished in the *International Journal of Refrigeration* (IJR), 20(8):606-615, December 1997 (11/10 pages with 12 figures and 2 tables, RDB8519)

heat transfer enhancement for R-23, R-134a, and R-23/134a

M. L. Huber, J. S. Gallagher, M. O. McLinden, and G. Morrison, **NIST Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database (REFPROP)**, Standard Reference Database (SRD) 23 version 5.0, National Institute of Standards and Technology (NIST), Gaithersburg, MD, 1996 (software and documentation available from NIST for $465.00 or $100.00 to upgrade from previous versions, RDB6C15)

Version 5.0 of REFPROP calculates properties for single-compound refrigerants as well mixtures of up to five of them. The refrigerants include R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-23, R-32*, R-113, R-114, R-115, R-116, R-123*, R-123a, R-124*, R-125*, R-134, R-134a*, R-E134, R-141b, R-142b, R-143, R-143a*, R-152a*, R-E170, R-218, R-227ea, R-236ea, R236fa*, R-245ca, R-245cb, R-E245fa1 (identified in the program as R-E245), R-C270 (cyclopropane), R-290 (propane)*, R-C318, R-600 (n-butane)*, R-600a (isobutane)*, R-601 (n-pentane)*, R-601a (isopentane)*, R-717 (ammonia), R-744 (carbon dioxide)*, and R-1270 (propylene). An option is provided to select use of a Carnahan-Starling-DeSantis (CSD) equation of state or an Extended-Corresponding-States (ECS) model with a highly accurate Modified Benedict-Webb-Rubin (MBWR) equation for the 14 fluids indicated with an asterisk (*). Measured interaction parameters are provided for common mixture pairs, along with a method to estimate interaction parameters for others from a correlation. Fourteen thermodynamic properties can be calculated, in user-selected units of measurement, including temperature, pressure, density, specific volume, enthalpy, entropy, speed of sound, specific heats at constant volume and pressure, viscosity, and thermal conductivity. REFPROP also provides information on single compound refrigerants including the ASHRAE Standard 34 designation (R number), chemical formula and name, Chemical Abstract Service registry number, molecular mass, triple-point temperature if applicable, normal boiling point temperature, critical temperature and pressure, polarizability and dipole moment if measured, and estimated surface tension values at representative temperatures. This update replaces version 4.0 (see RDB4101).

B. Mongey, N. J. Hewitt, and J. T. McMullan (University of Ulster, UK), **R407C as an Alternative to R22 in Refrigeration Systems**, *International Journal of Energy Research* (IJER), 20(1):245-254, 1996 (10 pages with 8 figures, RDB8513)

comparative performance of R22 and R-407C

S. M. Sami and B. Song (University of Moncton, Canada), **Performance Evaluation of a New Four Component HFC Blend in a Vapour-Compression Heat Pump System**, *Energy*, 21(5):361-369, 1996 (9 pages with 13 figures and 3 tables, RDB6745)

performance test results for R-32/125/143a/134a (40/25/25/10), proposed as a replacement for R-502; laboratory test rig and comparative tests for R-407B, R-502, and R-507A are outlined; plots show the comparative heating and cooling coefficients of performance (COP), capacities, compression pressure ratios, discharge temperatures, and mass flow rates, as functions of the evaporator temperature; also presents comparative tests of the tetrary blend and R-502 performed by the National Research Council of Canada (NRCC)

S. M. Sami and P. J. Tulej (University of Moncton, Canada), **A Drop-In-Replacement Blend for Air-Refrigerant Equipment,** *International Journal of Energy Research* (IJER), 20:787-796, 1996 (20 pages with 10 figures and 1 table, RDB6744)

performance evaluation of R-23/22/152a in three different compositions (not disclosed in this paper) identified as *NARM-12, NARM-22,* and *NARM-502;* outlines the experimental approach and provides plots of the coefficients of performance (COPs) in a prototype air-to-air heat pump, home refrigerator, and four commercial refrigeration machines; a plot compares the pressure-temperature relationships for R-22, *NARM-502,* and R-502; concludes that the three tested blends offer similar pressure-temperature relations to R-12, R-22, and R-502, respectively, and potential to enhance performance by 7-30%

J. Y. Shin, M. S. Kim, and S. T. Ro (Seoul National University, Korea), **Experimental Study on Convective Heat Transfer for Pure Refrigerants and Refrigerant Mixtures in a Horizontal Tube**, *Transactions*, Korean Society of Mechanical Engineers (KSME), Seoul, Korea, 20(2):730-740, 1996 (11 pages, rdb6831)

heat transfer

C. Y. Yang and R. L. Webb (Pennsylvania State University), **Condensation of R-12 in Small Hydraulic Diameter Extruded Aluminum Tubes With and Without Micro-Fins**, *International Journal of Heat and Mass Transfer*, 39(4):791-800, 1996 (10 pages, rdb6398)

R-12, heat transfer

C. Y. Yang and R. L. Webb (Pennsylvania State University), **Friction Pressure Drop of R-12 in Small Hydraulic Diameter Extruded Aluminum Tubes With and Without Micro-Fins**, *International Journal of Heat and Mass Transfer*, 39(4):801-809, 1996 (9 pages, rdb9828)

R-12, pressure drop, heat and mass transfer

1996 Threshold Limit Values for Chemical Substances in the Work Environment, *1996 TLVs(R) and BEIs(R): Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1-52 and notes, 1996 (52 of 148 pages with 5 tables and 4 appendices, available from ACGIH for $14.00, RDB6901)

This book provides data for use as guidelines or recommendations in the control of potential hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document flags TLVs and other data for compounds included in the Notice of Intended Changes (NIC), to flag data for which future revision has been proposed. It also provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter. The refrigerants addressed include R-11, R-12, R-13B1, R-20, R-21, R-22, R-30, R-40, R-113, R-114, R-115, R-160, R-160B1, R-170 (ethane), R-290 (propane), R-600 (butane), R-601 (pentane), R-610, R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-1150, R-1270, R-7146 (sulfur hexafluoride), and others. The carcinogenicity designations are revised for approximately 200 substances in this edition; such designations are added for many of the covered refrigerants.

Handbook for the International Treaties for the Protection of the Ozone Layer (fourth edition), United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, 1996 (326 pages, RDB6904)

This document contains the complete texts of the Vienna Convention and the Montreal Protocol as amended. These international treaties are formally titled the *Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer*. They are administered under the auspices of the United Nations Environment Programme (UNEP). The handbook summarizes the resulting control measures, the signature and ratification status by treaty and amendment for the 159 Parties (countries) that have adopted them, and the rules of procedure for meetings of the Parties. The decisions of the Parties and annexes to the Montreal Protocol, that relate to its interpretation, at meetings in Helsinki in (April-May 1989), London (June 1990), Nairobi (June 1991), Geneva (July 1992), Copenhagen (November 1992), Bangkok (November 1993), Nairobi (October 1994), and Vienna (December 1995) are presented and indexed to the Articles to which they pertain. The handbook lists approved destruction procedures and essential use exemptions, composition and procedures (terms of reference) for scientific and economic assessment panels, remedies for noncompliance, procedures for and details of the Interim Multilateral Fund and Multilateral Fund to assist Article 5 (developing) countries, finance of and procedures for the Trust Fund for administration of the treaties, and declarations adopted from 1989 through 1995. They include the *Helsinki Declaration on Protection of the Ozone Layer* (1989); declarations by Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, Liechtenstein, Netherlands, New Zealand, Norway, Sweden, and Switzerland on advancing the phase out of chlorofluorocarbons (CFCs) to not later than 1997 (1990); a resolution on more stringent measures for ozone depleting substances (1990); statements by Austria, Denmark, Germany, Finland, Norway, Sweden, and Switzerland on more control measures (1991); a resolution on methyl bromide (1992); statements on representation of Yugoslavia (1992); a memorandum on hydrochlorofluorocarbons (HCFCs) (1993); and declarations on methyl bromide (1993), by countries with economies in transition (1993), on the Multilateral Fund (1994), on HCFCs (1995), and methyl bromide (1995). The handbook then lists sources, contacts, and publications for further information, primarily from United Nations and international organizations. A concluding section presents the evolution of the Montreal Protocol from its original text through successive amendments. The Vienna Convention was adopted on 22 March 1985 and entered into force on 22 September 1988. The Montreal Protocol was adopted on 16 September 1987 and entered into force on 1 January 1989, the London Amendment 29 June 1990 and 10 August 1992, and the Copenhagen Amendment on 23 November 1992 and 14 June 1994. Entry into force follows ratification, accession, acceptance, or approval by prescribed numbers of Parties.

The AIHA 1996 Emergency Response Planning Guidelines and Workplace Environmental Exposure Level Guides Handbook, document 215-EA-96, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1996 (68 pages with 2 figures and 3 tables, RDB6451)

summarizes development and intended uses for Emergency Response Planning Guideline (ERPG) concentrations, to "assist emergency response personnel planning for catastrophic chemical releases to the community;" discuses other occupational and emergency exposure guides; summarizes the rationales for ERPG values based on "the maximum airborne concentration below which it is believed nearly all individuals could be exposed for 1 hour" without specified responses; identifies three levels, namely the ERPG-1 ("without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor), ERPG-2 ("without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action"), and ERPG-3 ("without experiencing or developing life-threatening health effects"); tabulates ERPGs for R-10, R-30, R-40, R-40I1, R-630, R-717 (ammonia), R-764 (sulfur dioxide), R-1113, R-1114, and others; describes Workplace Environmental Exposure Level (WEEL) Guides as "the workplace exposure levels to which it is believed that nearly all employees could be exposed repeatedly without adverse health effects;" tabulates WEELs for R-32, R-124, R-125, R-134a, R-141b, R-142b, R-143a, R-152a, R-E170, R-1113, and others; provides related definitions to assist users of ERPG and WEEL values in applying them

1995

December 1995

November 1995

October 1995

S. C. Bhaduri (Indian Institute of Technology, India), **Assessment of HFC-143a as an Alternative of HCFC-22 and R-502**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 87-95, October 1995 (8 pages with 6 figures and 2 tables, available from JMC as RDB5A49)

R-22, R-143a, R-502

P. G. Blacklock (Calor Gas Refrigeration, UK), **HC Refrigeration and Air Conditioning - A Developing Technology**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 404-411, October 1995 (10 pages with 9 figures and 7 tables, available from JMC as RDB5B12)

R-290 (CARE 40), R-170/290 (CARE 50), R-600a (CARE 10), R-290/600a (CARE 30): product development, performance comparison of R-22 and R-170/290, safety, training, technology transfer

J. M. Calm (Engineering Consultant), **Alternative Refrigerants and Lubricants - Data for Screening and Evaluation**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 169-178, October 1995 (10 pages with 2 tables, available from JMC as RDB5A02)

This paper describes the ARTI Refrigerant Database and provides a tabular summary for 86 common and candidate refrigerants. The key elements identified include a collection of documents, a computerized search system, a set of refrigerant summaries, and an information dissemination operation. The document collection, which includes both published and unpublished works, grew from an informal sharing of information on thermophysical properties, materials compatibility, and lubricants for alternative refrigerants. The current set also includes reports from the Air-Conditioning and Refrigeration Technology Institute's (ARTI's) Materials Compatibility and Lubricant Research (MCLR) Program, the Air-Conditioning and Refrigeration Institute's (ARI's) Alternative Refrigerants Evaluation Program (AREP), contributed works, and other sources. The search and retrieval system is based on a set of bibliographic citations and extended abstracts on refrigerant and lubricants, their properties, compatibility with other materials found in refrigeration systems, effects on heat transfer, system capacity and efficiency, computational and test methods to estimate or determine the preceding data, research, application data, and regulatory information. Two tables present refrigerant identifications, safety classifications, environmental data, and physical property data from the database for 109 of the most common refrigerants. The tabular data include the ANSI/ASHRAE Standard 34 designation, chemical name and formula, flammability limits, safety group, ozone depletion potential (ODP), global warming potential (GWP), molecular mass, freezing point, normal boiling point, and critical parameters (temperature, pressure, and density). The focus of the database and its sponsorship by ARTI, under a grant from the U.S. Department of Energy (DOE), are outlined.

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-61C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 31 October 1995 (346 pages with 1 table, available from JMC as RDB5A28)

This document provides bibliographic citations for more than 2400 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment.

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Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-23, R-32, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 3000 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes nearly 400 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 3,500 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated *thesaurus* of synonyms and related terms, chain searches to broaden or narrow prior searches, a *wildcard* capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

N. J. Cox (Morris & Young Refrigeration and Air Conditioning Limited, UK), **The Practical Use of Hydrocarbons in Air Conditioning and Refrigeration**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 412-416, October 1995 (5 pages with 1 table, available from JMC as RDB5B13)

R-170/290 (CARE 50) in a split-system heat pump and in chillers, R-290 in a split-system heat pump

R. G. Doerr and T. D. Waite (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials Under Retrofit Conditions**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 159-168, October 1995; republished as paper DOE/CE/23810-65A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1995 (10 pages with 2 tables, available from JMC as RDB5A56)

This paper summarizes tests conducted on motor materials, to determine whether prior exposure to the original refrigerant and mineral oil would affect compatibility with an alternative refrigerant and lubricant after retrofit. The materials were exposed first to the original refrigerant and lubricant and then to the alternatives, for 500 hours at elevated temperature for each refrigerant-lubricant system. R-11, R-12, R-22, and R-502 were tested as original refrigerants; R-123, R-134a, R-245ca, R-404A, and R-407C were tested as retrofit alternatives, the last four with polyolester (POE) lubricants. The test materials included motor insulation, magnet wire varnishes, sleeving, tapes, and tie cord. The paper outlines the test methods and materials, provides a qualitative table of findings, and discusses the specific observations for each material tested. It concludes that the tested materials appeared to be as compatible with the alternatives as with the original refrigerants and lubricants. One exceptions was sheet insulation containing DuPont Nomex® sheet insulation, which showed delamination and blistering particularly after removal of absorbed refrigerant at high temperature. A second was polyethylene terephthalate (PET) sheet and sleeving insulation, which became embrittled. Subsequent tests, under extremely dry conditions, showed that embrittlement of the PET materials could be attributed to moisture present during the exposure.

I. Haider, K. E. Simmons, K. Kim, and R. K. Radermacher (University of Maryland), **Independent Compartment Temperature Control of a Modified Lorenz-Meutzner-Cycle Refrigerator with a Hydrocarbon Mixture**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 206-215, October 1995 (10 pages with 5 figures and 2 tables, available from JMC as RDB5A61)

R-12, R-290/600 (70/30)

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-64A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1995 (30 pages with 7 figures and 2 tables, available from JMC as RDB5C11)

This interim report summarizes progress in measuring primary thermodynamic data for seven binary and one ternary blends as potential replacements for R-22 or R-502. They include R-32/125/134a, R-32/143a, R-32/290, R-125/-134a, R-125/143a, R-125/290, R-143a/134a, and R-290/134a. Measurements also are being made for R-41 and R-41/744 as potential replacements for R-13. The work consists of simultaneous measurements of the coexisting liquid and vapor densities, compositions, and bubble point pressures over a wide range of temperatures and compositions. These data will be used to determine the mixing parameters, including any temperature and/or composition dependence, for the Carnahan-Staling-DeSantis (CSD) equation of state and an extended corresponding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and virial coefficients; and the critical point parameters. The report describes measurement of mixture data for R-32/143a, R-32/290, R-125/134a, R-125/143a, R-125/290, R-143a/134a, and R-290/134a. It outlines development of new apparatus and its calibration. The report discusses preparation of an R-41/744 sample and completion of R-125/143a measurements. It also outlines ongoing measurements of R-41. A discussion of related work describes thermodynamic property measurements for alternative refrigerants, participation in an international comparison of property data, and improvements made to the REFPROP property model. Figures show the apparatus calibrations, locus of measurements for R-41, and comparisons of calculated and measured data for R-32/134a and R-32/125. Tables present the compressed gas and liquid-phase pressure-volume-temperature (PVT) data for R-41, in metric (SI) and inch-pound (IP) units of measure.

U. Hesse (Spauschus Associates, Incorporated), **Secondary Refrigerant System Options for Supermarket Refrigeration**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 322-330, October 1995 (9 pages with 5 figures and 6 tables, RDB5B06)

indirect systems for refrigeration: R-22, R-410A, R-507A, R-717, R-744; propylene glycol and organic salt heat transfer fluids

P. H. Howard, J. L. Tunkel (Syracuse Research Corporation, SRC), and R. V. Hendriks (U.S. Environmental Protection Agency, EPA), **Identification of CFC and HCFC Substitutes for Blowing Polyurethane Foam Insulation Products**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 417-426, October 1995 (10 pages with 1 figure and 1 table, RDB5B14)

screening of candidates for use as foam blowing agents, tabulates the global warming potential (GWP), molecular mass (MW), and thermal conductivity, and normal boiling point (NP) of the 105 candidates (mostly hydrocarbons and hydrofluorocarbons) ranked highest in potential

G. S. Kazachki (Acurex Environmental Corporation), C. L. Gage, and R. V. Hendriks (U.S. Environmental Protection Agency, EPA), **Evaluation of HFE-125 as an R-502 Replacement in Supermarket Low Temperature Refrigeration**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 238-247, October 1995 (10 pages with 16 figures and 1 table, available from JMC as RDB5A65)

R-E125, theoretical evaluation, compressor calorimeter tests

J. Köhler, M. Sonnekalb (Konvecta/IPEK, Germany), H. Kaiser, and W. Köcher, **Carbon Dioxide as a Refrigerant for Vehicle Air-Conditioning with Application to Bus Air-Conditioning**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 376-385, October 1995 (10 pages with 8 figures, available from JMC as RDB5B09)

R-744, mobile air-conditioning (MAC) systems

H. H. Kruse (Universität Hannover, Germany), **Energy Savings When Using Hydrocarbons as Refrigerant**, *Stratospheric Ozone Protection for the*

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90's (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 386-395, October 1995 (10 pages with 9 figures and 7 tables, available from JMC as RDB5B10)

R-C270; R-290; R-600; R-600a; R-601 (n-C5 or pentane); R-601b (2,2-dimethylpropane); R-1250 (propadiene); R-1270; R-290/600; R-290/600/601; R-290/600a (28/72), (40/60), (50/50), and (72/28); R-290/601 (R-290/n-C5); butene, 2methyl-1,3-butadiene, 2-methylbutane, 1,2-pentadiene, 1,4-pentadiene, pentene

Y. Mianmian, D. Changwei, Y. Zida, L. Zhikun, H. Chuanqiao, and W. Donning (Haier Group, China), **Latest Developments on CFC Substitution in China**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 331-340, October 1995 (10 pages with 3 figures and 6 tables, available from JMC as RDB5B07)

use of R-600a (isobutane) as a refrigerant and cyclopentane as an insulation blowing agent in a domestic refrigerator

S. Misaki (Research Institute of Innovative Technology for the Earth, RITE, Japan) and A. Sekiya (National Institute of Materials and Chemical Research, NIMC, Japan), **Development of a New Refrigerant**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 278-285, October 1995 (8 pages with 1 figure and 10 tables, available from JMC as RDB5B02)

R-E245cb1 [$CH_3OCF_2CF_3$] R-E347mmy1 [$CH_3OCF(CF_3)_2$ or $CF_3CF(OCH_3)CF_3$], R-E347mcc3 [$CH_3OCF_2CF_2CF_3$]; physical properties, synthesis, stability with lubricants and metals (aluminum, copper, and steel), flash point, toxicity, atmospheric lifetime, GWP, HGWP

D. R. Riffe (Americold / White Consolidated Industries, Incorporated), **Dual Cycle Isobutane Refrigerator/Freezer**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 258-267, October 1995 (10 pages with 5 figures and 10 tables, available from JMC as RDB5A67)

R-600a, consideration, outlook, theoretical performance (R-12, R-134a, R-600a), efficiency, capacity, compressor calorimeter tests, dual cycle, compressor options

J. D. Roux, A. Albouy (Elf Atochem SA, France), J. Murphy, and J. Costa (Elf Atochem North America, Incorporated, USA), **Recent Developments in Zero ODP Blowing Agents for Rigid Polyurethane Foams,** *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 448-452, October 1995 (5 pages with 4 tables, RDB5B15)

R-141b, R-245ca, R-245eb, R-245fa, R-365mfc

S. R. Szymurski, G. C. Hourahan, D. S. Godwin, and K. Amrane, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-64, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1995 (138 pages with 25 figures and 31 tables, available from JMC as RDB5A27)

This progress report summarizes the status and key findings of the Materials Compatibility and Lubricant Research (MCLR) Program. The program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. This work is jointly funded under a grant from the Office of Building Technology of the U.S. Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program began in September 1991 and will run through September 1996. The report provides descriptions for each of 31 projects, highlighting their objectives and results. One will measure thermophysical properties for one single-compound and nine blends as HCFC alternatives. Four others will examine the compatibility of 64 manufacturing process fluids with hydrofluorocarbon (HFC) refrigerants and two ester lubricants, the compatibility of motor materials with alternative refrigerants and lubricants for retrofit, compatibility of lubricant additives with HFC refrigerants and synthetic lubricants, and products resulting from motor burnouts. The report also summarizes a project to develop accelerated screening and test methods to predict the life of motor materials exposed to refrigerant-lubricant mixtures. Three others will develop alternative flushing and clean-out methods, investigate the fractionation of refrigerant blends, and evaluate lean flammability limits as a fundamental refrigerant property. Two projects address the effect of selected contaminants in air-conditioning and refrigeration equipment and the infrared spectra needed to quantitatively identify the components of refrigerant mixtures. Three others are studying the foaming characteristics of HFC refrigerants with polyolester lubricants, lubricant circulation in systems, and the performance and viability of R-245ca in low-pressure chillers. An ongoing project collects and facilitates dissemination of data, through development and administration of the ARTI Refrigerant Database; a related project is locating and consolidating information on the toxicity of alternative refrigerants. Among completed projects are those to measure thermophysical properties of R-32, R-123, R-124, R-125, R-143a, and R-152a; model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502; test the chemical and thermal stability of refrigerant-lubricant mixtures with metals; measure the miscibility of lubricants with refrigerants; measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures; measure the viscosity, density, and solubility for three azeotropic and zeotropic blends to replace R-22 and R-502; provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, engineering plastics, and desiccants; investigate electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants; and three projects to develop accelerated screening methods to predict lubricant performance in compressors, to predict the chemical and thermal stability of refrigerant-lubricant mixtures, and to measure and classify the flammability and combustibility of refrigerants. The program summary also identifies the research contractors and reports prepared for individual projects. Tables and figures illustrate significant findings of selected projects.

L. Voers (L&E Teknik og Management, Denmark), **A Scheme for Collecting and Registration of CFC, HCFC, HFC, etc.**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 482-489, October 1995 (8 pages with 1 table, available from JMC as RDB5B17)

Danish program for increasing on-site recycling and recovery of refrigerants as well as leak reduction

W. Wei, T. Liancheng, and X. Hongwei (Xi'an Jiaotong University, China), **A Simple Vapor Pressure Equation for New Refrigerants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 117-122c, October 1995 (8 pages with 3 tables, available from JMC as RDB5A52)

R-11, R-12, R-22, R-32, R-113, R-123, R-125, R-134a, R-142b, R-152a, R-290 (propane), R-600a (isobutane), R-1270 (propene), vapor pressure prediction, corresponding states

U. G. Wenning (Bosch-Siemens Hausgeräte GmbH, Germany), **No-Frost Refrigeration: A Retrospect After Conversion**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 396-411, October 1995 (6 pages with 1 figure and 4 tables, available from JMC as RDB5B11)

R-12, R-134a, R-C270, R-290, R-600, R-600a, refrigerators, refrigerator/freezers

P. Weiss, M. Barreau, and P. Fauvarque (Elf Atochem S.A., France), **Long Term Issues in Selection of Refrigerants for the Future**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 268-277, October 1995 (10 pages with 4 tables, available from JMC as RDB5B01)

R-134a, R-404A, R-407C, R-408A, R-409A, R-600a, R-717; comparative safety, environmental impact, and performance

X-Y. Zhao, L. Shi, M-S. Zhu, and L-Z. Han (Tsinghua University, China), **A New Generation of Long-Term Refrigerants as CFC-12 Alternatives**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, 286-293, October 1995 (8 pages with 6 figures and 3 tables, available from JMC as RDB5B03)

THR02 blend (undisclosed but believed to be R-290/152a/13I1), R-13I1 mixtures

Emissions of Greenhouse Gases in the United States, 1987-1994, report DOE/EIA-0573(87-94), Energy Information Administration, U.S. Department of Energy, Washington, DC, October 1995 (140 pages with 7 figures and 58 tables, available from GPO as document 061-003-00926-3, limited copies available from JMC as RDB5B63)

estimated emissions in the USA of carbon dioxide (R-744), methane (R-50), nitrous oxide (R-744A), halocarbons, sulfur hexafluoride (R-7146), criteria pollutants (carbon monoxide, nitrogen oxides, and nonmethane volatile organic compounds, VOCs), and other greenhouse gases: the halocarbons addressed include R-10 (carbon tetrachloride), R-11, R-12, R-12B1 (halon 1211), R-13B1 (halon 1301), R-14, R-20

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(chloroform), R-22, R-23, R-30 (methylene chloride), R-113, R-114, R-115, R-116, R-123, R-124, R-134a, R-140a (methyl chloroform), R-141b, R-142b, R-152a, and R-227ea; the halocarbon data are presented individually and collectively for the bromofluorocarbon (BFC, halon), chlorofluorocarbon (CFC), hydrochlorofluorocarbons (HCFC), hydrofluorocarbons (HFC), perfluorocarbon (PFC) groups; depending on the substance, data cover the period from 1988 through 1995; estimated emissions are from all uses - refrigerant components are a small fraction of the total; report identifies the data sources, conversion methods, and limitations

September 1995

D. J. Williams, M. C. Bogdan, R. C. Parker, and G. M. Knopeck (AlliedSignal Incorporated), **Update on the Development of HFC-245fa as a Liquid HFC Blowing Agent**, *Polyurethanes 1995* (proceedings of the 38th Annual Technical and Marketing Conference, 26-29 September 1995), Society of the Plastics Industry (SPI), Washington, DC, 1995 (10 pages with 8 figures and 16 tables, RDB5C95)

R-245fa, physical properties, flammability, environmental data, toxicity (4-hr LC_{50} mouse >101,300 ppm, cardiac sensitization >20,000 ppm), compatibility, foaming characteristics, foam aging effects

Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) Summaries, AFEAS, Washington, DC, September 1995 (28 pages with 6 figures and 3 tables, available from JMC as RDB-5C37)

This series of eleven leaflets presents key AFEAS objectives and findings. A summary of the *Montreal Protocol on Substances that Deplete the Ozone Layer* reviews the history of this international accord to phase out production of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants among other chemicals. It also recaps the schedules under the Protocol as well as the U.S. Clean Air Act and European regulations. A sheet on *Production and Sales of Fluorocarbons* reviews and provides a plot of the worldwide production of R-11, R-12, R-22, R-113, R-114, R-115, R-134a, R-141b, and R-142b for 1980-1994. It highlights key changes for CFCs relative to 1986, the base year in the Montreal Protocol, and for CFCs and HCFCs to 1993 production. A summary on *Atmospheric Chlorine: CFCs and Alternative Fluorocarbons* reviews the mechanisms of stratospheric ozone depletion and provides values for ozone-depletion potentials (ODPs). It also illustrates how substitution of HCFCs for CFCs reduces chlorine in the atmosphere. The illustration further shows that use of HCFCs for a limited time will not delay return of atmospheric chlorine to pre-1970s levels. A synopsis of the *Contributions of Greenhouse Gas Emissions to Climate Forcing Relative to CO_2* discusses radiative forcing, a parameter used to perturb the heat balance in modeling of the earth-atmosphere system. It outlines understanding and uncertainties associated with GWP values, atmospheric persistence of greenhouse gas emissions, and the quantitative influence of *integration time horizon* (ITH) on analyses of impacts. A table provides estimates for the atmospheric lifetimes and GWP values for 20, 100, and 500 yr ITH. A sheet on *Total Global Warming Impact* compares the Total Equivalent Warming Impacts (TEWIs) explains the significance of direct (emission related) and indirect (energy related) effects of alternative technologies and fluids. A plot shows the radiative forcing associated with the direct (refrigerant and insulation blowing agent) and indirect components of use of a refrigerator freezer. The discussion notes that the direct effect is much smaller and eliminated within 100 years, whereas significant carbon dioxide from the associated energy production persists more than 500 years later. The summary discusses the outlook for "not-in-kind" alternative technologies, suggesting that efficiency improvement for conventional technologies is more promising to mitigate future climate change. A review of the *Breakdown Products of Alternatives* outlines the mechanisms and consequences of CFC, HCFC, and hydrofluorocarbon (HFC) breakdown. It notes that they readily decompose into simple inorganic species in the lower atmosphere, that the ultimate breakdown products are acidic compounds that are washed out in rain, that the acidic concentrations are so low as to have no appreciable effect, and that the alternatives do not contribute to photochemical smog formation in urban areas. A further summary of the *Environmental Fate of Trifluoroacetyl Halides* addresses the atmospheric breakdown of R-123, R-124, and R-134a, producing trace quantities of trifluoroacetyl halides. These halides hydrolyze, in cloud water droplets or surface waters, to form trifluoroacetic (TFA) acid and hydrofluoric or hydrochloric acid. The fate of TFA ions is discussed. While not expected to have an impact on humans, plants, animals, or microorganisms, further study of the ultimate physiochemical and biological fate is underway. A summary on *TFA and Seasonal Wetlands* responds to a published analysis that suggests TFA buildup in transient wetlands. The summary outlines factors that may enhance local TFA concentrations in rain and in wetlands. It also discusses the assumptions used in the analyses and interprets the findings. A sheet on *UV-B Radiation Measurements* discusses the importance of the ozone layer in shielding ultraviolet-B (UV-B) radiation in sunlight as well as efforts to monitor and observed trends of incoming UV-B intensity. A *Glossary of Terms* defines terminology for discussion of the atmospheric effects of alternative fluorocarbons. The last sheet briefly outlines the history and activities of both AFEAS and the companion Programme for Alternative Fluorocarbon Toxicity Testing (PAFT).

The Hydrocarbon Forum, proceedings of a seminar (London Heathrow, UK), Calor Gas Limited, Slough, UK, 15 September 1995 (164 pages, RDB6707)

This documents consolidates lecture texts, presentation charts, and product literature on the introduction and use of hydrocarbon refrigerants in the UK. It includes a review of the 1995 revision to the British safety standard for refrigeration appliances and systems, BS4434, with emphasis on provisions for hydrocarbon use. A series of presentations address use of hydrocarbons in supermarket refrigeration, 1-50 kW (0.3-14 ton) air conditioners, 46 kW (13 ton) chillers with scroll compressors, packaged terminal air conditioners, dehumidifiers, and refrigerator cabinets (display cases and boxes). One presentation outlines implications of using hydrocarbon refrigerants in appliance manufacture, the choice and supply of hydrocarbons, charging equipment, and risk assessment studies. Another covers the need for technician training. The hydrocarbons addressed in these proceedings are R-290 (Calor Gas Refrigeration CARE 40), R-600a (CARE 10), R-170/290 (CARE 50), and R-290/600a (CARE 30).

<u>August 1995</u>

A. Cavallini (Università di Padova, Italy), **Working Fluids for Mechanical Refrigeration**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:25-42, 1995; republished in *International Journal of Refrigeration* (IJR*),* 19(8):485-496, November 1996 (18/12 pages with 6 figures and 2 tables, RDB7726)

issues associated with alternative refrigerants including behavior with lubricants, flammability, efficient use of temperature glides, fractionation and heat transfer degradation with zeotropic mixtures: tabular summary of the normal boiling point (bubble point temperature and glide for blends), ozone depletion potential (ODP), global warming potential (GWP), refrigerant replaced, trade names, and - for blends - the composition for alternatives; they include R-22, R-123, R-124, R-141b, R-142b, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-405A, R-406A, R-408A, R-409A, R-409B, R-509A, R-411A, R-411B, R-412A, R-22/124/600 (50/47/3), and R-125/143a/290/22 (42/6/2/50); a second table similarly summarizes chlorine-free alternatives including R-23, R-32, R-125, R-134a, R-143a, R-152a, R-404A, R-407A, R-407B, R-407C, R-410A, R-410B, R-507A, R-508A, R-508B, R-717, R-23/32/134a (4.5/21.5/74), R-32/125/143a (10/45/45), R-32/125/143a/134a (10/33/36/21), R-32/134a (25/75), and R-290/600 (50/50); use of "natural fluids" including hydrocarbons, R-717 (ammonia), R-744 (carbon dioxide), R-718 (water), and R-729 (air)

J. D. Douglas, J. E. Braun, E. A. Groll, and D. R. Tree (Purdue University), **Trade-Off Between Flammability and Performance of Hydrocarbon/Flame Suppressant Mixtures as Refrigerants**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:155-162, 1995 (8 pages with 4 figures and 2 tables, rdb6749)

R-290, R-32/134a (25/75) and (30/70), R-32/125/134a, R-290/227ea, cost-based evaluation of propane and propane-blends as replacements for R-22

T. Engler, F. Mößner, and L. R. Oellrich (Universität Karlsruhe, Germany), **Experimental Results and Theoretical Investigations with Alternative Refrigerants**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:774-781, 1995 (8 pages with 4 figures and 7 tables, rdb7918)

performance tests and evaluation of the total equivalent warming impact (TEWI) for candidate refrigerants for commercial refrigeration: direct (refrigerant related) effect dominates over indirect (energy related) effect for systems with a high charge amount per unit capacity ("filling ratio"); mixtures of R-125 and R-143a result in a high TEWI while those containing R-32, R-134a, R-290, and R-1270 offer lower TEWI values; concludes that future reductions in TEWI will be achieved mainly by the charge amount per unit capacity, employing the refrigerant with the highest coefficient of performance (COP), and if applicable taking advantage of temperature glide in mixtures; refrigerants examined included R-32, R-125, R-143a, R-C270, R-290 (propane), R-717 (ammonia), R-744 (carbon dioxide), R-1270, R-404A, R-407A, R-407B, R407C, R-410A, R-507A, R-32/125/134a (30/10/-

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60) and (30/20/50), R-32/125/143a (10/45/45), R-32/125/143a/134a (10/33/36/21), R-32/134a (38/62) and (56/44), R-125/143a/134a (45/45/10), and R-290/600a (70/30) and (73/27)

E. Granryd (Kungliga Tekniska Högskolan, KTH, Sweden), **Energy Considerations in Heat Pump Technology**, *Proceedings of the 19th international Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:17-24, 1995 (8 pages with 9 figures and 3 tables, rdb7725)

options for efficiency improvement in heat pumps and refrigeration with emphasis on vapor compression equipment: findings of cycle analyses with plots of volumetric cooling capacities and theoretical cycle efficiencies for R-12, R-22, R-134a, R-152a, R-290, R-404A, R-407A, R-407B, R-407C, and R-717; losses and ways to offset them for cycles depend on the refrigerant and application; influence of design parameters

Z. L. Gu and Y. Z. Yu (Xi'an Jiatong University, China), **Stirling-Rankine Hybrid Cycle Heat Pump with Propane**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:-1128-1135, 1995 (8 pages with 6 figures, rdb7942)

R-290 use in a cycle suggested as overcoming limitations of the Stirling-Stirling and Vuilleumier cycles

H. Halozan (Technische Universität Graz, Graz, Austria), **Propane for Heat Pumps**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:1136-1143, 1995 (8 pages with 5 figures, RDB7943)

advocates use of R-290 (propane) as a replacement for R-22: argues that the efficiency of R-290 can be improved with use of an internal (suction-liquid) heat exchanger (LSHX) and that it offers lower compressor discharge temperatures, can be used to retrofit existing R-22 systems, and requires a lower charge

N. J. Hewitt, J. T. McMullan, and B. Mongey (University of Ulster, UK), **The Replacement of R22 in Refrigeration Systems**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:283-289, 1995 (7 pages with 4 figures, RDB7815)

performance comparison of R-22 and R-407C in a laboratory test facility: the capacity of R-407C was similar to that of R-22 at higher evaporator temperatures, but lower at decreasing evaporator temperatures; circulating polyolester (POE) lubricant reduced the evaporator performance

L. C. M. Itard, V. Fedetov, and C. H. M. Machielsen (Delft University of Technology, The Netherlands), **Thermodynamic Efficiency of Several Non-Azeotropic Mixtures in the Wet Compression/Resorption Heat Pump Cycle**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:1152-1159, 1995 (8 pages with 1 figure and 4 tables, RDB7944)

comparative coefficients of performance (COPs) and specific compressor displacements (SCDs) for a theoretical Lorenz cycle, Carnot efficiency, R-123, R-600 (n-butane), R-601 (n-pentane), R-23/123, R-125/123, R-125/152a/123, R-134a/123, R-152a/123, R-290/600 (propane/butane), R-290/-600/601 (propane/butane/pentane), R-290/601 (propane/pentane), and R-717/718 (ammonia/-water) for four cases: they include a food processing plant, industrial application, poultry processing, and low-temperature district heating; concludes that mixtures with a relatively large difference in normal boiling point temperatures offer the highest COPs in applications utilizing the temperature glide

J. F. Judge, Y. H. Hwang, and R. K. Radermacher (University of Maryland), **Experimental Results of Two Drop-In Replacement Refrigerants for R-22**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:1168-1175, 1995 (8 pages with 4 figures and 5 tables; the pages are out of sequence in the published proceedings and page 1170 appears to have been inserted from another paper; RDB8307)

performance of R-22, R-407C, and R-32/125/134a (30/10/60) [candidate for the R-407 series] in a laboratory test facility following standard rating (ANSI/ASHRAE 116-1993) procedures

E. I. Kaapola (AX-Consulting, Finland), **Experiences in Using R404A in Refrigerated Storage**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:868-873, 1995 (6 pages with 4 figures, rdb7924)

R-404A with polyolester (POE, Mobil EAL Arctic(R) 15) lubricant in industrial refrigeration for a cold storage warehouse: limited miscibility and operational data

G. S. Kazachki (Acurex Environmental Corporation), C. L Gage, and R. V. Hendriks (U.S. Environmental Protection Agency, EPA), **Chlorine-Free Alternatives for CFC-114: Theoretical and Experimental Investigations**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:-874-881, 1995 (8 pages with 16 figures, rdb7927)

alternatives for R-114 for centrifugal chillers, especially for naval applications, and high-temperature heat pumps: examination of R-E134, R-236ca, R-236cb, R-236ea, R-236fa, R-254cb, and their binary blends, notably including R-E134/236ca (58/42), R-236cb/236ca (45/55), R-236ea/236ca (95/5), R-236fa/236ca (52/48), R-254cb/236ca (30/70); role of "*k*", a dimensionless quantity for which large positive values indicate a refrigerant that will incur significant superheating during compression and for which a negative value indicates a refrigerant that incurs significant loss during the throttling process; R-236fa was found to have both higher capacity and coefficient of performance (COP) than R-114, but is long atmospheric lifetime is indicated as a disadvantage

R. Krauss and K. Stephan (Universität Stuttgart, Germany), **Viscosity and Thermal Conductivity of R152a**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:366-374, 1995 (9 pages with 4 figures and 2 tables, rdb7826)

R-152a, transport properties, thermophysical data

D. E. Legheraba, M. Diboun, and S. Belaadi (USTHB-ICR, Algeria), **The Substitution of the Refrigerating Fluids by the GPL / Contribution to the Ozone Layer Protection**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:890-892, 1995 (3 pages with 1 table, rdb7925)

environmental benefits from use of liquified petroleum gas (LPG) as a replacement for chlorofluorocarbon (CFC) refrigerants

S. Macaudiere (Elf Atochem S.A., France), **HCFCs Replacement - An up to Date Review**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:391-395, 1995 (5 pages with 3 figures and 1 table, rdb7837)

replacements for R-22 including R-404, R-407C, and R-23/32/134a (4.5/21.5/74); identification of blend components to replace R-11, R-114 and R-123

I. M. Mazurin, A. S. Doronin, and A. Y. Stolyarevski (NIPK Elegaz, Russia), **New Refrigerators and Air Conditioners**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:914-924, 1995 (11 pages with 2 figures and 1 table, rdb-7930)

Khladon-M (Chladon-M) and Khladon-MT, near-azeotropic, binary and ternary blends, respectively, of unidentified fluorochemicals proposed as replacements for R-12: results of tests in domestic refrigerators

D. Mosemann and A. Görlitz (Grasso*Kühlautomat Berlin GmbH, Grasso*KAB, Germany), **Safety Concept for Ammonia Water Chillers**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:699-711, 1995 (13 pages with 10 figures and 1 table, rdb7912)

safety measures for use of R-717 (ammonia) with emphasis on its classification as a toxic and combustible substance in Germany; illustrates approaches that minimize the refrigerant charge amount, through advanced chiller technologies, and that locate the chillers in machinery rooms; discusses allowed locations, refrigerant amounts, ventilation requirements, and machinery room classifications under the German VBG 20 Regulation for the Prevention of Accidents and the German 4th Emission Control Regulations; illustrates accepted static and dynamic air washer to absorb ammonia from purge and ventilation releases

S. Nowotny (United Nations Industrial Development Organization, UNIDO, Austria), **Conversion of Refrigerators and Freezers Manufactured in Developing Countries to the Application of Environmental**[ly] **Benign Refrigerants and Foam Blowing Agents**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:939-946, 1995 (8 pages with 4 figures and 3 tables, rdb-7933)

comparative volumetric efficiency and coefficient of performance (COP) for R-12, R-134a, R-152a R-290 (propane), R-401A, R-600a (isobu-

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tane), R-290/600a in refrigerators and freezers; impacts on manufacturing with attention to added safety provisions for use of hydrocarbons and other flammable refrigerants

M. Paulus-Lanckriet and D. Balthasart (Solvay Research and Technology, Belgium), **1,1-Difluoroethylene - Useful Fluid for the Refrigeration Industry Revisited**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:472-480, 1995 (9 pages with 8 figures and 1 table, rdb-7849)

R-1132a, VF2: use to replace R-13, R-23, and R-503; use as a component in blends to replace R-22; R-1132a/134a (5/95), (10/90), and (20/80); physical and thermodynamic properties

S. F. Pearson (Star Refrigeration Limited, UK), **Automatic Calorimeter for Mixed Refrigerants**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:481-487, 1995 (7 pages with 5 figures, rdb7854)

apparatus for efficiency tests of refrigerants with similar properties; results for R-12, R-134a, and R-413A show the blend to have marginally better performance than R-12 or R-134a

J. Pettersen, P. Nekså, O. M. Schiefloe, and H. Rekstad (Norgest Tekniska Högskole, NTH, Norway), **Recent Advances in CO_2 Refrigeration**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:961-968, 1995 (8 pages with 7 figures and 2 tables, rdb7935)

use of R-744 (carbon dioxide) as a refrigerant: properties and characteristics of R-744 and the need for a trans-critical cycle; comparisons of the cycles, saturation-pressure-curve slopes, and relative coefficients of performance (COPs) with R-22 and R-134a; applications of R-744 in heat pumps for heating, vehicle air conditioners, marine refrigeration, and commercial refrigeration; comparisons of compressor displacement and COP between R-717 (ammonia) and R-744; concludes that R-744 offers competitive energy efficiency and favorable size and safety

A. J. Pitt (APV Refrigeration and Freezer, UK), **The Use of Ammonia in New Application and Markets**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:712-719, 1995 (8 pages with 3 figures and 1 table, rdb7913)

perceived advantages and disadvantages of R-717 (ammonia); rapid increase in the use of ammonia in chillers and air conditioning in Europe; advantages of ammonia vapor-compression over ammonia absorption systems; development of ammonia chillers with attention to the miscibility of polyglycol lubricants with ammonia; qualitative comparison of risks and economics to ammonia alternatives

M. Reiss (Hoechst Aktiengesellschaft, Germany), **New Working Fluids to Replace CFCs and HCFCs in Refrigeration and Air-Conditioning Applications**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:503-510, 1995 (8 pages with 12 figures and 2 tables, rdb7855)

R-404A, R-407C, R-32/125/143a/134a (10/33/-36/21) (Hoechst blend HX4) leakage tests, compressor discharge temperatures, and volumetric refrigerating effect

A. Suwono, H. M. Samudro, N. Tandian, and W. Adriansyah (Bandung Institute of Technology, Indonesia), **Theoretical and Experimental Study of the Application of Propane/n-Butane Mixture as Refrigerant Replacing R-12**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:313-320, 1995 (8 pages with 9 figures, rdb7902)

Redlich-Kwong equation of state for R-290, R-600, and R-290/600; theoretical and experimental coefficients of performance for R-290/600 with 40 and 50% R-290 by molar fractions

S. R. Szymurski, G. C. Hourahan, D. S. Godwin, and K. Amrane, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-61, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, August 1995 (120 pages with 25 figures and 31 tables, available from JMC as RDB5910)

This progress report summarizes the status and key findings of the Materials Compatibility and Lubricant Research (MCLR) Program. The program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. This work is jointly funded under a grant from the Office of Building Technology of the U.S. Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program began in September 1991 and will run through September 1996. The report provides descriptions for each of 31 projects, highlighting their objectives and results. One will measure thermophysical properties for one single-compound and nine blends as HCFC alternatives. Four others will examine the compatibility of 64 manufacturing process fluids with hydrofluorocarbon (HFC) refrigerants and two ester lubricants, the compatibility of motor materials with alternative refrigerants and lubricants for retrofit, compatibility of lubricant additives with HFC refrigerants and synthetic lubricants, and products resulting from motor burnouts. The report also summarizes a project to develop accelerated screening and test methods to predict the life of motor materials exposed to refrigerant-lubricant mixtures. Three others will develop alternative flushing and clean-out methods, investigate the fractionation of refrigerant blends, and evaluate lean flammability limits as a fundamental refrigerant property. Two new projects address the effect of selected contaminants in air-conditioning and refrigeration equipment and the infrared spectra needed to quantitatively identify the components of refrigerant mixtures. Three others are studying the foaming characteristics of HFC refrigerants with polyolester lubricants, lubricant circulation in systems, and the performance and viability of R-245ca in low-pressure chillers. An ongoing project collects and facilitates dissemination of data, through development and administration of the ARTI Refrigerant Database; a related project is locating and consolidating information on the toxicity of alternative refrigerants. Among completed projects are those to measure thermophysical properties of R-32, R-123, R-124, R-125, R-143a, and R-152a; model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502; test the chemical and thermal stability of refrigerant-lubricant mixtures with metals; measure the miscibility of lubricants with refrigerants; measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures; measure the viscosity, density, and solubility for three azeotropic and zeotropic blends to replace R-22 and R-502; provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, engineering plastics, and desiccants; investigate electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants; and three projects to develop accelerated screening methods to predict lubricant performance in compressors, to predict the chemical and thermal stability of refrigerant-lubricant mixtures, and to measure and classify the flammability and combustibility of refrigerants. The program summary also identifies the research contractors and reports prepared for individual projects. Tables and figures illustrate significant findings of selected projects.

B. J. C. van der Wekken and R. J. M. van Gerwen (Netherlands Organization for Applied Scientific Research, TNO, The Netherlands), **Development of an Air Cycle Plant**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:-1037-1044, 1995 (8 pages with 7 figures, rdb7941)

> R-729: concludes that the air-cycle concept can be used both in heat pumps and refrigeration machines, but that the low isentropic efficiency of commercially available compressors and expanders, approximately 60%, results in a low overall efficiency; speculates that air-cycle systems would become competitive if the efficiency of these components can be raised to 0.8-0.9; notes that the condensation and ice formation problems inherent to open air cycles can be avoided by use of regenerative heat exchangers

C. Wahlberg, V. W. Goldschmidt (Purdue University), and G. de Souza Damasceno (Universidade Federal de Vicosa, Brazil), **Anticipating the Performance of Drop-In Refrigerant Alternatives**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:1029-1036, 1995 (8 pages with 11 figures and 1 table, RDB7940)

> effects of refrigerant charge variations on capacity and subcooling in a domestic refrigerator; effects of expansion valve position on evaporator superheat; correlation of charge with capacity and power draw; correlation of optimum charge and capacity with molecular weight; correlation of average power to refrigerant suction pressure

July 1995

S. Goktun (Istanbul Technical University, Turkey), **Selection of Working Fluids for High-Temperature Heat Pumps**, *Energy,* 20(7):623-625, July 1995 (3 pages, rdb8209)

> describes criteria for working fluids in high-temperature heat pumps (HTHPs): examines a range of hydrochlorofluorocarbon (HCFC), hydrofluorocarbon (HFC) and hydrofluoroether (HFE) candidates in terms of environmental and thermophysical properties; identifies three HCFCs (R-123, R-235ca, and R-244ca), two HFCs (R-152 and R-245ca), and five HFEs (R-E143, R-E245, R-E245cb, R-E245fa, and R-E254cb) as promising refrigerants for high-temperature applications

R. A. Kerr, **Research News, Meeting Briefs: At Quadrennial Geophysics Fest, Earth Scientists**

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Think Globally, *Science*, 269:477-478, 28 July 1995 (2 pages with 1 figure, RDB7923)

This meeting summary highlights two presentations from the General Assembly of the International Union of Geodesy and Geophysics (IUGG, Boulder, CO, July 1995) that addressed ozone depletion. The first, by H. van Loon and J. Hurrell (National Center for Atmospheric Research, NCAR), proposed a linkage between ocean surface warming and the Antarctic ozone hole. The connection is based on comparisons of the semiannual oscillation (SAO) in atmospheric pressure differences and the strength of Antarctic vortex winds. Weakening of the SAO would intensify the vortex in the spring and delay its annual breakup. That would have intensified the cold in the vortex and given the spring sunshine extra time to drive ozone-depleting chemical reactions. This theory suggests that while chlorine trapped in the vortex caused the ozone destruction, the hole might not have appeared without the SAO. If so, the strengthened vortex from global warming may contribute to more frequent appearance or longer persistence of the Antarctic ozone hole. The second presentation by J. Herman (Goddard Space Flight Center) interpreted new ozone-loss data from the Total Ozone Mapping Spectrometer (TOMS) project as an indicator of increases in the ultraviolet (UV) radiation reaching the Earth's surface. The author reported increases of UV light at DNA-damaging wavelengths at a rate of approximately 8 percent per decade at the latitudes of major developed countries and 10-12% at higher latitudes.

Equilibrium Water Capacity of Desiccants in Mixtures of HFC Refrigerants and Appropriate Lubricants, research project 867-RP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1995 - July 1995, extended to 1998 (ASH0867)

This research project measured the equilibrium water capacity of three desiccants in contact with R-134a and a polyolester lubricant at 24 and 54 °C (75 and 125 °C). The contractor for the project was Imagination Resources, Incorporated (IRI), led by R. C. Cavestri; it was sponsored by ASHRAE Technical Committee 3.2, *Refrigerant System Chemistry*.

June 1995

M. J. Assael (Aristotle University, Greece) and W. A. Wakeham (Imperial College, UK), **A Round Robin Project on the Transport Properties of R134a**, *International Journal of Refrigeration* (IJR), 18(5):355-357, June 1995 (3 pages with no figures or tables, RDB5876)

outlines an international project to investigate the large discrepancies between the results of various researchers for the viscosity and thermal conductivity of refrigerant R-134a: The investigation will involve new measurements with a single sample in nine or more laboratories throughout the world. The use of a single sample will test whether the reported differences stem from sample purity. The project is coordinated by the Subcommittee on Transport Properties of Commission I.2 of the International Union of Pure and Applied Chemistry (IUPAC).

D. B. Bivens, M. B. Shiflett, W. D. Wells, G. S. Shealy, A. Yokozeki, D. M. Patron, K. A. Kolliopoulos, C. C. Allgood, and T. E. C. Chisolm (DuPont Chemicals), **HCFC-22 Alternatives for Air Conditioners and Heat Pumps**, paper SD-95-12-2, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 101(2):1065-1071, 1995 (7 pages with 5 figures and 1 table, RDB6385)

R-22 alternatives, R-134a, 407C [R-32/125/134a (23/25/52)], and R-410B [R-32/125 (45/55)], capacity, efficiency, performance, discharge temperature and pressure

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-59C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 30 June 1995 (322 pages, available from JMC as RDB5651)

This document provides bibliographic citations for more than 2100 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-23, R-32, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-408A, R-409A, R-410A, R-410B, R-411A, R-411B, R-412A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester

(POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 2700 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes more than 350 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 3,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

V. C. Mei, F. C. Chen, D. T. Chen (Oak Ridge National Laboratory, ORNL) and E-P. HuangFu (U.S. Department of Energy, DOE), **Performance Tests of R-22 and R-32/R-125/R-134a Mixture for Baseline Air Conditioning and Liquid Over-Feeding Operations**, paper SD-95-12-3, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 101(2):1072-1077, 1995 (6 pages with 8 figures, RDB6393)

R-22, R-32/125/134a (30/10/60), performance tests in room (window) air conditioner, modification to flooded evaporator with liquid overfeed (LOF): drop-in cooling capacity was 7.7% lower with the blend, 1.1% lower with the LOF modification

P. Popovic and H. N. Shapiro (Iowa State University of Science and Technology), **A Semi-Empirical Method for Modeling a Reciprocating Compressor in Refrigeration Systems**, paper 3912, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 101(2):367-382, 1995 (25 pages with 17 figures and 5 tables, RDB6336)

R-12, R-22, R-134a, R-401A (tested with R-22/-152a/124 (52/15/33)], R-401C, R-32/134a (25/75), and R-32/125/134a (30/10/60) and (23/20/57), simplified compressor model, prediction of mass flow rates and input power

Heat Transfer and Fluid Flow Study of Ammonia Spray Evaporators, research project 725-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1992 - June 1995, extended to 1998 (ASH0725)

This research addressed heat transfer and fluid flow for ammonia in falling-film (spray) evaporators with horizontal tubes. The work included performance of a literature search, experimental measurement of heat transfer on both single tubes and tube bundles. Both plain and enhanced tube surfaces were addressed under varied temperature and flow to determine the optimum conditions. Correlations or charts were developed for use in heat exchanger design. A goal was to enable design of equipment for comfort cooling using reduced inventories of ammonia. An overall goal was to provide basic information to permit potential users to evaluate counterflow, brazed-plate heat exchangers as refrigerant evaporators and condensers. The contractor for the project was the Texas Technological University, led by M-C. Chyu; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

May 1995

Genetron(R) AZ-20 (R-410A) Product Brochure, bulletin G525-012, AlliedSignal Incorporated, Morristown, NJ, May 1995 (16 pages with 4 figures and 7 tables, RDB5A32)

This bulletin supplies information on R-410A, a patented blend of R-32 and R-125 - R-32/125 (50/50) - that behaves like an azeotrope. It was designed to replace R-22 in a variety of new equipment including unitary air-conditioners, chillers, and commercial refrigeration. The document outlines potential applications and provides physical property data including the chemical name and formula, appearance, molecular weight, normal boiling point, corresponding heat of vaporization and vapor density, critical parameters (temperature, pressure, specific volume, and density), and flammability. It also indicates the liquid density, vapor pressure, and the vapor and liquid heat capacity, thermal conductivity, and viscosity at 25 °C (77

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°F). The bulletin then presents product specifications and provides both a pressure-temperature table and pressure-enthalpy (Mollier) diagrams. It reviews servicing considerations presents a tabular summary of the stability of R-410A with polyolester lubricants and metals (aluminum, copper, and steel). The text refers inquiries on desiccants to drier manufacturers, but provides a solubility plot for water in R-410A and lists suitability indications for 27 elastomers and plastics. The bulletin suggests use of polyolester lubricants, but indicates that compressor and lubricant manufacturers should be contacted for specific recommendations. It then reviews safety information, addressing general toxicity, inhalation effects, skin and eye contact, responses to leaks, flammability, combustibility, and thermal stability. The bulletin offers guidance for storage, handling, leak detection, retrofit, recycling, reclamation, and disposal. It also provides tabular thermodynamic properties (pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -30 to 70 °C (-60 to 160 °F) [tables cover dissimilar ranges for the two sets of units]. Formulae are presented to calculate thermodynamic properties, including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. The data are provided in both inch-pound (IP) and metric (SI) units. AlliedSignal's product name for R-410A is Genetron(R) AZ-20.

Genetron(R) AZ-50 Product Brochure, bulletin G-525-030, AlliedSignal Incorporated, Morristown, NJ, May 1995 (16 pages with 4 figures and 8 tables, RDB5546)

This bulletin supplies information on R-507A, a patented, azeotropic blend of R-125 and R-143a - R-125/143a (50/50). It was developed to replace R-502 in low- and medium-temperature commercial refrigeration such as display cases, transport refrigeration, and ice machines. The document outlines potential applications. It provides physical property data including the chemical name and formula, appearance, molecular weight, normal boiling point, corresponding heat of vaporization and vapor density, critical parameters (temperature, pressure, specific volume, and density), and flammability. It also indicates the liquid density, vapor pressure, and the vapor and liquid heat capacity, thermal conductivity, and viscosity at 25 °C (77 °F). The bulletin then presents product specifications, performance data, a pressure-temperature table, and pressure-enthalpy (Mollier) diagrams. The bulletin suggests use of polyolester lubricants and provides a generic miscibility diagram, but indicates that compressor and lubricant manufacturers should be contacted for specific recommendations. A table summarizes the stability of R-507A with polyolester lubricants and metals (aluminum, copper, and steel). The document recommends against introduction of chlorinated materials in systems using R-507A with polyolester lubricants. It identifies potential sources and indicates that the lubricants may be incompatible with them. It also counsels against mixing R-502 and R-507A, since R-115 from the former and R-125 from the latter may form an azeotrope, making recycling and reclamation very difficult. The bulletin lists suitability indications for 29 elastomers and plastics, provides a solubility plot for water in R-507A, and offers recommendations on desiccant driers. It then reviews safety information, addressing general toxicity, inhalation effects, skin and eye contact, responses to leaks, flammability, combustibility, and thermal stability. The bulletin offers guidance for storage, handling, leak detection, retrofit, recycling, reclamation, and disposal. It also provides tabular thermodynamic properties (pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -30 to 70 °C (-60 to 158 °F). Formulae are presented to calculate thermodynamic properties, including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. The data are provided in both inch-pound (IP) and metric (SI) units. AlliedSignal's product name for R-507A is Genetron(R) AZ-50.

HFC-245fa, bulletin G525-513, AlliedSignal Incorporated, Morristown, NJ, May 1995 (2 pages with 3 figures and 1 table, RDB5A34)

This bulletin introduces R-245fa as a potential replacement for R-141b and other chemicals. It is being developed for use as a blowing agent for rigid insulating foams. The preliminary bulletin presents selected data for R-245fa, described as a nonflammable liquid having a boiling point slightly below room temperature. A table lists physical properties including the molecular formula and weight, boiling point, and water solubility. It indicates the liquid density and vapor pressure at 20 °C (68 °F) and the vapor thermal conductivity at 40 °C (104 °F). It also states that R-245fa exhibits neither a flash point nor flame limits, based on identified tests. Plots show the pressure-temperature relation and miscibility in polyether polyols (BASF Pluracol® 975 and 824, Dow Chemical Voranol® 390, Bayer Corporation Multranol® 4063, and Eastman Chemical Thanol® 470X) as well as aromatic polyester polyols (Hoechst Celanese Terate® 203, 254, and 2541 and Oxid Terol® 235). The bulletin briefly reviews the environmental benefits of the hydrofluorocarbon (HFC), toxicity inventory listings and data, and performance as a blowing agent. It outlines laboratory stability tests, which showed high thermal and hydrolytic stability. It then indicates that compatibility tests are underway, with favorable results to date for neoprene, EPDM, nylon, polytetrafluoroethylene (PTFE, DuPont Teflon(R)), HIPS, and ABS. It suggests unfavorable findings for fluoroelastomers, nitrile, and HNBR. The bulletin concludes with recommendations for storage and handling.

April 1995

P. R. Glamm, E. F. Keuper, and F. B. Hamm (The Trane Company), **Evaluation of HFC-245ca for Commercial Use in Low Pressure Chillers**, report DOE/CE/23810-60, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 30 April 1995 (16 pages with 2 figures and 6 tables, available from JMC as RDB5801)

This report outlines preliminary performance estimates for R-245ca, a potential replacement for both R-11 and R-123, in multistage, centrifugal chillers. The report tabulates and discusses the theoretical performance of the three refrigerants. It notes dependence on precise property data, for which refinement is underway for R-245ca. The single- and three-stage cycles examined, the latter with two interstage economizers, are illustrated on temperature-enthalpy diagrams. The analyses were based on thermodynamic properties and predicted compressor efficiency, but excluded variations in heat transfer. The discussion notes that R-245ca would require a new compressor for retrofit of either R-11 or R-123 machines, to provide similar performance, due differences in displacement and - especially for R-123 conversions - isentropic work. Impeller and diffuser sizes, compressor adiabatic efficiency, power draw, and cycle efficiency (specific power) are tabulated for three-stage, 700 and 2800 kW (200 and 800 ton) chillers optimized for the three refrigerants. The report concludes that the theoretical efficiency of R-245ca is very close to those for R-11 and R-123, but that retrofit would be unattractive due to the required compressor modifications or changes in design temperatures. The report identifies further, planned work to evaluate the commercial viability of R-245ca, including laboratory tests and assessment of the toxicity and flammability risks. The report also indicates that the projected cost of R-245ca could be a concern.

R. Hawley-Fedder (Lawrence Livermore National Laboratory, LLNL), **Products of Motor Burnout**, report DOE/CE/23810-59D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 April 1995 (16 pages with 4 figures and 4 tables, available from JMC as RDB5814)

This interim report summarizes progress to identify and quantify the products of motor failures in hermetic and semihermetic refrigeration compressors. The study also will assess their corrosive effects on power-supply terminals, evaluate the efficacy of current clean-up procedures, and assess whether hydrofluorocarbon (HFC) refrigerants will increase or decrease the incidence of motor burnouts. The primary focus of this report is on quantitation of breakdown products formed during atmospheric pressure testing. Plots are included of the breakdown fraction as a function of energy deposition for R-22, R-134a, and R-507A. They show the total decomposition products as well as the key products for each of these refrigerants. Tabular data, indicating the identified breakdown products and quantities, also are given. The report notes continued monitoring of literature on chlorofluorocarbon (CFC) refrigerant degradation and breakdown by thermal and electrical mechanisms. It also describes the electrical breakdown tests at atmospheric pressure and describes preparations for similar tests elevated pressures and temperatures as well as during induced motor burnouts.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-61A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1995 (70 pages with 16 figures and 18 tables, available from JMC as RDB6602)

This interim report summarizes progress in measuring primary thermodynamic data for seven binary and one ternary blends as potential replacements for R-22 or R-502. They include R-32/125/134a, R-32/143a, R-32/290, R-125/-134a, R-125/143a, R-125/290, R-143a/134a, and R-290/134a. Measurements also are being made for R-41 and R-41/744 as potential replacements for R-13. The work consists of simultaneous measurements of the coexisting liquid and vapor densities, compositions, and bubble point pressures over a wide range of temperatures and compositions. These data will be used to determine the mixing parameters, including any temperature and/or composition dependence, for both the Carnahan-Starling-DeSantis (CSD) equation of state and an extended corresponding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and

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virial coefficients; and the critical point parameters. The report describes detailed analyses of vapor-liquid equilibria (VLE) and density data, including the findings of independent studies, as well as performance tests on an existing and development of a new VLE apparatus. The performance tests on the VLE apparatus included evaluation of the effects of adsorption, heats of vaporization, phase-envelope widths (difference between vapor and liquid composition), and the slopes of the density-versus-temperature curves on the quality of measurements. The report also outlines comparisons to REFPROP, comprehensive isochoric measurement of pressure-volume-temperature (PVT) data in an equimolar mixture of R-125 and R-143a, and vapor pressure and density measurements on R-41. Plots compare the data from published studies to those calculated using an ECS model from REFPROP and show the locus of PVT measurements for R-41. A table provide the heats of vaporization phase-envelope widths for the cited blends and R-290/600 (propane/n-butane) and R-600/601 (n-butane/n-pentane) at 25 °C (77 °F). Further tables present the measured VLE data for R-32/134a, R-32/125, R-32/290, R-125/143a, R-125/290, and R-290/134a in both metric (SI) and inch-pound (IP) units of measure.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-59A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1995 (30 pages with 12 figures and 5 tables, available from JMC as RDB5525)

This interim report summarizes progress in measuring primary thermodynamic data for seven binary and a ternary blends as potential replacements for R-22 or R-502. They include R-32/125/134a, R-32/143a, R-32/290, R-125/-134a, R-125/143a, R-125/290, R-143a/134a, and R-290/134a. Measurements also are being made for R-41 and R-41/744 as potential replacements for R-13. The work consists of simultaneous measurements of the coexisting liquid and vapor densities, compositions, and bubble point pressures over a wide range of temperatures and compositions. These data will be used to determine the mixing parameters, including any temperature and/or composition dependence, for the Carnahan-Starling-DeSantis (CSD) equation of state and an extended corresponding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and virial coefficients; and the critical point parameters. The report describes preparation of samples for the R-125/143a, R-32/134a/125, R-290 series, and R-143a series of blends. It also discusses ongoing measurements. Two figures show the measured pressures at the bubble and dew points and the vapor and liquid densities for R-32/134a. An ECS model is being developed from the data and will be included in the spring 1995 update of REFPROP (version 5.0). A series of figures compare the measurements obtained for R-32/134a with those from other studies. The text discusses the extent of agreement and differences. Five tables give the measured coexisting liquid and vapor mole fractions, bubble point pressures, and liquid and vapor densities of five binary blends in metric (SI) and inch-pound (IP) units. They include R-32/125 for 7-79 °C (43-173 °F), R-32/134a 7-97 °C (44-206 °F), R-32/290 for 7-92 °C (44-197 °F), R-125/290 7-91 °C (45-196 °F), and R-290/134a for 6-99 °C (43-210 °F).

Z. Liu, I. Haider, and R. K. Radermacher (University of Maryland), **Simulation and Test Results of Hydrocarbon Mixtures in a Modified-Lorenz-Meutzner-Cycle Domestic Refrigerator**, *HVAC&R Research,* 1(2):127-142, April 1995 (16 pages with 6 figures and 6 tables, RDB5C08)

R-22/123, R-290/600, R-290/41-12 (R-290/601, R-290/n-C5)

S. R. Szymurski, G. C. Hourahan, and D. S. Godwin, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/-23810-59, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1995 (110 pages with 23 figures and 28 tables, available from JMC as RDB5903)

This progress report summarizes the status and key findings of the Materials Compatibility and Lubricant Research (MCLR) Program. The program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. This work is jointly funded under a grant from the Office of Building Technology of the U.S. Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program began in September 1991 and will run through September 1996. The report provides descriptions for each of 29 projects, highlighting their objectives and results. One will measure thermophysical properties for one single-compound and nine blends as HCFC alternatives. Another will obtain compatibility data on 16 desiccants with 13 refrigerant-lubricant mixtures. Three others will examine the compatibility of 64 manufacturing process fluids with hydrofluorocarbon (HFC) refrigerants and two ester lubricants, the compatibility of motor materials with alternative refrigerants and lubricants for retrofit, and products resulting from motor burnouts. The report also summarizes projects to develop accelerated screening and test methods to predict the life of motor materials exposed to refrigerant-lubricant mixtures and the chemical and thermal stability of refrigerant-lubricant mixtures. Four others will develop alternative flushing and clean-out methods, investigate the fractionation of refrigerant blends, develop methods to measure and classify the flammability and combustibility of refrigerants, and a new project to evaluate lean flammability limits as a fundamental refrigerant property. Other new projects address the compatibility of lubricant additives with HFC refrigerants and synthetic lubricants, the foaming characteristics of HFC refrigerants with polyolester lubricants, lubricant circulation in systems, and the performance and viability of R-245ca in low-pressure chillers. An ongoing project collects and facilitates dissemination of data, through development and administration of the ARTI Refrigerant Database; a related project is locating and consolidating information on the toxicity of alternative refrigerants. Among completed projects are those to measure thermophysical properties of R-32, R-123, R-124, R-125, R-143a, and R-152a; model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502; test the chemical and thermal stability of refrigerant-lubricant mixtures with metals; measure the miscibility of lubricants with refrigerants; measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures; measure the viscosity, density, and solubility for three azeotropic and zeotropic blends to replace R-22 and R-502; provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics; investigate electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants; and develop accelerated screening methods to predict lubricant performance in compressors. The program summary also identifies the research contractors and reports prepared for individual projects. Tables and figures illustrate significant findings of selected projects.

March 1995

B. Stuij, **CFC and HCFC Replacement**, *IEA Heat Pump Newsletter - CFC and HFC Replacement*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, 13(1):13-18, March 1995 (6 pages with 4 figures, RDB5683)

environmental concerns, international regulations, economics, safety issues

C. Womeldorf, M. King, and W. L. Grosshandler (National Institute of Standards and Technology, NIST), **Lean Flammability Limit as a Fundamental Refrigerant Property (Interim Technical Report - Phase I)**, report DOE/CE/23810-58, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 31 March 1995 (34 pages with 17 figures and 2 tables, available from JMC as RDB5601)

The report presents an investigation of a fundamental flammability limit that is independent of the ignition source. It defines the limit as the fuel-air mixture that extinguishes an adiabatic flame when the strain rate (i.e., the normal gradient of velocity) is zero. The report explains that no method currently exists to measure this fundamental limit directly, but that measurements with a counterflow burner provide a quantifiable basis for extrapolating to the zero value. Preliminary results of the lean flammability limit of R-32 and of the critical flammability ratio of R-125 in R-32 are reported. The report reviews the background, describes the experimental apparatus and procedures, discusses the fundamental flammability limit, and summarizes the equilibrium chemistry involved. It summarizes measurements for R-50 (methane), R-32, R-125, and R-32/125. Figures illustrate the counterflow burner, burner flow control system, extinction curve for methane as a function of the local strain rate, and the definition of the global strain rate. Plots show the equilibrium composition and temperature of R-32, R-125, and R-290 (propane) in air as well as the adiabatic equilibrium temperature of R-32 and R-32/125 (90/10) in air. Further plots show the determination of peak equilibrium temperatures, global and local strain rates at extinction for methane, range of lean flammability limits for R-32, a comparison of flammability limits (LFL and UFL) for R-32 using various methods at ambient temperatures. Two final plots show the extinction points for R-32 and R-125 and extrapolation of the global strain rate, to determine the critical flammability ratio of R-125 in R-32.

R. Yamamoto, O. Kitao, and K. Nakanishi (Kyoto University, Japan), **Monte Carlo Simulation of Fluoropropane**, *Proceedings of the 1st International Conference on Molecular Thermodynamics and Molecular Simulation* (Kyoto, Japan, 9-13 January 1994); republished in *Fluid Phase Equilibria*, 104:349-361, March 1995 (13 pages, rdb8923)

summarizes Monte Carlo (MC) simulations for R-218, R-236fa, R-245ca, R-245cb, and R-290 using a transferable potential model: notes that the quantitative agreements are not satisfactory even though the results show qualitative agreement with the experimental data; presents a modification involving use of an empirical scal-

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ing factor into the potential function; concludes that the agreement are clearly improved with the new factor; compares the carbon-carbon pair distribution functions obtained from the MC simulations with experimental x-ray scattering data for propane

K. Yamashita and A. Yabe (Toshiba Corporation, Japan), **EHD Enhancement of Falling Film Evaporation Heat Transfer and Durability of EHD Heat Exchanger**, *Proceedings of the ASME/JSME Thermal Engineering Joint Conference* (Maui, HI, 19-24 March 1995), American Society of Mechanical Engineers (ASME), New York, NY, and Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, 4:253-260, 1995 (8 pages, rdb6225)

electrohydrodynamic (EHD) enhancement of heat transfer for evaporation of R-123 in a falling-film heat exchanger fabricated of stainless steel: of the five electrodes, rolled punched plates with vertically-arrayed, offset slits provided the maximum enhancement effect; the improvement in heat transfer was six times that for a smooth tube without EHD; tests for durability, based on 1,000 hr of operation followed by careful examination of the test section, found that the EHD falling film evaporator and the EHD condenser can be are suited for industrial use

Capillary Tube Performance with Alternative Refrigerants, research project 762-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1993 - March 1995, extended to 1998 (ASH0762)

This project developed a methodology to predict refrigerant mass flow rate through a straight, adiabatic capillary tube, based on tube geometry, refrigerant properties, and operating conditions. The goal was to provide a method applicable to any refrigerant, single component or blend, to replace existing charts, developed primarily for R-12 and R-22. The work included both a theoretical analysis and laboratory effort, to validate the rating method developed. The contractor was the Iowa State University of Science and Technology, led by M. B. Pate; it was sponsored by ASHRAE Technical Committee 8.8, *Refrigerant System Controls and Accessories*.

Production, Sales and Atmospheric Release of Fluorocarbons through 1993, Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Washington, DC, March 1995 (84 pages with 29 tables, limited copies available from JMC as RDB5501)

R-11, R-12, R-22, R-113, R-114, R-115, R-142b, production and emission data

February 1995

J. M. Calm (Engineering Consultant), **Copper in Air Conditioning and Refrigeration - Supplement to the ARTI Refrigerant Database**, report JMC/-ARTI/CDA-9502D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, and the Copper Development Association (CDA), New York, NY, February 1995 (50 pages, available from JMC as RDB5260)

This document provides bibliographic citations for 240 publications that may be useful in research, design, and application of air-conditioning and refrigeration (ACR) equipment. Synopses of the content, materials addressed, and key conclusions are provided for more than a third of these documents. This supplement to the Refrigerant Database increases the information provided, by focusing on the suitability of and application data for copper and copper alloys with refrigerants. The key concentration areas are application data, compatibility, and heat transfer (including surface enhancement). An introduction outlines the reasons copper is the preferred fabrication material in many ACR components. It cites the metal's superior heat transfer properties, corrosion resistance, ease of fabrication and joining, strength, and machinability. It also notes the latitude afforded by copper, brass, bronze, and other alloys in manufacturing processes such as casting, forging, machining, drawing, sintering, and forming. A concluding section provides descriptions of both the Refrigerant Database and the Copper Data Center (CDC) database.

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-51E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 28 February 1995 (282 pages, available from JMC as RDB5261)

This document provides bibliographic citations for more than 2300 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-23, R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-408A, R-409A, R-410A, R-410B, R-411A, R-411B, R-412A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-

508A, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes the same citations and abstracts as the report version plus 240 from a supplement on copper in air conditioning and refrigeration, 266 for superseded and historical documents, data summaries for 270 refrigerants (single compound and blends), and 50 tabular compatibility summaries for plastics and elastomers - a total of 2625 entries. It is accompanied by retrieval software to facilitate searches for specific information; the software enables searches for user selected terms, or combinations of terms. It offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, and a "wildcard" capability to allow entry of word segments. The software also enables printing of selected citations, abstracts, and data summaries as well as preparation of a document order lists. Both versions of the database include instructions to obtain cited documents or subscriptions for updates to the database.

M. Chwalowski, **Climate Change Update,** unpublished seminar presentation charts (Winter Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE, Chicago, 28 January - 1 February 1995), Edison Electric Institute, Washington, DC, 1995 (4 pages with 4 figures, available from JMC as RDB5349)

This series of 20 presentation charts summarizes a discussion of basic trends, climate modeling, observed differences, and conclusions. It presents extremes of suggested long-term cooling trends and predictions of dire climate changes. It then critically reviews the basis for and projections of warming, and contrasts temperature records and predictions. The presentation concludes that disagreement exists among scientists, measured and predicted data differ, less is known than not known about the atmosphere, and the politics of climate change have overtaken the science.

Scientific Assessment of Ozone Depletion: 1994, chaired by D. L. Albritton, R. T. Watson, and P. J. Aucamp, report 37, World Meteorological Organization (WMO), Global Ozone Research and Monitoring Project, Geneva, Switzerland; United Nations Environment Program (UNEP), Nairobi, Kenya; National Oceanic and Atmospheric Administration (NOAA), Washington, DC, USA; and National Aeronautics and Space Administration (NASA), Washington, DC, USA; February 1995 (582 pages with 146 figures and 76 tables, available from WMO, RDB5301)

This definitive work, the seventh in a series, updates the assessment used in governmental and international decision-making for protection of the stratospheric ozone layer. The volume addresses common questions about ozone depletion, observed changes in ozone and source gases, atmospheric processes responsible for these changes, simulations of global ozone, consequences of ozone change, and scientific information for future decisions. It was prepared by 13 international panels, consisting of 230 of the world's leading experts in the atmospheric sciences, and subjected to an intensive peer review by 147 scientists. The product summarizes understanding of the stratospheric ozone layer and its relation to humankind. The assessment was initiated in November 1992 by the 4th meeting of the parties to the Montreal Protocol in Copenhagen. The results are scheduled for consideration by the parties to the Protocol, for potential revision of the Protocol in 1995 at the 5th meeting in Vienna. The report provides internationally recognized values for atmospheric lifetimes, response times, chlorine and bromine loading, ozone depletion potential (ODP), and global warming potential (GWP) for natural and anthropogenic chemicals impacting the global environment.

January 1995

F. R. Biancardi (United Technologies Research Center, UTRC), **Investigation into the Fractionation of Refrigerant Blends**, report DOE/CE/-23810-51C (also identified as UTRC R94-970566-3), Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1995 (26 pages with 14 figures and 1 table, available from JMC as RDB5602)

This report summarizes the progress of research to investigate composition changes in refrigerant blends. The project entails four technical tasks addressing lubricant solubility effects, fractionation effects from successive charges, fractionation within system components, and fractionation during leaks. The report outlines contractual compliance and work status. It describes a model based on non ideal, Wohl solution theory to assess lubricant-solubil-

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ity effects. Figures illustrate model predictions of vapor pressure and R-32 mass fraction with liquid R-32/134a (25/75) as functions of the mass fraction of oil in the sump and sump temperature. Three others show the vapor pressure and vapor mass fraction versus mass fraction of oil and R-32 liquid mass fraction at representative temperatures. The report then summarizes modeling of fractionation within components for a typical heat pump; the model currently addresses the evaporator, condenser, compressor, expansion valve, and accumulator. A figure shows the extreme operating conditions of constant temperature and constant mass fraction conditions. Four figures show the R-32 concentration by component and the refrigerant location with time, after starting, with 0 and 100% temperature glide. Three schematics illustrate an experimental facility and equipment that will be used to conduct verification tests. The heat pump and instrumentation are described. Planned tests are outlined and the specific sequence and operating conditions are summarized in a table. Presentation charts on the objectives, deliverables, and schedule are appended.

F. R. Biancardi (United Technologies Research Center, UTRC), **Investigation into the Fractionation of Refrigerant Blends**, presentation (ARI Alternative Refrigerants Evaluation Program, AREP, Meeting, Chicago, IL, 27 January 1995), report DOE/CE/23810-52B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1995 (24 pages with 14 figures, available from JMC as RDB5257)

This report comprises presentation charts on research to investigate composition changes in refrigerant blends. The charts outline the work scope, deliverables, and schedule. They identify four technical tasks addressing lubricant solubility effects, fractionation effects from successive charges, fractionation within system components, and fractionation during leaks. Charts show the binary activity coefficients, predicted vapor pressures, and experimental and measured vapor pressures for R-32/134a (25/75) with a polyolester (POE) lubricant (Castrol Icematic® SW68). Four figures summarize analyses of fractionation based on both an isothermal, static equilibrium model and a more rigorous, dynamic simulation model. They include a sample mass loss and composition plot with the static model, a schematic and corresponding thermal circuit diagram for the transient model, plots of mass loss, and temperature, and composition plots for discharges at constant temperature and with a temperature change. Five additional plots show predicted internal fractionation for these components during start-up and at steady state, assuming 0 and 100% of maximum glide and for a system with half the initial refrigerant charge for 0% glide. A summary chart indicates that different solubility of blend components can affect fractionation, but modeling predicts trends accurately. Further, tank charging effects can be modeled with verified accuracy, but verification of modeling for fractionation inside systems is more difficult. The summary also notes that the work performed has been limited to a single blend with moderate glide.

R. G. Doerr and T. D. Waite (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials Under Retrofit Conditions**, report DOE/CE/23810-51B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 12 January 1995 (86 pages with 66 tables, available from JMC as RDB5511)

This interim report summarizes a study of the compatibility of materials used in motors, for hermetic compressors, with refrigerants and lubricants. These materials were tested by exposures first to "original" refrigerant-oil mixtures and then to alternative refrigerant-lubricants mixtures. The sequential, 500-hour exposures simulate the effects of retrofit. Some samples were exposed to the original refrigerant-oil mixture for a total of 1000 hours as a control. The report identifies the materials used, test procedures, and sample evaluations and quantities. It summarizes the status of the work, recommendations for further tests, and significant results. Testing was performed in accordance with UL Standard 2171. The original and retrofit combinations were R-11/paraffinic mineral oil (MO, Penreco Sontex 300LT) and R-123/mineral oil (same), R-12/naphthenic MO (Witco Suniso(R) 3GS) and R-134a/polyolester (POE, CPI(R) Solest(R) 68), R-502/MO (Suniso(R) 3GS) and R-404A/POE branched acid (Castrol Icematic(R) SW32), and R-22/MO (Suniso(R) 3GS) and R-407C/POE mixed acids (ICI Emkarate(TM) RL 32H). The magnet wire insulations tested were a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a polyester imide overcoated with polyamide-imide (Phelps Dodge / Schenectady Chemical), and a modified polyester base overcoated with polyamide imide and epoxy saturated glass (Phelps Dodge Armored Poly-Thermaleze Daglass 2000). They were tested for dielectric breakdown and burnout strength. The varnishes included a water-base epoxy phenolic (Schenectady Isopoxy(R) 800), a solvent epoxy phenolic (P. D. George 923), and a solvent epoxy (Sterling(R) U-475 EH). Coated helical coils tested for bond strength. The sheet insulations tested were a standard polyester film

(DuPont Mylar(R) 900 MO), a low oligomer polyester film (ICI Melinex(R) 228), a polyester composite (Westinghouse Dacron-Mylar-Dacron(R)), an aramid fiber mat (DuPont Nomex(R) 410 10 mil), an aramid fiber mica mat (DuPont Nomex(R) Mica 418), and an aramid mat, polyester film composite (Westinghouse Nomex-Mylar-Nomex(R)). These insulation sheets were tested for tensile strength, elongation, and dielectric breakdown. The spiral-wrapped sleeving materials tested were a polyester film (Insulations Sales Mylar(R)) and an aramid mat, polyester film composite (Insulations Sales Nomex-Mylar(R)). The lead wires tested were a polyester composite (A. O. Smith Dacron-Mylar-Dacron(R)) and a polyester, fluoropolymer composite (A. O. Smith Dacron-Teflon-Dacron(R)). The sleeving and lead wires were tested for dielectric breakdown. Other materials tested were a polyester tie cord (Ludlow Textiles); braided polyester, acrylic binder assembly tape; and polyester mat assembly tape. They were tested for tensile strength and elongation. Assembled motorettes with the three wire types were tested for their ability to withstand applied voltages. In addition, all materials were inspected visually. The tests performed to date generally found the materials exposed to be compatible. Concerns are noted with embrittlement of polyethylene terephthalate (PET) sheet and sleeving insulation as well as delamination and blistering of the Nomex sheet insulation in R-12, R-22, and R-502. Also, the solvent epoxy varnish separated from the metal surface in R-123, possibly due to the condition of the metal surface. The causes of these problems are being investigated; an appendix in the report indicates that some of materials may have been inadequately dried in testing.

R. Hawley-Fedder (Lawrence Livermore National Laboratory, LLNL), **Products of Motor Burnout** report DOE/CE/23810-51D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 January 1995 (10 pages with 1 figure and 1 table, available from JMC as RDB5345)

This interim report summarizes progress to identify and quantify the products of motor failures in hermetic and semihermetic refrigeration compressors. The study also will assess their corrosive effects on power-supply terminals, evaluate the efficacy of current clean-up procedures, and assess whether hydrofluorocarbon (HFC) refrigerants will increase or decrease the incidence of motor burn-outs. The report notes continuation of a literature search on chlorofluorocarbon (CFC) refrigerant degradation and breakdown by thermal and electrical mechanisms. It outlines electrical breakdown tests at atmospheric pressure on R-22, R-134a, and R-507A. The decomposition products were identified by gas chromatography (GC), flame ionization detection (FID), and GC/mass spectrometry (GC/MS). The approximate concentrations are qualitatively tabulated for 52 identified compounds. The report briefly outlines and schematically shows the arc testing procedure. It notes that no difference was seen in the volatile compounds formed with or without lubricant present. Those tested included a mineral oil (Calgon C4) and a polyolester (ICI Emkarate(TM) 32S). The report also identifies progress in planning and acquiring components for elevated pressure-temperature tests and motor burnout tests.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-51A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1995 (16 pages with 2 figures and 2 tables, available from JMC as RDB5512)

This interim report summarizes progress in measuring primary thermodynamic data for seven binary and one ternary blends as potential replacements for R-22 or R-502. They include R-32/125/134a, R-32/143a, R-32/290, R-125/-134a, R-125/143a, R-125/290, R-143a/134a, and R-290/134a. Measurements also are being made for R-41 and R-41/744 as potential replacements for R-13. The work consists of simultaneous measurements of the coexisting liquid and vapor densities, compositions, and bubble point pressures over a wide range of temperatures and compositions. These data will be used to determine the mixing parameters, including any temperature and/or composition dependence, for the Carnahan-Starling-DeSantis (CSD) equation of state and an extended corresponding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and virial coefficients; and the critical point parameters. The report describes preparation of samples and initial measurements. It notes that both R-32/290 and R-290/134a exhibited azeotropic behavior. The report discusses the influence of component polarity on prediction of these azeotropes. It also notes that differences in polarity can produce regions of liquid-liquid immiscibility as the temperature is reduced. Figures illustrate the immiscible region on a pressure-composition diagram and the liquid densities against bubble point pressures with immiscibility for a positive azeotrope. Two tables present measured vapor-liquid equilibria (VLE) compositions and pressures as well as coexisting densities for the R-32/134a and R-32/125 mixtures.

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R. W. Yost, **Impact of Alternative Refrigerants on Equipment Design**, unpublished seminar presentation (Winter Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE, Chicago, 28 January - 1 February 1995), ICI Klea, New Castle, DE, January 1995 (22 pages with 21 charts, available from JMC as RDB-5341)

These charts summarize a presentation on the equipment changes needed for alternative refrigerants and associated lubricants. The introduction outlines the objectives of charge reduction, leak reduction, and efficiency improvement, to manage utility loads and address global warming concerns. Four charts identify the selection requirements for alternative refrigerants and new lubricants. The presentation then summarizes the implications of polyolesters and polyalkylene glycols on equipment design. A series of charts review the design changes needed for reciprocating pistons compressors, centrifugal, rotary rolling piston, scroll, and screw compressors to address alternative refrigerants and lubricants. Further charts address considerations for driers, sight glasses, expansion devices, heat exchangers, and use of zeotropic blends. The presentation concludes that the transition has given industry opportunities for advancement, and that the transition has gone "remarkably well."

1995-1996 Research Plan, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1 January 1995 (28 pages with 8 tables, RDB5134)

This list of prospective research subjects identifies 328 proposed projects, 67 designated as *priority* status. The projects are grouped into eight project classifications, based on approved funding guidelines. Projects relating to refrigerants fall in several of these categories, primarily including the third and sixth highest areas, *Environmentally-Safe Materials and Refrigeration Systems*. The research areas were proposed by ASHRAE Technical Committees, Task Groups, and other committees; they were prioritized by ASHRAE's Research and Technical Committee. The highest priority group (*three stars*) includes research of *Thermophysical Properties of Alternative Refrigerants* and to *Develop Solubility and Viscosity Data for Various Oil/Refrigerant Mixtures at High Discharge Temperatures and Pressures*. The next classification includes *Flammability Properties of Alternative Refrigerants, Comprehensive Thermodynamic Property Data for Refrigerant Blends,* and *Develop Corrosion Data with Materials of Construction and New Refrigerant/Lubricants at Various Moisture Levels*. The *one-star* priority group includes *Develop Refrigerant-Lubricant-Desiccant-Moisture Equilibrium Data with New HFC Refrigerants and Relevant Lubricants* and *In Tube Evaporation of Ammonia in Smooth and Enhanced Tubes with Miscible and Immiscible Oils. Biological Degradation of CFCs* is listed as one of two projects in a new priority grouping designated as *high risk*. Among nonpriority projects are *Performance Comparison of Different Refrigerants in Flat-Plate, Microchannel Evaporators, Performance Comparison of Different Refrigerants in Flat-Plate, Microchannel Condensers, Thermophysical Properties of R-23, A Uniform Equation of State for Alternatives to the CFC Refrigerants, Measurement of R-22 and Alternative Refrigerant Leakage Rates from Open-Shaft Compressors, Double-Walled Heat Exchangers for Class 2 Refrigerants, and Heat and Mass Transfer Additives in Aqua Ammonia Systems*. Further projects will examine *Evaporation of Ammonia Outside Smooth and Enhanced Tubes with Miscible and Immiscible Oils, Boiling and Two-Phase Flow of Ammonia and Ammonia/Oil Mixtures in Corrugated Passages Simulating a Plate Heat Exchanger, Investigation of a Theoretical Method to Predict Solubility of Refrigerant/Oil Solutions at Several Temperatures and Pressures, Develop Solubility and Viscosity Data for Various Oil-Refrigerant Mixtures at High Discharge Temperatures and Pressures, Separating Velocities for Ammonia in Horizontal and Vertical Vessels, Laboratory Verification of Modeling Transients in Refrigerant Lines, and Refrigerant Piping Pressure Drop Computer Programs*. This plan summarizes anticipated funding and procedures for implementing the research identified; it replaces versions published for preceding years [see RDB4679).

Genetron(R) 407C Product Brochure, bulletin G525-013, AlliedSignal Incorporated, Morristown, NJ, January 1995 (16 pages with 1 figure and 7 tables, RDB5339)

This bulletin supplies information on R-407C, a zeotropic blend of R-32, R-125, and R-134a - R-32/125/134a (23/25/52). It was designed to replace R-22 in existing and new equipment including unitary air-conditioners, chillers without flooded evaporators, and commercial refrigeration. The document outlines potential applications and provides physical property information. The data include the chemical name and formula, appearance, molecular weight, normal bubble and dew point temperatures, corresponding heat of vaporization and vapor density, critical parameters (temperature, pressure, specific volume, and density), and flammability. The data also include the bubble and dew point pressure, liquid density, and the vapor and liquid heat capacity, thermal conductivity, and viscosity at 25 °C (77 °F). The bulletin then presents product specifications, provides a pressure-temperature table, and reviews servicing considerations. It describes tests and indicates that R-407C is stable with metals (aluminum, copper, and steel). The text refers inquiries on desiccants to drier manufacturers. It lists suitability indications for 27 elastomers and plastics. The bulletin suggests use of polyolester lubricants, but indicates that compressor and lubricant manufacturers should be contacted for specific recommendations. It then reviews safety information, addressing general toxicity, inhalation effects, skin and eye contact, responses to leaks, flammability, combustibility, and thermal stability. The bulletin offers guidance for storage, handling, leak detection, retrofit, recycling, reclamation, and disposal. It also provides tabular thermodynamic properties (bubble and dew point pressures, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -30 to 70 °C (-60 to 160 °F). The data are provided in both inch-pound (IP) and metric (SI) units. AlliedSignal's product name for R-407C is Genetron(R) 407C. [see RDB5A31 for revised property data]

Genetron(R) AZ-20 Product Brochure, bulletin G525-012, AlliedSignal Incorporated, Morristown, NJ, January 1995 (16 pages with 2 figures and 7 tables, RDB5338)

This bulletin supplies information on R-410A, a patented blend of R-32 and R-125 - R-32/125 (50/50) - that behaves like an azeotrope. It was designed to replace R-22 in a variety of new equipment including unitary air-conditioners, chillers, and commercial refrigeration. The document outlines potential applications and provides physical property data including the chemical name and formula, appearance, molecular weight, normal boiling point, corresponding heat of vaporization and vapor density, critical parameters (temperature, pressure, specific volume, and density), and flammability. It also indicates the liquid density, vapor pressure, and the vapor and liquid heat capacity, thermal conductivity, and viscosity at 25 °C (77 °F). The bulletin then presents product specifications, provides a pressure-temperature table, and reviews servicing considerations. A table summarizes the stability of R-410A with polyolester lubricants and metals (aluminum, copper, and steel). The text refers inquiries on desiccants to drier manufacturers, but provides a solubility plot for water in R-410A and lists suitability indications for 27 elastomers and plastics. The bulletin suggests use of polyolester lubricants, but indicates that compressor and lubricant manufacturers should be contacted for specific recommendations. It then reviews safety information, addressing general toxicity, inhalation effects, skin and eye contact, responses to leaks, flammability, combustibility, and thermal stability. The bulletin offers guidance for storage, handling, leak detection, retrofit, recycling, reclamation, and disposal. It also provides tabular thermodynamic properties (pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -30 to 70 °C (-60 to 160 °F) [tables cover dissimilar ranges for the two sets of units]. Formulae are presented to calculate thermodynamic properties, including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. The data are provided in both inch-pound (IP) and metric (SI) units. AlliedSignal's product name for R-410A is Genetron(R) AZ-20.

1995 (month not indicated)

A. Abdul-Razzak, M. Shoukri, and J-S. Chang (McMaster University, Canada), **Measurement of Two Phase Refrigerant Liquid-Vapor Mass Flow Rate**, final report for 722-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1995 (RDB6367)

refrigerant mass-flow rate, instrumentation

M. A. Anisimov, E. E. Gorodetskii, V. D. Kulikov, A. A. A. Povodyrev, and J. V. Sengers (University of Maryland), **A General Isomorphism Approach to Thermodynamic and Transport Properties of Binary Fluid Mixtures Near Critical Points**, *Physica A*, 220:277-324, 1995, plus erratum, 223:272, 1996 (49 pages with 4 figures, RDB6407)

equation of state (EOS), critical point

R. Brinkmann (York International GmbH, Germany), **Influence on the Transition of Chlorofluorocarbons to Alternative Refrigerants**, *Ki Luft- und Kältetechnik*, 31(10):472-474, 1995 (3 pages in German, RDB6310)

technical, economic, and safety considerations; refrigerant selection

Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, **List of MAK and BAT Values 1995: Maximum Concentrations and Biological Tolerance Values at the Workplace**, report 31, Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Bonn, Germany; VCH Verlagsgesellschaft mbH, Weinheim, Germany, 1995 (RDB6938)

English language version of the *MAK- und BAT-Werte-Liste*; maximale Arbeitsplatz Konzentration [maximum workplace concentration] and biologischer Arbeitsstoff-Toleranz-Wert [biological tolerance value]; German occupational exposure limits for chemicals for approximately 600 chemicals including R-11, R-12, R-12B2, R-13, R-21, R-22, R-114, R-123, R-142b, R-E170, R-290, R-600, R-600a, R-610, R-611, R-717, R-744, R-744, R-764, R-7146, and others; classification of carcinogenic, embryotoxicant, and sensitizing substances

International Union of Pure and Applied Chemistry (IUPAC) Commission on Atomic Weights and Isotopic Abundances, **Atomic Weights of the Elements 1993**, *Journal of Physical and Chemical Reference Data*, 24(4):1561-1575, 1995 (15 pages with 2 tables, RDB6303)

definitive atomic weights used to calculate the molecular mass of refrigerants; superseded (see RDB7B48)

H. Kaiser, **Entwicklung und Erprobung eines Prototypenverdichters für Kohlendioxid** [Development and Test of a Prototype Compressor for Carbon Dioxide], *Neu CO_2-Anwendungen in der Kälte- und Klimatechnik* [New Carbon Dioxide Applications in Refrigeration and Air Conditioning] (proceedings of FKW seminar XVII), Forschungszentrum für Kältetechnik und Wärmepumpen GmbH (FKW), Hannover, Germany, 1995 (in German, RDB8351)

modification of an open, two-cylinder, reciprocating-piston compressor (Bock FKX3*CO2) with reed valves, derived from an R-134a design, for use with R-744 (carbon dioxide): major parts other than the crankshaft were reinforced and the displacement was reduced by 75% - as reported in RDB8348

S. M. Sami and P. J. Tulej (University of Moncton, Canada), **A New Design for an Air-Source Heat Pump Using a Ternary Mixture for Cold Climates**, *Heat Recovery Systems and CHP,* 15(6):521-529, 1995 (9 pages with 17 figures, RDB6743)

performance analysis of an air-to-air heat pump using R-23/22/152a (>20/50/<30), identified as NARM/UM, proposed for use in cold regions; paper presents experimental set up and reports field tests of 6 units; plots show calculated coefficients of performance (COPs) and operating parameters; reports an average heating-mode COP of 1.57

S. M. Sami and M. A. Comeau (University of Moncton, Canada), **Development of a Simulation Model for Predicting Dynamic Behaviour of Heat Pump with Nonazeotropic Refrigerant Mixtures**, *International Journal of Energy Research* (IJER), 16:431-444, 1995 (14 pages with 11 figures, RDB-6716)

lumped parameter model to predict the dynamic behavior of heat pumps using zeotropic blends as refrigerants; presents the mathematical formulation of the model based on mass, momentum, and energy balances; effects of flow regimes and dynamic phase changes; comparison of predicted and experimental power consumption, pressures, and temperatures for R-22/114 (80/20) and (60/40) and for R-22/152a (80/20)

S. M. Sami and Y. Zhou (University of Moncton, Canada), **Numerical Prediction of Heat Pumps' Dynamic Behavior Using Ternary Nonazeotropic Refrigerant Mixtures**, *International Journal of Energy Research* (IJER), 1995 (rdb4C12)

zeotropic blends, performance

S. M. Sami and P. J. Tulej (University of Moncton, Canada), **Performance of Residential Refrigerators with Ternary Blends**, *International Journal of Energy Research* (IJER), 19:631-637, 1995 (RDB-6742)

drop-in performance tests of R-22/152a/114 (53/19/28) identified as *MP33*, R-22/152a/124 (47.4/15.7/36.9) identified as [a developmental formulation of] *MP39,* R-23/22/152a (5/65/30) identified as *NARM-12,* R-23/22/124 (5/60/35), identified as *NARM-12/124,* R-23/22/134a (5/-40/55) identified as *NARM-12/134a* in a domestic refrigerator using a mineral oil lubricant; provides plots of and discusses operating parameters and performance; concludes that R-23/22/152a (5/65/30) "could be considered as a 'drop-in replacement' for CFC-12, in domestic refrigerators"

J. Süß and H. H. Kruse, **Energetische Untersuchungen eines Verdichters für Kohlendioxid** [Investigation of the Efficiency of a Compressor for Carbon Dioxide], *Die Kälte- und Klimatechnik,* Germany, 48(7):494-504, 1995 (11 pages in German, rdb8350)

modifications and performance tests of an open, two-cylinder, reciprocating-piston compressor (Bock FKX3*CO2) with reed valves, derived from an R-134a design, for use with R-744 (carbon dioxide): major parts other than the crankshaft were reinforced and the displacement was reduced by 75% - as reported in RDB8348

W. Wei, **Studies on General Vapor Pressure of Equation of Fluids and Experimental Measurement of PVTx Properties for HFC134a/HFC152a**, masters degree dissertation, Xi'an Jiaotong University, China, 1995 (rdb6815)

thermodynamic properties of R-134a/152a blends; thermophysical data

1995-1996 Threshold Limit Values for Chemical Substances in the Work Environment, *1995-1996 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1-54 and notes, 1995 (54 of 144 pages with 4 tables and 4 appendices, available from ACGIH for $11.00, RDB5901)

This book provides data for use as guidelines or recommendations in the control of potential hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document also lists intended changes and provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter. The refrigerants addressed include R-11, R-12, R-13B1, R-20, R-21, R-22, R-30, R-40, R-113, R-114, R-115, R-160, R-160B1, R-170 (ethane), R-290 (propane), R-600 (butane), R-601 (pentane), R-610, R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-1150, R-1270, R-7146 (sulfur hexafluoride), and others.

Addenda to Number Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34a-o and 34q-s (Addenda to ANSI/ASHRAE 34-1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1995 (20 pages with 2 tables, RDB6101)

This cumulative addendum combines addenda a through o, addenda q through s, and errata sheet number 1 to ANSI/ASHRAE Standard 34-1992. The errata correct a conversion error in the metric units for flammability classifications. The addenda provide a designation distinction for zeotropic blends having the same components in different proportions, expand the applicability of dual classifications (as formulated and worst case of fractionation) to azeotropes, and add new definitions. The last address acute toxicity, azeotropic temperature, cardiac sensitization, ceiling (as in exposure limits), chronic toxicity, committee, maximum temperature glide, ppm, permissible exposure level (PEL), short-term exposure limit (STEL), and Workplace Environmental Exposure Limit (WEEL). The addenda clarify that concentrations identified as "ppm" for safety classifications are "ppm by volume", expand the purpose, and provide detailed instructions for designation and classification applications. They also modify the designation system for miscellaneous organic compounds as well as inorganic compounds, and add a new reference. Composite tables remove the "provisional" notation previously appended to some safety classifications, correct a number of chemical names for consistency with the International Union of Pure and Applied Chemistry (IUPAC) conventions, correct informational (not part of the standard) data on refrigerants, and add safety classifications for R-23, R-32, R-116, R-124, R-125, R-143a, and R-218. The addenda also add designations, tolerances, and safety classifications for R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-408A, R-409A, R-410A, R-410B, R-411A, R-411B, R-412A, R-507, R-508, and R-509. A foreword and table identify the changes by specific addendum.

FRIGC(R) FR-12(TM) Specifications, InterCool Energy Corporation, Latham, NY, 1995 (2 pages with 1 figure and 2 tables, limited copies available from JMC as RDB5A41)

This product specification sheet provides data on a ternary zeotropic blend of R-124, R-134a, and R-600 - R-134a/124/600 (59/39/2) - in inch-pound (IP) and metric (SI) units of measure. The blend is described as a replacement for R-12 in mobile air-conditioning (MAC) applications. The bulletin indicates that the blend operates in the same pressure range as R-12, even at high ambient temperatures, and is compatible the mineral oil used in MAC compressors. A table summarizes selected physical properties including the normal bubble and dew points, corresponding vapor densities, latent heat of vaporization, and critical parameters (temperature, pressure, and density). It also includes the vapor pressure, solubility in water, and the liquid and vapor thermal conductivities and heat capacities at 25 °C (77 °F). It concludes with the ozone depletion potential (ODP), global warming potential (GWP), and flammability limits (indicated as none). The product sheet then discusses service considerations including charging and recovery. It briefly reviews compatibility findings with plastics, elastomers, metals, desiccants, and lubricants as well as leak detection. A table and plot compare the vapor pressure for the blend at its bubble and dew points to that for R-12 at -7 to

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93 °C (20-200 °F). InterCool Energy Corporation's product name for this blend is FRIGC(R) FR-12(TM).

Guide to Occupational Exposure Values - 1995, publication 0373, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1995 (132 pages, rdb5902)

This reference document compares the most recent concentrations for widely cited toxicity exposure limits. It includes Threshold Limit Values (TLV) from the American Conference of Governmental Industrial Hygienists (ACGIH), Permissible Exposure Limits (PEL) from the Occupational Safety and Health Administration (OSHA), the Recommended Exposure Limits (REL) from the National Institute for Occupational Safety and Health (NIOSH), and the 1989 maximale Arbeitsplatz Konzentration [maximum workplace concentration] (MAK) and biologischer Arbeitsstoff-Toleranz-Wert [biological tolerance value] (BAT) from the Deutsche Forschungsgemeinschaft [German Research Association] (DFG) Commission for the Investigation of Health Hazards of Chemical Compounds in the Workplace. It also identifies carcinogens found in the workplace that are identified by the above organizations, the International Agency for Research on Cancer (IARC), the U.S. National Toxicology Program (NTP), and the U.S. Environmental Protection Agency (EPA). The refrigerants addressed include R-11, R-12, R-12B2, R-21, R-22, R-30, R-40, R-114, R-115, R-170 (ethane), R-290 (propane), R-600 (butane), R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-7146 (sulfur hexafluoride), and others.

Refrigerants (SBQT2), *Supplement to the 1995 Editions of the Recognized Component Directory and Plastics Recognized Component Directory*, Underwriters Laboratories Incorporated (UL), Northbrook, IL, 222, 1995 (1 page, RDB5C10)

These supplemental listings cover refrigerants intended for use as components of air-conditioning and refrigerating equipment. The refrigerants have been evaluated for flammability and toxicity as specifically indicated for individual products; pressure hazards were not evaluated. The supplemental listings cover product versions of R-123, R-134a, and R-508B. The listings indicate the UL flammability group (nonflammable, practically nonflammable, or flammable) at 100 °C (212 °F). They also indicate the chemical constituents, phase as shipped, and container markings.

Refrigerants (SBQT2), *Recognized Component Directory*, Underwriters Laboratories Incorporated (UL), Northbrook, IL, 2:1572-1574, 1995 (3 pages, RDB5931)

These listings cover refrigerants intended for use as components of air-conditioning and refrigerating equipment. The refrigerants have been evaluated for flammability and toxicity as specifically indicated for individual products; pressure hazards were not evaluated. The listings cover product versions of R-11, R-12, R-22, R-23, R-113, R-114, R-115, R-123, R-125, R-134a, R-401A, R-401B, R-402A, R-402B, R-404A, R-407A, R-407B, R-407C, R-408A, R-409A, R-410A, R-410B, R-500, R-502, R-503, R-507A, and R-22/152a/124 (40/17/43). The listings indicate the UL flammability group (nonflammable, practically nonflammable, or flammable) at 100 °C (212 °F) as well as the UL toxicity group (1-6) in the absence of flames or hot objects, which may result in decomposition. They also indicate the chemical constituents, phase as shipped, and container markings.

Status Report on the Development of HFC-245fa, A Non-Flammable Liquid Blowing Agent, AlliedSignal Incorporated, Morristown, NJ, 1995 (29 charts, RDB5C94)

R-245fa, physical properties, environmental data, toxicity (4-hr LC_{50} >200,000 ppm, cardiac sensitization >20,000 ppm, no toxicity at 100,000 ppm), compatibility, foaming characteristics, trial as a foam blowing agent, foam aging effects

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S. Baliunas (George C. Marshall Institute), **Ozone and Global Warming: Are the Problems Real?**, West-Coast Roundtable on Science and Public Policy, 13 December 1994 (22 pages with 6 figures, RDB7536)

presentation transcript argues that scientific findings suggest that anthropogenic chemicals, including chlorofluorocarbons (CFCs), have not eroded the ozone layer, that there has not been an increase in global temperature to correspond to increased use of fossil fuels, and that federal regulations to address these issues is both economically devastating and scientifically irresponsible

J. J. Byrne (Integral Sciences, Incorporated, ISI), **Investigation of Flushing and Clean-Out Methods for Refrigeration Equipment to Ensure Sys-**

tem Compatibility, report DOE/CE/23810-51F, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 December 1994 (16 pages with 2 tables, available from JMC as RDB-5803)

This report addresses a procedure to remove mineral oil from a refrigeration system for conversion to R-134a. It notes that R-134a is immiscible with the oil, leading to impeded oil return and interference with refrigerant flow and heat transfer. The method uses a low-side, oil separator to prevent oil from contaminating the new polyolester (POE) lubricant. It is described as requiring less time and materials compared to the prevailing "triple-flush" approach, without compromising the reliability of the result. The report describes a 12 kW (3 ton) test system, employing a bolted hermetic reciprocating-piston compressor. It also describes the system preparation and oil measurement methods used. It then outlines both the triple-flush and advanced methods. The report notes that the advanced method requires increased effort to install and remove additional components, but eliminates two site visits. It notes a second drawback of transfer of most of the oil from high-side separators to the system, a problem circumvented with use of 99.994% efficient separators. The report describes and a table compares the materials and labor for a "triple flush" and three variants of the advanced method. A second table adds comparisons of the waste generated and site visits required. The low-side, oil separator method shows cost savings of 5-15%. The report identifies three planned field tests, two with R-12 to R-134a and a one entailing an R-502 conversion.

W. Goetzler and H. Ozog (Arthur D. Little, Incorporated, ADL), **Risk Assessments for Flammable Refrigerants**, paper 7.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 181-186, December 1994 (6 pages with 2 figures, RDB5433)

R-32, R-152a, flammability, zeotropic blends, fractionation, safety, refrigerator, air conditioning

D. P. Grob (Underwriters Laboratories, Incorporated), **Current Status for UL 2182, Flammability Testing of Refrigerant Blends for Flammability Rating**, paper 7.2-1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 168-173, December 1994 (6 pages, RDB5431)

flammability, blends, fractionation, safety

H. Hirano, H. Kawano, Y. Watanabe, H. Fukuoka, and A. Miyazaki (Matsushita Electric Industrial Company, Limited, Japan), **Evaluation of Lubricants for HFC Refrigerants**, paper 6.4, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 150-155, December 1994 (6 pages with 13 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5428)

naphthenic mineral oil, alkylbenzene, polyolester, ether, and carbonate lubricants, additives, lubricity, rotary rolling-piston compressor

S. Komatsu and K. Yamamoto (Sanden Corporation, Japan), **Performance of Chest Freezer with R125/143a/134a**, paper 3.5, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 68-71, December 1994 (4 pages with 13 figures and 2 tables; in Japanese with abstract, figures, and tables in English; RDB5414)

performance test of R-404A [R-125/143a/134a (44/52/4)] without system optimization

S. L. Kwon, J. Berge, and L. Naley (Thermo King Corporation), **Evaluations of Alternatives for Transport Refrigeration**, paper 3.6, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 72-77, December 1994 (6 pages with 1 figure and 3 tables, RDB5415)

This paper reviews the requirements for R-22 and R-502 alternatives for transport refrigeration, describes a test program to evaluate 12 candidates, and presents a tabular summary of the findings. Four lists, in outline format, describe the methods of refrigerating commodities during transport, application requirements for general purpose transport equipment, performance criteria for alternative refrigerants, and a

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process for screening refrigerants for transport refrigeration. Notes differentiate between transport (e.g., highway, intermodal, marine, or straight truck) and stationary (e.g., storage or supermarket) refrigeration. A table contrasts the differences between supermarket and transport factors. The paper then discusses refrigerant selection criteria with attention to safety and thermodynamic requirements, discharge vapor temperature, discharge pressure, and compatibility - in terms of capacity, service, and reliability - with existing equipment. The paper briefly describes a test program and schematically shows the system used for laboratory tests of alternative refrigerants. The results are tabulated for transitional and long-term replacements, namely those containing hydrochlorofluorocarbons (HCFCs) and those based on hydrofluorocarbons (HFCs). The former include R-402A, R-402B, R-290/22/218 (6/85/9) and (6/74/20), R-290/22/218 (6/55/39), and R-408A. The tested long-term replacements include R-404A, R-407A, R-407B, R-125/143a (45/55), R-507A, and R-32/125/143a (10/45/45). The tables identify the discharge pressure and temperature, energy rate, and capacity normalized to data for R-502 with an alkylbenzene lubricant. Data are presented for R-502 with a polyolester lubricant and for R-22 with liquid injection and an alkylbenzene lubricant for comparison. The ambient and box temperatures, based on tests following ARI Standard 1110-92, are indicated. The conclusions note that some of the alternatives that may be acceptable for supermarket use are unacceptable for transport refrigeration, due to their higher discharge temperatures. With redesign, the higher discharge pressures may be accommodated and modifications can improve the efficiency in most systems. The paper also concludes that R-404A is the leading alternative from the standpoint of performance, as confirmed by extended field trials. [The blend identified as R-290/22/218 (6/74/20) also is identified as R-403A in the paper; R-403A is R-290/22/218 (5/75/20). The blend identified as R-290/22/218 (6/55/39 also is identified as R-403B in the paper; R-403B is R-290/22/218 (5/56/39).]

K. Marumoto and N. Nakagawa (Matsushita Refrigeration Company, Japan), **Composition Shift of R32/125/134a in Multiple Air-Conditioning System**, paper 4.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 88-93, December 1994 (6 pages with 14 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5418)

R-407C, R-32/125/134a, capacity modulation by composition management, composition change, simulation, zeotropic blend, multisplit (multicoil) air conditioner

K. Maruo (Daikin Industries, Limited, Japan), **The Development of CFC and HCFC Alternatives for Refrigerant**, paper 1.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 1-6, December 1994 (6 pages with 5 figures and 6 tables; in Japanese with abstract, figures, and tables in English; RDB5401)

CFC, HCFC, HFC, alternatives, refrigerant, ODP, GWP, TEWI, PAFT, AFEAS

A. Matsui (Kobe Steel, Limited, Japan), **As to Drop-In Test of R-32/125/134a in Screw Chiller**, paper 3.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 47-51, December 1994 (5 pages with 10 figures and 1 table; in Japanese with abstract, figures, and table in English; RDB5410)

This paper summarizes a drop-in performance test of R-32/125/134a (32/10/60) (sic, probably 30/10/60) in a water-cooled chiller, with and without an economizer. The zeotropic hydrofluorocarbon (HFC) blend yielded a 10% lower coefficient of performance (COP) than R-22, attributed to degraded heat exchanger performance. Plots show the chiller configuration, flow schematic, compressor volumetric and adiabatic efficiency as functions of the entering temperature, and the overall heat transfer coefficients, heat fluxes, and superheat for the condenser and evaporator. Additional plots compare the R-22 and blend capacities, input powers, and COPs as functions of the chilled water temperature both with and without a single-stage economizer. Ratios are tabulated for these data at 7 °C (45 °F). The economizer appears to increase capacity and performance by 5.7 and 3.4%, respectively, with the blend and 3.4 and 1.7% with R-22.

M. Nakayama, H. Iijima, and Y. Tanimura (Mitsubishi Electric Corporation, Japan), **R32/125/134a Cycle Composition Change and its Effect on the**

System Performance, paper 4.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 79-83, December 1994 (5 pages with 10 figures and 1 table; in Japanese with abstract, figures, and tables in English; RDB5416)

This paper examines the performance changes in an inverter-driven heat pump using R-407C. The nominal 23% mass fraction was found to increase to 27.8% as surplus refrigerant was retained in the accumulator, resulting in a 6% increase in heating capacity. The test facility is shown schematically and test conditions are tabulated. Plots show the composition shifts of the components with refrigerant accumulation. Further plots show the changes in suction and discharge pressure as well as the capacity at both low and high speed heating operation, 30 and 90 Hz respectively, with accumulation. Capacity and coefficient of performance (COP) ratios are plotted for increasing surplus refrigerant ratios for both the heating and cooling modes. Two final plots compare measured and predicted heating capacity and COP with changes in the circulating R-32 fraction.

H. Namiki (Mayekawa Manufacturing Company, Limited, Japan), **The Trends in Ammonia for Industrial Refrigeration Plants**, paper 3.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 57-62, December 1994 (6 pages with 4 figures and 12 tables; in Japanese with abstract, figures, and tables in English; RDB5412)

This paper describes the development of a new industrial refrigeration system using R-717 (ammonia) as the refrigerant. The development objectives are noted as a system that is entirely leak proof, uses a minimum amount of refrigerant, and can be operated automatically. Key features of the new system are use of a polyalkylene glycol (PAG) lubricant, a direct-expansion evaporator, and a compressor with a "canned motor." Environmental and performance advantages as well as safety concerns are cited for ammonia. A table summarizes the common refrigerants and alternatives used in selected, large-scale industrial refrigeration systems along with the applicable temperature ranges and cooling media. Two further tables list the merits and concerns for ammonia and compare its properties with those of R-22. Plots compare the capacity and coefficients of performance (COPs) for the two refrigerants as functions of evaporating temperatures. A table outlines the challenges of reducing the refrigerant charge, minimizing leakage, and achieving operational safety and high efficiency. Three tables give the characteristics of the PAG, compare its solubility and fluidity to a naphthenic mineral oil, and similarly compare effects on heat transfer. Schematics show the canned-motor drive integration with a reciprocating-piston compressor as well as the system. Tables describe the key component specifications and summarize key parameters for use in cold storage, food processing, marine refrigeration, and air conditioning. The paper describes the resulting system as safe, environmentally friendly, and efficient.

K. Oguni, K. Urata, and H. Matsushima (Hitachi Limited, Japan), **Characteristics of Refrigeration System Utilizing Refrigerant Mixture R32/125/-134a**, paper 4.2, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 84-87, December 1994 (4 pages with 7 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5417)

This paper outlines a capacity modulation method by composition control using R-32/125/134a - a zeotropic blend to replace R-22 - in an air-to-air heat pump. The concept is based on alternate storing of excess liquid refrigerant in the low and high pressure sides of the refrigeration circuit. By holding refrigerant on the low side, in the accumulator, the circulating refrigerant becomes richer in R-32. When stored in a receiver on the high side, the R-32 fraction is decreased. Schematics show the refrigerant mixture phase equilibria with composition change, the basic cycle on a pressure-enthalpy chart, and the experimental equipment tested. The equipment specifications and test conditions are tabulated. Plots show the component changes in circulating refrigerant with accumulation and changes in refrigerant phase quality. Predicted and measured fractions are tabulated and the capacity, coefficient of performance (COP) and discharge pressure shifts are plotted. The results show a 10% increase in COP for both heating and cooling with composition management.

R. S. Ohling, **Ammonia: The New/Old Refrigerant**, *ASHRAE Journal*, 32(12):36-42, December 1994 (7 pages, RDB4B65)

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R-717

S. R. Szymurski (Air-Conditioning and Refrigeration Technology Institute, ARTI), **Materials Compatibility and Lubricants Research (MCLR) Program,** paper 4.4, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 94-99, December 1994; republished as report DOE/CE/23810-49, ARTI, Arlington, VA, December 1994 (8 pages with 1 table, available from JMC as RDB5210)

This paper highlights accomplishments of the Materials Compatibility and Lubricants Research (MCLR) Program and outlines individual projects including new ones to be conducted in the final phase. It briefly reviews the introduction of alternative refrigerants, to replace those that deplete the ozone layer, and the consequent research needs to evaluate and test the new fluids. The paper outlines early projects to obtain thermophysical properties and equations of state (EOS), theoretical evaluations R-22 and R-502 alternatives, chemical and thermal stability of refrigerants and lubricants, miscibility of lubricants in refrigerants, and compatibility with motor materials, elastomers, and engineering plastics. Two tables identify the property and compatibility studies performed by refrigerant. The paper also cites three projects to develop accelerated screening methods for chemical and thermal stability, evaluate lubricant performance, predict the life of motor materials, and investigate electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants. On-going research projects are identified for the current third phase. They include compatibility of manufacturing process fluids with hydrofluorocarbon (HFC) refrigerants and ester lubricants, effects of lubricant additives on HFC refrigerant stability, compatibility problems resulting from the products of motor burnouts, and investigation into the fractionation of refrigerant blends. They also include investigation of flushing and clean-out methods after motor burnout, methods development for measuring and classifying flammability and combustibility of refrigerants, and thermophysical properties measurements for R-41, R-245ca, and a number of binary and ternary blends. The paper outlines projects planned for the final phase, including those to determine system contaminant levels, measure how the solubility and viscosity of lubricants affect oil return, and investigate lubricant foaming characteristics. Two studies will examine compatibility and potential of R-245ca as a low-pressure refrigerant and assess its flammability risk. Two related projects will measure the flammability of marginally flammable refrigerants and develop test methods for flammability in equipment applications. A series of projects will evaluate the potential of promising new compounds and transform materials compatibility test methods into national or international standards. The paper concludes that much has been accomplished by the MCLR program, but more work still remains. The research is jointly supported by a grant from the Department of Energy and cost sharing by the Air-Conditioning and Refrigeration Institute (ARI).

T. E. Watson (McQuay International), **ASHRAE Standards and Alternative Refrigerants**, paper 7.4, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 187-192, December 1994 (6 pages with 1 figure and 5 tables, available from JMC as RDB5103)

This paper presents an overview of the ASHRAE standards for refrigerant and refrigeration safety. It also discusses potential changes to address alternative refrigerants. The paper describes the role of Standard 34, *Number Designation and Safety Classification of Refrigerants*, in providing an unambiguous numbering system and safety classifications for refrigerants. It outlines this classification system, illustrates the six safety groups in a matrix of increasing toxicity and flammability, and explains the dual classifications - as formulated and worst case of fractionation - for zeotropic blends. The paper then describes Standard 15, noting that the latest revision has been written in code language to accelerate its adoption in building regulations. It notes that the requirements are based on three classifications, namely occupancy, system leak probability into occupied space(s), and refrigerant safety (from Standard 34). A table summarizes application requirements based on these three classifications. A second table indicates the maximum allowed quantities without location of equipment in a specified machinery room. The paper then discusses future considerations, identifying increased attention to acute toxicity of refrigerants. It also notes a coordinated effort between Standards 15 and 34 to make the latter the definitive source of safety and property data for refrigerants and the former the standard for application requirements. It discusses data needs and issues being addressed, including thermodynamic property data, the definition of "azeotropic," refinement of flammability criteria, and pressure relief valve calculations for blends. Two tables illustrate the data for R-407C and proposed "f factors" for relief valve sizing for R-22, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-407C, R-502, and R-507A.

November 1994

J. M. Calm (Engineering Consultant), **Copper in Air Conditioning and Refrigeration - Supplement to the ARTI Refrigerant Database**, report JMC/-ARTI/CDA-9411D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, and the Copper Development Association (CDA), New York, NY, November 1994 (44 pages, available from JMC as RDB4B15)

This document provides bibliographic citations for more than 200 publications that may be useful in research, design, and application of air-conditioning and refrigeration (ACR) equipment. Synopses of the content, materials addressed, and key conclusions are provided for more than a third of these documents. This supplement to the Refrigerant Database increases the information provided, by focusing on the suitability of and application data for copper and copper alloys with refrigerants. The key concentration areas are application data, compatibility, and heat transfer (including surface enhancement). An introduction outlines the reasons copper is the preferred fabrication material in many ACR components. A concluding section provides descriptions of both the Refrigerant Database and the Copper Data Center (CDC) database.

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-48F, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 30 November 1994 (268 pages, available from JMC as RDB4B70)

This document provides bibliographic citations for 1871 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately a third of these documents. The database identifies sources of specific information on R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-408A, R-409A, R-410A, R-411A, R-411B, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507, R-508, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes the same citations and abstracts as the report version plus 203 from a supplement on copper in air conditioning and refrigeration, 216 for superseded and historical documents, data summaries for 244 refrigerants (single compound and blends), and 33 tabular compatibility summaries for plastics and elastomers - a total of 2351 entries. It is accompanied by retrieval software to facilitate searches for specific information; the software enables searches for user-selected terms, or combinations of terms. It offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, and a "wildcard" capability to allow entry of word segments. The software also enables printing of selected citations, abstracts, and data summaries as well as preparation of a document order lists. Both versions of the database include instructions to obtain cited documents or subscriptions for updates to the database.

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Compatibility of Manufacturing Process Fluids with HFC Refrigerants and Ester Lubricants**, report DOE/CE/23810-43, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, November 1994 (38 pages with 4 missing figures and 13 tables, available from JMC as RDB5650)

This report introduces a project to compile a list of and evaluate the process fluids used in the manufacture of compressors and other components for air-conditioning and refrigeration equipment. The objective is to develop guidelines for selection of those that are compatible with hydrofluorocarbon (HFC) refrigerants and polyolester (POE) lubricants. The report presents a partial list and discuses an analytical methodology in terms of observed immiscibility in HFC/POE solutions. The list includes brazing fluxes, cleaning agents, degreasers, detergents, coolants, iron phosphatizers, processing and assembly lubricants, rust inhibitors, rust preventatives, sealants, and other compounds.

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The report also lists seven replacements for selected materials that are no longer sold.

J. Kosko, **Fact Sheet: Energy Performance of Ternary Refrigerant Mixtures**, press release, National Bureau of Standards (NBS), Gaithersburg, MD, 29 November 1984 (2 pages, available from JMC as RDB1209)

This press release summarizes research of the characteristics and performance of refrigerant mixtures in heat pumps. It indicates a general finding that blends can increase the heating efficiency of a conventional, residential heat pump by as much as 30%. The bulletin outlines the history and sponsorship of this work. It also discusses property measurements and computer programs developed to assist manufacturers in blend evaluations. It then reports on a specific evaluation, performed at the request of the U.S. Department of Energy (DOE), of R-22/12/142b. This ternary zeotropic blend is commercially identified as "R-176". The press release outlines two laboratory tests to measure heating and cooling capacity and efficiency. It reports that the heating and cooling capacities, total of sensible and latent for the latter, were 40-45% less for R-22/12/142b than with R-22. The efficiencies were found to be 10-24% and 5-13% lower for heating and cooling, respectively. The bulletin concludes with discussion of the reasons identified for these findings, attributed to the lower heat of vaporization per unit volume of vapor for "R-176." It notes that in certain systems, particularly those with undersized heat exchangers, some increase in efficiency may be observed.

S. R. Szymurski, M. Hawley, G. C. Hourahan, and D. S. Godwin, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-48, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, November 1994 (94 pages with 14 figures and 25 tables, available from JMC as RDB5101)

This progress report summarizes the status and key findings of the Materials Compatibility and Lubricant Research (MCLR) Program. The program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. Primary elements include data collection and dissemination, materials compatibility testing, and methods development. This work is jointly funded under a grant from the Office of Building Technology of the U.S. Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program began in September 1991 and will run through September 1996. The report provides descriptions for each of 24 projects, highlighting their objectives and results. Those underway will measure thermophysical properties of one single-compound and nine blends as HCFC alternatives; measure the viscosity, density, and solubility for three azeotropic and zeotropic blends to replace R-22 and R-502; and obtain compatibility data on 16 desiccants with 13 refrigerant-lubricant mixtures. Three others will examine the compatibility of 52 manufacturing process fluids with hydrofluorocarbon (HFC) refrigerants and two ester lubricants, motor materials with alternative refrigerants and lubricants for retrofit, and products resulting from motor burnouts. The report also summarizes projects to develop accelerated screening and test methods to predict lubricant performance in compressors, the life of motor materials exposed to refrigerant-lubricant mixtures, and chemical and thermal stability of refrigerant lubricant mixtures. Four others will develop alternative flushing and clean-out methods, investigate the fractionation of refrigerant blends, develop methods to measure and classify the flammability and combustibility of refrigerants, and a new project to locate and consolidate information on the toxicity of alternative refrigerants. It outlines a continuing project to collect and facilitate dissemination of data, through development and administration of the ARTI Refrigerant Database. The progress report summarizes completed projects to measure thermophysical properties of R-32, R-123, R-124, R-125, R-143a, and R-152a; model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502; test the chemical and thermal stability of refrigerant-lubricant mixtures with metals; measure the miscibility of lubricants with refrigerants; measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures; provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics; and investigate electrohydrodynamic (EHD) enhancement of pool and in tube boiling of alternative refrigerants. This program summary also identifies the research contractors and reports prepared for individual projects. Tables and figures illustrate significant findings of selected projects, including test data on 16 molecular sieves, schematics and measurements for the stability test method, miscibility of lubricants with ten refrigerants, and refrigerant-lubricant viscosity, solubility, and density correlations; sample Daniel charts are included. Two figures compare the modelled performance of alternative refrigerants to the capacities and efficiencies of R-22 and R-502. The equations of state developed for R-32, R-123, R-124, R-125, R-143a, and R-152a are summarized. A table indicates the relative swelling of 17 elastomer groups in refrigerants and lubricants.

Addendum to Number Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34a-34j (Addenda to ANSI/ASHRAE 34-1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, November 1994 (10 pages with 3 tables, RDB-4B71)

This cumulative addendum combines addenda a through j to ANSI/ASHRAE Standard 34-1992 (see RDB2909). The addenda add safety classifications of "*A1 provisional*" for R-124 and R-125, "*A1*" for R-218, "*A2*" for R-32, and remove the "*provisional*" status of prior classifications for R-123 and R-134a. "*Provisional*" classifications *will be reviewed when toxicological testing is completed*. The addenda also add designations for R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, and R-407B. Formulation tolerances and safety classifications, both "*as formulated*" and for the "*worst case of fractionation*", are indicated for each of them. A new azeotrope, R-507A, consisting of R-125/143a (50/50) is recognized and assigned a safety classification of A1. The addendum revises the chemical names listed for 13 refrigerants to be consistent with the nomenclature convention of the International Union of Pure and Applied Chemistry (IUPAC) and includes the text of an earlier errata notice on flammability classifications. The addenda change two subsections of the standard. The first provides for serial letter suffixes to differentiate among zeotropes with the same components (i.e., the same basic number). The second removes the distinction between azeotropic and zeotropic refrigerant blends as regards assignment of dual safety classifications for the "as formulated" and "worst case of fractionation" conditions. This second change provides for future assignment of safety classifications for the "worst case of fractionation" for azeotropes. A foreword summarizes the changes.

DuPont HFC-134a: Properties, Uses, Storage and Handling, bulletin P134a (H-45945-2, 233264C), DuPont Chemicals, Wilmington, DE, November 1994 (32 pages with 10 figures and 20 tables, RDB6739)

This document provides extensive application information for R-134a. It reviews identifiers and potential uses, shows an infrared spectrum for laboratory analyses, compares theoretical performance to R-12, and summarizes physical properties as well as flammability, environmental, and toxicity indices. Plots of solubility in water, pressure-temperature relationships, and vapor thermal conductivity are included. Pressure-enthalpy diagrams, in both inch-pound (IP) and metric (SI) units, are provided. The bulletin reviews chemical and thermal stability data, including thermal decomposition, stability with metals and refrigeration lubricants, stability with foam chemicals, and concerns if mixed with R-12. It then addresses compatibility with plastics, elastomers, desiccants, and refrigeration lubricants. A table summarizes compatibility with plastics including ABS polymer (Kralastic®), acetal (DuPont Delrin®), acrylic (Lucite®), cellulosic (Ethocel®), epoxy, polytetrafluoroethylene (PTFE, DuPont Teflon®), ETFE (Tefzel®), PVDF, ionomer (Surlyn®), nylon 6/6 polyamide (DuPont Zytel®), polyarylate (Arylon®), polycarbonate (Tuffak®), polybutylene terephthalate (PBT, GE Valox®), polyethylene terephthalate (PET, DuPont Rynite®), polyetherimide (GE Ultem®), polyethylene-HD (Alathon®), polyphenylene oxide (PPE, GE Noryl®), polyphenylene sulfide (Ryton®), polypropylene, polystyrene (Styron®), polysulfone (Polysufone®), and polyvinyl chloride (PVC and CPVC). Tabular summaries also are provided for R-134a compatibility with a urethane rubber (Uniroyal Adiprene® L), Buna N, Buna S, butyl rubber, synthetic rubber (DuPont Hypalon® 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel®), silicone rubber, polysulfide rubber (Thiokol® FA), and fluoroelastomer (DuPont Viton® A). These summaries indicate changes in length, weight, Shore A hardness, elasticity, and appearance after exposures at 25 and 80 °C (77 and 176 °F). A table summarizes permeation through elastomeric hoses made of nylon, Hypalon 48, and two nitriles with identified liners, reinforcement, and covers. Solubility data are provided for R-134a in unidentified naphthenic and paraffinic mineral oils, dialkylbenzene, alkylbenzene, polyalkylene glycol (PAG), and ester lubricants. Safety data are then presented including a review of inhalation toxicity, cardiac sensitization, responses to spills or leaks, and skin and eye contact. Flammability data, exposure monitors, and leak detection are discussed as are storage, handling, and shipping. The bulletin concludes with discussion of recovery, reclamation, recycling, and disposal.

October 1994

J. J. Beall (Calpine Corporation), M. C. Adams (University of Utah Research Institute), and P. N. Hirtz (Thermochem, Incorporated), **R-13 Tracing of Injection in the Geysers**, *Transactions,* Geothermal Resources Council, 18:151-159, October 1994 (9 pages with 9 figures and 1 table, RDB8B32)

field tests of R-13 to map flow paths in hydrogeological studies; differences in recovery rates between low- and high-pressure reservoirs and

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those with low and high liquid saturation; suggests that R-13 stays in solution until boiling occurs; consequent detection of high R-13 concentrations identifies wells with potential to produce high injection-derived steam rates; notes that R-12 displayed significant decay in the geothermal field, but that R-13 showed little or none; also notes that the R-12 decay was reduced for some conditions, possibly movement outside an oxidized zone surrounding the injection well or other geochemical conditions

J. Berghmans (Katholieke Universiteit Leuven, Belgium), **Working Fluid Safety**, report HPP-AN20-1, International Energy Agency (IEA) Heat Pump Centre (HPC), Sittard, The Netherlands, October 1994 (162 pages, rdb6B04)

flammability and other hazards from use of refrigerants

F. R. Biancardi (United Technologies Research Center, UTRC), **Investigation into the Fractionation of Refrigerant Blends**, report DOE/CE/-23810-48D (also identified as UTRC R94-970566-2), Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1994 (38 pages with 20 figures, available from JMC as RDB-5256)

This report summarizes the progress of research to investigate composition changes in refrigerant blends. The project entails four technical tasks addressing lubricant solubility effects, fractionation effects from successive charges, fractionation within system components, and fractionation during leaks. The report describes a model based on nonideal, Wohl solution theory to assess lubricant-solubility effects. Published data and measurements of R-32/134a (25/75) with a polyolester (POE) lubricant (Castrol Icematic(R) SW68) at 40 and 90% refrigerant by weight at 21-38 °C (70-100 °F) were used to validate the model. The binary activity coefficients, predicted vapor pressures, and experimental and measured vapor pressures are plotted. The report notes that the model is less accurate at low refrigerant concentrations, and that extrapolation of the results for other blends will require further work not in the present project. The report then outlines analyses of fractionation based on both an isothermal, static equilibrium model for a liquid leak and a more rigorous, dynamic simulation model. The former is described as similar to the effects of equipment charging from a storage tank in an assembly line. A sample mass loss and a composition plot are shown. The transient model addresses heat transfer, tank geometry, tank materials, external cooling, and operating temperature. A schematic and corresponding thermal circuit diagram are provided to explain the model. The results are discussed and illustrated with plots of temperature, tank size, and discharge rate effects. Mass loss, temperature, and composition plots are included for representative cases. A schematic illustrates the sampling approach used for verification. The report then summarizes modeling of fractionation within components for a typical heat pump; the model currently addresses the evaporator, condenser, compressor, and expansion valve. Eight plots show predicted internal fractionation for these components during start-up and at steady state, assuming 0, 50, and 100% of maximum glide and for a system with half the initial refrigerant charge for 0% glide. Preparations for verification measurements are noted. Presentation charts on the objectives, deliverables, and schedule are appended.

R. G. Doerr and T. D. Waite (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials Under Retrofit Conditions**, report DOE/CE/23810-48B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 19 October 1994 (16 pages with 2 tables, available from JMC as RDB4C17)

This progress report introduces a study of the compatibility of materials used in motors, for hermetic compressors, with refrigerants and lubricants under retrofit conditions. The assessment is distinguished from a related study (see RDB3857, RDB3858, and RDB3859) by exposures first to "old" refrigerant-oil mixtures and then to alternative refrigerant-lubricants mixtures. The sequential, 500-hour exposures simulate the effects of retrofit. The report identifies the materials used, test procedures, and sample evaluations and quantities. It summarizes the status of the work, recommendations for further tests, and significant results. Testing was performed in accordance with UL Standard 2171. The old and retrofit combinations were R-11/paraffinic mineral oil (MO, Penreco Sontex 300LT) and R-123/mineral oil (same), R-12/naphthenic MO (Witco Suniso(R) 3GS) and R-134a/polyolester (POE, CPI(R) Solest(R) 68), R-502/MO (Suniso(R) 3GS) and R-404A/POE branched acid (Castrol Icematic(R) SW32), and R-22/MO (Suniso(R) 3GS) and R-407C/POE mixed acids (ICI Emkarate(TM) RL 32H). The magnet wire insulations tested were a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a polyester imide overcoated with polyamide-imide (Phelps Dodge / Schenectady Chemical), and a modified polyester base overcoated with polyamide imide and epoxy saturated glass (Phelps Dodge Armored Poly-Thermaleze Daglass 2000). The varnishes included a water-base epoxy phenolic (Schenectady Isopoxy(R) 800), a solvent epoxy phenolic (P. D. George 923), and a solvent epoxy (Sterling(R) U-475 EH). The sheet insulations tested were a standard polyester film (DuPont Mylar(R) 900 MO), a low oligomer polyester film (ICI Melinex(R) 228), a polyester composite (Westinghouse Dacron-Mylar-Dacron(R)), an aramid fiber mat (DuPont Nomex(R) 410 10 mil), an aramid fiber mica mat (DuPont Nomex(R) Mica 418), and an aramid mat, polyester film composite (Westinghouse Nomex-Mylar-Nomex(R)). The spiral-wrapped sleevings tested were a polyester film (Insulations Sales Mylar(R)) and an aramid mat, polyester film composite (Insulations Sales Nomex-Mylar(R)). The lead wires tested were a polyester composite (A. O. Smith Dacron-Mylar-Dacron(R)) and a polyester, fluoropolymer composite (A. O. Smith Dacron-Teflon-Dacron(R)). Other materials tested were a polyester tie cord (Ludlow Textiles); braided polyester, acrylic binder assembly tape; and polyester mat assembly tape. The tests performed to date generally found the materials exposed to be compatible. Concerns are noted with embrittlement of polyethylene terephthalate (PET) sheet and sleeving insulation as well as delamination and blistering of the Nomex sheet insulation in R-12, R-22, and R-502. Also, the solvent epoxy varnish separated from the metal surface in R-123, possibly due to the condition of the metal surface.

J. E. Field (Spauschus Associates, Incorporated), **Sealed Tube Comparisons of the Compatibility of Desiccants with Refrigerants and Lubricants**, report DOE/CE/23810-48C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1994 (98 pages with 67 tables, available from JMC as RDB5102)

This progress report presents the interim findings of a study to determine the compatibility of desiccants with refrigerant-lubricant combinations, using sealed-tube tests with aluminum, copper, and steel catalysts. The report generically identifies the test materials, outlines the preparation and analysis methods, and summarizes the desiccant specifications. The moisture content and contaminants of the refrigerants specimens and the moisture content, total acid number (TAN), and ion content of the lubricants are tabulated. A table for each desiccant summarizes findings before and after aging, with both 50 and 1000 ppm of added moisture. These results include liquid and desiccant colors, copper plating, solids formation, steel corrosion, crush strength, fraction of reacted refrigerant based on gas chromatography, TAN, fluoride and chloride ion content in the liquid phase and retained in the desiccant, and organic acid retained in the desiccant. Additional tables detail the crush strength results and the acid ion and gas chromatographic analyses. The 16 desiccants include samples from two suppliers for each of eight types, namely: 3Å and 4Å molecular sieves, alumina, silica gel, and four core types. They include 10-25% molecular sieve and alumina with carbon and 15-30% molecular sieve and alumina without carbon, each with type 3Å and 4Å molecular sieves. The lubricants include a naphthenic mineral oil (MO), alkylbenzene (AB), and two classes of polyolester (POE) lubricants - pentaerythritol ester branched acid (POE-BA) and pentaerythritol ester mixed acid (POE-MA). Compatibility data are being obtained for each of the desiccants with 13 refrigerant-lubricant combinations: R-11, R-12, R-22, and R-123 with MO; R-32, R-125, and R-134a with both POE-BA and POE-MA; R-124 with AB; R-143a with POE-BA; and R-152a with AB (or with POE-MA). The progress report provides detailed results for 11 of the 13 combinations; the R-11 and R-123 tests with mineral oil are excluded. It also presents a number of conclusions: Addition of 1000 ppm moisture produces no significant difference. The desiccant solid phase contains most of the chloride and fluoride ions for molecular sieves, but not always with alumina and silica gel desiccants. All of the desiccants tested contained chloride, fluoride, and - for most - sulfate and other ions when received, and they do not perform as well in retaining organic anions as they do for inorganic anions. The crush strength was reduced approximately 20% after aging. None of the desiccants tested are compatible with R-32, and steel corrosion seems to be prevalent with the core-type desiccants.

R. Hawley-Fedder (Lawrence Livermore National Laboratory, LLNL), **Products of Motor Burnout**, report UCRL-ID-118670, LLNL, Livermore, CA, 21 October 1994; republished as report DOE/CE/-23810-48E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 21 October 1994 (12 pages with 1 figure, available from JMC as RDB5211)

This progress report introduces a new project to identify and quantify the products of motor failures in hermetic and semihermetic refrigeration compressors. The study also will assess their corrosive effects on power-supply terminals, evaluate the efficacy of current clean-up procedures, and assess whether hydrofluorocarbon (HFC) refrigerants will increase or decrease the incidence of motor burn-outs. The report outlines initial steps to design a test cell, acquire materials, process safety documentation, and perform a literature search. Few articles were found on thermal stability of refrigerants; 18 ci-

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tations are listed of which most address pyrolysis, reactions in the upper atmosphere, or kinetics. The report identifies the ARTI Refrigerant Database as "the most useful source of information on thermal decomposition" of hydrochlorofluorocarbon (HCFC) refrigerants. The references found in it are described, but not listed. The report also outlines a test stand designed for testing at elevated temperatures, up to 200 °C (392 °F). It shows a schematic of the proposed test stand and identifies future work.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-48A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1994 (10 pages with 2 figures, available from JMC as RDB-4B08)

This interim report summarizes progress in measuring primary thermodynamic data for seven binary and one ternary blends as potential replacements for R-22 or R-502. They include R-32/125/134a, R-32/143a, R-32/290, R-125/134a, R-125/143a, R-125/290, R-143a/134a, and R-290/134a. Measurements also are being made for R-41 and R-41/744 as potential replacements for R-13. The work consists of simultaneous measurements of the coexisting vapor and liquid compositions as well as the bubble point pressures over a wide range of densities and compositions. These data will be used to determine the mixing parameters, including any temperature and/or composition dependence, for the Carnahan-Starling-DeSantis (CSD) equation of state and an extended corresponding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and virial coefficients; and the critical point parameters. The report describes preparatory steps to obtain sample cylinders and valves, for a comprehensive gas chromatographic (GC) calibration procedure, as well as high purity refrigerant samples. It outlines prior measurements of vapor liquid equilibrium (VLE) data for R-32/134a and R-32/125, and compares new VLE and coexisting density apparatus to those previously used. Schematics show the old and new apparatus.

W. L. Martz and A. M. Jacobi, **Refrigerant-Oil Mixtures and Local Composition Modeling**, report TR-68, Air-Conditioning and Refrigeration Center (ACRC), University of Illinois at Urbana-Champaign, Urbana, IL, October 1994 (rdb5B24)

refrigerant-lubricant properties

C. S. Munday, B. Yudin, and R. Stephenson, **FRIGC™ FR-12 Refrigerant, A Replacement for CFC-12 in Mobile Air Conditioning Systems**, unpublished presentation (International CFC and Halon Alternatives Conference, Washington, DC, 24-26 October 1994), Intermagnetics General Corporation, Latham, NY, 1994 (6 pages with 5 figures and 4 tables, RDB4C58)

R-134a/124/600, thermodynamic properties, environmental considerations, toxicology, flammability, compatibility, hose permeation, lubricants, performance, commercialization plan

T. Sato, H. Kiyoura, H. Sato, and K. Watanabe (Keio University, Japan), **PVTX Properties of the Binary Difluoromethane Plus 1,1,1,2-Tetrafluoroethane System**, *Journal of Chemical and Engineering Data*, 39(4):855-858, October 1994 (4 pages, rdb8C53)

measurements of the pressure-volume-temperature-composition (PVTx) properties of R-32/134a blends with a constant-volume apparatus and an expansion procedure; presents 260 sets of PVTx data for 47-167 °C (116-332 °F), pressures of 1.5-6.2 MPa (218-900 psia), and densities of 61-183 kg/m^3 (3.8-11.4 lb/ft^3)

N. D. Smith (U.S. Environmental Protection Agency, EPA), A. S. Ng, M. W. Tufts, A. M. Drago, and K. Ratanaphruks (Acurex Environmental Corporation), **Evaluation of HFC-245fa as a Potential Alternative for R-11 in Low-Pressure Chillers**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 24-26 October 1994), Alliance for Responsible Atmospheric Policy, Arlington, VA, 894-901, October 1994 (8 pages with 4 figures and 4 tables, available from JMC as RDB5805)

R-245fa, R-245ca, R-11, R-123, thermophysical properties, chiller performance modeling, flammability, miscibility, stability, materials compatibility, atmospheric stability, global warming potential (GWP)

Emissions of Greenhouse Gases in the United States, 1987-1992, report DOE/EIA-0573, Energy Information Administration, U.S. Department of Energy, Washington, DC, October 1994 (146 pages with 10 figures and 57 tables, available from GPO as document 1994-386-802/00033, limited copies available from JMC as RDB4B69)

estimated emissions in the USA of carbon dioxide (R-744), methane (R-50), nitrous oxide (R-744A), halocarbons, sulfur hexafluoride (R-7146), criteria pollutants (carbon monoxide, nitrogen oxides, and nonmethane volatile organic compounds, VOCs), and other greenhouse gases: the halocarbons addressed include R-10 (carbon tetrachloride), R-11, R-12, R-12B1 (halon 1211), R-13B1 (halon 1301), R-14, R-20 (chloroform), R-22, R-23, R-30 (methylene chloride), R-113, R-114, R-115, R-116, R-123, R-124, R-134a, R-140a (methyl chloroform), R-141b, R-142b, and R-152a; the halocarbon data are presented individually and collectively for the bromofluorocarbon (BFC, halon), chlorofluorocarbon (CFC), hydrochlorofluorocarbons (HCFC), hydrofluorocarbons (HFC), perfluorocarbon (PFC) groups; depending on the substance, data cover the period from 1987 through 1993; estimated emissions are from all uses - refrigerant components are a small fraction of the total; report identifies the data sources, conversion methods, and limitations

September 1994

E. Bas, **Miami Campus Cools with Ammonia District System**, *Engineered Systems,* 11(9):65, 66, and 68, September 1994 (3 pages with 1 figure, RDB5450)

R-717, application

A. Bensafi and G. G. Haselden (University of Leeds, UK), **Wide-Boiling Refrigerant Mixtures for Energy Savings**, *International Journal of Refrigeration* (IJR), 17(7):469-474, September 1994; republished in *Proceedings of the Institute of Refrigeration*, London, UK, November 1994 (6 pages with 5 figures and 2 tables, RDB4A08)

R-22/142b (50/50), R-23/134a (18/82), R-23/-125/134a (15/5/80) and (15/25/60), R-23/32/-125/134a (10/15/15/60) and (20/10/10/60), R-32/134a (35/65)

G. K. Lavrenchenko, M. G. Khmelnuk, G. Ya. Ruvinskij, and S. V. Iljushenko (Institute of Energy Conversion Systems, Ukraine), **Thermodynamic Properties of a New Refrigerant: A Binary Azeotrope Based on R152a and R218**, *International Journal of Refrigeration* (IJR), 17(7):461-468, September 1994 (8 pages with 3 tables and 9 figures, RDB4A07)

This article presents data on the phase equilibrium and thermal properties of a binary azeotrope of R-152a and R-218, R-218/152a, in the range of -70 to 40 °C (-94 to 104 °F) up to 2000 kPa (290 psia). Liquid-liquid coexistence curves and equilibrium isotherms, as functions of the R-218 concentration, are plotted. An equation of state (EOS), in polynomial form, and pressure-enthalpy (Mollier) diagram are presented. Saturation properties (temperature, pressure, latent heat of vaporization, and liquid and vapor density, enthalpy, and entropy) are tabulated for -50 to 70 °C (-58 to 158 °F). The paper provides detailed tabular comparisons of the efficiency and operating parameters of the blend with R-12, R-22, R-134a, and R-502. The blend is recommended as an alternative for R-12, R-22, and R-502. The authors identify it as "R-507" [a designation assigned to R-125/143a (50/50) by ANSI/ASHRAE Standard 34]. [See discussion by P. E. Liley (Purdue University and by J. M. Calm (Engineering Consultant) in **Letters to the Editor**, *International Journal of Refrigeration* (IJR), 19(2):147, February 1996.]

Intergovernmental Panel on Climate Change, **Radiative Forcing of Climate Change 1994 - Report to IPCC from the Scientific Assessment Working Group (WGI) - Summary for Policymakers**, document IPCC-X/Doc3 Part I, edited by J. T. Houghton and L. G. Meira Filho, IPCC Secretariat, World Meteorological Organization (WMO), Geneva, Switzerland, September 1994 (44 pages with 15 figures and 5 tables, RDB4B13)

consensus global warming potential (GWP) values

E. B. Muir (Copeland Corporation), **HFC Replacements for R-22**, *CFCs, the Day After* (proceedings of the IIR meeting, Padova, Italy, 21-23 September 1994), International Institute of Refrigeration (IIR), Paris, France, 249-258, September 1994 (10 pages, RDB6862)

R-407C, R-410A, and others

August 1994

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-42E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 31 August 1994 (236 pages, available from JMC as RDB4894)

This document provides bibliographic citations for 1531 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately a third of these documents. The database identifies sources of specific information on R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-408A, R-409A, R-410A, R-411A, R-411B, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507, and others for which information is available, even though standard designations may

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not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes the same citations and abstracts as the report version plus 156 from a supplement on copper in air conditioning and refrigeration, 173 for superseded and historical documents, data summaries for 210 individual refrigerants and blends, and 33 tabular compatibility summaries for plastics and elastomers - a total of 2103 entries. It is accompanied by retrieval software to facilitate searches for specific information; the software enables searches for user selected terms, or combinations of terms. It offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, and a "wildcard" capability to allow entry of word segments. The software also enables printing of selected citations, abstracts, and data summaries as well as preparation of a document order lists. Both versions of the database include instructions to obtain cited documents or subscriptions for updates to the database.

D. A. Fisher (E. I. duPont de Nemours and Company, USA) and P. M. Midgley (M&D Consulting, Germany), **Uncertainties in the Calculation of Atmospheric Releases of Chlorofluorocarbons**, *Journal of Geophysical Research* (JGR), 99(D8):-16,643-16,659, 20 August 1994 (7 pages with 5 figures and 1 table, RDB5502)

R-11, R-12, R-22, R-113, R-114, R-115, production and emission data

M. Hawley, **Documentation of Newly Developed Methods to Assess Material Compatibility in Refrigeration and Air-Conditioning Applications**, report DOE/CE/23810-47, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, August 1994 (50 pages with 6 figures and 6 tables, available from JMC as RDB6B02)

This document summarizes the experimental methods used in tests performed for the ARTI Materials Compatibility and Lubricants Research Program (MCLR). The methods addressed were used to investigate the miscibility of alternative refrigerant candidates and associated lubricants; their stability in the presence of metals, and their compatibility with desiccants, elastomers, plastics, and motor materials. The introduction briefly summarizes the MCLR Program and standards applied to assure the purity of refrigerants and lubricants tested. Six sections describe the purpose and use for each method; the nature of the tests; test materials, procedures, conditions, apparatus, and analyses; measured or observed parameters; and reporting. Each section concludes with pertinent references on the experimental materials and methods.

S. R. Szymurski, M. Hawley, G. C. Hourahan, and D. S. Godwin, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-42, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, August 1994 (84 pages with 14 figures and 17 tables, available from JMC as RDB4A21)

This progress report summarizes the status and key findings of the Materials Compatibility and Lubricant Research (MCLR) Program. The program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. Primary elements include data collection and dissemination, materials compatibility testing, and methods development. This work is jointly funded under a grant from the Office of Building Technology of the U.S. Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program began in September 1991 and will run through September 1995; a decision to continue through September 1996 is pending. The report provides descriptions for each of 23 projects, highlighting their objectives and results. Those underway will measure thermophysical properties of ten HCFC alternatives; measure the viscosity, density, and solubility for three azeotropic and zeotropic blends to replace R-22 and R-502; and obtain compatibility data on 16 desiccants with 13 refrigerant-lubricant mixtures. Three others will examine the compatibility of manufacturing process fluids with hydrofluorocarbon (HFC) refrigerants and ester lubricants, motor materials with the alternative refrigerants and lubricants for retrofit, and products resulting from motor burnouts. The report also summarizes projects to develop accelerated screening and test methods to predict lubricant performance in compressors, the life of motor materials exposed to refrigerant-lubricant mixtures, and chemical and thermal stability of refrigerant-lubricant mixtures. Three others will develop alternative flushing and clean out methods, investigate the fractionation of refrigerant blends, and develop methods to measure and classify the flammability and combustibility of refrigerants. It outlines a continuing project to collect and facilitate dissemination of data, through development and administration of the ARTI Refrigerant Database. The progress report summarizes completed projects to measure thermophysical properties of R-32, R-123, R-124, R-125, R-143a, and R-152a; model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502; test the chemical and thermal stability of refrigerant lubricant mixtures with metals; measure the miscibility of lubricants with refrigerants; measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures; provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics; and investigate electrohydrodynamic (EHD) enhancement of pool and in tube boiling of alternative refrigerants. This program summary also identifies the research contractors and reports prepared for individual projects. Tables and figures illustrate significant findings of selected projects, including test data on ten molecular sieves in refrigerants and lubricants, schematics and measurements for the stability test method, miscibility of lubricants with ten refrigerants, and refrigerant-lubricant viscosity, solubility, and density correlations. Two figures compare the modelled performance of alternative refrigerants to the capacities and efficiencies of R-22 and R-502. The equations of state developed for R-32, R-123, R-124, R-125, R-143a, and R-152a are summarized and the relative swelling of 17 elastomer groups in refrigerants and lubricants is tabulated.

R. E. Tapscott, S. R. Skaggs (University of New Mexico), and D. Dierdorf (Pacific Scientific), **Perfluoroalkyl Iodides and Other New-Generation Halon Replacements**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, chapter 14, 151-160, 1995 (10 pages with 3 tables, RDB6208)

screening of potential halon replacements with emphasis on fluoroiodocarbons (FICs) R-13I1, R-217bal1, and R-217cal1; carbonyl compounds, alcohols, alkenes, ethers, aromatics, amines, phosphonitriles, and silicon derivates; ozone depletion and global warming potential; toxicity, cardiac sensitization; use as fire suppressants

July 1994

M. M. Bagaman (Southland Industries Services Company, SISCO), **After CFCs: What a Changeover Means for Maintenance**, *Maintenance Solutions*, 10 and 12, July/August 1994 (2 pages, RDB-5126)

This article reviews requirements for record keeping, system maintenance and monitoring, and refrigerant safety and handling, including training of personnel. The discussion of record keeping centers on compliance with regulations promulgated in May 1993, pursuant to Section 608 of the U.S. Clean Air Act Amendments. Six top record types are listed, namely those covering service, maintenance, repair, or disposal; copies of service invoices; and indications of the quantities of appliances serviced, maintained, repaired, or disposed. They also include records of the amount of refrigerant used, recovered, or recycled; the equipment used to recover or recycle refrigerants; and of other methods used to prevent releases into the atmosphere. The article summarizes guidelines for maintenance and monitoring, dominantly focusing on the recommendations of ASHRAE Guideline 3-1990. It identifies parameters to be checked and logged routinely. Turning to safety, the article outlines training requirements and identifies responsibilities for maintenance managers. The latter include providing a safe workplace, compliance with laws, and attention to the interests of facility owners. The article stresses the importance of regulatory and code compliance as well as attention to safety in improving the environment.

E. Baskin and R. B. Berry (U.S. Environmental Protection Agency), **The Performance of Hydrocarbons in a Household Refrigerator/Freezer**, *Proceedings of the 1994 International Refrigeration Conference at Purdue,* edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 237-244, July 1994 (8 pages with 2 figures and 7 tables, RDB4829)

R-290/600a, propane/isobutane

F. R. Biancardi (United Technologies Research Center, UTRC), **Investigation into the Fractionation of Refrigerant Blends**, report DOE/CE/-23810-42C (also identified as UTRC R94-970566-1), Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1994 (18 pages with 6 figures, available from JMC as RDB5255)

This progress report introduces a research project to investigate composition changes in refrigerant blends. The work includes analysis and laboratory tests, developing approaches or techniques to predict fractionation or to overcome it, and conveying the results to industry. The project entails four technical tasks addressing lubricant solubility effects, fractionation effects from successive charges, fractionation within system components, and fractionation during leaks. The report briefly summarizes a project review and appends presentation charts on the objectives, deliverables, and schedule. It

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then outlines progress on model development, citing examination based on both solution theory and an equation of state (NIST REFPROP). Mixtures of R-32/134a (25/75) with two polyolester (POE) lubricants (Castrol Icematic® SW68 and Mobil EAL Arctic® 32), are being used for the study. A calculated pressure-temperature plot is provided for R-134a with 0, 70, 80, and 90% POE; experimental data at 0 and 91% lubricant are shown for verification. Analysis of fractionation is outlined, based on both an isothermal, static equilibrium model for a liquid leak and a more rigorous, dynamic simulation model that addresses heat transfer, tank geometry, tank materials, external cooling, and operating temperature. Sample mass loss and composition plots are shown for both the static and transient model; temperature plots are included for the latter. Examination of fractionation within components is outlined based on model development, by adapting the UTRC READER model, and planned experimental verification using a Carrier scroll compressor. Simplified heat exchanger models are being examined for simulation of leakage scenarios.

J. M. Calm (Engineering Consultant), **Information on Alternative Refrigerants: Status of the Refrigerant Database**, *Proceedings of the 1994 International Refrigeration Conference at Purdue,* edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 443-448, July 1994 (6 pages with 1 table, RDB4860)

This paper describes the ARTI Refrigerant Database and provides a tabular summary for 86 common and candidate refrigerants. The key elements identified include a collection of documents, a computerized search system, a set of refrigerant summaries, and an information dissemination operation. The document collection, which includes both published and unpublished works, grew from an informal sharing of information on thermophysical properties, materials compatibility, and lubricants for alternative refrigerants. The current set also includes reports from the Air-Conditioning and Refrigeration Technology Institute's (ARTI's) Materials Compatibility and Lubricant Research (MCLR) Program, the Air-Conditioning and Refrigeration Institute's (ARI's) Alternative Refrigerants Evaluation Program (AREP), contributed works, and other sources. The search and retrieval system is based on a set of bibliographic citations and extended abstracts on refrigerant and lubricants, their properties, compatibility with other materials found in refrigeration systems, effects on heat transfer, system capacity and efficiency, computational and test methods to estimate or determine the preceding data, research, application data, and regulatory information. The article illustrates the computerized version of the database by showing how searches are performed. It also describes the manual, or report, version. It then describes refrigerant summaries, approximately 100 [now more than 200] of which are incorporated into the database. Two tables present refrigerant identifications, safety classifications, environmental data, and physical property data from the database for 88 of the most common refrigerants. The tabular data include the ANSI/ASHRAE Standard 34 designation, chemical name and formula, flammability limits, safety group, ozone depletion potential (ODP), global warming potential (GWP), molecular mass, freezing point, normal boiling point, and critical parameters (temperature, pressure, and density). The focus of the database and its sponsorship by ARTI, under a grant from the U.S. Department of Energy (DOE), are outlined.

R. Camporese, S. Bobbo (Consiglio Nazionale della Ricerche, CNR, Italy), and F. Rozza (Necchi Compressori, Italy), **Hydrocarbons as Substitutes for Halogenated Refrigerants in Refrigerating Systems**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 231-236, July 1994 (6 pages with 8 figures and 2 tables, RDB4828)

R-290/600a (50/50), propane/isobutane, R-600a

S. Corr, B. E. Gilbert, R. Low, F. T. Murphy (ICI Klea), and G. Davies (Cadbury Limited), **Trials with Zeotropic Refrigerants as Replacements for R-22 in an Instrumented Glycol/Water Chiller**, *Proceedings of the 1994 International Refrigeration Conference at Purdue,* edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 13-18, July 1994 (6 pages with 6 figures, RDB4803)

R-32/134a (25/75), R-32/134a (30/70), R-32/-125/134a (30/10/60), R-407C [R-32/125/134a (23/25/52)]

G. Cortella (Università di Udine, Italy), G. Bigolaro, M. Scattolini (Consiglio Nazionale delle Ricerche, CNR, Italy), G. Basile, and E. Musso (Ausimont S.p.A., Italy), **Drop-In Substitutes for R502: The Role of HCFC-22 and HC-290**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 171-176, July 1994 (6 pages with 9 figures and 1 table, RDB4823)

R-22, R-290 (propane), R-502

C. Ellis, O. Hanson, and L. J. Van Essen (Lennox Industries, Incorporated), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 177, Air-

Conditioning and Refrigeration Institute (ARI), Arlington, VA, July 1994 (6 pages with 2 tables, available from JMC as RDB5677)

R-32/125 (60/40) compared to R-22 both with an unidentified ester lubricant in a 10.6 kW (3 ton), split-system heat pump using a scroll compressor in both the cooling and heating modes

P. E. Hansen and V. Gustafsson (Danfoss Compressors GmbH, Germany), I. Drabæk, A. Schmidt, and P. B. Pedersen (dk-Teknik, Denmark), **Total Environmental Impact of a Small Hermetic Compressor**, *Proceedings of the 1994 International Refrigeration Conference at Purdue,* edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 177-181, July 1994 (5 pages with 4 figures and 1 table, RDB4824)

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-42A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1994 (10 pages, available from JMC as RDB4888)

This progress report introduces a new project to measure primary thermodynamic data for binary and one ternary mixtures as potential replacements for R-22 or R-502. They include mixtures of R-32/125/134a, R-32/143a, R-32/290, R-125/143a, R-143a/134a, R-125/290, and R-290/134a. Measurements also will be made for R-41 and R-41/744 as potential replacements R-13. The work will consist of simultaneous measurements of the coexisting vapor and liquid compositions as well as the bubble point pressures over a wide range of densities and compositions. These data will be used to determine the mixing parameters, including any temperature and/or composition dependence, for the Carnahan-Starling-DeSantis (CSD) equation of state and an extended corresponding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and virial coefficients; and the critical point parameters. The project plan originally included R-245ca, now being separately addressed; the report proposes five substitutions. It also outlines the methods and ranges for the program. The report concludes with a proposed task to complete a two-year project to develop comprehensive thermodynamic property data for R-32/125 and R-32/134a.

E. W. Heinonen and R. E. Tapscott (New Mexico Engineering Research Institute, NMERI), **Methods Development for Measuring and Classifying Flammability/Combustibility of Refrigerants: Task 1 - Annotated Bibliography and Summary**, report DOE/CE/23810-42G also identified as NMERI OC 94/31, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1994 (128 pages with 8 figures, available from JMC as RDB5258)

This progress report describes literature search to identify references on the flammability of refrigerants to support development of flammability test methods. It outlines the search approach and specific databases examined. A summary of the results reviews definitions of flammability, the lower and upper flammability limits (LFL and UFL), and modes of burning - pre-mixed or diffusion. It distinguishes between combustibility and flammability, the latter indicating the ability to propagate a flame. The summary also identifies indications of flammability beyond visual and presents the parameters that affect flammability. They include the ignition source, temperature and pressure of the mixture, humidity of the air, size and shape of the test vessel, turbulence, concentration of the test gas, reactivity and mixing of the components, and altitude and resulting barometric pressure. The report then discusses and identifies advantages and disadvantages for five types of apparatus. They include the NMERI explosion sphere which is illustrated schematically, ASTM E681 test flask, bomb calorimeter, a light emission detector, and a flame tube or other glass vessel. The report summarizes the findings of eight published studies on refrigerant flammability and then describes a database, REFLIBRY, into which more than 90 document citations have been entered. Appendices illustrate REFLIBRY, provide instructions for its use, and list the contents in both short and long (with summaries if available) formats.

E. W. Heinonen and R. E. Tapscott (New Mexico Engineering Research Institute, NMERI), **Methods Development for Measuring and Classifying Flammability/Combustibility of Refrigerants: Task 2 - Test Plan**, report DOE/CE/23810-42H also identified as NMERI OC 94/32, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1994 (72 pages with 6 figures and 1 table, limited copies available from JMC as RDB5259)

This progress report proposes a test plan to measure the flammability of refrigerants and to examine variables that may impact such measurements. A detailed introduction reviews definitions of flammability, the lower and upper flammability limits (LFL and UFL), and modes of burning - pre-mixed or diffusion. It distinguishes between combustibility and flammability, the

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latter indicating the ability to propagate a flame. The introduction also identifies indications of flammability beyond visual and presents the parameters that affect flammability. They include the ignition source, temperature and pressure of the mixture, humidity of the air, size and shape of the test vessel, turbulence, concentration of the test gas, reactivity and mixing of the components, and altitude and resulting barometric pressure. The report then discusses and schematically illustrates test apparatus including the NMERI explosion sphere, ASTM E681 test flask, bomb calorimeter, a light emission detector, and a flame tube or other glass vessel. It presents a test matrix of the cited parameters and first four of the apparatus types. The report also outlines data analysis and safety plans for the study. Material Safety Data Sheets (MSDSs) are appended for candidate agents and fuels including nitrogen, propane, R-32, R-125, and R-134a.

H. M. Hughes (AlliedSignal Incorporated), **Azeotrope of HFC-125 and HFC-143a as an Alternative for R-502**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 377-382, July 1994 (6 pages with 5 figures, RDB4849)

R-507A, AZ-50, R-125/143a (50/50)

K. Inoue, M. Sunami, and A. Nakao (Nippon Oil Company, Limited, Japan), **Mutual Solubility of Refrigerants and Polyol Esters**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 147-152, July 1994 (6 pages with 6 figures and 2 tables, RDB4819)

R-32, R-125, R-134a, R-143a, tetraesters, pentaerythritol, polyolesters

B. Jacobson (SKF Engineering & Research Centre B.V, Nieuwegein, The Netherlands), **Lubrication of Screw Compressor Bearings Used in the Presence of Refrigerants**, *Proceedings of the 1994 International Compressor Engineering Conference at Purdue*, edited by W. Soedel, Purdue University, West Lafayette, IN, I:115-120, July 1994 (6 pages with 3 figures and 3 tables, RDB5A03)

R-22 and naphthenic mineral oil; R-134a and polyolester lubricant, EHL theory

R. E. Kauffman (University of Dayton Research Institute), **Accelerated Screening Methods for Determining Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures, Part II: Experimental Comparison and Verification of Methods**, report DOE/CE/23810-38C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1994 (56 pages with 5 figures and 7 tables, available from JMC as RDB4A22)

This incremental report summarizes progress to evaluate analytical techniques for development into an accelerated method for compatibility testing. It presents measured data to compare decomposition determination by in situ conductivity and conventional sealed-tube tests. Schematics illustrate a modified, sealed glass tube and a three-well, heated block - made of aluminum or graphite - used for the conductivity measurements. The report indicates a number of potential advantages for the in situ approach including increased safety, by eliminating direct viewing and the need to open tubes for evaluation. It also cites the opportunity to shorten tests to less than a day when early decomposition is detected, obtain time-dependent information on the decomposition, and detect low levels of decomposition that may not be found with conventional methods. Tests were performed with and without valve steel coupons as catalysts for R-12, R-22, R-134a, and R-32/134a (30/70), in equal mixtures with 10 different lubricants, for temperatures ramped from 175 to 205 °C (347 to 401 °F). Isothermal tests also were performed with R-12 and the lubricants, with and without steel catalysts, at 175 °C (347 °F). The conductivity-based rankings were compared to those by color measurements, gas chromatographic analyses, and trace metal analyses; the measured data are tabulated. The report concludes that in situ conductivity measurements have good potential for development into an accelerated screening method, and that trace metal measurement are more sensitive than color measurements and gas chromatography. It raises questions on the roles of additives in observed instability of R-12 with polyolester (POE) lubricants. An appendix shows the gas chromatograms for the pretest and aged refrigerant-lubricant mixtures. A second provides plots of the in situ conductivity measurements for the R-12-lubricant mixtures for up to a week of aging. A final appendix identifies the lubricant samples including a naphthenic mineral oil (Witco Suniso(R) 3GS), two paraffinic mineral oils (Penreco Sontex 160LT and 200LT), an alkylbenzene (Shrieve Zerol(R) 150), two polyglycols (Dow P-425 and ICI Emkarox(R) RL 118D), and four polyolesters (POEs). The POEs include two pentaerythritol ester mixed acids (ICI Emkarate(TM) RL 22H and Mobil EAL Arctic(R) 22A) and two pentaerythritol ester branched acids (Henkel Emery(R) 2928 and Castrol Icematic(R) SW32). The refrigerant specimens were obtained from PCR Incorporated.

G. S. Kazachki (Acurex Environmental Corporation) and R. V. Hendriks (U.S. Environmental Protection Agency, EPA), **Performance Testing of a Semi-Hermetic Compressor with HFC-236ea and CFC-114 at Chiller Conditions**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 407-411, July 1994 (5 pages with 12 figures, RDB4854)

R-114, R-236ea

H. M. Lee Kang, S. C. Zoz and M. B. Pate (Iowa State University of Science and Technology), **Solubility of HFC-32, HFC-125, and HFC-134a with Three Potential Lubricants**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 437-442, July 1994 (6 pages with 9 figures and 1 table, RDB4859)

R-32, R-125, R-134a

J. A. McGovern and B. Duignan (University of Dublin, Ireland), **An Air Cycle Design Concept for Domestic or Small Commercial Refrigerators**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 261-266, July 1994 (6 pages with 6 figures, RDB-4832)

R-729

J. Nimitz and L. Lankford (Ikon Corporation), **Refrigerants Containing Fluoroiodocarbons (FICs)**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 255-260, July 1994 (6 pages with 2 figures and 2 tables, RDB4831)

T. Ohuchi, M. Aizawa (Hitachi Limited, Japan), R. Kawakami (Osaka Gas Company, Limited, Japan), A. Nishiguchi, T. Hatada, and Y. Kunugi (Hitachi Limited, Japan), **A Study on a Hot-Water Driven Air-Cooled Absorption Refrigerating Machine**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 275-280, July 1994 (6 pages with 13 figures and 5 tables, RDB4833)

R. W. Pokelwaldt (York International Corporation), **Challenges and Opportunities in the HVAC&R Business Today**, keynote address to the Twelfth International Compressor and Fifth International Refrigeration Conferences (Purdue University, West Lafayette, IN), 19 July 1994; published as a late paper in *Proceedings of the 1996 International Refrigeration Conference at Purdue*, edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 533-538, July 1996 (6 pages, limited copies available from JMC as RDB4864)

D. R. Riffe (Americold / White Consolidated Industries, Incorporated), **Is There a Relationship Between the Ideal Carnot Cycle and the Actual Vapor-Compression Cycle?**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 205-212, July 1994 (8 pages with 12 figures and 1 table, RDB4826)

theoretical performance, refrigeration effect, isentropic compression efficiency, coefficient of performance, COP, R-12, R-22, R-115, R-124, R-134, R-134a, R-142b, R-143a, R-152a, R-218, R-C270, R-290, R-C318, R-600a

D. R. Riffe (Americold / White Consolidated Industries, Incorporated), **Isobutane as a Refrigerator Freezer Refrigerant**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 245-254, July 1994 (10 pages with 4 figures and 4 tables, RDB4830)

R-12, R-134a, R-600a

M. Seki, A. Osajima, Y. Nakane, H. Sato, K. Watanabe (Keio University, Japan), N. Kagawa (National Defense Academy, Japan), and T. Yajima (Toshiba Corporation, Japan), **Performance of Refrigeration Cycle with R-32/134a and R-32/125 Based on the Reliable Thermodynamic Property Data**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 67-72, July 1994 (6 pages with 6 figures and 2 tables, RDB4812)

M. W. Spatz and J. Zheng (AlliedSignal Incorporated), **Experimental Evaluation of R-22 Alternative Refrigerants in Unitary Air Conditioning Equipment**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 19-24, July 1994 (6 pages with 2 tables, RDB4804)

performance tests of R-134a, R-410A [R-32/125 (50/50), identified in the paper as by AlliedSignal's trade name AZ-20], and R-407C (R-32/125/134a (23/25/52)]

H. O. Spauschus (Spauschus Associates, Incorporated), **Status of Transition to Alternative Refrigerants and Lubricants (1994), Recent Developments, and Some Predictions**, unpublished plenary presentation to the Twelfth International Compressor and Fifth International Refrigeration Conferences (Purdue University, West Lafayette, IN), 20

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July 1994 (27 pages with presentation charts, limited copies available from JMC as RDB4865)

L. A. Weber and A. M. Silva (National Institute of Standards and Technology, NIST), **Report on the Design and Testing of a New High Pressure Ebulliometer for Studying the Thermodynamics of Refrigerant Mixtures**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 31-36, July 1994 (6 pages with 4 figures, rdb4806)

J. Xinqiao, Z. Xinxi, and X. Dazhong (Shanghai Jiao Tong University, China), **Comparing of Several EOS for Evaluation of NARMs' Thermodynamic Properties**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 55-60, July 1994 (6 pages with 3 tables, RDB4810)

R-12, R-22, R-142b, R-22/12, R-22/142, zeotropes, thermodynamic properties; Martin-Hou (MH), Redlich-Kwong-Soave (RKS), Starling-Han-Benedict-Webb-Rubin (SHBWR), equation of state (EOS)

J. Xinqiao, X. Dazhong, and Z. Xinxi (Shanghai Jiao Tong University, China), **Performance Evaluation of Air-Condition**[ing] **System Using NARM by Equation of State**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 287-292, July 1994 (6 pages with 4 figures, RDB4836)

R-22, R-142, R-22/142, zeotropes, thermodynamic properties; Martin-Hou (MH) equation of state (EOS), cycle analysis

C. Zhang (B-JAC International, Incorporated), **A Chemically-Assisted Mechanical Refrigeration System**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 281-285, July 1994 (5 pages with 2 figures and 1 table, RDB4834)

ammonia/water, CAM, hybrid absorption-vapor-compression

June 1994

D. B. Bivens, C. C. Allgood, J. J. Rizzo, M. B. Shiflett, D. M. Patron, T. E. C. Chisolm, G. S. Shealy, A. Yokozeki, W. D. Wells, and K. A. Geiger (DuPont Fluoroproducts), **HCFC-22 Alternative for Air Conditioners and Heat Pumps**, paper OR-94-1-5, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(2):566-572, 1994 (7 pages with 8 figures and 3 tables, RDB4705)

R-407C [R-32/125/134a (23/25/52)], capacity, efficiency, performance, discharge temperature and pressure, leakage

C-B. Chiou (National Chiao Tung University, Taiwan), C-C. Wang, Y-J. Chang (Industrial Technology Research Institute, ITRI, Taiwan), and D. C. Lu (National Chiao Tung University, Taiwan), **Experimental Study of Heat Transfer and Flow Friction Characteristics of Automotive Evaporators**, paper OR-94-2-1, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(2):575-581, 1994 (7 pages with 9 figures and 2 tables, RDB4706)

A. Fujitaka (Matsushita Electric Industrial Company Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 164, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (12 pages with 4 figures and 5 tables, available from JMC as RDB5664)

R-407C compared to R-22 and to R-32/125/134a (30/10/60) with an unidentified polyolester (POE) lubricant in an air-source, room heat pump with a rotary, rolling-piston compressor in both the cooling and heating modes

A. Fujitaka (Matsushita Electric Industrial Company Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 165, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (10 pages with 2 figures and 4 tables, available from JMC as RDB5665)

R-407C compared to R-22 and to R-32/125/134a (30/10/60) with an unidentified polyolester (POE) lubricant in an air-source, room heat pump with a scroll compressor in both the cooling and heating modes

G. G. Haselden and J. Chen (University of Leeds, UK), **A Computer Simulation Program for Mixed-Refrigerant Air-Conditioning**, *International Journal of Refrigeration* (IJR), 17(5):343-350, June 1994 (8 pages with 11 figures, RDB5813)

zeotropic blends, performance

J. A. Khan and J. H. Morehouse (University of South Carolina), **A Metal Matrix for Heat Transfer Enhancement During Phase-Change Processes**, paper OR-94-7-1, *Transactions* (Annual Meeting Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(2):707-714, 1994 (8 pages with 6 figures and 1 table, RDB4710)

S. D. Labinov (Thermodynamic Center, Ukraine) and J. R. Sand (Oak Ridge National Laboratory, ORNL, USA), **An Analytical Method of Predicting Lee-Kesler-Plöcker Interaction Coefficients - Part I: For Non-Polar Hydrocarbon Mixtures**, *Preprints of the 12th Symposium on Thermophysical Properties* (Boulder, CO, 19-24 June 1994), American Society of Mechanical Engineers (ASME), New York, NY, 1994 (12 pages with 1 figure and 2 tables, preprint available from JMC as RDB4902)

This paper presents a method to calculate binary interaction coefficients for nonpolar hydrocarbon mixtures for the Lee-Kesler (LK) equation of state. The method is based on solving simultaneous equations, which are Plöcker's mixing rules for pseudocritical parameters of a mixture, and the Lee-Kesler equation for the saturation line. This approach requires use of the critical parameters of the components and their normal boiling temperatures. The paper indicates that calculated and measured coefficients agree within ±0.4% for hydrocarbons with 2-9 carbon atoms. The paper also discusses extension of the method to other nonpolar substances. A table summarizes the interaction coefficients published in other studies for R-22/114, R-22/142b, and R-22/152a for the Lee-Kesler-Plöcker (LKP) equation of state. A second table compares experimental and calculated coefficients for R-170 (ethane) mixed with R-290 (propane), R-600 (n-butane), n-pentane, n-hexane, n-heptane, n-octane, and n-nonane. A figure compares calculated and experimental values of these coefficients. A second figure compares the experimental and compressibility factors plotted against the acentric factor for methane through n-decane (alkanes with 1-10 carbon atoms). A final figure compares reduced properties (normalized to critical parameters) for boiling temperature for the pure substances and mixtures of ethane with nonane and ethane with propane.

V. Patnaik (Phillips Engineering Company), W. A. Miller (Oak Ridge National Laboratory, ORNL), and H. Perez-Blanco (Pennsylvania State University), **An Empirical Methodology for the Design of Vertical Tube Absorbers**, paper 3801, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(2):185-196, 1994 (12 pages with 18 figures and 1 table, RDB4714)

lithium bromide water, enhanced surface tubes, heat transfer

B. Ouazia and W. K. Snelson (National Research Council, Canada, NRCC), **Predicting System Performance of Alternative Refrigerants Using a Water-Water Heat Pump,** paper 3797, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(2):140-147, 1994 (8 pages with 8 figures, RDB4708)

R-134a

S. T. Ro, H. S. Jun, Y. S. Chang, and J. Y. Shin (Seoul National University, Korea), **Condensation Heat Transfer of a Heat Pump System Using the Refrigerant Mixture of R-32/R-134a,** paper OR-94-7-2, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(2):715-720, 1994 (6 pages with 7 figures and 1 table, RDB4711)

R-32/134a

J. S. Seewald (The Trane Company), **A Simple Model for Calculating the Performance of a Lithium Bromide / Water Coil Absorber**, paper 3814, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(2):318-328, 1994 (11 pages with 12 figures and 2 tables, RDB4723)

K. Wakahara (Sharp Corporation, Japan), **Drop-In Test of Refrigerant Blends R-32/125/134a (30/-10/60) and R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 174, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (12 pages with 1 figure and 4 tables, available from JMC as RDB5674)

R-407C and R-32/125/134a (30/10/60) with an unidentified ester lubricant compared to R-22 with mineral oil in a room heat pump using a rotary, rolling-piston compressor in both the cooling and heating modes

R. Yajima and O. Kataoka (Daikin Industries, Limited, Japan), **Drop-In Test of Refrigerant Blends R-23/32/134a (1.5/27/71.5), R-23/32/134a (1.5/20/-78.5), and R-23/32/134a (2/29.4/68.6)**, Alternative Refrigerants Evaluation Program (AREP) report 168, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (12 pages with 5 figures and 4 tables, available from JMC as RDB5668)

R-23/32/134a (1.5/27/71.5), (1.5/20/78.5), and (2/29.4/68.6) with an unidentified polyolester

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(POE) lubricant compared to R-22 with a mineral oil and to R-32/134a with a POE in a room heat pump using a rotary, rolling-piston compressor

X. Zhao, G. Zhao, and X. Song (Xi'an Jiaotong University, China), **Calculation of Properties of PVT and Entropy for Real Gases by Using BH Perturbation Theory**, *Huagong Xuebao* [Journal of Chemical Industry and Engineering], China, 45(3):-375-379, June 1994 (5 pages, rdb8927)

presents calculated pressures of normal gases, hydrocarbons, fluorochemicals, R-717 (ammonia), and R-718 (water) in the superheated vapor region; also presents the entropies of normal gases, hydrocarbons, and fluorochemicals close to the saturated vapor line; these data were calculated with perturbation theory; concludes that the calculated results are in good agreement with published data and that the calculation method holds practical value

Handling and Reuse of Refrigerants in the United States, Industry Recycling Guideline IRG-1, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (12 pages with 1 figure and 1 table, available from JMC as RDB4780)

This manual provides procedures and guidelines to maintain the quality of refrigerants used in air-conditioning and refrigeration (ACR) equipment. It identifies three options and guidance to determine which should be used. They include reuse of the refrigerant - without recycling - in the equipment from which it was removed, recycling the refrigerant into the system same or another system from the same owner, or reclaim of the refrigerant. Five considerations are discussed as a basis for selecting the appropriate action. They include the reason the system is being serviced, condition of the refrigerant and system, equipment manufacturers' policies, refrigerant cleaning capability of recycling equipment, and feasibility and owner's preference. A flow chart diagrams the decision process. The document indicates that used refrigerants shall not be sold, or used in a different owner's equipment, unless the refrigerant has been analyzed and found to meet the requirements of ARI Standard 700, *"Specifications for Fluorocarbon and Other Refrigerants."* The document also provides a table of maximum contaminant levels for recycled refrigerants in the same owner's equipment, and notes that the owner's consent should be obtained for such reuse. It provides guidance for identification and avoidance of mixed refrigerants (other than manufactured blends) as well as handling of blends with compositions that were altered by selective leakage. This guideline was developed by a broad base of interests, including refrigerant reclaimers, manufacturers, contractors, engineers, government, building owners and managers, and consumers. It responds to a mandated sunset provision in regulation of reused refrigerants. The underlying goal is indicated as protection of end users, consumers, and ACR products owned by consumers.

Heat Transfer and Fluid Flow in Spray Evaporators with Application to Reducing Refrigerant Inventory, research project 668-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1991 - June 1994 (ASH0668)

This research addressed the heat transfer and fluid flow for R-22, R-123, and R-134a in falling-film (spray) evaporators with horizontal tubes. The work included performance of a literature search, experimental measurement of heat transfer on both single tubes and tube bundles. Both plain and enhanced tube surfaces were addressed under varied temperature and flow to determine the optimum conditions. Correlations or charts were developed for use in heat exchanger design. A goal was to enable design of equipment for comfort cooling using reduced inventories of refrigerants. An overall goal was to provide basic information to permit potential users to evaluate counterflow, brazed-plate heat exchangers as refrigerant evaporators and condensers. The contractor for the project was Iowa State University of Science and Technology led by M. B. Pate; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

May 1994

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-38D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 27 May 1994 (206 pages, available from JMC as RDB4555)

This document provides bibliographic citations for 1264 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately a third of these documents. The database identifies sources of specific information on R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. It addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It also references documents on compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes the same citations and abstracts as the report version plus 127 from a supplement on copper in air conditioning and refrigeration (see RDB4137), 159 for superseded and historical documents, and data summaries for 210 individual refrigerants and blends - a total of 1760 entries. It is accompanied by retrieval software to facilitate searches for specific information; the software enables searches for user-selected terms, or combinations of terms. It offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, and a "wildcard" capability to allow entry of word segments. The software also enables printing of selected citations, abstracts, and refrigerant summaries as well as preparation of a document order lists. Both versions of the database include instructions to obtain cited documents or subscriptions for updates to the database.

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Compatibility of Refrigerants and Lubricants with Engineering Plastics**, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, 349-360, May 1994 (12 pages with 1 table, RDB4566)

G. de Souza Damasceno (Universidade Federal de Vicosa, Brazil), J. M. Dubrouillet (Catholic University), V. W. Goldschmidt (Purdue University), M. L. Robin (Great Lakes Chemical Corporation), and D. R. Tree (Purdue University), **Testing Refrigerant Alternatives in a Household Refrigerator**, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, 505-516, May 1994 (12 pages with 6 figures and 2 tables, RDB4A29)

This paper presents the results of drop-in performance tests for R-12 alternatives in a household refrigerator-freezer (Frigidaire model FP1-17TF). The paper outlines the test procedure and the evacuation methods used between tests of individual refrigerants. Those tested were R-12; R-22B1; R-114; R-134a; R-152a; R-227ea; R-152a/22B1 (23/77); R-152a/227ea (20/80), (50/50), and (80/20); R-290/227ea (10/90) and (50/50); R-E170/227ea (30/70); and R-227ea/-600a (75/25). The paper indicates that the charge amount was varied to achieve maximum capacity for each test refrigerant when possible; the resultant charge was considered the optimum. Figures show the food storage temperature and power consumption though five test cycles, the relation of charge and power draw to charge, and the relations between capacity and mass (charge) to their respective maximums. The concluding figure in this series shows the relationship between optimum charge and molecular weight to be approximately linear. A plot shows power draw versus suction pressure. The test results are tabulated including charge amount, suction and discharge pressure, projected energy use per day, capacity, coefficient of performance (COP), and molecular mass.

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Refrigerants and Lubricants with Electrical Sheet Insulation**, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, 493-504, May 1994 (12 pages with 9 tables, RDB4A28)

This paper summarizes an investigation (see RDB3857) of the effects of 11 refrigerants and 17 refrigerant-lubricant combinations on sheet insulation materials for hermetic compressor motors. The introduction outlines the mechanisms by which insulation properties are impacted, including absorption of refrigerants, subsequent desorption, and solvent extraction. It notes that absorption may change the dielectric strength or physical integrity. Absorption can cause excessive swelling, softening, or decreased strength. Rapid desorption may cause blisters, crazing, surface craters, delamination, or bubbles within the insulating materials. Extraction of materials may result in a range of effects from dissolving of unpolymerized materials to complete dissolution. Extraction and dissolution, in turn, may cause other components to stick or lead to clogging of passage such as capillary tubes. The paper outlines the experimental procedures followed, which comprised immersions in liquid refrigerant or refrigerant-lubricant pairs at 2068 kPa (300 psia). Properties were measured immediately after 500 hr exposures and again after baking at 150 °C (302 °F) in air, to remove absorbed refrigerant. The refrigerants tested included R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, R-152a, and R-245ca. The lubricants included naphthenic mineral oil (Witco Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150), polyolester (POE) mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244), POE branched acid (Henkel Emery(R) 2927), a polyalkylene glycol (PAG) butyl monoether (ICI Emkarox(R) VG32), PAG modified with a fluoroalkyl group (AlliedSignal BRL-150), and a PAG diol (Dow Chemical

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P425). The sheet insulations tested were Westinghouse Nomex-Mylar-Nomex(R), Westinghouse Dacron-Mylar-Dacron(R), DuPont Mylar(R) 900 MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228. Tabular results are presented and discussed for weight changes for 17 refrigerant-lubricant pairs, tensile strength, moisture changes as an indication of potential hydrolysis and embrittlement, weight and flexibility changes, and effects on dielectric strength. The paper concludes that the combinations of R-22 with mineral and alkylbenzene lubricants have the greatest effects on motor materials. Whereas these systems have an excellent history of reliability with many of the materials tested, the alternative refrigerants and lubricants tested are expected to be reliable with most materials.

J. E. Field (Spauschus Associates, Incorporated), **Sealed Tube Comparisons of the Compatibility of Desiccants with Refrigerants and Lubricants**, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, 361-374, May 1994; republished as paper DOE/CE/23810-40B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, May 1994 (14 pages with 6 figures and 5 tables, available from JMC as RDB4514)

This paper introduces an ongoing study to determine the compatibility of 16 desiccants with 13 refrigerant-lubricant combinations. It reports results for two molecular sieves in R-12, R-32, and R-134a with associated lubricants. Two tables identify the desiccants and refrigerant-lubricant systems to be examined. The desiccants are tested by exposures in sealed glass tubes with aluminum, copper, and steel catalysts. The resulting liquid and gas phases as well as the desiccants are then examined for changes. The paper outlines the preparation and analysis methods, including experimental procedures rejected based on preliminary testing. Representative chromatograms are presented for a 4Å molecular sieve aged in R-134a with a polyolester (POE) lubricant, a pentaerythritol ester mixed acid (POE-MA), and for the aged liquid phase. Summary test results also are tabulated for both 3Å and 4Å molecular sieves in R-12 with mineral oil (MO) and for R-32 and R-134a with POE-MA. The tables present liquid color, copper plating, solids formation, crush strength, fraction of reacted refrigerant based on gas chromatography, fluoride and chloride ion content in the liquid phase and retained in the desiccant, total acid number, and organic acid retained in the desiccant. Data are provided for the original specimens as well as after aging with both 50 and 1000 ppm of added moisture. Four figures illustrate the findings of organic acid and halide analyses for the two desiccants. After discussing the results, the paper concludes that none of the molecular sieves tested are compatible with R-32, but that the halide acid anions are largely contained by the desiccant for R-12 and R-134a. The paper notes that this retention of reactive species indicates that traditional analysis lubricant and refrigerant from operating systems may not reveal the true states of systems. It suggests that the desiccants also should be analyzed.

E. Günther (Foron Hausgeräte GmbH, Germany), **Hydrocarbons as Refrigerants in Domestic Refrigerators**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 37-48, 1994 (12 pages, rdb5331)

R-290/600a, R-600a/600 (50/50), R-600a

H. Halozan and T. Ebner (Technische Universität Graz, Graz, Austria), **Propane - A Realistic Alternative**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 331-338, 1994 (8 pages, rdb6751)

R-290

U. Hesse and H. Arnemann (Universität Hannover, Germany), **Carbon Dioxide - Hydrocarbon Mixtures as Alternative Fluids in Refrigeration Systems**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 711-719, 1994 (9 pages with 5 figures and 2 tables, RDB4A65)

carbon dioxide/hydrocarbon blends, R-744/600a (carbon dioxide/isobutane), lubricant solubility, flammability, properties

N. J. Hewitt, J. T. McMullan, and B. Mongey (University of Ulster, UK), **Some Aspects of Using Hydrocarbons as Components in Refrigerant Mixtures**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 143-152, 1994 (10 pages with 10 figures and 2 tables, RDB4A64)

R-218, R-290 (propane), R-C270 (cyclopropane), R-227ea, R-236ea, R-245cb, R-C318, R-600 (n-butane), R-600a (isobutane), R-32/290/134a (30/10/60), R-125/290/134a (10/30/60), R-125/290/134a (44/52/4), hydrocarbon blends

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **The Use of Natural Refrigerants - A Complete Solution to the CFC/HCFC Predicament**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 21-36, 1994; republished in the *International Journal of Refrigeration* (IJR), 18(3):190-197, March 1995 (7/8 pages with 8 figures and 1 table, RDB5328)

R-290, R-717, R-718, R-744

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Use of CO_2 in Commercial Refrigeration; An Energy Efficient Solution**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 703-709, 1994 (7 pages with 3 figures, RDB4A62)

R-744, carbon dioxide, transcritical cycle

H. Lotz (Bosch-Siemens Hausgeräte GmbH, Germany), **Light Hydrocarbons as Refrigerants and Blowing Agents for Insulation in Household Appliances,** *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 49-64, 1994 (16 pages with 11 figures and 2 tables, RDB-5332)

R-290/600a, R-600a

D. Mosemann (Kühlautomat Berlin GmbH KAB, Germany), **Ammonia Chillers for Air Conditioning**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 71-96, 1994 (26 pages with 20 figures and 1 table, RDB5334)

R-717

J. Paul (Integral Technologie GmbH, Germany), **Water as Alternative Refrigerant**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 97-108, 1994 (12 pages with 3 figures and 2 tables, RDB5335)

R-718

J. Pettersen and G. Skaugen (Norgest Tekniska Högskole, NTH, Norway), **Operation of Transcritical CO_2 Vapour-Compression Circuits in Vehicle Air-Conditioning**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 495-505, 1994 (11 pages, rdb9708)

R-744, carbon dioxide, transcritical cycle

A. Reinhart, **Ammonia in Liquid Chillers and Heat Pumps**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 65-70, 1994 (6 pages with 4 figures and 3 tables, RDB5333)

R-717, ammonia

H. Schömann (SMS Schloemann Siemag AG, Germany), A. Luke, and D. Gorenflo (Universität Paderborn, Germany), **Prediction of Pool Boiling Heat Transfer with Hydrocarbons - Influence of the Surface Roughness of the Heated Wall**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 131-142, 1994 (12 pages with 7 figures and 1 table, RDB5720)

R-290 (propane), R-602 (n-hexane), steel tube, heat transfer, surface enhancement

W. K. Snelson, J. W. Linton, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **Soft-Optimized System Test of Refrigerant Blend R-23/32/125 (5/25/70)**, Alternative Refrigerants Evaluation Program (AREP) report 161, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1994 (16 pages with 6 figures and 4 tables, available from JMC as RDB5661)

R-23/32/125 (5/25/70) [identified in the report as "R-32/125/23 (25/70/5)"] compared to R-502 in a test loop using a reciprocating-piston compressor with an unidentified polyolester (POE) lubricant

S. R. Szymurski (Air-Conditioning and Refrigeration Technology Institute, ARTI), **Research Update: Materials Compatibility and Lubricant Research (MCLR) Program**, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, 387-396, May 1994; republished as paper DOE/CE/23810-40A, ARTI, Arlington, VA, May 1994 (10 pages with 1 table, available from JMC as RDB4513)

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This paper reviews the introduction of alternative refrigerants to replace those that deplete the ozone layer, the consequent research needs to evaluate and test the new fluids, and the history of the Materials Compatibility and Lubricant Research (MCLR) Program. Cumulative funding for the first three phases, from September 1991 to the present, is $6.45 million. The research is jointly supported by a grant from the Department of Energy and cost sharing by the Air-Conditioning and Refrigeration Institute (ARI). The paper outlines seven research projects in phase I, addressing thermophysical properties, theoretical evaluation of R-22 and R-502 alternatives, chemical and thermal stability of refrigerants and lubricants, miscibility of lubricants in refrigerants, and compatibility with motor materials, elastomers, and engineering plastics. A table presents the coefficients of performance and volumetric capacities relative to those of R-22 and R-502 for the twelve refrigerants examined in the theoretical evaluation. The paper then reviews five additional projects in phase II, three of which involve accelerated screening methods to determine chemical and thermal stability, predict the life of motor materials, and to predict lubricant performance. The two others address compatibility of refrigerant-lubricant mixtures with desiccants and electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants. Seven top priority projects are identified for Phase III. They include compatibility of manufacturing process fluids with hydrofluorocarbon (HFC) refrigerants and ester lubricants, effects of lubricant additives on HFC refrigerant stability, compatibility problems resulting from the products of motor burnouts, and investigation into the fractionation of refrigerant blends. They also include investigation of flushing and clean-out methods after motor burnout or refrigerant and lubricant conversion, methods development for measuring and classifying flammability/combustibility of refrigerants, and thermophysical properties measurements for R-41, R-245ca, and a number of binary and ternary blends. The paper notes that planning is underway for phase IV and that, while much has been accomplished in the first two years, much more remains. The materials compatibility results so far have been favorable for the HFC refrigerants tested.

T. Tiedemann and H. H. Kruse (Universität Hannover, Germany), **Evaluation of Zeotropic Hydrocarbon Mixtures in a Lorenz-Meutzner Refrigerator-Freezer**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 607-620, 1994 (14 pages with 6 figures and 6 tables, RDB5B29)

R-134a, R-C270; R-290; R-600; R-600a; R-601 (n-C5 or pentane); R-601b (2,2-dimethylpropane); R-1250 (propadiene); R-1270 R-290/600; R-290/600/601; R-290/600a (28/72), (40/60), (50/50), and (72/28); R-290/601 (R-290/n-C5); butene, 2-methyl-1,3-butadiene, 2-methylbutane, 1,2-pentadiene, 1,4-pentadiene, pentene, R-E170

Combustion of Ammonia With and Without Oil Vapor, research project 682-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1991 - May 1994 (ASH0682)

The objective of this project was to establish the combustibility of R-717 (ammonia), mixtures of ammonia with oil and air, and mixtures of ammonia, natural gas, and air in concentrations of 100-250,000 ppm. Both mineral oil and synthetic lubricants were examined. It also examined the geometric configurations for release that facilitate combustion, in order to improve discharge designs for flaring. The contractor for this research was Kansas State University (KSU), led by D. L. Fenton and K. S. Chapman; it was sponsored by ASHRAE Technical Committee 10.1, *Custom Engineered Refrigeration Systems.*

Genetron(R) 134a Product Brochure, bulletin G-525-009, AlliedSignal Incorporated, Morristown, NJ, May 1994 (14 pages with 5 figures and 7 tables, RDB4940)

This bulletin supplies information on R-134a and application data in metric (SI) and inch-pound (IP) units. R-134a is described as a replacement for R-12 in automobile air conditioning; residential and commercial refrigeration; residential, commercial, and industrial air conditioning including centrifugal chillers; and as a blowing agent and aerosol propellant. The bulletin describes these applications and lists basic physical properties including the chemical name and formula, appearance, molecular weight, normal boiling and freezing points, and critical parameters (temperature, pressure, density, and specific volume). The property data also include the vapor density, latent heat of vaporization at the boiling point, flammability limits (none), autoignition temperature, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP). Representative data are provided for 25 °C (77 °F) including the liquid density; vapor pressure; solubility in and of water; and vapor and liquid heat capacity, thermal conductivity, and viscosity. The bulletin provides Mollier (pressure-enthalpy) charts, product purity specifications, a tabular comparison of performance with R-12, and tabular pressure-temperature data for -45 to 70 °C (-60 to 160 °F). It then discusses lubricant suitability with primary focus on polyalkylene glycol (PAG) and polyolester (POE) synthetics. Characteristic miscibility plots are shown. The document discusses copper plating with PAG and POE lubricants. It notes that plating levels are lower for R-134a with the cited lubricants than with R-12 and mineral oil. While plating does not appear in laboratory tests with two POEs (Castrol Icematic(R) SW32 and Mobil EAL Arctic(R) 22), field occurrence suggests that it may result in the presence of other materials. The bulletin tabulates stability data for the same POEs in the presence of aluminum, copper, and steel. It discusses the effects of chlorinated solvents and residual refrigerants, noting that R-134a is chemically compatible with chlorinated materials, but that the associated PAG and POE lubricants may not be. It notes, however, that R-12 and R-134a form a higher-pressure azeotrope. The bulletin then discusses materials compatibility and provides tabular, qualitative indications for elastomers and plastics. It discusses suitability with polyethylene terephthalate (PET) and desiccants, and also provides a plot of solubility of water in R-134a. The bulletin then discusses safety, including both toxicity and flammability. It describes the former as intrinsically low. While it suggests that R-134a is nonflammable, it notes that R-134a can become combustible at higher pressures when mixed with more than 60% air. The bulletin discusses storage, handling, safety guidelines, and leak detection methods. It briefly outlines environmental considerations, reclamation, retrofit procedures for R-12 equipment, and R-134a packaging. AlliedSignal's product name for R-134a is Genetron(R) 134a.

Genetron(R) AZ-50 Product Brochure, bulletin G-525-030, AlliedSignal Incorporated, Morristown, NJ, January 1994, reprinted March 1994, reprinted May 1994 (12 pages with 4 figures and 5 tables, RDB-4941)

This bulletin supplies information on R-507A, a blend of R-125 and R-143a - R-125/143a (50/50) - and application data in metric (SI) and inch-pound (IP) units. R-507A is described as a long-term replacement for R-502 in commercial refrigeration, for both new equipment and retrofits. The bulletin describes these applications and lists basic physical properties including the chemical name and formula, appearance, molecular weight, normal boiling point, and critical parameters (temperature, pressure, density, and specific volume). The property data also include the vapor density, latent heat of vaporization at the boiling point, flammability limits (none), ozone depletion potential (ODP), and halocarbon global warming potential (HGWP). Representative data are provided for 25 °C (77 °F) including the liquid density; vapor pressure; and vapor and liquid heat capacity, thermal conductivity, and viscosity. The bulletin provides Mollier (pressure-enthalpy) charts, product purity specifications, a tabular comparison of performance with R-502, and tabular pressure-temperature data for -45 to 70 °C (-60 to 160 °F). It then discusses lubricant suitability with primary focus on polyolester (POE) synthetics. A characteristic miscibility plot is shown. The bulletin tabulates stability data three POEs (Castrol Icematic(R) SW32 and Mobil EAL Arctic(R) 22 and 32) in the presence of aluminum, copper, and steel. It discusses the effects of chlorinated solvents and residual refrigerants, noting that R-507A is chemically compatible with chlorinated materials, but that the associated POE lubricants may not be. It notes, however, that R-502 and R-507A should not be mixed; while each is an azeotrope, two of their components, R-115 and R-502 also form an azeotrope, resulting in a four-component mixture that is difficult to separate. The bulletin then discusses materials compatibility and provides tabular, qualitative indications for elastomers and plastics with R-507A, with and without an unidentified POE. It discusses desiccant suitabilities, and also provides a plot of solubility of water in R-507A. The bulletin then discusses safety, including both toxicity and flammability. It describes the former as intrinsically low. While it suggests that R-507A is nonflammable ("practically nonflammable" by Underwriters' Laboratories, UL, classification), it notes that R507A can become combustible at higher pressures when mixed with air. The bulletin discusses thermal stability, storage, handling, safety guidelines, and leak detection methods. It briefly outlines environmental considerations, reclamation, retrofit procedures for R-502 equipment, and R-507A packaging. AlliedSignal's product name for R-507A is Genetron(R) AZ-50.

April 1994

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Measurement of Viscosity, Density, and Gas Solubility of Refrigerant Blends in Selected Synthetic Lubricants**, report DOE/CE/23810-38B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1994 (124 pages with 103 figures and 12 tables, available from JMC as RDB4537)

This interim report summarizes progress to measure the viscosity, density, and solubility of

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three refrigerant blends with lubricants. These blends are candidates to replace R-22 and R-502. They include R-32/125/134a (23/25/52), R-125/143a (50/50), and R-404A [R-125/143a/-134a (44/52/4)]. They were tested with unidentified, 32 ISO VG polyolester (POE) lubricants, including one branched acid (POE-BA) and one mixed acid (POE-MA). Data on R-22 and R-502 with a naphthenic mineral oil (MO, Witco Suniso(R) 3GS) also are included for comparison. Selection of the refrigerant blends was based on miscibility evaluations and commercial reformulations of R-32/125 (60/40), R-32/125/134a (30/10/60), R-32/125/290/134a (20/55/5/20), R-32/134a (30/70), R-125/143a (45/55), and R-125/143a/-134a (44/54/2). Their miscibilities were determined for five lubricants, including two POE-BA (Castrol Icematic(R) SW32 and Henkel Emery(R) 2968a), two POE-MA (ICI Emkarate(TM) RL 32S, formerly RL 184, and Mobil Arctic(R) EAL 224R), and an alkylbenzene (AB, Shrieve Zerol(R) 150). The report presents the methods and apparatus used, and provides schematics for an oscillating body viscometer and blend sampling apparatus. The former is described as a unique means to accurately determine viscosity, density, equilibrium refrigerant gas solubility, and pressure over a broad range of temperatures. Plots relate pressure to viscosity and temperature, show the viscosity and pressure at constant concentrations in modified Daniel Charts, and relate pressure to density. These plots are provided for R-134a, R-143a, R-125/143a (50/50), and R-404A for POE-BA and POE-MA at 0 to 125 °C (32 to 257 °F), except R-134a/POE-BA at -25 to 125 °C (-13 to 257 °F). These plots cover pressures of approximately 70-1700 kPa (10-250 psia) and 0-60% refrigerant by weight. An appendix provides plots showing the miscibility, partial miscibility, and immiscibility ranges by temperature for -62 to 82 °C (-80 to 180 °F) for combinations of the six screening blends and five synthetic lubricants. A second appendix presents plots and tabular raw data for the viscosity and solubility of R-22 with mineral oil at -20, 0, 20, 40, 60, 80, 100, and 125 °C (-4, 32, 68, 104, 140, 176, 212, and 257 °F). A third similarly presents viscosity, solubility, and vapor fractionation for R-22 with mineral oil at -10, 0, 20, 40, 60, 80, 100, and 125 °C (14, 32, 68, 104, 140, 176, 212, and 257 °F). Eight concluding appendices gives plots and tabular raw data for the viscosity, density, and gas solubility of R-134a, R-143a, R-125/143a (50/50) and R-404A, each with both POE-BA POE-MA, at 0, 20, 40, 60, 80 or 90, and 125 °C (32, 68, 104, 140, 176 or 194, and 257 °F) and also at -30, -15, and 100 °C (-22, 5, 212 °F) for the R-134a/POE-MA mixture. [A designation of R-507A has been recommended for R-125/143a (50/50).]

J. E. Field (Spauschus Associates, Incorporated), **Sealed Tube Comparisons of the Compatibility of Desiccants with Refrigerants and Lubricants**, report DOE/CE/23810-38A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1994 (24 pages with 12 tables, available from JMC as RDB4602)

This progress report presents the interim findings of a study to determine the compatibility of desiccants with refrigerant-lubricant combinations, using sealed-tube tests with aluminum, copper, and steel catalysts. The report generically identifies the test materials, outlines the preparation and analysis methods, and summarizes the desiccant specifications. The moisture content and contaminants of the refrigerants specimens and the moisture content, total acid number, and ion content of the lubricants are tabulated. A table for each desiccant summarizes findings before and after aging, with both 50 and 1000 ppm of added moisture. These results include liquid color, copper plating, solids formation, crush strength, fraction of reacted refrigerant based on gas chromatography, fluoride and chloride ion content in the liquid phase and retained in the desiccant, total acid number, and organic acid retained in the desiccant. The 16 desiccants include samples from two suppliers for each of eight types, namely: 3Å and 4Å molecular sieves, alumina, silica gel, and four core types. They include 10-25% molecular sieve and alumina with carbon and 15-30% molecular sieve and alumina without carbon, each with type 3Å and 4Å molecular sieves. The lubricants include a naphthenic mineral oil (MO), alkylbenzene (AB), and two classes of polyolester (POE) lubricants - pentaerythritol ester branched acid (POE-BA) and pentaerythritol ester mixed acid (POE-MA). Compatibility data are being obtained for each of the desiccants with 13 refrigerant-lubricant combinations: R-11, R-12, R-22, and R-123 with MO; R-32, R-125, and R-134a with both POE-BA and POE-MA; R-124 with AB; R-143a with POE-BA; and R-152a with AB (or with POE-MA). The progress report provides detailed results for six of the bead type, molecular sieves as well as partial results, primarily at the 50 ppm moisture level, for alumina and silica gel. It also presents a number of conclusions: Addition of 1000 ppm moisture produces no significant difference. The desiccant solid phase contains most of the chloride and fluoride ions for molecular sieves, but not always with alumina and silica gel desiccants. All of the desiccants tested contained chloride, fluoride, and other ions when received, and they do not perform as well in retaining organic anions as they do for inorganic anions. The crush strength was reduced approximately 20% after aging. None of the desiccants tested are compatible with R-32.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermophysical Properties of HFC-143a and HFC-152a**, report DOE/CE/23810-38E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1994 (86 pages with including 8 figures and 13 tables, available from JMC as RDB4515)

This progress report summarizes experimental measurements to provide highly accurate, thermophysical property data for R-143a and R-152a. The project also includes data fitting to modified Benedict-Webb-Rubin (MBWR) equations of state and detailed transport property models. The objective is to fill gaps in current data and resolve problems and uncertainties that exist in and between such data. The report outlines progress during the preceding quarter. It describes use of a cylindrical acoustic resonator to measure the speed of sound in R143a, and analytical determination of a virial relation for ideal gas heat capacity using the data. The report reviews measurements of the refractive index and capillary with an optical cell, from which the critical temperature and density were determined, 73.60 °C (164.48 °F) and 432.7 kg/m^3 (27.01 lb/ft^3), respectively. New 32-term MBWR equations of state are presented for both R-143a and R-152a. The report also describes use of transient, hot-wire instruments to determine the thermal conductivity of both refrigerants. Figures show the deviations of the equations of state from ancillary equations for the vapor pressure and saturated liquid and vapor densities and from measured data. Plots of the thermal conductivity surfaces also are included. An appendix provides tables with measured speeds of sound, ideal gas heat capacities, and acoustic virial coefficients for R-143a. It also presents the equations of state (EOS), critical parameters, ideal gas heat capacity equations, and derived thermodynamic properties for both R-143a and R-152a. Except for the equations and critical parameters, all of the data are provided in both metric (SI) and inch-pound (IP) units.

S. R. Szymurski, M. Hawley, G. C. Hourahan, and D. S. Godwin, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-38, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1994 (72 pages with 12 figures and 18 tables, available from JMC as RDB4601)

This progress report summarizes the goals and status of the Materials Compatibility and Lubricant Research (MCLR) Program, jointly funded under a grant from the Office of Building Technology of the U.S. Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program was implemented on 30 September 1991 and, as currently funded, will run through 30 September 1995. It supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. The primary elements include materials compatibility testing, methods development, and data collection and dissemination. The report provides a status update on research to measure thermophysical properties of R-143a and R-152a; measure the viscosity, density, and solubility for three azeotropic and zeotropic blends to replace R-22 and R-502; measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures; obtain compatibility data on desiccants with refrigerants and lubricants; and obtain compatibility of manufacturing process fluids with hydrofluorocarbon (HFC) refrigerants and ester lubricants. The report also summarizes three projects to develop accelerated screening and test methods to predict lubricant performance in compressors, the life of motor materials exposed to refrigerant-lubricant mixtures, and chemical and thermal stability of refrigerant-lubricant mixtures. It reviews the progress of a continuing project to collect and facilitate dissemination of data, through development and administration of the ARTI Refrigerant Database. The progress report summarizes completed projects to measure thermophysical properties of R-32, R-123, R-124, and R-125; model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502; test the chemical and thermal stability of refrigerant-lubricant mixtures with metals; measure the miscibility of lubricants with refrigerants; provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics; and investigate electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants. The scope of the program, objectives of the individual projects, and significant interim findings are presented. This program summary also identifies reports resulting from the individual projects. Tables and figures summarize significant findings of the individual projects including the miscibility of lubricants with 10 refrigerants; equations of state developed for R-32, R-123, R-124, R-125, R-143a, and R-152a; refrigerant-lubricant viscosity, solubility, and density correlations; test data on molecular sieves in refrigerants and lubricants; and relative elastomer swelling in refrigerants and lubricants. Two figures compare the modelled performance of alternative refrigerants to the capacities and efficiencies of R-22 and R-502.

G. B. Wetzel (McQuay International), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants

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Evaluation Program (AREP) report 175, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (14 pages with 7 tables, available from JMC as RDB5675)

R-32/125/134a (30/10/60) with a polyolester (POE) lubricant (Mobil EAL Arctic(R) 22 CC) compared to R-22 in water-source heat pump (McQuay model CCH-036) using a hermetic, reciprocating piston compressor (Copeland model CR32K6-TFD) in both the cooling and heating modes

Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) Summaries, AFEAS, Washington, DC, June 1994 (24 pages with 6 figures and 2 tables, available from JMC in English or Japanese as RDB4A67)

This series of ten leaflets presents key AFEAS objectives and findings. A summary of the *Montreal Protocol on Substances that Deplete the Ozone Layer* reviews the history of this international accord to phase out production of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants among other chemicals. It also recaps the schedules under the Protocol as well as the U.S. Clean Air Act and European regulations. A sheet on *Production and Sales of Fluorocarbons* reports annual production of R-11, R-12, R-22, R-113, R-114, and R-115 for 1970-1992 on a worldwide basis (participating companies only for 1992). A summary on *Atmospheric Chlorine: CFCs and Alternative Fluorocarbons* reviews the mechanisms of stratospheric ozone depletion and provides values for ozone-depletion potentials (ODPs). It also illustrates how substitution of HCFCs for chlorofluorocarbons (CFCs) reduces chlorine in the atmosphere. The illustration further shows that use of HCFCs for a limited time will not delay return of atmospheric chlorine to pre-1970s levels. This summary quotes an international assessment that notes a three-year advance on the phaseout requirements of the Montreal Protocol. A synopsis of the *Relative Contributions of Greenhouse Gas Emissions to Climate Forcing* discusses radiative forcing, a parameter used to perturb the heat balance in modeling of the earth-atmosphere system. It outlines understanding and uncertainties associated with GWP values, atmospheric persistence of greenhouse gas emissions, and the quantitative influence of *integration time horizon* (ITH) on analyses of impacts. A table provides estimates for the atmospheric lifetimes and GWP values for 20, 100, and 500 yr ITH. A sheet on *Total Global Warming Impact* compares the Total Equivalent Warming Impacts (TEWIs), considering both direct (emission related) and indirect (energy related) effects of alternative technologies and fluids. It notes that a not-in-kind (NIK) refrigerant option, with more than a 1% increase in energy use, would have a larger total warming impact than HCFC and HFC options. A review of the *Breakdown Products of Alternatives* outlines the mechanisms and consequences of HCFC and hydrofluorocarbon (HFC) breakdown. It notes that they readily decompose into simple inorganic species in the lower atmosphere, that the ultimate breakdown products are acidic compounds that are washed out in rain, that the acidic concentrations are so low as to have no appreciable effect, and that the alternatives do not contribute to photochemical smog formation in urban areas. A further summary of the *Environmental Fate of Trifluoroacetyl Halides* addresses the atmospheric breakdown of R-123, R-124, and R-134a, producing trace quantities of trifluoroacetyl halides. These halides hydrolyze, in cloud water droplets or surface waters, to form trifluoroacetic (TFA) acid and hydrofluoric or hydrochloric acid. The fate of TFA ions is discussed. While not expected to have an impact on humans, plants, animals, or microorganisms, further study of the ultimate physiochemical and biological fate is underway. A sheet on UV-B *Radiation Measurements* discusses the importance of the ozone layer in shielding ultraviolet-B (UV-B) radiation in sunlight as well as efforts to monitor and observed trends of incoming UV-B intensity. A *Glossary of Terms* defines terminology for discussion of the atmospheric effects of alternative fluorocarbons. The last sheet briefly outlines the history and activities of both AFEAS and the companion Programme for Alternative Fluorocarbon Toxicity Testing (PAFT).

Klea® 66, Replacement for HCFC 22, technical note 620250470, ICI Klea, Wilmington, DE, April 1994 (12 pages with 2 figures and 3 tables, available from JMC as RDB4887)

This document describes and provides data on R-407C, a ternary, zeotropic blend of R-32, R-125, and R-134a [R-32/125/134a (23/25/52)], developed as a replacement for R-22 in new equipment. The technical note summarizes the phase out of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, the need for alternatives to R-22, and ICI's search for likely replacements. It then compares atmospheric lifetime, ozone depletion potentials (ODP) and halocarbon global warming potential (HGWP) data for R-22, R-32, R-125, R-134a, and R-407C. It also provides a comparison of physical properties, at the normal boiling point, and theoretical performance comparison between R-22 and the blend. Two plots compare the coefficient of performance (COP) and cool ing capacity, for evaporator temperatures of -20 to 10 °C (-4 to 50 °F) for R-22 and the blend. They show the blend's performance to be equal to, or slightly better than that of R-22. The document then discusses the flammability and toxicity of both the blend and its components, noting that the composition was designed to be nonflammable despite its R-32 content. The bulletin briefly reviews handling and leakage. It advises that the blend always should be liquid charged into systems, and that investigation has shown that degradation of performance will not be significant with anticipated leakage. The document next discusses appropriate lubricants, with focus on the ICI Emkarate(R) RL family of synthetic, neopentyl polyolesters. Several documents are cited as available or under preparation to provide thermophysical properties, flammability specifics, blend design information, handling and storage advice, and retrofit guidance. ICI's product name for R-407C is Klea(R) 66.

Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries, PAFT, Bristol, United Kingdom, April 1994 (16 pages, available from JMC in English or Japanese as RDB-4A66)

Eight data sheets summarize the status and findings of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). They outline studies of acute toxicity (short-term exposures to high concentrations, such as accidental leakage), genotoxicity (effects on genetic material, an early screen for possible carcinogenic activity), sub-chronic toxicity (repeated exposure to determine any overall toxicological effect), reproductive and developmental toxicity (teratology, assessment of the effects on the reproductive system and of the potential for causing birth defects), chronic toxicity/carcinogenicity (lifetime testing to assess late-in-life toxicity or increased evidence of cancer), and ecotoxicity (assessment of potential to affect living organisms in the environment). Toxicology summaries for R-123, R-124, R-125, R-134a, and R-141b indicate that all have low or very low toxicity; test results show them to be neither developmental toxicants nor genotoxic. Additionally, R-123 and R-141b were found to have low acute dermal and inhalation toxicity, but caused an increased incidence of benign - but not life threatening - tumors in animals following long-term exposures. R-134a also caused an increased incidence of benign - but not life threatening - tumors in animals following long-term exposure to high concentrations. R-124, R-125, and R-134a were found to have very low acute and subchronic inhalation toxicity. No current findings preclude use of R-32 in general industrial uses, provided that recommended normal hygiene practices are observed. R-225ca and R-225cb (candidate solvents to replace R-113) were found to have low acute, oral, dermal, and inhalation toxicity. Neither is mutagenic or deemed a genetic hazard. R-225ca concentrations of 650-1000 ppm produced effects on the liver in rodents, but minor effects in a primate; 1000-5000 ppm R-225cb resulted in only marginal effects in either. A *Glossary of Terms* is provided.

March 1994

J. Berghmans (Katholieke Universiteit Leuven, Belgium), **Effects of Accidents with Flammable Refrigerants and the European Attitude Towards their Use**, presentation 5.1, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (12 pages with 10 presentation charts, available from JMC as RDB-4795)

flammability

W. Goetzler (Arthur D. Little, Incorporated, ADL), **Development of a Risk Assessment for Flammable Refrigerants**, presentation 4.1, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (18 pages with 28 presentation charts, available from JMC as RDB4794)

W. L. Grosshandler (National Institute of Standards and Technology, NIST), **Lean Flammability Limit as a Fundamental Material Property**, presentation 3.4, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994, (24 pages with 21 presentation charts, available from JMC as RDB4793)

P. S. Squair (Air-Conditioning and Refrigeration Institute, ARI), **ARI Code Activity on Refrigerants**, presentation 1.2, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), ARI, Arlington, VA, 1994 (12 pages with 10 presentation charts, available from JMC as RDB-4783)

R. E. Tapscott and E. W. Heinonen (New Mexico Engineering Research Institute, NMERI), **Methods Development for Measuring and Classifying Flammability/Combustibility of Refrigerants**, presentation 2.4, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (16 pages with 13 presentation charts, available from JMC as RDB4787)

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These charts outline a research project to develop procedures and equipment to measure refrigerant flammability. A second objective is to characterize parameters affecting flammability. The charts outline three tasks, to gather and review available data, establish a test plan, and perform laboratory testing. Each task is described. The first includes performance of a structured literature search, development of an information storage system, and preparation of an annotated bibliography and summary. Proposed search topics are listed. The second task will use the information found, to identify data shortfalls and to design experiments and methods to address them. Parameters affecting flammability are noted, including apparatus size and construction, composition of the refrigerant, humidity, pressure, temperature, and ignition type and strength. Data to be addressed in laboratory testing, analyses, and consultations with others are identified. They include autoignition temperatures, source ignition energy, pressure rise trace, temperature rise, lower and upper flammability limits (LFL and UFL), and visual indications of flammability. Potential modifications to the ASTM E681 apparatus, including an increase to the vessel volume, an additional ignition point, and use of heating to raise the test temperature are noted. The charts conclude with a description and schematic of the NMERI explosion sphere, which is based on a Fenwal design.

February 1994

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-33E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, February 1994 (186 pages, available from JMC as RDB4217)

This document provides bibliographic citations for 1087 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately half of these documents. The database identifies sources of specific information on R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. It addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It also references documents on compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes the same citations and abstracts as the report version plus 109 for a supplement on copper in air conditioning and refrigeration (see RDB4137), 114 for superseded and historical documents, and data summaries for 209 individual refrigerants and blends - a total of 1519 entries. It is accompanied by retrieval software to facilitate searches for specific information; the software enables searches for user-selected terms, or combinations of terms. It offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, and a "wildcard" capability to allow entry of word segments. The software also enables printing of selected citations, abstracts, and refrigerant summaries as well as preparation of a document order lists. Both versions of the database include instructions to obtain cited documents or subscriptions for updates to the database.

Refrigerant Reclin(R) HX4, product bulletin AF2612e, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, 22 February 1994 (8 pages with 3 figures and 3 tables, RDB4778)

This bulletin provides data for a tetrary zeotropic blend of R-32, R-125, R-143a, and R-134a - R-32/125/143a/134a (10/33/36/21) - in metric (SI) units of measure. The blend is described as a substitute for R-22 and R-502. A table summarizes physical and thermodynamic property data for R-22, R-502, and HX4, including the chemical formulation, molecular mass, normal freezing and boiling points, and critical parameters (temperature, pressure, and density). It also gives the heat of vaporization, liquid density, isentropic exponent, and flammability limits (none) at selected conditions. The bulletin indicates that the blend is nonflammable and that it would be unlikely to fractionate to a flammable mixture with air in the event of leakage. It notes that toxicity testing is not complete for the components, but that no adverse toxicological properties are indicated. Ozone depletion and halocarbon global warming potentials (ODP and HGWP) of 0 and 0.73, respectively, are indicated. The bulletin notes that only ester lubricants are suitable for HX4. It then reviews the thermodynamic similarities of the blend with those of R-22 and R-502. Two plots compare their pressure-temperature and density-temperature relationships for -50 to 60 °C (-58 to 140 °F). A table provides thermodynamic property data including the bubble and dew point pressures; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover HX4 at saturated (wet vapor) conditions from -50 to 70 °C (-76 to 158 °F). The bulletin concludes with a pressure-enthalpy (Mollier) diagram

January 1994

J. M. Calm (Engineering Consultant), **Copper in Air Conditioning and Refrigeration - Supplement to the ARTI Refrigerant Database**, report JMC/-ARTI/CDA-9401D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, and the Copper Development Association (CDA), New York, NY, January 1994 (28 pages, available from JMC as RDB4137)

This document provides bibliographic citations for 109 publications that may be useful in research, design, and application of air-conditioning and refrigeration (ACR) equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately half of these documents. This supplement to the Refrigerant Database increases the information provided, by focusing on the suitability of and application data for copper and copper alloys with refrigerants. The key concentration areas include heat transfer, surface enhancement, and materials compatibility. An introduction outlines the reasons copper is the preferred fabrication material in many ACR components. A concluding section provides descriptions of both the Refrigerant Database and the Copper Data Center (CDC) database.

B. Carter (Copeland Corporation), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 157, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (16 pages with 3 figures and 4 tables, available from JMC as RDB5657)

R-410A with a polyolester lubricant (Mobil EAL Arctic(R) 22 CC) in a hermetic, compliant scroll compressor (Copeland ZR18K1-PFV)

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Measurement of Viscosity, Density, and Gas Solubility of Refrigerant Blends in Selected Synthetic Lubricants**, report DOE/CE/23810-33C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1994 (86 pages with 67 figures and 8 tables, available from JMC as RDB4301)

This interim report summarizes progress to measure the viscosity, density, and solubility of refrigerant/lubricant mixtures using six blends of R-32, R-125, R-134a, R-143a, and R-290 (propane). The specific mixtures include R-32/125 (60/40), R-32/125/134a (30/10/60), R-32/125/-290/134a (20/55/5/20), R-32/134a (30/70), R-125/143a (45/55), and R-404A [R-125/143a/134a (44/54/2)]. Their miscibilities were determined in five lubricants, including two polyolester (POE) branched acids (POE-BA, Castrol Icematic(R) SW32 and Henkel Emery(R) 2927a), two POE mixed acids (POE-MA, ICI Emkarate(TM) RL 32S, formerly RL 184, and Mobil EAL Arctic(R) 224R), and an alkylbenzene (AB, Shrieve Zerol(R) 150). The last of these is used to examine the aromatic properties of miscibility. R-22 and R-502 also were examined with a mineral oil (MO, Witco Suniso(R) 3GS) for comparison. The report presents the methods and apparatus used, and provides schematics for an oscillating body viscometer and blend sampling apparatus. The former is described as a unique means to accurately determine viscosity, density, equilibrium refrigerant gas solubility, and pressure over a broad range of temperatures. Plots relate viscosity to temperature for R-22/MO, R-134a/POE-MA, R-502/MO for -25 to 125 °C (-13 to 257 °F) and R-134a/POE-BA, R-143a/POE-BA, and R-143a/-POE-MA for 0 to 125 °C (32 to 257 °F). These plots cover pressures of approximately 70-1700 kPa (10-250 psia) and 0-60% refrigerant by weight. Viscosities and pressures for these refrigerant-lubricant mixtures are presented as modified Daniel Charts. Densities also are plotted, as a function of temperature at constant concentration. An appendix provides plots showing the miscibility, partial miscibility, and immiscibility ranges by temperature for -62 to 82 °C (-80 to 180 °F) for combinations of the six blends and five synthetic lubricants. A second appendix presents plots and tabular raw data for viscosity and solubility for R-22 with mineral oil at -20, 0, 20, 40, 60, 80, 100, and 125 °C (-4, 32, 68, 104, 140, 176, 212, and 257 °F). A third similarly presents viscosity, solubility, and vapor fractionation for R-502 with mineral oil at -10, 0, 20, 40, 60, 80, 100, and 125 °C (14, 32, 68, 104, 140, 176, 212, and 257 °F). Four concluding appendices gives plots and tabular raw data for the viscosity, density, and gas solubility of R-134a/POE-BA, R-134a/POE-MA, R-143a/-POE-BA, and R-143a/POE-MA at 0, 20, 40, 60, 80, and 125 °C (32, 68, 104, 140, 176, and 257 °F) and also at -30, -15, and 100 °C (-22, 5, 212 °F) for the R-134a/POE-MA mixture.

C. Cusano (University of Illinois at Urbana-Champaign), **Accelerated Screening Methods for Predicting Lubricant Performance in Refrigerant Compressors**, report DOE/CE/23810-35, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1994 (64 pages with

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39 figures and 7 tables, available from JMC as RDB4538)

This interim report summarizes progress to identify more effective bench testers, to screen lubricants for air-conditioning and refrigeration compressors. The report reviews the general requirements for simulative, specimen testing. It also discusses problems encountered in scaling and test acceleration, the latter by increasing the load or speed to obtain measurable wear in a short period of time. The report notes drawbacks in popular methods, such as Falex testing and compressor bench tests. It then describes and schematically illustrates a high pressure tribometer (HPT). This apparatus is characterized as representing the temperature and pressure environment found in specific contact points in compressors. The report also explains the experimental procedure for comparison of HPT data with those taken with Falex testers, supplied by three compressor manufacturers. The purpose of the comparison is to determine if the controlled environment and lower loads used with the HPT produce different rankings than the Falex tests. The specimen data, test parameters, and refrigerant-lubricant combinations are tabulated. Tests were performed using grey cast iron (GCI) with SAE 333 die cast aluminum, SAE 356 die cast aluminum with hardened drill rod, SAE 380 die cast aluminum and grey cast iron with carburized 1018 steel paired to the three manufacturers' conditions. The last involved both oscillatory and unidirectional tests. The friction and wear data are plotted, and resulting rankings of lubricants are compared to those for three combinations of load and speed with the HPT. The report concludes that lubricant rankings based on data obtained with the HPT generally differ under various speeds and loads and also with those obtained by Falex testing. Moreover, no correlation exists between friction and wear; a contact that experiences low friction still can exhibit high wear and vice versa. And finally, the ranking of lubricants can be a function of the contact material. Future work in this project will identify representative contact geometries, analyze the tribological effectiveness of selected refrigerant/lubricant mixtures, and compare the HPT data those obtained in manufacturer component tests.

C. Cusano (University of Illinois at Urbana-Champaign), **Accelerated Screening Methods for Predicting Lubricant Performance in Refrigerant Compressors**, seminar presentation (ASHRAE Winter Meeting, New Orleans, LA, January 1994), report DOE/CE/23810-31, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 24 January 1994 (28 pages with 24 charts, available from JMC as RDB4214)

This report comprises presentation charts summarizing a study to develop an accelerated screening method, to predict lubricant performance in refrigerant compressors. The charts outline the objective, namely to develop a more effective bench tester to screen lubricants for air-conditioning and refrigeration systems. The approach obtained Falex and underlying wear data from compressor manufacturers and then compared these data to measurements with a high pressure tribometer (HPT). Diagrams illustrate the Falex test, contact geometry for unidirectional motion, and the HPT. A series of tables then summarize Falex test loads and speeds from three unidentified manufacturers, corresponding HPT and environmental conditions, and the refrigerant-lubricant pairs tested. They include R-12 and R-22 with mineral oils for reference and R-134a and an unidentified blend with nine also unidentified polyolesters. Six plots show representative friction and wear data at low speed and load, high speed and low load, and high speed and load for the refrigerant-lubricant combinations. The lubricants are then ranked by wear and the rankings compared to those from Falex tests. The plots and comparisons are repeated for conditions and refrigerant-lubricant systems corresponding to each compressor manufacturers' tests. The tests were performed using grey cast iron (GCI) with SAE 333 die cast aluminum, SAE 356 die cast aluminum with hardened drill rod, SAE 380 die cast aluminum and grey cast iron with carburized 1018 steel paired to the three manufacturers' conditions. The last involved both oscillatory and unidirectional tests. The presentation charts cite five conclusions: 1) lubricant rankings based on wear from HPT tests do not correlate either with each other or with Falex data, 2) consistent lubricant rankings are obtained even with different lubricant qualities, 3) lubricant rankings can be a function of the materials in contact, 4) material pairs that produce high friction do not necessarily produce high wear, and vice versa, and 5) for the conditions examined, R-134a/POE and the refrigerant blend/POE generally yielded higher wear than R-12 or R-22 with mineral oils.

S. Devotta, S. Gopichand, and V. R. Pendyala (National Chemical Laboratory, India), **Comparative Assessment of Some HCFCs, HFCs and HFEs as Alternatives to CFC-11**, *International Journal of Refrigeration* (IJR), 17(1):32-39, January 1994 (8 pages, rdb8207)

theoretical performance comparison based on pressure ratio, specific compressor displacement, and theoretical coefficient of performance (COP): concludes that R-11 "is the best thermodynamically efficient fluid" and that R-123 offers similar characteristics; also notes that R-245ca offers reasonable COP and that R-E143 may be suitable for the lower range of R-11 cooling capacities

N. Downs and M. Lindsay (Hussmann Corporation), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 159, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (10 pages with 2 figures and 2 tables, available from JMC as RDB5659)

R-410B compared to R-502 with a polyolester lubricant (Mobil EAL Arctic(R) 22) in a commercial refrigeration system

J. E. Field (Spauschus Associates, Incorporated), **Sealed Tube Comparisons of the Compatibility of Desiccants with Refrigerants and Lubricants**, report DOE/CE/23810-33B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1994 (80 pages with 35 figures and 40 tables, available from JMC as RDB4429)

This progress report presents the interim findings of a study to determine the compatibility of desiccants with refrigerant-lubricant combinations, using sealed-tube tests with aluminum, copper, and steel catalysts. The report generically identifies the test materials, outlines the preparation and analysis methods, and summarizes the desiccant specifications. The moisture content and contaminants of the refrigerants specimens and the moisture content, total acid number, and ion content of the lubricants are tabulated. A table for each desiccant summarizes findings before and after aging, with both 50 and 1000 ppm of added moisture. These results include liquid color, copper plating, solids formation, crush strength, fraction of reacted refrigerant based on gas chromatography, fluoride and chloride ion content in the liquid phase and retained in the desiccant, total acid number, and organic acid retained in the desiccant. The 16 desiccants include samples from two suppliers for each of eight types, namely: 3Å and 4Å molecular sieves, alumina, silica gel, and four core types. They include 10-25% molecular sieve and alumina with carbon and 15-30% molecular sieve and alumina without carbon, each with type 3Å and 4Å molecular sieves. The lubricants include a naphthenic mineral oil (MO), alkylbenzene (AB), and two classes of polyolester (POE) lubricants - pentaerythritol ester branched acid (POE-BA) and pentaerythritol ester mixed acid (POE-MA). Compatibility data are being obtained for each of the desiccants with 13 refrigerant-lubricant combinations: R-11, R-12, R-22, and R-123 with MO; R-32, R-125, and R-134a with both POE-BA and POE-MA; R-124 with AB; R-143a with POE-BA; and R-152a with AB (or with POE-MA). The progress report provides results for six of the bead type desiccants in R-12/MO. Detailed results are appended for each of these desiccants, including ion chromatograms and tabular crush strength data.

K. K. Fung (Tyler Refrigeration Company), **Soft-Optimized System Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 154, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (16 pages with 5 tables, available from JMC as RDB4754)

R-125/143a (45/55) compared to R-502 with polyolester lubricant (Mobil EAL Arctic(R) 22 CC) in a commercial refrigeration system

E. A. Groll and R. K. Radermacher (University of Maryland), **Vapor-Compression Refrigeration Cycle with Solution Circuit and Desorber-Absorber Heat Exchange**, paper 3743, *Transactions* (Winter Meeting, New Orleans, LA, January 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(1):73-83, 1994 (11 pages with 10 figures and 2 tables, RDB4414)

This paper discusses a modified vapor-compression cycle incorporating a solution circuit (VCCSC) and a further enhancement incorporating a desorber/absorber heat exchanger (DAHX). The modifications enable internal heat exchange between the desorption and absorption processes, resulting in extremely low pressure ratios compared to those of conventional cycles with pure refrigerants. Figures show the modifications schematically and on a pressure-temperature plot. A simulation program is outlined, and calculated performance is presented for five concentrations of an ammonia/water mixture. Parametric analyses of concentrations and impacts on pressure ratio, capacity, and efficiency are presented. A table compares the condensing and evaporating temperatures, pressure ratios, and cooling coefficients of performance (COPs) for ammonia/water DAHX and VCCSC cycles to those for ammonia and R-22 in a simple vapor-compression cycle. The paper concludes that the DAHX COP is up to 10 or 26% higher than with ammonia or R-22, respectively, in conventional cycles while the pressure ratio is up to 70 and 62% lower, respectively. The result allows use of low cost, low lift compressors, but requires significantly greater - 50-100% - heat exchange surface and introduction of a circulation pump.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermophysical Properties of HFC-143a and HFC-152a**, report DOE/CE/23810-33A, Air-Conditioning and Refrigeration Technology

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Institute (ARTI), Arlington, VA, January 1994 (50 pages, including 11 figures and 14 tables, available from JMC as RDB4427)

This progress report summarizes experimental measurements to provide highly accurate, thermophysical property data for R-143a and R-152a. The project also includes data fitting to modified Benedict-Webb-Rubin (MBWR) equations of state and detailed transport property models. The objective is to fill gaps in current data and resolve problems and uncertainties that exist in and between such data. The report briefly reviews progress during the preceding quarter. Efforts focused on analysis of vapor pressures and measurement of vapor phase pressure-volume-temperature (PVT) behavior and liquid phase isochoric heat capacities of R-143a. The report outlines measurements with a Burnett apparatus, revision for a small air impurity, and reduction to a Wagner-type equation. It also describes use of an adiabatic calorimeter to measure the molar heat capacity. The report then summarizes work to develop an interim MBWR equation and measure sound speeds and thermal conductivities for R-152a, using a cylindrical acoustic resonator and a hot-wire apparatus. Figures illustrate the pressures, temperatures, and correlation deviations of the measurements. Two plots show the isochoric and saturated heat capacities of R-143a in the liquid-phase. An appendix presents tabular summaries of measured isochoric and isothermal vapor phase PVT and final vapor pressure data for R-143a in both metric (SI) and inch-pound (IP) units. Measurements also are presented for its liquid and two-phase heat capacities. Speed of sound measurements, ideal-gas heat capacity, and acoustic virial coefficients are tabulated for R-152a. The interim, 32-term MBWR equation of state and a table of derived thermodynamic properties complete the report.

K. E. Hickman (York International Corporation), **Redesigning Equipment for R-22 and R-502 Alternatives**, *ASHRAE Journal*, 36(1):42-44 and 46-47, January 1994 (5 pages with 1 table, RDB4215)

This insightful article reviews candidates being tested to replace R-22 and R-502, in the Alternative Refrigerants Evaluation Program (AREP). The introduction explains that AREP was organized by the Air-Conditioning and Refrigeration Institute (ARI), to identify the most promising replacements. It notes participation by government and university laboratories and support by the U.S. Department of Energy (DOE), Electric Power Research Institute (EPRI), and the National Institute of Standards and Technology (NIST) in addition to the primary testing by manufacturers. A table summarizes the alternatives, their characteristics, and commercial examples. The article traces blend reformulations to resolve identified concerns. It describes considerations for three application categories, starting with packaged equipment for residential and commercial air conditioning and heat pump systems. Testing is focusing on an azeotrope, R-32/125 (50/50), and three zeotropes, R-32/134a (25/75) and (30/70), and R-32/125/134a (30/10/60). The article outlines their advantages and disadvantages, comments on test results, and summarizes comparative findings by evaluations in Japan. The article concludes that the zeotropes are close to R-22 in behavior and would require only minor changes in design, but would not be easy to use in systems with multiple evaporators. R-32/125 shows the best promise to increase efficiency, and its lower volumetric flow rate may allow reductions in equipment size. However, its use would require substantial compressor and heat exchanger redesign. R-134a also is a candidate, but compressors would need approximately 50% larger volumetric displacement. The replacements addressed for R-22 engineered systems - water chillers for centralized plants - include R-32/125 (50/50), R-32/134a (25/75) and (30/70), R-125/143a/134a (44/52/4) [R-404A], R-134a, and R-717 (ammonia). R-32/125 again offers potential performance advantages, but its high condensing pressure may limit its application unless compressors and heat exchangers are redesigned. R-134a already is used in centrifugal chillers, for which the higher flow volumes do not substantially increase costs, but is limited for positive displacement machines (with screw and reciprocating piston compressors) by the larger displacement requirement. Ammonia offers a viable technical alternative, but its consideration is primarily for industrial applications due to safety issues and building code requirements. The article addresses three alternatives to replace R-502 in commercial refrigeration systems, namely R-125/143a (50/50) [R-507A], R-125/143a/134a (44/52/4) [R-404A], R-32/125/134a (20/40/40), and R-32/125/143a (10/45/45). The author notes greatest interest and testing for R-32/125/134a, despite earlier announcements of other replacements spurred by impending phase out of R-115, a component of R-502. The article concludes that considerable testing remains to be done for product development to prove system reliability and durability. It also notes that better property data are needed for manufacturers to predict and certify performance with the accuracy that is now standard. Most of the alternatives either do not improve efficiencies or require substantial changes and testing. The author suggests that the alternatives will offer neither performance or cost advantages to customers for systems now designed for R-22. While manufacturers believe that the refrigerants under test will be viable, testing is still at an early stage and a service infrastructure must be put in place. R-290 (propane) also is listed as a candidate, but is not discussed. [This article is an edited version of RDB4524.]

R. E. Kauffman (University of Dayton Research Institute), **Accelerated Screening Methods for Determining Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures, Part II: Experimental Comparison and Verification of Methods**, seminar presentation (ASHRAE Winter Meeting, New Orleans, LA, January 1994), report DOE/CE/-23810-30, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 24 January 1994 (14 pages with 10 charts, available from JMC as RDB4213)

This report comprises presentation charts summarizing a study to develop an accelerated test method, to determine the chemical and thermal stability of refrigerant-lubricant mixtures. The charts identify evaluation criteria for candidate tests. A diagram shows the modified sealed tube used, with two tungsten electrode rods sealed into the bottom. Figures then depict the findings of methods evaluated, including a plot of electrical conductivity during thermal aging for R-11, R-12, and R-22 with mineral oil. A similar chart shows the results for R-134a with 4 polyolester lubricants. A table compares the experimental results for standard and modified sealed tube tests of R-12 and R-22. A summary chart indicates that in-situ conductivity measurements monitor thermal and chemical stabilities of refrigerant-oil mixtures, generally agree with tests based on ANSI/ASHRAE Standard 97-1989 evaluations, and reduce safety risk and time requirements. An additional chart outlines future work. [see RDB4211 for elaboration]

S. Komatsu (Sanden Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a**, Alternative Refrigerants Evaluation Program (AREP) report 146, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 3 figures and 2 tables, available from JMC as RDB5646)

This report summarizes performance measurements of R-125/143a (45/55) with an unidentified ester lubricant in a rotary, rolling-piston compressor.

T. Nitta (Mitsubishi Heavy Industries, Limited, Japan), **Soft-Optimized Test of Refrigerant R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 148, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 3 figures and 3 tables, available from JMC as RDB4748)

This report summarizes performance measurements of R-32/125/134a (30/10/60) with an unidentified ester lubricant in a 2.75 kW (3/4 ton) split-system room air conditioner (RAC) / heat pump with a rotary rolling-piston compressor. The results are compared to corresponding data for R-22 with alkylbenzene. Two schematics illustrate the refrigerant circuit and modifications to the heat exchangers for the zeotropic blend. The data for the cooling and heating modes are summarized in two tables. The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor, condenser, expansion device, and evaporator. The results show a 1% increase in capacity for both cooling and heating and decreases of 5 and 4% in efficiency for the cooling and heating modes, respectively, compared to R-22. These findings are plotted. The report notes that the discharge pressure with R-32/125/134a (30/10/60) is approximately 10% higher than with R-22, but the discharge temperature is approximately 7% lower.

J. Pannock, R. K. Radermacher, Z. Liu, and K. Yu (University of Maryland), **Evaluation of HFC-134a and HFC-152a as Working Fluids in a Domestic Refrigerator/Freezer**, paper NO-94-20-2, *Transactions* (Winter Meeting, New Orleans, LA, January 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(1):1344-1350, 1994 (7 pages with 6 figures and 4 tables, RDB4411)

R-134a, R-152a

J. Pettersen (Norgest Tekniska Högskole, NTH, Norway), **A New and Efficient Vehicle Air-Conditioning System Based on CO_2 Vapor Compression**, paper OR-94-5-3, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(2):657-665, 1994 (9 page with 7 figures and 1 table, RDB4709)

use of R-744 (carbon dioxide) as a refrigerant in mobile air conditioner (MAC) systems

J. R. Sand and S. K. Fischer (Oak Ridge National Laboratory, ORNL), **Modelled Performance of Nonchlorinated Substitutes for CFC-11 and CFC-12 in Centrifugal Chillers**, *International Journal of Refrigeration* (IJR), 17(1):40-48, January 1994 (9 pages with 5 figures and 3 tables, available from JMC as RDB2411)

This article presents data on candidate refrigerants to replace R-11 and R-12 in chillers with

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centrifugal compressors. The partially fluorinated alkanes and ethers examined were identified from earlier studies. The article outlines the sources for and methods used to estimate missing thermophysical property data, to enable analyses. It then discusses the benefits and limitations of various equation of state models considered, leading to selection and fitting of the data to the Carnahan-Starling-DeSantis (CSD) and Lee-Kesler-Plöcker (LKP) equations of state. The article describes a simple chiller model, based on a single-stage compressor, used to simulate performance. The modelled results are tabulated including ideal-cycle isentropic coefficients of performance (COPs), kW electricity input per thermal kW of cooling, and calculated compression superheat for candidates with efficiencies equal to or exceeding that of R-134a. They include - in ascending order of normal boiling point - R-E254cb (CHF_2-O-CF_2CH_3), R-E245cb (CF_3-O-CF_2CH_3), R-152, R-E143, R-123, R-245ca, R-11, R-245fa, R-236ea, R-E134, R-236ca, R-143, R-114, R-236fa, R-236cb, R-134, R-152a, R-134a, and R-12. Indications are given on the flammability (or anticipated flammability) of these refrigerants. Modelled results also are tabulated for eight binary blends of flammable and nonflammable components expected to exhibit near-azeotropic performance. They include R-E143/245ca (21/79) and (45/55), R-143/236ea (11/89) and (48/52), R-143/E134, R-143/R-236ca (11/89) and (48/52), and R-152a/134 (19/81). The paper concludes that while there are potential alternatives for R-11 and R-123, with efficiencies higher than with R-12 or R-134a, several candidates with the best performance are likely to be flammable. Near-azeotropic blends of flammable and nonflammable components with similar vapor pressures may afford solutions, but further studies are needed particularly for the fluorinated ethers and flammability characterization. The article notes that cycle modifications, such as adding subcooling or suction-to-liquid heat exchangers, will preferentially benefit the performance of refrigerants with more complex molecular structures and larger molecular heat capacities. Also, multistage designs with interstage flash cooling (economizer cycles) need verification.

S. R. Szymurski, G. C. Hourahan, and D. S. Godwin, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-33, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1994 (54 pages with 8 figures and 9 tables, available from JMC as RDB4428)

This progress report summarizes the goals and status of the Materials Compatibility and Lubricant Research (MCLR) Program, jointly funded under a grant from the Office of Building Technology of the U.S. Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program was implemented on 30 September 1991 and, as currently funded, will run through 30 September 1995. It supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. The primary elements include materials compatibility testing, methods development, and data collection and dissemination. The report provides a status update on research to measure thermophysical properties of R-143a and R-152a; measure the viscosity, density, and solubility for three azeotropic and zeotropic blends to replace R-22 and R-502; measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures; and obtain compatibility data on desiccants with refrigerants and lubricants. The report also summarizes three projects to develop accelerated screening and test methods to predict lubricant performance in compressors, the life of motor materials exposed to refrigerant-lubricant mixtures, and chemical and thermal stability of refrigerant-lubricant mixtures. It reviews the progress of a continuing project to collect and facilitate dissemination of data, through development and administration of the ARTI Refrigerant Database. The progress report summarizes completed projects to measure thermophysical properties of R-32, R-123, R-124, and R-125; model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502; test the chemical and thermal stability of refrigerant lubricant mixtures with metals; measure the miscibility of lubricants with refrigerants; provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics; and investigate electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants. The scope of the program, objectives of the individual projects, and significant interim findings are presented. This program summary also identifies reports resulting from the individual projects. Tables summarize significant findings of the individual projects including the miscibility of lubricants with 10 refrigerants; equations of state developed for R-32, R-123, R-124, R-125, and R-152a; and relative elastomer swelling in refrigerants and lubricants. Two figures compare the modelled performance of alternative refrigerants to the capacities and efficiencies of R-22 and R-502.

H. Wakabayashi and A. Aoki (Matsushita Electric Industrial Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 138, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (12 pages with 3 figures and 7 tables, available from JMC as RDB4738)

K. Wakahara (Sharp Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 139, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 3 figures and 2 tables, available from JMC as RDB4739)

J. M. Wallace (University of Washington) and S. Vogel (science writer), **Reports to the Nation on our Changing Planet: El Niño and Climate Protection**, report 3, University Corporation for Atmospheric Research (UCAR) Office for Interdisciplinary Earth Studies (OIES), Boulder, CO, spring 1994 (28 pages with 19 figures, RDB4A74)

> explains in simple terms the disruption in climate conditions and flows in the Pacific Ocean known as El Niño: describes the consequences in natural disasters and linkages to climate prediction; reviews historic occurrences, how the phenomenon affects the ocean, and ties between winds and the seas; outlines the ability to predict El Niño occurrence and strength; provides estimates of the global costs of El Niño and the relation to global climate change

R. Yajima and O. Kataoka (Daikin Industries, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 151, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (10 pages with 1 figure and 2 tables, available from JMC as RDB4751)

> This report summarizes performance tests of R-32/134a (30/70) with an unidentified ester lubricant. They were tested in a 2.4 kW (8300 Btu/hr) room air conditioner (RAC) / heat pump with a 750 W (1 hp) rotary, rolling-piston compressor. The tests included both an unmodified (drop-in) and optimized system, the latter with modified circuiting of the indoor and outdoor heat exchangers. These modifications are shown in a schematic. The results are tabulated with corresponding data for R-22 with an unidentified mineral oil. The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor and evaporator as well as the outlets from the condenser and expansion device. The results show nearly identical capacity and efficiency in the cooling mode except for a 10.4% efficiency loss for the drop-in case. Capacity increases of less than 1%, and efficiency decreases of 5 and 1.2%, were measured for the drop-in and soft-optimized versions, respectively, in the heating mode.

X. Zeng, M. C. Chyu (Texas Tech University), and Z. H. Ayub (Ayub and Associates, Incorporated), **Characteristic Study of Sprayed Fluid Flow in a Tube Bundle**, paper 3742 (725-RP), *Transactions* (Winter Meeting, New Orleans, LA, January 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(1):63-72, 1994 (10 pages with 16 figures, RDB-4A13)

> fluid flow in plain, low-finned, and grooved copper tubes in square and triangular pitch tube bundles subjected an overhead water spray: effects on performance of liquid distribution

Q. Zhou, J. Pannock, and R. K. Radermacher (University of Maryland), **Development and Testing of a High Efficiency Refrigerator**, paper NO-94-20-3, *Transactions* (Winter Meeting, New Orleans, LA, January 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 100(1):1351-1358, 1994 (8 pages with 2 figures and 5 tables, RDB4421)

> refrigerant mixture used not identified pending patent application review

1994-1995 Research Plan, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1 January 1994 (25 pages with 7 tables, RDB4679)

> This list of prospective research subjects identifies 305 proposed projects, 64 designated as *priority* status. The projects are grouped into nine project classifications, based on approved funding guidelines. Projects relating to refrigerants fall in several of these categories, including the third and sixth highest priority topics, *Environmentally-Safe Materials and Refrigeration Systems*. The research areas were proposed by ASHRAE Technical Committees, Task Groups, and other committees; they were prioritized by ASHRAE's Research and Technical Committee. The highest priority group (*three stars*) includes research of *"Thermophysical Properties of Alternative Refrigerants"* and to *"Develop Solubility and Viscosity Data for Various Oil/Refrigerant Mixtures at High Discharge Temperatures and Pressures."* The next classification includes *"Flammability Properties of Alternative Refrigerants"* and *"Develop Corrosion Data with Materials of Construction and New Refrigerant/Lubricants at Various Moisture Levels."* The *one-star* priority group includes *"Comprehensive Thermodynamic Property Data for Refrigerant Blends," "Develop Refrigerant-Lubricant-*

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Desiccant Moisture Equilibrium Data with New HFC Refrigerants and Relevant Lubricants," "Double-Walled Heat Exchangers for Class 2 Refrigerants," and *"In-Tube Evaporation of Ammonia in Smooth and Enhanced Tubes with Miscible and Immiscible Oils."* Among nonpriority projects are *"Thermophysical Properties of R-23," "A Uniform Equation of State for Alternatives to the CFC Refrigerants," "Measurement of R-22 and Alternative Refrigerant Leakage Rates from Open-Shaft Compressors,"* and *"Heat and Mass Transfer Additives in Aqua-Ammonia Systems."* Further projects will examine *"Evaporation of Ammonia Outside Smooth and Enhanced Tubes with Miscible and Immiscible Oils," "Boiling and Two-Phase Flow of Ammonia and Ammonia/Oil Mixtures in Corrugated Passages Simulating a Plate Heat Exchanger," "Investigation of a Theoretical Method to Predict Solubility of Refrigerant/Oil Solutions at Several Temperatures and Pressures," "Develop Solubility and Viscosity Data for Various Oil-Refrigerant Mixtures at High Discharge Temperatures and Pressures," "Separating Velocities for Ammonia in Horizontal and Vertical Vessels," "Laboratory Verification of Modeling Transients in Refrigerant Lines,"* and *"Refrigerant Piping Pressure Drop Computer Programs."* This plan summarizes anticipated funding and procedures for implementing the research identified; it replaces versions published for preceding years [see RDB3118].

Genetron(R) 134a Product Brochure, bulletin B-525-009, AlliedSignal Incorporated, Morristown, NJ, January 1994 (16 pages with 6 figures and 6 tables, RDB4682)

This bulletin supplies information on R-134a and application data in metric (SI) and inch-pound (IP) units. R-134a is described as a replacement for R-12 in automobile air conditioning; residential and commercial refrigeration; residential, commercial, and industrial air conditioning including centrifugal chillers; and as a blowing agent and aerosol propellant. The bulletin describes these applications and lists basic physical properties including the chemical name and formula, appearance, molecular weight, normal boiling and freezing points, and critical parameters (temperature, pressure, density, and specific volume). The property data also include the vapor density, latent heat of vaporization at the boiling point, flammability limits (none), autoignition temperature, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP). Representative data are provided for 25 °C (77 °F) including the liquid density; vapor pressure; solubility in and of water; and vapor and liquid heat capacity, thermal conductivity, and viscosity. The bulletin provides Mollier (pressure-enthalpy) charts, product purity specifications, a tabular comparison of performance with R-12, and tabular pressure-temperature data for -45 to 70 °C (-60 to 160 °F). It then discusses lubricant suitability with primary focus on polyalkylene glycol (PAG) and polyolester (POE) synthetics. Characteristic miscibility plots are shown. The document discusses copper plating with PAG and POE lubricants. It notes that plating levels are lower for R-134a with the cited lubricants than with R-12 and mineral oil. While plating does not appear in laboratory tests with two POEs (Castrol Icematic(R) SW32 and Mobil EAL Arctic(R) 22), field occurrence suggests that it may result in the presence of other materials. The bulletin tabulates stability data for the same POEs in the presence of aluminum, copper, and steel. It discusses the effects of chlorinated solvents and residual refrigerants, noting that R-134a is chemically compatible with chlorinated materials, but that the associated PAG and POE lubricants may not be. It notes, however, that R-12 and R-134a form a higher-pressure azeotrope. The bulletin then discusses materials compatibility and provides tabular, qualitative indications for elastomers and plastics. It discusses suitability with polyethylene terephthalate (PET) and desiccants, and also provides a plot of solubility of water in R-134a. The bulletin then discusses safety, including both toxicity and flammability. It describes the former as intrinsically low. While it suggests that R-134a is nonflammable, it notes that R-134a can become combustible at higher pressures when mixed with more than 60% air. The bulletin discusses storage, handling, safety guidelines, and leak detection methods. It briefly outlines environmental considerations, reclamation, retrofit procedures for R-12 equipment, and R-134a packaging. AlliedSignal's product name for R-134a is Genetron(R) 134a.

Genetron(R) AZ-50 Product Brochure, bulletin B-525-030, AlliedSignal Incorporated, Morristown, NJ, January 1994 (12 pages with 4 figures and 5 tables, RDB4683)

This bulletin supplies information on R-507, a blend of R-125 and R-143a - R-125/143a (50/50) - and application data in metric (SI) and inch-pound (IP) units. R-507 is described as a long-term replacement for R-502 in commercial refrigeration, for both new equipment and retrofits. The bulletin describes these applications and lists basic physical properties including the chemical name and formula, appearance, molecular weight, normal boiling point, and critical parameters (temperature, pressure, density, and specific volume). The property data also include the vapor density, latent heat of vaporization at the boiling point, flammability limits (none), ozone depletion potential (ODP), and halocarbon global warming potential (HGWP). Representative data are provided for 25 °C (77 °F) including the liquid density; vapor pressure; and vapor and liquid heat capacity, thermal conductivity, and viscosity. The bulletin provides Mollier (pressure-enthalpy) charts, product purity specifications, a tabular comparison of performance with R-502, and tabular pressure-temperature data for -45 to 70 °C (-60 to 160 °F). It then discusses lubricant suitability with primary focus on polyolester (POE) synthetics. A characteristic miscibility plot is shown. The bulletin tabulates stability data three POEs (Castrol Icematic(R) SW32 and Mobil EAL Arctic(R) 22 and 32) in the presence of aluminum, copper, and steel. It discusses the effects of chlorinated solvents and residual refrigerants, noting that R-507 is chemically compatible with chlorinated materials, but that the associated POE lubricants may not be. It notes, however, that R-502 and R-507 should not be mixed; while each is an azeotrope, two of their components, R-115 and R-502 also form an azeotrope, resulting in a four-component mixture that is difficult to separate. The bulletin then discusses materials compatibility and provides tabular, qualitative indications for elastomers and plastics with R-507, with and without an unidentified POE. It discusses desiccant suitabilities, and also provides a plot of solubility of water in R-507. The bulletin then discusses safety, including both toxicity and flammability. It describes the former as intrinsically low. While it suggests that R-507 is nonflammable (practically nonflammable by Underwriters' Laboratories, UL, classification), it notes that R-507 can become combustible at higher pressures when mixed with air. The bulletin discusses thermal stability, storage, handling, safety guidelines, and leak detection methods. It briefly outlines environmental considerations, reclamation, retrofit procedures for R-502 equipment, and R-507 packaging. AlliedSignal's product name for R-507 is Genetron(R) AZ-50.

Klea(R) 66 Data Sheet, bulletin 620250610, ICI Klea, Wilmington, DE, January 1994 (8 pages with 1 table, RDB4134)

This bulletin provides summary property data and equations to calculate thermophysical properties for R-407C, a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/125/134a (23/25/52) - in inch-pound (IP) units of measure. This formulation was selected to replace R-22 in new low temperature refrigeration equipment and also for retrofit in many existing systems. The bulletin tabulates physical properties including the atmospheric bubble and dew points, estimated critical temperature, Trouton's constant, and coefficient of thermal expansion. It also indicates the bubble point pressure and latent heat of vaporization at 21 °C (70 °F) and the saturated vapor density at 1 atmosphere (14.7 psia). The bulletin then presents a Martin-Hou equation of state and formulae to calculate the bubble, mid, and dew point temperatures for the saturation envelope. It also provides formulae for the latent heat of vaporization, ideal gas heat capacity, saturated liquid enthalpy, speed of sound, and liquid and vapor density, viscosity, and thermal conductivity. The document concludes with four tables giving calculated values for these properties at representative pressures of 70-2760 kPa (10-400 psia) and temperatures of -51 to 49 °C (-60 to 120 °F). ICI's product name for R-407C is Klea(R) 66.

Moisture Solubility in R-123 and R-134a, research project 602-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, March 1989 - January 1994 (ASH0602)

This project determined the moisture solubility of R-123 and R-134a. Measurements were made in the range of -23 to 66 °C (-10 to 150 °F) for the liquid phase and at a single temperature in the vapor phase. The data were needed to determine the corrosion characteristics of these refrigerants. The contractor was the University of Alabama, led by J. S. Thrasher; the project was sponsored by ASHRAE Technical Committee 3.3, *Contaminant Control in Refrigerating Systems.*

Thermodynamic Properties of Klea(R) 66, 32/125/134a (23/25/52 wt %), British Units, bulletin 620250410, ICI Klea, Wilmington, DE, January 1994 (28 pages with 1 figure and 3 tables, RDB4135)

This bulletin provides detailed thermodynamic properties for saturated and superheated conditions for R-407C, a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/-125/134a (23/25/52) - in inch-pound (IP) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 7-69 kPa (1-10 psi) increments for 70-2960 kPa (10-430 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 70-2960 kPa (10-430 psia) to temperatures as high as 216 °C (420 °F). The last table

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presents evaporator inlet temperatures as functions of pressure and enthalpy for 70-690 kPa (10-100 psia). ICI's product name for R-407C is Klea(R) 66.

1994 (month not indicated)

M. S. Collins, **An Experimental Study of the Performance of R-32/134a, R-32/125/134a, and R-134a as Drop-In Replacements for R-22 in Air Conditioning Applications**, MS thesis, Iowa State University of Science and Technology, Ames, IA, 1994 (rdb6337)

drop-in performance tests

Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, **List of MAK and BAT Values 1994: Maximum Concentrations and Biological Tolerance Values at the Workplace**, report 30, Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Bonn, Germany; VCH Verlagsgesellschaft mbH, Weinheim, Germany, 1994 (RDB5561)

English language version of the *MAK- und BAT-Werte-Liste*; maximale Arbeitsplatz Konzentration [maximum workplace concentration] and biologischer Arbeitsstoff-Toleranz-Wert [biological tolerance value]; German occupational exposure limits for chemicals for approximately 600 chemicals including R-11, R-12, R-12B2, R-13, R-21, R-22, R-114, R-123, R-142b, R-E170, R-290, R-600, R-600a, R-610, R-611, R-717, R-744, R-744, R-764, R-7146, and others; classification of carcinogenic, embryotoxicant, and sensitizing substances

M. K. Dobson, **Heat Transfer and Flow Regimes During Condensation in a Horizontal Tube**, PhD thesis (Department of Mechanical Engineering), University of Illinois at Urbana-Champaign, 1994 (rdb6704)

refrigerants

T. Ebner and H. Halozan (Technische Universität Graz, Graz, Austria), **Testing the Available Alternatives - An Examination of R-134a, R-152a, and R-290**, *IEA Heat Pump Newsletter*, International Energy Agency (IEA) Heat Pump Centre (HPC), Sittard, The Netherlands, 12(1), 1994 (rdb5721)

I. Golobic and B. Gaspersic (University of Ljubljana, Slovenia), **Method of Predicting the Pool Boiling Critical Heat Flux Based on Thermodynamic Similarity**, *Proceedings of the Tenth International Heat Transfer Conference*, Institution of Chemical Engineers, Rugby, UK, 36-ff, 1994 (rdb7810)

nucleate pool boiling heat transfer coefficients on plain tubes, method based on heat flux, the thermophysical properties of the fluid, properties of the heating surface, and surface geometry

D. Gorenflo (Universität Paderborn, Germany), **Abschnitt Hab Belhaltersieden**, *VDI-Wärmeatlas* [Thermal Atlas of the Association of German Engineers] (seventh edition), Verein Deutscher Ingenieure (VDI) Verlag, Düsseldorf, Germany, 1994 (rdb8A06)

heat transfer; pool boiling correlations by a reduced pressure method; heat transfer coefficients for R-22, R-123, R-134a, R-717 (ammonia), and others

A. N. Gurova, C. A. Nieto de Castro, and U. V. Mardolcar (Universidade de Lisboa, Portugal), **The Thermal Conductivity of Environmentally Acceptable Liquid Refrigerants**, *Thermal Conductivity 22*, Technomic Publishing Company, Tempe, AZ, 189-199, 1994 (11 pages, rdb8458)

transport properties of R-123 and others; thermophysical data

G. Hammarberg and H. Nyman, **R407C Zeotrope as an Alternative to R22**, MS thesis, Kungliga Tekniska Högskolan (KTH), Stockholm, Sweden, 1994 (rdb6863)

R-22, R-407C

R. K. Hewstone, **Environmental Health Aspects of Lubricant Additives**, paper 11.7, *Ecological and Economical Aspects of Tribology* (proceedings of the Ninth International Colloquium), Technische Academie Esslingen, Germany, 1994 (rdb6379)

lubricants, environmental impacts

L. Kinne, **Luft als Kältemittel** [Air as a Refrigerant], *Ki Luft- und Kältetechnik*, Germany, 30(5):220-222, 1994 (3 pages in German, RDB4A63)

R-729

S. Komatsuzaki and Y. Homma (Hitachi Limited, Japan), **Lubricants for HFC Refrigerant Compressors**, *Sekiyu Gakkaishi*, Japan, 37(3):226-235, 1994 (10 pages, rdb6371)

polyalkylene glycol (PAG) polyolester (POE) lubricants

G. K. Lavrenchenko, M. G. Khmelnuk, and E. Tikhonova (Institute of Energy Conversion Systems, Ukraine), **Thermodynamical Aspects of Using Mixtures of Substances in Refrigerating Machines**, *CFCs, the Day After* (proceedings of the IIR meeting, Padova, Italy, 21-23 September 1994), International Institute of Refrigeration (IIR), Paris, France, 9:65-70, September 1994 (6 pages with 2 tables, rdb5849) blends

J. Millat, H. Hendl, and E. Bich, **Quasi-Isochoric p-ro-T Measurements and 2nd Virial Coefficient of n-Heptane**, *International Journal of Thermophysics*, 15(5):903 ff, 1994 (rdb8C43)

thermodynamic properties of R-602 (n-heptane); thermophysical data

S. M. Sami and P. J. Tulej (University of Moncton, Canada), **Performance Analysis of a Drop-In Replacement Blend for CFC-12, CFC-502, and HCFC-22**, *International Journal of Energy Research* (IJER), 18:49-56, 1994 (8 pages, rdb4C16)

R-12, R-22, and R-502 alternatives; zeotropic blends

J. V. Sengers (University of Maryland), **Effects of Critical Fluctuations on the Thermodynamic and Transport Properties of Supercritical Fluids**, *Supercritical Fluids*, edited by E. Kiran and J. M. H. Levelt Sengers, Kluwer Academic Publishers, Dordrecht, The Netherlands, and Norwell, MA, USA, 231-271, 1994 (41 pages with 17 figures, RDB6406)

long-range density fluctuations in the critical phase transition, thermodynamic and transport properties around the critical point

Y. M. Suleiman, S. A. M. Said, and B. Ismail (King Fahd University of Petroleum and Minerals, Saudi Arabia), **HCFC 22 as a Replacement for CFC 12**, *Applied Energy*, 49(1)1-8, 1994 (8 pages, rdb8928)

discusses the theoretical differences in performance between R-12 and R-22 based on thermodynamic properties; assesses the potential for use of R-22 to replace R-12 in air-conditioner with a reciprocating-piston compressor

L. A. Weber and D. R. Defibaugh (National Institute of Standards and Technology, NIST), **The Virial Coefficients of Five Binary Mixtures of Fluorinated Methanes and Ethanes**, *International Journal of Thermophysics*, 15(5):863 ff, 1994 (28 page preprint with 6 figures and 2 tables available from JMC as Rdb4B68).

thermodynamic properties of R-32/125, R-32/-134a, R-125/134a, R-125/143a, and R-134a/-152a: thermophysical data

L. A. Weber (National Institute of Standards and Technology, NIST), **Estimating the Virial Coefficients of Small Polar Molecules**, *International Journal of Thermophysics*, 15(3):461-482, May 1994 (22 pages with 10 figures and 1 table, available from JMC as RDB4912)

This paper presents a physically based, semiempirical scheme for estimating the second and third virial coefficients of halogenated methanes and ethanes. The paper tabulates the critical parameters (temperature, pressure, and specific volume), reduced dipole moment, Pitzer acentric factor, and volume of a hard-sphere model for 18 refrigerants. They include R-11, R-12, R-13, R-14, R-22, R-23, R-32, R-41, R-114, R-115, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-143a, and R-152a. The paper compares predicted and measured data, concluding that the model provides an accurate method of predicting densities. It outlines the development and presents equations and parameters for estimating the properties of pure refrigerants, and their mixtures, when thermodynamic data are not available.

J. V. Widiatmo, H. Sato, and K. Watanabe (Keio University, Japan), **Measurement of the Liquid Densities of the Binary HFC-32 + HFC-134a System**, *Fluid Phase Equilibria*, 99:199-207, 1994 (9 pages with 7 figures and 2 tables, rdb4871)

thermodynamic properties of R-32/134a blends; thermophysical data

1994-1995 Threshold Limit Values for Chemical Substances in the Work Environment, 1994-1995 *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Government Industrial Hygienists (ACGIH), Cincinnati, OH, 1-50 and notes, 1994 (50 of 132 pages with 2 tables and 4 appendices, available from ACGIH for $11.00, RDB5208)

This book provides data for use as guidelines or recommendations in the control of potential hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document also lists intended changes and provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter. The refrigerants addressed include R-11, R-12, R-12B2, R-21, R-22, R-30, R40, R-114, R-115, R-170 (ethane), R-290 (propane), R-600 (butane), R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-7146 (sulfur hexafluoride), and others.

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Fouling in Enhanced Tubes, proposed research project 795-URP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1993-1994 (ASH0795)

This project was disapproved based on the recommendation of ASHRAE Technical Committee 8.5, *Liquid-to-Refrigerant Heat Exchangers.*

R-406A Technical Data Bulletin, information packet, Indianapolis Refrigeration Products, Indianapolis, IN, 1994 (12 pages containing 1 figure and 2 tables, RDB4886)

This information packet contains a summary data sheet on R-406A, a table of thermodynamic properties, and an instruction and information manual. R-406A is identified as a zeotropic blend of R-22, R-600a (isobutane), and R-142b - R-22/600a/142b (55/4/41). It was formulated as a service fluid to replace R-12. The data sheet provides identifiers, specifications, safety classifications, ozone depletion potential (ODP), halocarbon global warming potential (HGWP), and physical property data. The thermodynamic property sheet tabulates saturated liquid and vapor data in inch-pound (IP) units of measure for -71 to 107 °C (-95 to 225 °F). It includes liquid (bubble point) and vapor (dew point) pressures; vapor specific volume; liquid density; and vapor and liquid entropy, enthalpy, and thermal conductivity. The manual describes R-406A as a "drop-in" replacement for R-12, although differences are documented between these two refrigerants. It provides information on the history, flammability, warranties, and safety precautions. It then provides further information in the form of frequent questions and replies. The manual discusses applications and charging procedures, summarizes specifications, and discusses recovery and shipping. It also explains terminology including azeotropes, zeotropes, fractionation, glide, bubble point, and dew point. A plot compares the pressures of R-406A and R-12 for -40 to 60 °C (-40 to 140 °F). The manual concludes with a tabular comparison of pressures for R-12, R-22, R-134a, R-406A, and R-502 for the same range. Indianapolis Refrigeration markets R-406A under the product name GHG Refrigerant 12 Substitute.

Scientific Assessment of Ozone Depletion: 1994 - Executive Summary, chaired by D. L. Albritton (National Oceanic and Atmospheric Administration, NOAH, USA), R. T. Watson (National Aeronautics and Space Administration, NASA, USA), and P. J. Aucamp (Department of National Health, South Africa), report 37 Executive Summary, World Meteorological Organization (WMO), Global Ozone Research and Monitoring Project, Geneva, Switzerland, 1994 (40 pages with 9 figures, available from WMO, also available from JMC as RDB5302)

This report summarizes the definitive assessment used in governmental and international decision-making for protection of the stratospheric ozone layer. The volume addresses the major scientific findings and observations, supporting evidence, related issues, and implications. The second portion responds to common questions about ozone depletion. It discusses how chlorofluorocarbons get to the stratosphere, evidence of stratospheric ozone destruction by chlorine and bromine, and that the majority of the chlorine in the stratosphere comes from human-made (anthropogenic) sources. It also examines whether changes in the sun's output could be responsible, the first appearance of the Antarctic ozone hole, and why it occurred there rather than over the northern hemisphere. The summary concludes with discussion of the increase in ground-level ultraviolet radiation, the severity of the ozone depletion, and whether it will get worse. The executive summary and underlying report summarize understanding of the stratospheric ozone layer and is relation to humankind.

The Changing Pattern of Use of Fluorocarbons in the European Community 1976-1993, European Chemical Industry Council (CEFIC), Brussels, Belgium, 1994 (rdb6942)

production data and trends

1993

December 1993

S. Chen and T. Kennedy (The Trane Company), **Soft-Optimized System Test of Refrigerant Blend R-32/125/143a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 127, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (22 pages with 3 figures and 8 tables, available from JMC as RDB3D27)

This report summarizes a performance test of R-32/125/143a (30/10/60), with a polyolester lubricant (Mobil EAL Arctic(R) 22), in a 7 kW (2 ton) unitary, split-system heat pump. The system consisted of an outdoor unit (Trane TWR-024C100A), with a reciprocating-piston compressor (Trane Climatuf CP223-BC1-GA), matched to an indoor air handler (Trane TWV-036B140A). Performance was measured in an unmodified system, with the indoor heat exchanger recircuited for cross-counter flow in the cooling mode, with addition of a liquid-suction coaxial heat exchanger (LSHX), and with both recircuiting and an LSHX. The modifications are shown schematically in three figures. Eight tables summarize the test conditions, charge and lubricant quantities, operating parameters, capacity, input power, and efficiency in both metric (SI) and inch-pound (IP) units of measure. The data also are expressed as ratios to corresponding measurements with R-22 in the same system with the same lubricant. The report indicates that the capacity increased by 1% while the seasonal energy efficiency ratio (SEER) dropped 5% in the cooling mode. The capacity was nearly the same, but the heating season performance factor (HSPF) decreased by 6%. With recircuiting, the SEER and HSPF decreased by 2% and 14%, respectively, with corresponding changes in capacity of +1 and -19%. With recircuiting combined with the LSHX, the HSPF decreased by 6% while the capacity increased by 4%. With the LSHX alone, the SEER was restored and the cooling capacity decreased by 5%. Detailed test data are provided.

S. Chen and T. Kennedy (The Trane Company), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 128, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (10 pages with 4 tables, available from JMC as RDB3D28)

This report summarizes a performance test of R-32/125 (60/40), with a polyolester lubricant (Mobil EAL Arctic(R) 22), in a 10.6 kW (3 ton) unitary, split-system heat pump. The system consisted of an outdoor unit (Trane TWX036-C100A), with a reciprocating-piston compressor (Trane Climatuf CP223-BC1-GA for the blend and GP343-FG1-GA for R-22), matched to an indoor air handler (Trane TWE042C140A). Performance was measured with adjusted expansion devices and a substituted compressor. Four tables summarize the test conditions, charge and lubricant quantities, operating parameters, capacity, input power, and efficiency in both metric (SI) and inch-pound (IP) units of measure. The data also are expressed as ratios to corresponding measurements with R-22 with the same lubricant. The report indicates that the capacity increased by 0-2% depending on the outdoor temperature while the energy efficiency ratio (EER) dropped 0-2% in the cooling mode. The heating capacity increased by 3%, but the coefficient of performance (COP) decreased by 1-2%. Detailed test data are provided.

S. Chen and T. Kennedy (The Trane Company), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 129, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (16 pages with 2 figures and 6 tables, available from JMC as RDB3D29)

K. K. Fung (Tyler Refrigeration Company), **Soft-Optimized System Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 124, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (24 pages with 3 figures and 8 tables, available from JMC as RDB3D24)

R-125/143a (45/55) compared to R-502 with polyolester lubricant (Mobil EAL Arctic(R) 22 CC) in a commercial refrigeration system

K. K. Fung (Tyler Refrigeration Company), **Soft-Optimized System Test of Refrigerant Blend R125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 125, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (20 pages with 3 figures and 5 tables, available from JMC as RDB3D25)

This report summarizes a performance test of R-125/143a (45/55), with a polyolester lubricant (Mobil EAL Arctic(R) 22 CC), in a commercial refrigeration system with compressor speed and control optimization. The system consisted of a display case (Tyler D5FG 12'), a reciprocating-piston compressor (Copeland 2DB3-0600-TFC) with an adjustable-speed drive (Magnetek L710 type GPD 502 frequency inverter), and a water-cooled condenser (Standard Refrigeration T7-500D). Performance was measured at compressor speeds of 1070, 1217, 1379, 1584, and 1789 with a varied heater load, to maintain uniform evaporating temperature. The report outlines the test procedures and presents tabular results in both metric (SI) and inch-pound (IP) units of measure. Five tables summarize test conditions, charge and lubricant quantities, measured capacity, input power, and efficiency at each speed. The data also are expressed as ratios to corresponding measurements with R-502 in the same system with the same lubricant. Three plots show the capacities, input power, and coefficients of performance (COP) at the five tested speeds normalized to those for R-502 at 1760 RPM. The capacity ratios ranged from 0.92 to 1.40 and the efficiency ratios from 1.038 to 1.089.

K. K. Fung (Tyler Refrigeration Company), **Soft-Optimized System Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 126, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (6 pages with 1 table, available from JMC as RDB3D26)

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This report summarizes a performance test of R-125/143a (45/55), with a polyolester lubricant (Mobil EAL Arctic(R) 22 CC), in a commercial refrigeration system with heat exchanger and control optimization. The system consisted of a display case (Tyler D5FG 12'), a reciprocating-piston compressor (Copeland 2DB3-0600-TFC), and a water-cooled condenser (Standard Refrigeration T7-500D). Performance was measured with a regenerator-type heat exchanger, with twice the normal length, for the evaporator. The report outlines the test procedures and presents tabular results in both metric (SI) and inch-pound (IP) units of measure. A table summarizes test conditions, charge and lubricant quantities, measured capacity, input power, and efficiency. The data also are expressed as ratios to corresponding measurements with R-502 with a standard evaporator and the same lubricant. The capacity increased by 4.8%, but the efficiency dropped by 0.25%. Compared to another test of R-125/143a (45/55) with a standard evaporator, the coefficient of performance (COP) was 4.2% lower.

R. E. Kauffman (University of Dayton Research Institute), **Accelerated Screening Methods for Determining Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures, Part II: Experimental Comparison and Verification of Methods**, report DOE/CE/23810-22D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, December 1993 (32 pages with 5 figures and 2 tables, available from JMC as RDB4211)

This incremental report summarizes progress to evaluate analytical techniques for development into accelerated compatibility tests. It presents an initial study to assess in situ color measurements as a screening test. The approach, based on decreasing light transmission through a sealed tube undergoing thermal aging, is described. A plot shows the measured results for an R-11/naphthenic mineral oil mixture. The method was deemed not suitable due to insensitivity to initial degradation. Subsequent attempts using selective color filters are cited, but the report concludes that transmission was more dependent on temperature than refrigerant/oil color changes. It then describes measurements using in situ conductivity measurements, in a modified, sealed glass tube, to monitor degradation of R-134a/ester lubricant mixtures heated to 175 °C (347 °F) for two days. A diagram shows two tungsten electrode rods sealed into the bottom of a tube. Results are presented to show a correlation between the conductivity measurements and degradation. These results and verification analyses are described and tabular data are presented for mixtures with three polyolesters. The report concludes that in situ conductivity measurements have the best potential for development of the screening method. It then outlines refrigerant and oil analyses and present tabular purity, water content, and acid number data and requirements for 10 lubricants to be evaluated in further development of the screening method. The report discusses and illustrates a proposed heating-block design to be used and summarizes planned work. An appendix identifies the lubricant samples including a naphthenic mineral oil (Witco Suniso(R) 3GS), two paraffinic mineral oils (Penreco Sontex 160LT and 200LT), an alkylbenzene (Shrieve Zerol(R) 150), two polyglycols (Dow P-425 and ICI Emkarox(R) RL 118D), and four polyolesters (POEs). The POEs include two pentaerythritol ester mixed acids (ICI Emkarate(TM) RL 22H and Mobil EAL Arctic(R) 22A) and two pentaerythritol ester branched acids (Henkel Emery(R) 2928 and Castrol Icematic(R) SW32). The refrigerant laboratory specimens for R-11 and R-134a were obtained from PCR Incorporated. Two further appendices tabulate the conductivity measurements and provide representative infrared spectra and gas chromatographic results for aged R-134a with a POE branched acid.

T. Sato, H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Property Evaluation for a Binary HFC-32 + HFC-134a Refrigerant Based on Experimental PVTx Data**, paper 93-WA/HT-25 (Winter Annual Meeting, New Orleans, LA, 28 November - 3 December 1993), American Society of Mechanical Engineers (ASME), New York, NY, 1993 (rdb4874)

measurements of pressure-volume-temperature-composition (PVTx) properties for R-32/134a by means of a constant-mass method coupled with an expansion procedure: documents a total of 178 PVTx relationships were measured for R-32/134a (20/80), (40/60), (60/40), and (80/20) at 47-167 °C (116-332 °F), 1.5-6.2 MPa (218-899 psia), and 61-183 kg/m^3 (3.8-11.4 lb/ft^3) by a constant-mass method; presents derived second and third virial coefficients along with enthalpy and entropy values in the gaseous phase

C. N. Shores (York International Corporation), **Drop-In Test of Refrigerant Blend R-32/134a**, Alternative Refrigerants Evaluation Program (AREP) report 134, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (6 pages with 1 table, available from JMC as RDB5645)

R-32/134a (30/70), R-22 for reference, mineral oil, water-cooled reciprocating piston chiller

Retrofit Guidelines for Suva(R) MP39 and Suva(R) MP66, document ART-5 (H-42446-2), DuPont Chemicals, Wilmington, DE, December 1993

(14 pages with 4 tables, available from JMC as RDB4505)

This bulletin provides application information for R-401A and R-401B for retrofit use. These alternative refrigerants are identified as service replacements for R-12 and, for the latter, also R-500 in direct expansion systems using positive displacement (reciprocating piston, rolling rotary piston, scroll, and screw) compressors. The bulletin reviews and tabulates representative physical and environmental properties as well as comparative performance for R-12, R-500, R-401A, and R-401B. The data suggest 8 and 16% higher capacity and slightly higher efficiency, compared to R-12, and comparable efficiency and capacity to R-500. The bulletin then discusses lubricant selection, and recommends use of alkylbenzene lubricants to overcome miscibility concerns with mineral oils. It then discusses filter driers, suggests that they be changed during retrofits, and provides selection guidance for solid core, loose filled, and compacted bead driers. It outlines necessary system modifications with attention to hoses and gasket materials, and cautions against mixing R-401A and R-401B with other refrigerants, including R-12 and R-500, and additives. The bulletin summarizes the equipment, supplies, and procedures needed for retrofit with specific attention to lubricant changes, leak checking, charging, adjustments, and labeling. It also discusses the effects of temperature glide and provides pressure-temperature charts in both inch-pound (IP) and metric (SI) units. The bulletin concludes with discussion of superheat and subcooling, a retrofit checklist, and a system data sheet to record component data and operating parameters. DuPont's product names for R-401A and R-401B are Suva(R) MP39 and MP66, respectively.

November 1993

J. M. Calm (Engineering Consultant), **Status and Use of the Refrigerant Database**, *ASHRAE Journal*, 35(11):50-55, November 1993 (6 pages with 2 figures and 2 tables, available from JMC as RDB-3B97)

This article reviews the objectives, contents, and use of the Refrigerant Database. The key elements identified include a collection of documents, a computerized search system, a set of refrigerant summaries, and an information dissemination operation. The document collection, which includes both published and unpublished works, grew from an informal sharing of information on thermophysical properties, materials compatibility, and lubricants for alternative refrigerants. The current set also includes reports from the Air-Conditioning and Refrigeration Technology Institute's (ARTI's) Materials Compatibility and Lubricant Research (MCLR) Program, the Air-Conditioning and Refrigeration Institute's (ARI's) Alternative Refrigerants Evaluation Program (AREP), contributed works, and other sources. The search and retrieval system is based on a set of bibliographic citations and extended abstracts on refrigerant and lubricants, their properties, compatibility with other materials found in refrigeration systems, effects on heat transfer, system capacity and efficiency, computational and test methods to estimate or determine the preceding data, research, application data, and regulatory information. The article illustrates the computerized version of the database by showing how searches are performed. It also describes the manual, or report, version. It then describes refrigerant summaries, approximately 100 [now more than 200] of which are incorporated into the database. Two tables present refrigerant identifications, safety classifications, environmental data, and physical property data from the database for 38 of the most common refrigerants. The tabular data include the ANSI/ASHRAE Standard 34 designation, chemical name and formula, flammability limits, safety group, ozone depletion potential (ODP), global warming potential (GWP), molecular mass, freezing point, normal boiling point, and critical parameters (temperature, pressure, and density). The focus of the database and its sponsorship by ARTI, under a grant from the U.S. Department of Energy (DOE), are outlined.

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-22E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, November 1993 (166 pages, available from JMC as RDB3B21)

This document provides bibliographic citations for 954 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately half of these documents. The database identifies sources of specific information on R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. It addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It also references documents on compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation,

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and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes the same citations and abstracts as the report version plus 8 others for a supplement in preparation, 71 for superseded and historical documents, and data summaries for 175 individual refrigerants and blends. It is accompanied by retrieval software to facilitate searches for specific information; the software enables searches for user-selected terms, or combinations of terms. It offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, and a "wildcard" capability to allow entry of word segments. The software also enables printing of selected citations, abstracts, and refrigerant summaries as well as preparation of a document order lists. Both versions of the database include instructions to obtain cited documents or subscriptions for updates to the database.

J. Ferguson-Smith, **HFC 32 - Hygiene Standard Documentation**, document HSP/93/01, ICI Chemicals and Polymers Limited, Cheshire, United Kingdom, 23 November 1993 (4 pages, RDB5A76)

R-32, toxicity, literature review, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA, provisional; 10-min CNS EC_{50} rat = 370,000 ppm v/v

J. S. Gallagher, M. O. McLinden, G. Morrison, and M. L. Huber, **NIST Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database (REFPROP)**, Standard Reference Database (SRD) 23 version 4.0, National Institute of Standards and Technology (NIST), Gaithersburg, MD, November 1993 (software and 82 page documentation available from NIST for $465.00 or $100.00 to upgrade from previous versions, RDB4101)

Version 4.00 of REFPROP calculates properties for 38 pure refrigerants as well mixtures of up to five of them. Measured interaction parameters are provided 65 mixture pairs along with a method to estimate interaction parameters for others from a correlation. Highly accurate, multiparameter equations of state are available for 12 of the pure fluids; others are calculated using a modified Carnahan-Starling-DeSantis (CSD) equation of state. The refrigerants include R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-23, R-32, R-113, R-114, R-115, R-123, R-123a, R-124, R-125, R-134, R-134a, R-E134, R-141b, R-142b, R-143, R-143a, R-152a, R-218, R-227ea, R-236ea, R-245cb, R-E245 (incorrectly indicated as R-E224 in the documentation), R-C270 (cyclopropane), R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-744 (carbon dioxide), n-pentane, and isopentane. Fourteen thermodynamic properties can be calculated, in user-selected units of measurement, including temperature, pressure, density, specific volume, speed of sound, specific heats at constant volume and pressure, viscosity, and thermal conductivity. REFPROP also provides information on pure fluids, including the ASHRAE Standard 34 designation (R number), chemical formula and name, Chemical Abstract Service registry number, molecular mass, triple-point temperature if applicable, normal boiling point temperature, critical temperature and pressure, polarizability and dipole moment if measured, and estimated surface tension values at representative temperatures. This update replaces version 3.0 (see RDB2430).

H. M. Hunter and A. J. Pitt (APV Baker Limited, UK), **The Use of Ammonia and Secondary Refrigerants in Commercial Refrigeration**, *Refrigerants Beyond the Crisis: Practical Solutions* (London, UK, 4 November 1993), The Institute of Refrigeration, Surrey, UK; republished in *Engineered Systems*, 11(3):41-42 and 44, March 1994 (3 pages with 5 figures, RDB4439)

This paper explores the potential for use of R-717 (ammonia) for supermarket refrigeration. It characterizes ammonia refrigeration, indirect (secondary coolant) systems and even the combination as established. It suggests, however, that adoption of such systems in retail marketing would be both new and dramatic. The paper indicates that environmental concerns with chlorofluorocarbons, hydrochlorofluorocarbons, and hydrofluorocarbons coupled with the efficiency of ammonia would make it the refrigerant of choice, were it not for its toxicity and flammability. The paper suggests that these risks can be reduced by use of a secondary coolant, enabling containment of the ammonia in a restricted access, machinery room. It describes primary and secondary systems, connected by plate-and-shell heat exchangers. This type is described as providing the benefits of plate heat exchangers with the high integrity of shell-and-tube designs. Schematics illustrate the machinery room components and secondary distribution circuits for both two- and four-pipe systems. A plot compares projected maintenance costs of the ammonia-based secondary system to an R-22, direct expansion system. The paper concludes that the ammonia-based secondary system offers environmental and cost benefits, reduced refrigerant charge, lower costs of ownership, and flexibility in store layout. It notes that development work is still required.

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Revival of Carbon Dioxide as a Refrigerant**, *Refrigeration Beyond the Crisis* (London, UK, 4 November 1993), The Institute of Refrigeration and The Society of Environmental Engineers, London, UK, 1993; republished in *H&V Engineer*, 66(721):9-14, 1994; republished in *International Journal of Refrigeration* (IJR), 17(3):292-301, 1994 (6 pages, rdb5330)

R-744, carbon dioxide, transcritical cycle

M. O. McLinden, M. L. Huber, and S. Outcalt (National Institute of Standards and Technology, NIST), **Thermophysical Properties of Alternative Refrigerants**, paper presented at the Winter Annual Meeting (New Orleans, LA, 28 November - 3 December 1993), American Society of Mechanical Engineers (ASME), New York, NY, 1993 (16 pages with 7 figures and 11 tables, available from JMC as RDB4878)

This paper summarizes a survey of available thermophysical property data for seven hydrofluorocarbon (HFC) refrigerants: R-23, R-32, R-125, R-134, R-134a, R-143a, and R-152a. The paper discusses and tabulates the temperature at the triple point, temperature and liquid density at the NBP, and temperature, pressure, and density at the critical point. It then provides coefficients for vapor pressure data fits to Wagner or expanded Wagner equations. Coefficients also are provided for saturated-liquid density and ideal gas heat capacity fits to common equations. The paper tabulates and graphically shows the ranges of single-phase, pressure-volume-temperature (pVT) data available, for each of the refrigerants, to fit an equation of state. The tables and plots also identify the researchers that provided the data. The availability of data at the triple and critical points as well as ranges of data for saturated liquid and vapor densities, ideal gas heat capacity, speed of sound, surface tension, dielectric constant, dipole moment, thermal conductivity, and viscosity are tabulated. The paper notes that while extensive property research has been conducted in the last three years, considerable differences remain between refrigerants in the quantity and quality of information. The paper includes an extensive list of references on published property data.

S. Nowotny (United Nations Industrial Development Organization, UNIDO, Austria) and M. D. Mayer, **Alternative Refrigerants for Use in Domestic Refrigeration - A Case Study**, *Refrigeration Beyond the Crisis* (London, UK, 4 November 1993), The Institute of Refrigeration and the Society of Environmental Engineers, London, UK, 1993 (rdb5330)

A. Singh, A. Kumar, S. Dessiatoun, M. A. Faani, M. M. Ohadi, and A. I. Ansari (University of Maryland), **Compound EHD-Enhanced Pool Boiling of R-123 in a Liquid-to-Refrigerant Heat Exchanger**, paper 93-WA/HT-40 (Winter Annual Meeting, New Orleans, LA, 28 November - 3 December 1993), American Society of Mechanical Engineers (ASME), New York, NY, 1993 (rdb6443)

electrohydrodynamic enhancement, evaporation, heat transfer

H. Sumimoto (Kobe Steel, Limited, Japan), **Drop-In Test of Refrigerant R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 135, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, November 1993 (4 pages with 1 table, available from JMC as RDB3D35)

This report summarizes a performance test of R-32/125/134a (30/10/60) in a 40 hp, 207 kW (59 ton), water-cooled chiller with a twin-screw compressor and shell-and-tube heat exchangers. The results are tabulated for R-32/125/134a (30/10/60) along with corresponding data for R-22. Both refrigerants were tested with an unidentified polyolester lubricant. The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor, condenser, expansion device, and evaporator. The results show changes of -1.4 and +4.8% in capacity and decreases of 8.5 and 7.2% in efficiency, with and without an economizer, compared to R-22.

Addendum to Number Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34a-1993 (Addendum to ANSI/ASHRAE 34-1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, November 1993 (10 pages with 3 tables, RDB3B01)

This addendum adds safety classifications of *A1 provisional* for R-124 and R-125, *A1* for R-218, and removes the *provisional* status of prior classifications for R-123 and R-134a. *Provisional* classifications *will be reviewed when toxicological testing is completed.* The addendum also adds designations for R-401 (R-22/152a/124) and R-402 (R-125/290/22) and both formulation tolerances and safety classifications for five specific compositions of them: R-401 (53/13/34) [R-401A], (61/11/28) [R-401B], and (33/15/52) [R-401C] as well as R-402 (60/2/38) [R-402A] and (38/2/60) [R-402B]. The suffixed designations shown in brackets, to simplify identification of the specific formulations, were

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subsequently recommended and are being reviewed for publication. The safety classifications for all five blends are *A1/A1*, reflecting the *as formulated* and *worst case of fractionation* classifications, but all are flagged as *provisional*. Finally, the addendum revises the chemical names listed for 13 refrigerants to be consistent with the nomenclature convention of the International Union of Pure and Applied Chemistry (IUPAC) and includes the text of an earlier errata notice on flammability classifications.

October 1993

D. Arnaud, J. C. Tanguy, P. Weiss (Elf Atochem S.A., France), G. D. Rolotti (Elf Atochem North America), and M. Vauthier (Association pour la Formation Professionnelle des Adultes, AFPA, France), **An Example of R-502 Retrofit with Forane(R) FX 10 in Commercial Refrigeration**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 177-186, October 1993 (10 pages with 6 figures and 3 tables, RDB3A40)

FX10, R-143a/22

W. Atkinson (Sun Test Engineering), **Mobile Air Conditioning Overview**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 269-274, October 1993 (6 pages, RDB3A47)

H. Ax (Sanden International, Incorporated, USA), N. Jingu, and S. Komatu (Sanden Corporation, Japan), **The Development of a Retrofitting Procedure for CFC-12 Automotive A/C Systems to HFC-134a and P.A.G. Lubricant**, paper 932906 (SAE Worldwide Passenger Car Conference and Exposition, Dearborn, MI, 25-27 October 1993), Society of Automotive Engineers (SAE), Warrendale, PA, 1993 (12 pages with 8 figures and 18 tables, RDB5135)

R-134a, mobile air-conditioning (MAC) systems, retrofit conversion

S. C. Bhaduri (Indian Institute of Technology, India), **Performance of HCFC-22 Based Refrigerant-Absorbent Mixtures**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 129-140, October 1993 (12 pages with 11 figures and 3 tables, RDB3A35)

J. M. Calm (Engineering Consultant), **Global Warming Impacts of Chillers**, *IEA Heat Pump Center Newsletter - Heat Pumps and the Environment*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, 11(3):19-21, October 1993 (3 pages with 3 figures, available from JMC as RDB3A14)

This article presents key findings of a study (see RDB4440) of comparative impacts of chillers on global warming, including both direct (chemical) and indirect (energy-related) effects. It summarizes prior analyses of chiller warming impacts, and introduces a recent study performed for EPRI. The article outlines regional variations in fuels used to generate electricity, and presents calculated warming findings on both a national and regional bases. It notes that the regional data can be extrapolated to impacts for other locations or countries with similar generation mixes. The paper concludes that once high GWP CFCs are eliminated, global warming will be more readily influenced through efficiency improvement and emission reduction than by refrigerant substitutions. It reaffirms the findings of prior studies that indirect effect dominates over direct, including the combined impacts leakage, service, and ultimate disposal losses. It also notes that direct effect is equivalent to less than a 0.1 to 1.1% change in efficiency, depending on the refrigerant used, once service and disposal losses are reduced and CFCs eliminated. Three figures show comparative warming on a national and regional basis for chillers using R-11, R-12, R-22, R-123, and R-134a as well as direct-fired, absorption chillers (double-effect, water/lithium-bromide). A final plot shows the progressive reduction in total equivalent warming impact (TEWI) for R-11 and R-123 for 1985-1995 based on emission reductions and efficiency improvements

J. M. Calm (Engineering Consultant), **Information on Alternative Refrigerants and Lubricants - The ARTI Refrigerant Database,** *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 187-189, October 1993 (3 pages, RDB3A41)

This presentation summary briefly outlines the history, purpose, and contents of the Refrigerant Database. It cites initial efforts by the Air-Conditioning and Refrigeration Institute (ARI) and National Institute of Standards and Technology (NIST) to share information to accelerate introduction of alternative refrigerants. It summarizes the current form as comprising a collection of documents (many of them unpublished), a computerized search system, a set of refrigerant summaries, and an information dissemination operation. The focus of the database and its sponsorship by the Air-Conditioning and Refrigeration Technology Institute (ARTI), under a grant from the U.S. Department of Energy (DOE), and the Copper Development Association (CDA) are outlined.

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Measurement of Viscosity, Density, and Gas Solubility of Refrigerant Blends in Selected Synthetic Lubricants**, report DOE/CE/23810-22C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (68 pages with 41 figures and 11 tables, available from JMC as RDB3B20)

This interim report summarizes progress to measure the viscosity, density, and solubility of refrigerant/lubricant mixtures using six blends of R-32, R-125, R-134a, R-143a, and R-290 (propane). The specific mixtures include R-32/125 (60/40), R-32/125/134a (30/10/60), R-32/125/-290/134a (20/55/5/20), R-32/134a (30/70), R-125/143a (45/55), and R-125/143a/134a (44/-54/2). Their miscibilities were determined in five lubricants, including two polyolester (POE) branched acids (Castrol Icematic(R) SW32 and Henkel Emery(R) 2927a), two POE mixed acids (ICI Emkarate(TM) RL 32S, formerly RL 184, and Mobil EAL Arctic(R) 224R), and an alkylbenzene (Shrieve Zerol(R) 150). The last of these is used to examine the aromatic properties of miscibility. R-22 and R-502 also were examined with a mineral oil (Witco Suniso(R) 3GS) for comparison. The report presents the methods and apparatus used, and provides schematics for an oscillating body viscometer and blend sampling apparatus. The former is described as a unique means to accurately determine viscosity, density, equilibrium refrigerant gas solubility, and pressure over a broad range of temperatures. Plots relate viscosity to temperature for R-22 and R-502 with mineral oil for -20 to 125 °C (-4 to 257 °F), at pressures of 69-1720 kPa (10-250 psia) and 0-60% refrigerant by weight. Viscosity and pressure for these refrigerant-lubricant mixtures are presented as a modified Daniel Chart. Density also is plotted, as a function of temperature at constant concentration. The report compares the new findings to published data and addresses conflicting measurements by Iowa State University and Spauschus Associates. The report responds to specific questions raised by ARTI regarding concentration determinations, purity of the lubricant, viscosity comparisons for neat lubricant using the oscillating body and Cannon Fenske viscometers, and potential weight measurements stemming from small sample sizes or related oil hang up in the capillary tubes. An appendix provides plots showing the miscibility, partial miscibility, and immiscibility ranges by temperature for -62 to 82 °C (-80 to 180 °F) for combinations of the six blends and five synthetic lubricants. A second appendix presents plots and tabular raw data for viscosity and solubility for R-22 with mineral oil at -20, 0, 20, 40, 60, 80, 100, and 125 °C (-4, 32, 68, 104, 140, 176, 212, and 257 °F). A third similarly presents viscosity, solubility, and vapor fractionation for R-502 with mineral oil at -10, 0, 20, 40, 60, 80, 100, and 125 °C (14, 32, 68, 104, 140, 176, 212, and 257 °F). A final appendix gives plots and tabular raw data for the viscosity, density, and gas solubility of R-134a with a mixed acid POE at -30, -15, 0, 20, 40, 60, 80, 100, and 125 °C (-22, 5, 32, 68, 104, 140, 176, 212, and 257 °F).

J. L. Cox and Q. Wang (Rheem Manufacturing Company), **Soft-Optimized System Test of Refrigerant Blends R-32/125 (60/40) and R-32/125 (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 93, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (20 pages with 9 tables, available from JMC as RDB3C93)

T. W. Dekleva, S. H. Colmery (ICI Americas, Incorporated), and J. Bresnahan (ICI Australia Operations Pty Limited), **Fleet Trials with Vehicles Retrofitted to Klea(R) 134a Refrigerant and Emkarate RL(TM) Lubricants - A Perspective After Two Years on the Road**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 294-303, October 1993 (10 pages with 1 table, RDB3A50)

R-134a

T. W. Dekleva and R. W. Yost (ICI Americas Incorporated), **Responding to the CFC Challenge**, *Proceedings: Electrical Electronics Insulation Conference and Electrical Manufacturing and Coil Winding Conference* (EEIC/ICWA), Rosemont, IL, 495-500, October 1993 (6 pages with 3 figures and 5 tables, RDB4138)

This paper briefly reviews the environmental basis for phase out of chlorofluorocarbons (CFCs) and describes responding regulatory changes. It notes a program of research started in 1972 by the Chemical Manufacturers Association (CMA), the Fluorocarbon Program Panel, to support scientific studies of the environmental fate of CFCs. It also cites the published hypothesis by Rowland and Molina, in 1974, connecting CFCs and ozone depletion. The paper traces early regulatory responses, including a ban on CFC uses as aerosol propellants in the United States and a cap on CFC production and uses by the European Community in 1978. It outlines subsequent Montreal Protocol, U.S.,

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and European regulatory responses. It then outlines chemical industry research, beginning in the mid-1970s, to find alternatives. It explains the need to identify suitable lubricants for hydrofluorocarbons (HFCs). It also cites cooperative industry research efforts, including the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) as well as programs by industry associations. The paper outlines challenges and materials compatibility concerns in specific. The paper concludes that scientific information about ozone depletion is increasing and that new findings may lead to further regulatory changes, sometimes rapidly. It suggests that phaseout dates may move forward, but that industry has cooperated to speed the transition to alternatives. Figures and tables summarize the controlled chemicals, atmospheric chlorine loading, and phase out schedules. Further tables summarize basic properties for alternative refrigerants and lubricants and outline representative materials compatibility tests for motor materials and sheet insulation.

S. Devotta (National Chemical Laboratory, India), **An Assessment of Hydrocarbon Based Green Refrigerators for India**, Swiss Development Corporation, New Delhi, India, October 1993 (22 pages with 5 tables, available from JMC as RDB4906)

This report examines use of hydrocarbons as refrigerants and insulation blowing agents for refrigerators in developing countries and, specifically, in India. It recaps the motivations for phaseout of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. It then compares the paths and considerations to identify alternatives in developed and undeveloped countries. It contrasts countries such as China and India that are self reliant, with substantial domestic markets, to those that are dependent of developed countries either by imports or production for export. The report describes the Indian market for refrigerators, noting that approximately ten million are in use and that the inventory is expected to reach 130 million by 2010. Desired characteristics of refrigerants are outlined. The report discusses the suitability of R-134a, R-152a, R-290 (propane), R-290/600a (propane/isobutane), R-600a (isobutane), R-600 (n-butane) and R-600a blends, and R-E134. The discussion addresses performance, compatibility, flammability and other safety issues, and environmental acceptability. It also covers insulation alternatives, including foams blown with pentane or cyclopentane and vacuum panels. The report concludes that Indian industries usually follow the leads of industrialized counties, which are dominantly switching to R-134a. Whereas financial support for conversion will be available for only one option, the report notes that further evaluation of hydrocarbon options should be undertaken with other funding so both the R-134a and hydrocarbon options can be kept open.

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Alternative Refrigerants with Varnished Magnet Wire**, *Proceedings: Electrical Electronics Insulation Conference and Electrical Manufacturing and Coil Winding Conference* (EEIC/ICWA), Rosemont, IL, 513-517, October 1993; republished as paper DOE/CE/23810-23, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (5 pages with 4 tables, available from JMC as RDB3A22)

This paper summarizes an investigation (see RDB3857) of the effects of 11 refrigerants and 17 refrigerant-lubricant combinations on varnished magnet wires for hermetic compressor motors. The introduction discusses refrigerant compatibility with polymeric insulation material, citing absorption and extraction as the primary modes of interaction. It notes that absorption may change the dielectric strength or physical integrity. Absorption can cause excessive swelling, softening, or decreased strength. Rapid desorption may cause blisters, crazing, surface craters, delamination, or bubbles within the insulating materials. Extraction of materials may result in a range of effects from embrittlement to complete dissolution. Extraction and dissolution, in turn, may cause other components to stick or lead to clogging of passage such as capillary tubes. A table gives the change in weight of varnish disks following 500 hour exposures in the refrigerants (and nitrogen as a control) and a subsequent air bake. Three additional tables summarize change in bond, burnout, and dielectric strength following similar exposures of varnish-coated magnet wire. The paper notes that absorption of R-123 by most motor materials was higher than for other refrigerants. However, absorption of R-22, R-32, R-134, and R-152a followed by desorption, at higher temperatures, resulted in greater damage. These results suggest that high internal pressures and the desorption rate are as important as the amount of refrigerant absorbed. These changes decreased bond strength by as much as 95%, dielectric strength by as much as 70%, and decreased the physical integrity of the materials. Polyester-glass served magnet wire showed the highest burnout resistance and was influenced less by the refrigerants. Of the refrigerants tested, R-22 produced the greatest effects on the motor materials. Because R-22 has an excellent reliability history with many of them, the article concludes that the alternative refrigerants tested are expected to be compatible with most materials. Exposures were at 90 °C (194 °F) for R-22, R-123, R-124, R-134, R-134a, R-142b, and R-152a; R-32, R-125, R-143a were tested at 60 °C (140 °F) and R-245ca at 121 °C (250 °F). The varnishes included two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). The magnet wires included a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a modified polyester base overcoated with polyamide imide and epoxy saturated glass, and polyester imide overcoated with polyamide-imide, though the paper presents data only for the first.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermophysical Properties of HFC-143a and HFC-152a**, report DOE/CE/23810-22A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (242 pages, including 23 figures and 75 tables, available from JMC as RDB3C07)

This progress report summarizes experimental measurements to provide highly accurate, thermophysical property data for R-143a and R-152a as well as data fits to modified Benedict-Webb-Rubin (MBWR) equations of state and detailed transport property models. The objective is to fill gaps in existing data and resolve problems and uncertainties that exist in and between such data. The report briefly reviews the methods and apparatus used to measure liquid-phase densities, vapor pressure, liquid isochoric heat capacity, and vapor phase pressure-volume-temperature (PVT) behavior of R-143a. It also summarizes work to measure the isochoric heat capacity of R-152a. An appendix presents tabular summaries of measured liquid phase PVT and vapor pressure data for R-143a in both metric (SI) and inch-pound (IP) units. Measurements also are presented for liquid and two-phase heat capacity for R-152a.

D. R. Henderson (Spauschus Associates, Incorporated), **Solubility, Viscosity, and Density of Refrigerant-Lubricant Mixtures**, report DOE/CE/-23810-22B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (68 pages with 47 figures and 37 tables, available from JMC as RDB4102; page 53 is missing)

This interim report presents the findings of a study of the solubility, viscosity, and density of 35 refrigerant-lubricant mixtures for low- and high-refrigerant concentrations. It summarizes results for low concentrations (0, 10, 20, and 30% refrigerant by weight) for R-12, R-22, R-32, R-123, R-124, R-125, and R-134a with mineral oil (MO) alkylbenzene (AB), polyalkylene glycol (PAG), and two classes of polyolester (POE) lubricants - pentaerythritol ester branched acid (POE-BA) and pentaerythritol ester mixed acid (POE-MA). Data are provided for the following 23 combinations: R-12 with ISO 32 and 100 MO; R-22 with ISO 32 MO; R-32 with ISO 22 and 68 POE-MA; R-123 with ISO 32 and 100 MO and with 150 and 300 SUS AB; R-124 with 150 and 300 SUS AB; R-125 with ISO 22 and 68 POE-MA and with ISO 32 POE-BA; R-142b with 150 SUS AB; and R-134a with ISO 68 PAG, ISO 68 POE-BA, and ISO 22, 32, 68, and 100 POE-MA. The measurements generally cover 0-100 °C (32-212 °F) and 0-3450 kPa (0-500 psia). Equations and regression coefficients are tabulated for solubility, viscosity (dynamic and kinematic), and density for each mixture. These results also are shown as plots of density versus temperature and as Daniel Charts, showing kinematic viscosity and solubility (expressed as vapor pressure) versus temperature. An appendix explains the theoretical basis for corrections made for vapor space volume in the test apparatus. A second appendix provides details on the experimental approach used and explanations to resolve differences in measured data among the subject and two related projects. A third appendix summarizes the lubricant purities, including moisture content, total acid number (TAN), and iron and copper contents. A final appendix identifies the specific lubricants tested, including AB (Shrieve Chemical Zerol(R) 150 and 300), naphthenic MO (Witco Suniso(R) 3GS and 5GS), PAG (ICI Emkarox(R) DGLP 103), POE-BA (Henkel Emery(R) 2942A and 2968A), and POE-MA (Mobil EAL Arctic(R) 22 and 32 and Castrol Icematic(R) SW32, SW68, and SW100). The report lists 12 additional refrigerant-lubricant pairs to be studied.

D. R. Henderson (Spauschus Associates, Incorporated), **Solubility, Viscosity, and Density of Refrigerant-Lubricant Mixtures**, report DOE/CE/-23810-20B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (50 pages with 25 figures and 27 tables, available from JMC as RDB4426)

This interim report presents the findings of a study of the solubility, viscosity, and density of 35 refrigerant-lubricant mixtures for low- and high-refrigerant concentrations. It summarizes results for low refrigerant concentrations (0, 10, 20, and 30% refrigerant by weight) for R-12, R-22, R-123, and R-134a with mineral oil (MO), alkylbenzene (AB), and a polyolester (POE) lubricants - pentaerythritol ester mixed acid (POE-MA). Data are provided for the following 13 combinations: R-12 with ISO 32 and 100 MO;

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R-22 with ISO 32 MO; R-123 with ISO 32 and 100 MO and with 150 and 300 SUS AB; and R-134a with ISO 22, 32 (two types), 68, and 100 POE-MA. The measurements generally cover 0-100 °C (32-212 °F) and 0-3450 kPa (0-500 psia). Equations and regression coefficients are tabulated for solubility, viscosity (dynamic and kinematic), and density for each mixture. These results also are shown as plots of density versus temperature and as Daniel Charts, showing kinematic viscosity and solubility (expressed as vapor pressure) versus temperature. An appendix explains the theoretical basis for corrections made for vapor space volume in the test apparatus. A second appendix provides details on the experimental approach used and explanations to resolve differences in measured data among the subject and two related projects. A third appendix summarizes the lubricant purities, including moisture content, total acid number (TAN), and iron and copper contents. A final appendix identifies the specific lubricants tested, including AB (Shrieve Chemical Zerol(R) 150 and 300), naphthenic MO (Witco Suniso(R) 3GS and 5GS), and POE-MA (Mobil EAL Arctic(R) 22 and 32 and Castrol Icematic(R) SW32, SW68, and SW100). The report lists 22 additional refrigerant-lubricant pairs to be studied.

M. Jacobs, J. Kaschemekat, V. Simmons, and J. Wijmans (Membrane Technology and Research, Incorporated), **Membrane Systems for Improved Recovery of Refrigerant Vapor**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 232-242, October 1993 (11 pages with 7 figures and 2 tables, RDB3A45)

O. Kataoka (Daikin Industries, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 104, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (6 pages with 1 figure and 3 tables, available from JMC as RDB3D04)

G. S. Kazachki (Acurex Environmental Corporation) and C. L. Gage (U.S. Environmental Protection Agency, EPA), **Thermodynamic Evaluation and Compressor Characteristics of HFC-236ea and HFC-245ca as CFC-114 and CFC-11 Replacements in Chillers**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 167-176, October 1993 (10 pages with 4 figures and 3 tables, available from JMC as RDB3A39)

R-236ea, R-245ca

J. Iaconis (U.S. General Services Administration), **U.S. General Services Administration Public Building Services**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 259-268, October 1993 (10 pages, RDB3A46)

O. Kataoka (Daikin Industries, Limited, Japan), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 103, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 3 figures and 2 tables, available from JMC as RDB3D03)

T. Kato (Sanden Corporation, Japan), **Drop-In Test of Refrigerant Blends R-125/143a (45/55) and R-32/125/134a (10/45/45)**, Alternative Refrigerants Evaluation Program (AREP) report 112, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (6 pages with 2 tables, available from JMC as RDB3D12)

This report summarizes performance tests of two refrigerant blends, R-125/143a (45/55) and R-32/125/134a (10/45/45), in a 175 W (600 Btu/hr) chest freezer with a rotary, rolling-piston compressor. The results are tabulated along with corresponding data for a mixture of R-502 and propane, R-290/22/115 (6.0/45.9/48.1) identified as "R-502P". The blends were tested with an unidentified ester lubricant and R-502 with an unidentified mineral oil. Tests were performed at an ambient temperature of 34.7 °C (94.5 °F). Operating temperatures and pressures are given for the inlets and outlets of the compressor, condenser, expansion device, and evaporator. The results show decreases of 8.4 and 6.3% in efficiency for the binary and ternary blends, respectively, compared to "R-502P". The report notes that the discharge pressure with the two alternatives was slightly higher than with "R-502P", but the discharge temperature was slightly lower. It also suggests that the charge quantity can be reduced with the alternatives.

G. S. Kazachki (Acurex Environmental Corporation) and R. V. Hendriks (U.S. Environmental Protection Agency, EPA), **Calorimeter Tests of HFC-236ea as a CFC-114 Alternative and HFC-245ca as a CFC-11 Alternative**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 158-166, October 1993 (9 pages with 7 tables, RDB3A38)

H. Kitayama (Matsushita Refrigeration Company, Japan), **Drop-In Test of Refrigerant Blend R-**

32/125/134a (30/10/60), Alternative Refrigerants Evaluation Program (AREP) report 111, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (16 pages with 16 figures and 4 tables, available from JMC as RDB3D11)

R. E. Kauffman (University of Dayton Research Institute), **Accelerated Screening Methods for Determining Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures, Part II: Experimental Comparison and Verification of Methods**, report DOE/CE/23810-20D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (22 pages with 4 figures and 1 table, available from JMC as RDB3B02)

This report summarizes progress to evaluate analytical techniques for development into accelerated compatibility tests. Three methods are discussed, namely differential thermalysis analysis (DTA), ferric fluoride additions, and conductivity measurements. Tests of the DTA approach are described, and a diagram of a modified sealed glass tube used is shown. Only small temperature differences were measured for an R-12/mineral oil mixture. Whereas this combination is expected to be more reactive than those involving hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), DTA was deemed unsuitable. A test of accelerated degradation, by addition of ferric fluoride as a catalyst in conventional sealed-tube tests, is described. Gas chromatographic analyses detected only minor refrigerant degradation, as contrasted to observed color changes and acid formation. The technique is suggested to have potential for screening lubricant stability. Conductivity measurements, again using the modified sealed tube, are described. The tests explored use of direct current (DC), polarity reversal, and alternating current (AC). Plots show the degradation of R-11, R-12, and R-22 with mineral oil for thermal aging at 175 °C (347 °F). Tabular data indicate that the types of degradation products are the same as without applied AC voltage, suggesting that the degradation mechanisms are accelerated without mechanism changes. The effects of metal catalysts and need for further study are noted. The report concludes that in situ conductivity measurements have the best potential for development of the screening method. The naphthenic mineral oil tested was Witco Suniso(R) 3GS.

H. Kitayama (Matsushita Refrigeration Company, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 119, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (12 pages with 13 figures and 1 table, available from JMC as RDB-3D19)

performance test for R-407 series blend in a rotary rolling-piston compressor

H. Kitayama (Matsushita Refrigeration Company, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 120, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (12 pages with 11 figures and 1 table, available from JMC as RDB3D20)

performance test for R-407 series blend in a scroll compressor

D. Kolar (Navesink Environmental Testing), **Durability of Refrigerant Recovery Equipment**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 20-22 October 1993), Alliance for Responsible Atmospheric Policy, Arlington, VA, 222-231, October 1993 (10 pages with 1 figure, RDB6319)

recovery, reclaim

S. Komatsu (Sanden Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 121, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (6 pages with 2 tables, available from JMC as RDB3D21)

This report summarizes performance measurements of R-125/143a (45/55) with an unidentified ester lubricant in a rotary, rolling-piston compressor. The test rig is shown schematically. A table presents the evaporating and condensing temperatures and pressures as well as the superheat. It also gives the capacity, input power, and coefficient of performance (COP) normalized to those with R-502 at corresponding conditions. Measurements were made for -30, -25, -20, and -15 °C (-22, -13, -4, and 5 °F) evaporating and 45 °C (113 °F) condensing. The capacities and COPs increased by 1-12% and 13-22%, respectively, with R-125/143a (45/55). The report notes that the discharge temperature seemed to be lower than with R-502.

L. Lankford (J. J. Research Labs) and J. Nimitz (Environmental Technology and Education Center), **A New Class of High-Performance, Environmentally Sound Refrigerants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 141-149, October 1993 (9 pages with 3 figures and 4 tables, RDB3A36)

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fluoroiodocarbons, FICs; CF_3I, R-13I1; CF_3CF_2I, R-115I1; $CF_3CF_2CF_2I$, R-217I1, R-217caI1

S. Macaudiere, J. C. Tanguy (Elf Atochem SA, France), and P. F. Radice (Elf Atochem North America), **Properties and Performance Evaluation of HCFC-22 Alternatives in Air Conditioning**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 72-80, October 1993 (9 pages with 5 figures and 2 tables, RDB3A28)

K. W. Manz (Robinair Division of SPX Corporation), **Removing Restrictions on the Sale of Recycled Refrigerants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 20-22 October 1993), Alliance for Responsible Atmospheric Policy, Arlington, VA, 218-221, October 1993 (4 pages, RDB6318)

recovery, reclaim

K. Matsuo (Hitachi, Limited, Japan), **Compressor Calorimeter Test of Refrigerant R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 114, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (6 pages with 2 figures and 1 table, available from JMC as RDB3D14)

K. Matsuo (Hitachi, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 110, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 1 figure and 4 tables, available from JMC as RDB3D10)

K. Matsuo (Hitachi, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 97, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 2 figures and 3 tables, available from JMC as RDB3C97)

S. Misaki (Research Institute of Innovative Technology for the Earth, RITE, Japan) and A. Sekiya (National Institute of Materials and Chemical Research, NIMC, Japan), **Development of a New Refrigerant**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 24-26 October 1994), Alliance for Responsible Atmospheric Policy, Arlington, VA, 114-120, October 1994 (7 pages, RDB8315)

R-E245cb1 [$CH_3OCF_2CF_3$] R-E347mmy1 [$CH_3OCF(CF_3)_2$ or $CF_3CF(OCH_3)CF_3$], R-E347mcc3 [$CH_3OCF_2CF_2CF_3$]; physical properties, synthesis, stability with lubricants and metals (aluminum, copper, and steel), flash point, toxicity, atmospheric lifetime, GWP, HGWP

H. Namiki (Mayekawa Manufacturing Company, Limited, Japan), **Soft-Optimized System Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 108, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (4 pages with 2 tables, available from JMC as RDB3D08)

This report summarizes a performance test of R-134a in a 40 hp, 174 kW (49 ton), water-cooled chiller with a twin-screw compressor. The results are tabulated for R-134a along with corresponding data for R-22. Both refrigerants were tested with an unidentified synthetic lubricant and R-134a also was tested with an unidentified polyalkylene glycol (PAG). The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor and evaporator as well as the outlets from the condenser and expansion device. The results show decreases of 37 and 39% in capacity and 6 and 2% in efficiency for the synthetic and PAG lubricants, respectively, compared to R-22.

J. Nimitz (Environmental Technology and Education Center) and L. Lankford (J. J. Research Labs), **Fluoroiodocarbons as Halon Replacements**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 810-819, October 1993 (10 pages with 4 tables, RDB3A52)

fluoroiodocarbon (FIC) properties; CF_3I, R-13I1; CF_3CF_2I, R-115I1; $CF_3CF_2CF_2I$, R-217I1, R-217caI1

W. A. Phillips, **Implementation of a Refrigerant Management Program by the Service Industry**, unpublished paper presented at the International CFC and Halon Alternatives Conference (Washington, DC), York International Corporation, York, PA, October 1993 (8 pages, available from JMC as RDB3A69)

D. Ripple and O. Matar, **Viscosity of the Saturated Liquid Phase of Six Halogenated Compounds and Three Mixtures**, *Journal of Chemical and Engineering Data*, 38(4):560-564, October 1993 (5 pages, rdb8237)

reports liquid viscosity data for R-32, R-124, R-125, and others along with equimolar blends of R-32/134a, R-32/124, and R-125/134a for -23 to 57 °C (-10 to 134 °F): tests employed a coiled capillary viscometer constructed of stainless steel and sapphire; measurements are accurate to 3-5% of the kinematic viscosity; a free volume model of viscosity was used to correlate the data

K. Sakuma (Mitsubishi Electric Corporation, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 102, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 6 figures and 2 tables, available from JMC as RDB3D02; available copy is difficult to read)

T. Sano (Toshiba Corporation, Japan), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 98, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (12 pages with 5 figures and 3 tables, available from JMC as RDB3C98)

T. Sano (Toshiba Corporation, Japan**), Soft-Optimized Compressor Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 99, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 2 figures and 4 tables, available from JMC as RDB3C99)

N. Sawada (Sanyo Electric Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 116, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 4 figures and 1 table, available from JMC as RDB3D16)

N. Sawada (Sanyo Electric Company, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 100, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 2 figures and 5 tables, available from JMC as RDB3D00)

S. R. Skaggs, D. S. Dierdorf, and R. E. Tapscott (New Mexico Engineering Research Institute, NMERI), **Update on Iodides as Fire Extinguishing Agents**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 800-809, October 1993 (10 pages with 2 tables, RDB3A51)

fluoroiodocarbon (FIC) properties, toxicity; CF_3I, R-13I1; CF_3CF_2I, R-115I1; $CF_3CF_2CF_2I$, R-217caI1

N. D. Smith (U.S. Environmental Protection Agency, EPA), K. Ratanaphruks, M. W. Tufts, and A. S. Ng (Acurex Environmental Corporation), **HFC-236ea: A Potential Alternative for CFC-114**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 150-157, October 1993 (8 pages with 4 tables, RDB3A37)

examination of R-236ea as a candidate to replace R-114

S. R. Szymurski, **Research Update: ARTI Materials Compatibility and Lubricant Research (MCLR) Program**, presented at the International CFC and Halon Alternatives Conference (Washington, DC), paper DOE/CE/23810-24, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (10 pages with 1 table, available from JMC as RDB3A67)

This paper reviews the introduction of alternative refrigerants to replace those that deplete the ozone layer, the consequent research needs to evaluate and test the new fluids, and the history of the Materials Compatibility and Lubricant Research (MCLR) Program. Cumulative funding for the first three phases, from September 1991 to the present, will reach $6.45 million, jointly funded under a grant from the Department of Energy and cost sharing by the Air-Conditioning and Refrigeration Institute (ARI). The paper outlines seven research projects in phase I, addressing thermophysical properties, theoretical evaluation of R-22 and R-502 alternatives, chemical and thermal stability of refrigerants and lubricants, miscibility of lubricants in refrigerants, and compatibility with motor materials, elastomers, and engineering plastics. It also reviews five additional projects in phase II, namely compatibility with desiccants, electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants, accelerated screening methods for determining chemical and thermal stability, accelerated test methods for predicting the life of motor materials, and accelerated screening methods for predicting lubricant performance. Nine top priority projects, in planning, are identified for Phase III. They are compatibility of manufacturing process fluids with hydrofluorocarbon (HFC) refrigerants and ester lubricants, long-term compatibility of polyolester lubricants with HFC refrigerants, compatibility problems resulting from the products of motor burnouts, investigation into the fractionation of refrigerant blends, investigation of flushing and clean-out methods to ensure system compatibility, methods development for measuring and classifying flammability-combustibility of refrigerants, thermophysical properties, chemical and thermal stability of phase III

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refrigerants and lubricants, and miscibility of phase III refrigerants and lubricants. The paper notes that planning is underway for phase IV and that, while much has been accomplished in the first two years, much more remains. The materials compatibility results so far have been favorable for the HFC refrigerants tested. [see RDB3A68 for presentation charts]

S. R. Szymurskl, **Research Update: ARTI Materials Compatibility and Lubricant Research (MCLR) Program**, presentation charts (International CFC and Halon Alternatives Conference, Washington, DC, RDB3A67), Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (3 pages with 17 charts, available from JMC as RDB3A68)

This set of charts outlines the presentation summarized in RDB3A67.

S. R. Szymurski, G. C. Hourahan, and D. S. Godwin, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-22, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (50 pages with 9 figures and 6 tables, available from JMC as RDB3C06)

This progress report summarizes the goals and status of the Materials Compatibility and Lubricant Research (MCLR) Program, jointly funded under a grant from the Office of Building Technology of the U.S. Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program was implemented on 30 September 1991 and, as currently funded, will run through 30 September 1995. It supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. The primary elements include materials compatibility testing, methods development, and data collection and dissemination. The report provides a status update on research to measure thermophysical properties of R-143a and R-152a; measure the viscosity, density, and solubility for three azeotropic and zeotropic blends to replace R-22 and R-502; and measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures. The report also summarizes three projects to develop accelerated screening and test methods to predict lubricant performance in compressors, the life of motor materials exposed to refrigerant-lubricant mixtures, and chemical and thermal stability of refrigerant-lubricant mixtures. It reviews the progress of a continuing project to collect and facilitate dissemination of data, through development and administration of the ARTI Refrigerant Database. The progress report summarizes eight completed projects to measure thermophysical properties of R-32, R-123, R-124, and R-125; model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502; test the chemical and thermal stability of refrigerant-lubricant mixtures with metals; measure the miscibility of lubricants with refrigerants; provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics; and investigate electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants. The scope of the program, objectives of the individual projects, and significant interim findings are presented. This program summary also identifies reports resulting from the individual projects. Tables summarize significant findings of the individual projects including the miscibility of lubricants with 10 refrigerants; equations of state developed for R-32, R-123, R-124, and R-125; and relative elastomer swelling in refrigerants and lubricants. Two figures compare the modeled performance of alternative refrigerants to the capacities and efficiencies of R-22 and R-502.

F. A. Vogelsberg, Jr. (DuPont Chemicals), **Update: Alternative Fluorocarbon Environmental Acceptability Study**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 905-711, October 1993 (7 pages with 3 figures and 3 tables, RDB3A54)

AFEAS, environmental impacts

C. von Eynatten (Solvay Fluor und Derivate GmbH, Germany), R. Döring (Fachhochschule Münster, Germany), and H. Buchwald (Solvay Fluor and Derivate GmbH, Germany), **HFC-134a/HFC-23: A Very Promising Alternative to HCFC-22**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 119-128, October 1993 (11 pages with 10 figures, RDB3A34)

R-23/134a

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 117, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 3 figures and 1 table, available from JMC as RDB3D17)

rotary, rolling-piston compressor

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 118, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 3 figures and 1 table, available from JMC as RDB3D18)

scroll compressor

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125 (60/-40)**, Alternative Refrigerants Evaluation Program (AREP) report 105, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 2 figures and 4 tables, available from JMC as RDB3D05)

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 106, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 4 figures and 6 tables, available from JMC as RDB3D06)

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 107, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 2 figures and 6 tables, available from JMC as RDB3D07)

M-S. Zhu, L-Z. Han, X-Y. Zhao (Tsinghua University, China) and B. Lu (Beijing Snow Flake Electrical Appliance Group Corporation, China), **Dismantling Inspection and Retrofit of Domestic Refrigerator with HFC-134a**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 81-85, October 1993 (5 pages with 5 tables, RDB3A29)

M-S. Zhu and J. Li (Tsinghua University, China), **Several Prospective R-22 and R-502 Alternatives for Air-Conditioners and Refrigeration Equipment**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 61-71, October 1993 (11 pages with 6 figures and 5 tables, RDB3A27)

Genetron(R) AZ-20, technical bulletin B-525-652, AlliedSignal Incorporated, Morristown, NJ, October 1993, November 1993, and February 1994 (4 pages with 3 tables, RDB3A59)

This bulletin describes a patented azeotropic blend of R-32 and R-125, specifically R-32/125 (50/50) [R-410A], designed to replace R-22 in residential air-conditioners and heat pumps. It provides physical property data, in inch-pound (IP) units, including the chemical formula, molecular weight, atmospheric boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), and flammability. It also indicates the liquid density and specific heats of the liquid and vapor at 26.7 °C (80 °F). It then presents a performance comparison with R-22, R-32, R-125, and R-502. The report provides tabular thermodynamic properties (pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -29 to 71 °C (-20 to 160 °F). Formulae are provided to calculate thermodynamic properties including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. AlliedSignal's product name for R-32/125 (50/50) is Genetron(R) AZ-20.

Klea(R) 66, Replacement for HCFC 22, technical note 620250470, ICI Americas Incorporated, Wilmington, DE, October 1993 (12 pages with 2 figures and 3 tables, available from JMC as RDB3A63)

This document describes a ternary, zeotropic blend of R-32, R-125, and R-134a [R-32/125/134a (30/10/60)], developed as a replacement for R-22 in new equipment. The technical note summarizes the phase out of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, the need for alternatives to R-22, and ICI's search for likely replacements. It then compares the atmospheric lifetimes, ozone depletion potentials (ODPs) and halocarbon global warming potential (HGWPs) of R-22, R-32, R-125, R-134a, and the R-32/125/134a blend. It also provides a comparison of physical properties, at the normal boiling point, and theoretical performance comparison between R-22 and the blend. Two plots compare the coefficient of performance (COP) and cooling capacity, for evaporator temperatures of -20 to 10 °C (-4 to 50 °F) for R-22 and the blend. They show the blend's performance to be equal to, or slightly better than that of R-22. The document then discusses the flammability and toxicity of both the blend and its components, noting that the composition was designed to be nonflammable despite its R-32 content. The bulletin briefly reviews handling and leakage, noting that the blend always should be liquid charged into systems and that investigation has shown that

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degradation of performance will not be significant with anticipated leakage. The document next discusses appropriate lubricants, with focus on the ICI Emkarate(R) family of synthetic, neopentyl polyolesters. Several documents are cited as available or under preparation to provide thermophysical properties, flammability specifics, blend design information, handing and storage advice, and retrofit guidance. ICI's product name for the R-32/125/134a blend discussed is Klea(R) 66 [subsequently reformulated].

Measurement of Two-Phase Refrigerant Liquid-Vapor Mass Flow Rate, research project 722-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1992 - October 1993 (ASH0722)

This project sought to develop a meter to measure instantaneous mass flow of two-phase refrigerants for use in laboratories, rating procedures, and field monitoring. The contractor was McMaster University (Canada) led by M. Shoukri and J. S. Chang; it was sponsored by ASHRAE Technical Committee 1.2, *Instruments and Measurements.*

Thermodynamic Properties of Klea(R) 60, 32/125/134a (20/40/40 wt %), British Units, bulletin 620250370, ICI Klea, Wilmington, DE, October 1993 (28 pages with 1 figure and 3 tables, available from JMC as RDB4131)

This bulletin provides detailed thermodynamic properties for saturated and superheated R407A - a zeotropic blend containing R-32, R-125, and R-134a, specifically R-32/125/134a (20/40/40) - in inch-pound (IP) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 6.9-69 kPa (1-10 psi) increments for 70-3000 kPa (10-430 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 70-2960 kPa (10-430 psia) to temperatures as high as 213 °C (415 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 70-690 kPa (10-100 psia). ICI's product name for R-407A is Klea(R) 60.

Thermodynamic Properties of Klea(R) 61, 32/125/134a (10/70/20 wt %), British Units, bulletin 620250390, ICI Klea, Wilmington, DE, October 1993 (28 pages with 1 figure and 3 tables, available from JMC as RDB4133)

This bulletin provides detailed thermodynamic properties for saturated and superheated R407B - a zeotropic blend containing R-32, R-125, and R-134a, specifically R-32/125/134a (10/70/20) - in inch-pound (IP) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 7-69 kPa (1-10 psi) increments for 70-2960 kPa (10-430 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 100-3000 kPa (15-435 psia) to temperatures as high as 207 °C (405 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 70-690 kPa (10-100 psia). ICI's product name for R-407B is Klea(R) 61.

Thermodynamic Properties of Klea(R) 66, 32/125/134a (30/10/60 wt %), British Units, bulletin 620250410, ICI Klea, Wilmington, DE, October 1993 (28 pages with 1 figure and 3 tables, RDB3A83)

This bulletin provides detailed thermodynamic properties for saturated and superheated conditions for a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/125/134a (30/10/60) - in inch-pound (IP) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 7-69 kPa (1-10 psi) increments for 70-2960 kPa (10-430 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 70-2960 kPa (10-430 psia) to temperatures as high as 216 °C (420 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 70-690 kPa (10-100 psia). ICI's product name for R-32/125/134a (30/10/60) is Klea(R) 66 [subsequently reformulated].

September 1993

M. Katayama (Fujitsu General Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/-40)**, Alternative Refrigerants Evaluation Program (AREP) report 113, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1993 (10 pages with 5 figures and 2 tables, available from JMC as RDB3D13)

H. W. Sibley (Carrier Corporation), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 91, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1993 (14 pages with 6 figures and 9 tables, available from JMC as RDB3C91)

This report summarizes performance tests of R-32/125 (60/40) in a three-phase, hermetic scroll compressor (Carrier SR40) with a nominal capacity of 11.7 kW (3.3 ton). Tests were performed using a polyolester lubricant (Mobil EAL Arctic(R) 32). The operating conditions and measured results of the calorimeter tests are tabulated. The capacity, coefficient of performance (COP), mass flow rate, input power, and current draw are plotted as functions of saturated suction and condensing temperatures for suction temperatures of -32 to 13 °C (-25 to 55 °F). A plot summarizes the relative capacities and COPs are plotted for three further comparative tests in scroll compressors: R-22 with an alkylbenzene lubricant (Chevron Zerol(R) 150) in a Carrier SRD600AA, R-32/125 (60/40) in a "drop-in" test with a Copeland ZR61K2 compressor, and the same blend in an optimized Carrier SR40 compressor. The compressor operating conditions and R-22 measurements are tabulated. The comparisons show 50% higher capacity and approximately 10% lower efficiency for the "drop-in" compressor and slightly higher capacity and lower efficiency for the optimized compressor using the blend.

Alternative Fluorocarbons Environmental Acceptability Study, program description, AFEAS, Washington, DC, September 1993 (4 pages with 1 figure and 1 table, available from JMC in English or Japanese as RDB3B11)

This leaflet introduces the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), initiated in December 1988. The program was formed to assess the potential impacts of chlorofluorocarbon (CFC) refrigerant alternatives on the environment. AFEAS is a cooperative research effort sponsored by 12 leading chemical producers. Results were presented at the United Nations Environment Programme (UNEP) meeting in Nairobi in August 1989, and were incorporated as an appendix to the *Scientific Assessment* under the *Montreal Protocol on Substances that Deplete the Ozone Layer.* Further research, in a three-year, $6 million program, seeks to identify and help resolve uncertainties regarding potential environmental effects of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). A second objective is to stimulate prompt dissemination of scientific information to the research community, government decision makers, affected industries, and the public. A table lists potential alternatives to CFCs, including HCFCs R-22, R-123, R-124, R-141b, R-142b, R-225ca, and R-225cb, as transitional substances, and HFCs R-32, R-125, R-134a, R-143a, and R-152a. The summary notes that scientific studies show that use of HCFCs and HFCs to replace CFCs will reduce the amount of atmospheric chlorine, and thus decrease the risk of ozone depletion. Unlike CFCs, these alternatives will break down readily in the lower atmosphere, forming products with negligible contribution to either acid deposition or ozone pollution. Some of the HCFCs and HFCs can be expected to form trifluoroacetyl halides that will dissolve in water to form trifluoroacetic acid. While the concentrations are so low that adverse effects are unlikely, this issue is being investigated further. A figure contrasts the minor direct (chemical emission related) and larger indirect (energy related) contributions to total equivalent warming impact (TEWI) for a representative refrigerator. A cited AFEAS study of global warming, co-funded with the U.S. Department of Energy, indicates that HCFCs and HFCs provide substantial improvements in energy efficiency over CFCs in many applications.

Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) Summaries, AFEAS, Washington, DC, September 1993 (24 pages with 6 figures and 2 tables, available from JMC as RDB-3B12)

This series of ten leaflets presents key AFEAS objectives and findings. A summary of the *Montreal Protocol on Substances that Deplete the Ozone Layer* reviews the history of this international accord to phase out production of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants among other chemicals. It also recaps the schedules under the Protocol as well as the U.S. Clean Air Act and European regulations. A sheet on *Production and Sales of Fluorocarbons* reports annual production of R-11, R-12, R-22, R-113, R-114, and R-115 for 1970-1992 on a worldwide basis (participating companies only for 1992). A summary on *Atmospheric Chlorine: CFCs and Alternative Fluorocarbons* reviews the mechanisms of stratospheric ozone depletion and pro-

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vides values for ozone-depletion potentials (ODPs). It also illustrates how substitution of HCFCs for chlorofluorocarbons (CFCs) reduces chlorine in the atmosphere. The illustration further shows that use of HCFCs for a limited time will not delay return of atmospheric chlorine to pre-1970s levels. This summary quotes an international assessment that notes a three-year advance on the phaseout requirements of the Montreal Protocol. A sheet on *UV-B Radiation Measurements* discusses the importance of the ozone layer in shielding ultraviolet-B (UV-B) radiation in sunlight as well as efforts to monitor and observed trends of incoming UV-B intensity. A synopsis of the *Relative Contributions of Greenhouse Gas Emissions to Climate Forcing* discusses radiative forcing, a parameter used to perturb the heat balance in modeling of the earth-atmosphere system. It outlines understanding and uncertainties associated with GWP values, atmospheric persistence of greenhouse gas emissions, and the quantitative influence of *integration time horizon* (ITH) on analyses of impacts. A table provides estimates for the atmospheric lifetimes and GWP values for 20, 100, and 500 yr ITH. A sheet on *Total Global Warming Impact* compares the Total Equivalent Warming Impacts (TEWIs), considering both direct (emission related) and indirect (energy related) effects of alterative technologies and fluids. It notes that a not-in-kind (NIK) refrigerant option, with more than a 1% increase in energy use, would have a larger total warming impact than HCFC and HFC options. A review of the *Breakdown Products of Alternatives* outlines the mechanisms and consequences of HCFC and hydrofluorocarbon (HFC) breakdown. It notes that they readily decompose into simple inorganic species in the lower atmosphere, that the ultimate breakdown products are acidic compounds that are washed out in rain, that the acidic concentrations are so low as to have no appreciable effect, and that the alternatives do not contribute to photochemical smog formation in urban areas. A further summary of the *Environmental Fate of Trifluoroacetyl Halides* addresses the atmospheric breakdown of R-123, R-124, and R-134a, ultimately forming trifluoroacetate ion (TFA) in surface waters. While no impact is anticipated, further study is underway. A *Glossary of Terms* defines terminology for discussion of the atmospheric effects of alternative fluorocarbons. The last sheet briefly outlines the history and activities of both AFEAS and the companion Programme for Alternative Fluorocarbon Toxicity Testing (PAFT).

Emissions of Greenhouse Gases in the United States, 1985-1990, report DOE/EIA-0573, Energy Information Administration, U.S. Department of Energy, Washington, DC, September 1993 (126 pages with 64 tables, available from GPO as document 1993-300-813:80008, limited copies available from JMC as RDB4140)

Forane(R) for Refrigeration and Air Conditioning, bulletin DIREP-1921E, Elf Atochem S.A., Paris - La Défense, France, September 1993 (20 pages with 11 tables, RDB4136)

This bulletin outlines the replacement offerings of Elf Atochem for chlorofluorocarbon (CFC) refrigerants. It reviews the schedule for CFC phaseout and provides a table showing the applications of R-11, R-12, R-22, R-123, R-134a, R-142b, R-404A, R-409A, R-500, and R-502 as well as R-22/124/142b (65/25/10), R-32/125/143a (10/45/45), R-143a/22 (55/45), and FX-220 (composition not identified). It briefly discusses lubricants, including the Elf Atochem polyolesters (Planetelf(R)), and filter driers, including CECA's - an Elf Atochem subsidiary - molecular sieves (Siliporite(R)) for alternative refrigerants. The bulletin comments on leak detection methods and then discusses conversion of existing systems, with specific attention to R-123 for R-11; R-134a, R-409A, and R-22/124/142b (65/25/10) for R-12; R-404A, R-32/125/143a (10/45/45), and R-143a/22 (55/45) for R-502; and FX-220 for R-22. Tabular swell data are provided for the cited refrigerants with plastics and elastomers, including polychloroprene (Neoprene), butadiene acrylonitrile (BNR, Buna N), butadiene styrene (Buna S), hexafluoropropylene-vinylidene fluoride (Viton) butyl rubber (IIR), chlorosulfonated polyethylene (Hypalon), polyamide 11 (Rilsan), polystyrene (PS), and polyvinyl chloride (PVC). Summary property data (chemical formula, chemical name, molecular mass, bubble temperature, temperature drop (glide), critical temperature, critical pressure, pressure and density at representative conditions, ozone depletion potential (ODP), global warming potential (GWP), and flammability limits) and safety data (toxicity, recommended exposure limits, and flammability limits) also are tabulated. The bulletin concludes with brief discussion of handling, storage, recovery, recycling, and the company's quality program. Elf Atochem's product names for R-404A and R-409A are Forane(R) FX-70 and FX-56, respectively. Its names for R-22/124/142b (65/25/10), R-32/125/143a (10/45/45), and R-143a/22 (55/45) are Forane(R) FX-57, FX-40, and FX-10 [subsequently reformulated], respectively.

Genetron(R) AZ-50, technical bulletin #651 (B-525-651), AlliedSignal Incorporated, Morristown, NJ, September 1993 (4 pages with 3 tables, RDB3A60)

This bulletin describes R-507, an azeotropic blend of R-125 and R-143a - specifically R-125/-

143a (50/50) - designed to replace R-502 in low-temperature commercial refrigeration applications, such as supermarket display cases and ice machines. It provides physical property data, in inch-pound (IP) units, including the chemical formula, molecular weight, atmospheric boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), and flammability. It also indicates the liquid density and specific heats of the liquid and vapor at 26.7 °C (80 °F). It then presents a performance comparison with R-22 and R-502. The report provides tabular thermodynamic properties (pressure, density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -40 to 70 °C (-40 to 158 °F). Formulae are provided to calculate thermodynamic properties including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. AlliedSignal's product name for R-507 is Genetron(R) AZ-50.

Programme for Alternative Fluorocarbon Toxicity Testing, program description, PAFT, Bristol, United Kingdom, September 1993 (4 pages with 1 table, available from JMC in English or Japanese as RDB3B13)

This leaflet introduces the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), initiated in December 1987. The program is designed to expedite the development of toxicology data for possible substitute fluorocarbons to replace chlorofluorocarbons (CFCs), or more broadly halogenated fluoroalkanes, that may be catalyzing a decrease in stratospheric ozone levels. PAFT is a cooperative research effort sponsored by 15 of the leading CFC producers from nine countries. Five PAFT program sectors are identified including PAFT I to address R-123 and R-134a, PAFT II for R-141b, PAFT III for R-124 and R-125, PAFT IV for R-225ca and R-225cb, and PAFT V for R-32. The leaflet summarizes program objectives and schedules. It notes that there are more than 100 individual toxicology tests in the program, at a cost of $3-5 million per compound. It also indicates that more than a dozen testing laboratories in Europe, Japan, and the United States are performing tests, the results of which will be published in peer-reviewed journals and presented at scientific conferences. The program comprehensively addresses acute, sub-chronic, developmental and chronic toxicity/carcinogenicity studies, genotoxicity, and environmental toxicology studies.

Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries, PAFT, Bristol, United Kingdom, September 1993 (16 pages, available from JMC as RDB3B14)

Eight data sheets summarize the status and findings of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). They outline studies of acute toxicity (short-term exposures to high concentrations, such as accidental leakages), genotoxicity (effects on genetic material, an early screen for possible carcinogenic activity), sub-chronic toxicity (repeated exposure to determine any overall toxicological effect), reproductive and developmental toxicity (teratology, assessment of the effects on the reproductive system and of the potential for causing birth defects), chronic toxicity/carcinogenicity (lifetime testing to assess late-in-life toxicity or increased evidence of cancer), and ecotoxicity (assessment of potential to affect living organisms in the environment). Toxicology summaries for R-123, R-124, R-125, R-134a, and R-141b indicate that all have low or very low toxicity; test results show them to be neither developmental toxicants nor genotoxic. Additionally, R-123 and R-141b were found to have low acute dermal and inhalation toxicity, but caused an increased incidence of benign - but not life threatening - tumors in animals following long-term exposures. R-134a also caused an increased incidence of benign - but not life threatening - tumors in animals following long-term exposure to high concentrations. R-124, R-125, and R-134a were found to have very low acute and subchronic inhalation toxicity. No current findings preclude use of R-32 in general industrial uses, provided that recommended normal hygiene practices are observed. Further studies are being planned and conducted to address findings for R-225ca and R-225cb, though the acute toxicity was found to be low for both isomers and neither has shown evidence of genotoxic response. A *Glossary of Terms* is provided.

Thermodynamic Property Data for Klea 60, SI Units, bulletin CP/33524/1Ed/33/993, ICI Klea, Runcorn, Cheshire, UK, 1 September 1993 (32 pages with 1 figure and 3 tables, available from JMC as RDB4762)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-407A - a zeotropic blend containing R-32, R-125, and R-134a, specifically R-32/125/134a (20/40/40) - in metric (SI) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 0.1 bar (10 kPa, 1.5 psi increments) for 70-3000 kPa (10-435 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second

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table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 100-3000 kPa (15-430 psia) to temperatures as high as 168 °C (334 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 100-560 kPa (15-80 psia). ICI's product name for R-407A is Klea(R) 60.

Thermodynamic Property Data for Klea 61, SI Units, bulletin CP/33525/1Ed/33/993, ICI Klea, Runcorn, Cheshire, UK, September 1993 (32 pages with 1 figure and 3 tables, available from JMC as RDB4763)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-407B - a zeotropic blend containing R-32, R-125, and R-134a, specifically R-32/125/134a (10/70/20) - in metric (SI) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 0.1-0.5 bar (10-50 kPa, 1.5-7 psi) increments for 100-3000 kPa (10-435 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 100-3000 kPa (15-435 psia) to temperatures as high as 164 °C (327 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 100-560 kPa (15-80 psia). ICI's product name for R-407B is Klea(R) 61.

August 1993

L. W. Burgett (The Trane Company), **Revised Standards for Mechanical Refrigeration**, *ASHRAE Journal,* 35(8):31-35, August 1993 (5 pages with 3 figures and 1 table, RDB4303)

This article reviews the provisions of ANSI/ASHRAE Standards 34-1992, *"Number Designation and Safety Classification of Refrigerants*," and 15-1992 *"Safety Code for Mechanical Refrigeration."* These revised standards include new alternative refrigerants, a new safety classification matrix for refrigerants, and revised guidance for their application in mechanical refrigeration systems. The article focuses on key provisions and new application requirements. It describes the safety classification matrix, which comprises six groups combining two toxicity and three flammability classes. A table compares the safety groups for common refrigerants under the previous and new classification schemes. The article then reviews the occupancy (institutional, public assembly, residential, commercial, industrial, and mixed) and refrigerating system (high and low probability, referring to risk of occupant exposure in the event of a leak) groupings. These classifications along with that of the refrigerant are used to determine applicable requirements and permissible refrigerant quantities. The article outlines key requirements including those for machinery rooms, ventilation, and sensors. It also discusses efforts to gain recognition of Standards 15 and 34 in model building and fire codes and to further revise and update the two standards. The author concludes that understanding and implementation of the new requirements are essential to promote safe application and use of refrigeration systems. He also notes that all refrigerants present some degree of risk, necessitating care and respect in their use.

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-20E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, August 1993 (144 pages, available from JMC as RDB3865)

This document provides bibliographic citations for 809 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately half of these documents. The database identifies sources of specific information on R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-227ea, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. It addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester, and other lubricants. It also references documents on compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes the same citations and abstracts as the report version plus 42 additional citations, for superseded and historical documents, and data summaries for 90 individual refrigerants and blends. It is accompanied by retrieval software to facilitate searches for specific information; the software enables searches for user-selected terms, or combinations of terms. It offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, and a "wildcard" capability to allow entry of word segments. The software also enables printing of selected citations, abstracts, and refrigerant summaries as well as preparation of a document order lists. Both versions of the database include instructions to obtain cited documents or subscriptions for updates to the database.

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials**, *ASHRAE Journal*, 35(8):42-47, August 1993 (6 pages with 3 tables, RDB3A04)

This article summarizes a detailed investigation (see RDB3857) of the effects of 11 refrigerants and 17 refrigerant-lubricant combinations on 24 insulating materials for hermetic compressor motors. The introduction identifies absorption, extraction, and/or chemical dissolution as the primary deterioration mechanisms. It notes that absorption may change the dielectric strength or physical integrity or cause excessive swelling, softening, or decreased strength. Rapid desorption may cause blisters, crazing, surface craters, delamination, or bubbles within the insulating materials. Extraction of materials may result in a range of effects from embrittlement to complete dissolution. Extraction and dissolution, in turn, may cause other components to stick or lead to clogging of passage such as capillary tubes. Three tables classify motor materials as *compatible*, indicating a *concern*, or *incompatible with* pure refrigerants or refrigerant/lubricant mixtures. The effects of the pure refrigerants generally were greater than in combination with lubricants. The article notes that absorption of R-123 was higher than for other refrigerants by most motor materials. However, absorption of R-22, R-32, R-134, and R-152a followed by desorption, at higher temperatures, resulted in greater damage. These results suggest that high internal pressures and the desorption rate are as important as the amount of refrigerant absorbed. These changes decreased bond strength by as much as 95%, dielectric strength by as much as 70%, and decreased the physical integrity of the materials. Magnet wire with polyester-glass serving showed the highest burnout resistance and was influenced less by the refrigerants. Of the refrigerants tested, R-22 produced the greatest effects on the motor materials. Because R-22 has an excellent reliability history with many of them, the article concludes that the alternative refrigerants tested are expected to be compatible with most materials. The refrigerants tested included R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, R-152a, and R-245ca.

The lubricants included naphthenic mineral oil (Witco Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150), polyolester (POE) mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244), POE branched acid (Henkel Emery(R) 2927), a polyalkylene glycol (PAG) butyl monoether (ICI Emkarox(R) VG32), PAG modified with a fluoroalkyl group (AlliedSignal BRL-150), and a PAG diol (Dow Chemical P425). The varnishes included two solvent epoxies (P. D. George Sterling(R) U475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). The magnet wires included a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a modified polyester base overcoated with polyamide imide and epoxy saturated glass (Phelps Dodge Armored Poly-Thermaleze Daglass 2000), and polyester imide overcoated with polyamide-imide (Phelps Dodge/Schenectady Chemical). The sheet insulations tested were Westinghouse Nomex-Mylar-Nomex(R), Westinghouse Dacron-Mylar-Dacron(R), DuPont Mylar(R) 900 MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228. The spiral-wrapped sheet insulations tested were Insulations Sales Nomex(R), Mylar(R), and Nomex-Mylar(R). The lead wires tested were A. O. Smith Dacron-Mylar-Dacron(R) and Dacron-Teflon-Dacron(R). Other materials tested were woven glass tape (Carolina Narrow Heat Cleaned Fiberglass), heat shrinkable braided polyester tape (Electrolock), and glass-acrylic tape (Essex Permacel P247), and polyester tie cord (Ludlow Textiles).

R. Dowlati (AECL Research, Canada), A. M. C. Chan (Ontario Hydro, Canada), and M. Kawaji (University of Toronto, Canada), **Measurement of Void Fraction and Pressure Drop in Flow Boiling of R-113 Across Horizontal Tube Bundles**, 29th National Heat Transfer Conference (Atlanta, GA, 8-11 August 1993), American Society of Mechanical Engineers (ASME), New York, NY, 1993 (rdb3B66)

heat and mass transfer

S. Goktun and S. Ozkaynak (Turkish Naval Academy, Turkey), **Selection of Ozone-Safe Refrigerants for Heat Pumps**, *Energy*, 18(8):867-870, August 1993 (4 pages, rdb8939)

outlines criteria for selection of ozone-safe, high performance refrigerants for low- and high-temperature heat pumps; concludes that R-134, R-134a, R-E115, and possibly R-152a are promising alternatives to R-12 for low-temperature applications; identifies R-160 (ethyl chloride), R-160B1 (ethyl bromide), R-143, R-E134, "5FP",

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and propyl chloride as candidates to replace R-114 in high-temperature applications

G. R. Hamed and R. H. Seiple (University of Akron), **Compatibility of Refrigerants and Lubricants with Elastomers**, *ASHRAE Journal,* 35(8):173-176, August 1993 (4 pages with 4 tables, RDB3A05)

This article summarizes swell measurements for elastomer compounds comprising various base polymers, filler contents, and cure systems (see RDB3202). The introduction distinguishes between highly-filled gaskets, which require significant compressive forces to be effective, and more elastic polymers, which depend on internal restoring forces to seal mating components. The article outlines swell measurements on nearly 100 elastomers after submersion in refrigerants and lubricants for 14 days at 60 °C (140 °F). It identifies a second phase of the research, to determine strength retention following extended exposures, for materials found to best resist swelling. The article reviews the theoretical background for solvent uptake and interaction, based on the degree of crosslinking and filling in the material structure. Swell behavior is qualitatively (*good* or *poor*) tabulated for common elastomer classes, including polyisoprene, silicone, polychloroprene, thermoplastic elastomer (ME), butyl rubber, polysulfide rubber, styrene butadiene rubber (SBR), polyurethane, nitrile, chlorosulfonated and chlorinated polyethylene (PE), fluorinated rubber, epichlorohydrin, ethylene propylene rubber (EPR), ethylene propylene diene monomer (EPDM), and ethylene acrylic. A number of gasket materials supplied by industry also were examined. The refrigerants included both hydrochlorofluorocarbons (HCFCs R-22, R-123, R-124, and R-142b) and hydrofluorocarbons (HFCs R-32, R-125, R-134, R-134a, R-143a, and R-152a). The lubricants included a naphthenic mineral oil, alkylbenzene, and three polyalkylene glycols (PAGs), namely a polypropylene glycol butyl monoether, a polypropylene glycol diol, and a modified polyglycol. Two polyolester (POE) lubricants also are included, namely a pentaerythritol ester branched acid and a pentaerythritol ester mixed acid. The article notes that R-123 generally gave the greatest swelling and HFCs, as a group, the least. Some industrial gasket samples resisted swelling in all refrigerants. The lubricants that showed the most swell for the greatest number of elastomers were mineral oil and alkylbenzene. Outgassing of high pressure refrigerants (e.g., R-22, R-32, and R-125) following exposures may produce surface cracking, surface bubbling, and internal flaws. The article notes that gaskets using a wider, less-expensive range of polymers may be engineered for HFCs because of the limited swell found with them.

K. E. Hickman (York International Corporation), **Redesign for R-22 and R-502 Alternatives - Where Are We Now?**, *R-22 and R-502 Alternatives* (Proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97-101, 1994 (5 pages with 1 table, RDB4524)

This insightful paper reviews candidates being tested to replace R-22 and R-502, in the Alternative Refrigerants Evaluation Program (AREP). The introduction explains that AREP was organized by the Air-Conditioning and Refrigeration Institute (ARI), to identify the most promising replacements. It notes participation by government and university laboratories and support by the U.S. Department of Energy (DOE), Electric Power Research Institute (EPRI), and the National Institute of Standards and Technology (NIST) in addition to the primary testing by manufacturers. A table summarizes the alternatives, their characteristics, and commercial examples. The paper traces blend reformulations to resolve identified concerns. It describes considerations for three application categories, starting with packaged equipment for residential and commercial air conditioning and heat pump systems. Testing is focusing on an azeotrope, R-32/125 (50/50), and three zeotropes, R-32/134a (25/75) and (30/70), and R-32/125/134a (30/10/60). The paper outlines their advantages and disadvantages, comments on test results, and summarizes comparative findings by evaluations in Japan. The paper concludes that the zeotropes are close to R-22 in behavior and would require only minor changes in design, but would not be easy to use in systems with multiple evaporators. R-32/125 shows the best promise to increase efficiency, and its lower volumetric flow rate may allow reductions in equipment size. However, its use would require substantial compressor and heat exchanger redesign. R-134a also is a candidate, but compressors would need approximately 50% larger volumetric displacement. The replacements addressed for R-22 engineered systems - water chillers for centralized plants - include R-32/125 (50/50), R-32/134a (25/75) and (30/70), R-125/143a/134a (44/52/4) [R-404A], R-134a, and R-717 (ammonia). R-32/125 again offers potential performance advantages, but its high condensing pressure may limit is application unless compressors and heat exchangers are redesigned. R-134a already is used in centrifugal chillers, for which the higher flow volumes do not substantially increase costs, but is limited for positive displacement machines (with screw and reciprocating piston compressors) by the larger displacement requirement. Ammonia offers a viable technical alternative, but is consideration is primarily for industrial applications due to safety issues and building code requirements. The paper addresses three alternatives to replace R-502 in commercial refrigeration systems, namely R-125/143a (50/50) [R-507], R-125/143a/134a (44/52/4) [R-404A], R-32/125/134a (20/40/40), and R-32/125/143a (10/45/45). The author notes greatest interest and testing for R-32/125/134a, despite earlier announcements of other replacements spurred by impending phase out of R-115, a component of R-502. The paper concludes that considerable testing remains to be done for product development to prove system reliability and durability. It also notes that better property data are needed for manufacturers to predict and certify performance with the accuracy that is now standard. Most of the alternatives either do not improve efficiencies or require substantial changes and testing. The author suggests that the alternatives will offer neither performance or cost advantages to customers for systems now designed for R-22. While manufacturers believe that the refrigerants under test will be viable, testing is still at an early stage and a service infrastructure must be put in place. R-290 (propane) also is listed as a candidate, but is not discussed.

G. C. Hourahan and M. S. Menzer (Air-Conditioning and Refrigeration Institute, ARI), **Research Needs in Air-Conditioning and Refrigeration**, *Heat Transfer with Alternate Refrigerants* (proceedings of the 29th National Heat Transfer Conference, Atlanta, GA, 8-11 August 1993), edited by H. J. Sauer, Jr., and T. H. Kuehn, American Society of Mechanical Engineers (ASME), New York, NY, HTD-243:1-8, 1993 (8 pages with 5 figures and 1 table, available from JMC as RDB3421)

This paper outlines research needs stemming from introduction of alternative refrigerants and the concurrent desire to maintain or increase equipment efficiency. Its purpose is to seed interest in and identify sponsorship opportunities for necessary research. The paper briefly reviews potential impacts of refrigerants on ozone depletion and global warming. It then discusses vapor-compression and absorption cycles and equipment. Starting with their components, it identifies research needs to utilize alternative refrigerants. Research of heat exchanger enhancement, fundamental boiling heat transfer, considerations for glide utilization for zeotropes, and influences of lubricants are among the topics addressed. Design issues for compressors, both positive displacement and centrifugal, are surveyed with emphasis on discharge valve requirements, impeller improvement, oil-free possibilities, and seal refinement. Research needs are cited for materials compatibility and lubricants, composition management for zeotropic blends, and leak sensor requirements. The paper then discusses opportunities for not-in-kind technologies including absorption, adsorption (or desiccant), Stirling, and other cycles. It also mentions needs relating to distribution systems, training of service personnel, and conversions to alternative fluids. The paper mentions ongoing research by the Air-Conditioning and Refrigeration Technology Institute (ARTI) and provides a tabular summary of agencies funding research of air conditioning and refrigeration. They include the ARTI, American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), Electric Power Research Institute (EPRI), Gas Research Institute (GRI), U.S. Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA).

H. H. Kruse (Universität Hannover, Germany), **European Research and Development Concerning CFC and HCFC Substitution**, *R-22 and R-502 Alternatives* (proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 41-57, 1994 (17 pages with 13 figures and 7 tables, RDB4519)

G. A. Lamont and H. Kumar (APV Baker Therm Division), **Advances in Elastomer Materials for Use in Plate Heat Exchangers**, 29th National Heat Transfer Conference (Atlanta, GA, 8-11 August 1993), American Society of Mechanical Engineers (ASME), New York, NY, 1993 (rdb3B68)

compatibility

J. W. Linton, W. K. Snelson, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **Near Azeotropic Refrigerant Mixtures HP80 (R-402A) and HP81 (R-402B) as Potential Drop-in Substitutes for R-502**, *Heat Pumps in Cold Climates* (proceedings of the Second International Technical Conference, Moncton, NB, Canada, 16-17 August 1993), Caneta Research, Incorporated, Mississauga, ON, Canada, 59-70, January 1994 (12 pages, RDB4884)

M. O. McLinden, J. G. Gallagher, M. L. Huber, and G. Morrison (National Institute of Standards and Technology, NIST), **REFPROP Refrigerant Properties Database: Capabilities, Limitations, and Future Directions,** *R-22 and R-502 Alternatives* (proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta,

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GA, 59-71, 1994 (13 pages with 20 figures and 1 table, RDB4520)

C. K. Rice, L. S. Wright (Oak Ridge National Laboratory, ORNL), and P. K. Bansal (University of Auckland, New Zealand), **Thermodynamic Cycle Evaluation Model for R-22 Alternatives in Heat Pumps - Initial Results and Comparisons**, *Heat Pumps in Cold Climates* (proceedings of the Second International Technical Conference, Moncton, NB, Canada, 16-17 August 1993), Caneta Research, Incorporated, Mississauga, ON, Canada, 81-96, January 1994 (17 pages with 7 figures and 5 tables, RDB4869)

"Bicycle" model, R-32/125 (60/40), R-32/134a (30/70), R-32/125/134a (30/10/60), R-32/227ea (35/65)

O. K. Riegger and K. S. Sanvordenker (Tecumseh Products Company), **Mixtures as Candidate Replacements for R-22 - Is There a Choice?**, *R-22 and R-502 Alternatives* (Proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 23-29, 1994 (7 pages with 5 figures and 3 tables, RDB4517)

This paper reviews the requirements for alternatives to replace R-22 and discusses evaluations of candidates, both pure components and blends. The paper divides the requirements into three categories: "*must absolutely have*," "*need to have*," and "*like to have*." It discusses the ozone depletion potential (ODP), global warming potential (GWP) and related total equivalent warming potential (TEWI), toxicity, flammability, functionality, compressor operating parameters (pressures, volumetric capacities, and discharge temperatures), and system parameters for candidates. It then discusses six hydrofluorocarbons (HFCs) including R-23, R-32, R-125, R-134a, R-143a, and R-152a. The paper lists concerns with each, concluding that all fall short in one or more requirements. A table presents their boiling and critical point temperatures, atmospheric lifetimes, GWP, flammability, relative capacity and efficiency, and pressure at 7 °C (45 °F). The paper briefly discusses other candidates including fluoroethers, R-290 (propane), and R-717 (ammonia). It concludes that none of the pure compounds could replace R-22 in air conditioners and heat pumps, necessitating consideration of blends. Based on boiling points, flammability, and environmental aspects, the paper suggests combinations that can be eliminated from consideration or relegated to low priority. It discusses the first choice, R-32/134a and discusses compositions and considerations for capacity matching, heat transfer, evaporating and condensing temperatures, use of glide, and fractionation. It then presents the findings of experimental evaluations of R-32/134a (30/70) and R-32/125/134a (30/10/60) [a developmental formulation, since modified, of both DuPont Suva(R) AC9000 and ICI Klea(R) 66]. Four figures show the energy efficiency ratios (EERs) and capacity ratios for the two zeotropic blends compared to R-22 at evaporator temperatures from -18 to 15 °C (0-60 °F) and condensing temperatures of 38-60 °C (100-140 °F). The paper discusses chemical reactivity and other compatibility issues, including miscibility with lubricants as well as effects on motor insulation and desiccants, for the pure compounds. It also discusses resultant flammability test conditions and limits when blended with R-125. The authors conclude that refrigerant mixtures with capacities matching that of R-22 also suffer disadvantages. They note that the R-32/125/134a blend is a more desirable match for R-22, but that a spot check in an air conditioner showed significant deterioration in performance associated with pressure drops and heat transfer coefficients.

O. K. Riegger and K. S. Sanvordenker, **Mixtures as Candidate Replacements for R-22 - A Hobson's Choice**, paper preprint, ASHRAE/NIST Refrigerants Conference (Gaithersburg, MD, 19-20 August 1993), Tecumseh Products Company, Ann Arbor, MI, August 1993 (24 pages with 5 figures and 3 tables, available from JMC as RDB3864)

This paper reviews the requirements for alternatives to replace R-22 and discusses evaluations of candidates, both pure components and blends. Noting the history of the Montreal Protocol, the paper suggests that the phaseout of R-22 may be accelerated, and presents replacement candidates from a compressor manufacturer's point of view. It divides the requirements into three categories: "*must absolutely have*," "*need to have*," and "*like to have*." It discusses the ozone depletion potential (ODP), global warming potential (GWP) and related total equivalent warming potential (TEWI), toxicity, flammability, functionality, compressor operating parameters (pressures, volumetric capacities, and discharge temperatures), and system parameters for candidates. It then discusses six hydrofluorocarbons (HFCs) including R-23, R-32, R-125, R-134a, R-143a, and R-152a. The paper lists concerns with each, concluding that all fall short in one or more requirements. A table presents their boiling and critical point temperatures, atmospheric lifetimes, GWP, flammability, relative capacity and efficiency, and pressure at 7 °C (45 °F). The paper briefly discusses other candidates including fluoroethers, R-290 (propane), and R-717 (ammonia). It concludes that none of the pure compounds could replace R-22 in air conditioners and heat pumps. This finding forces the Hobson's choice to evaluate blends. Based on boiling points, flammability, and environmental aspects, the paper suggests combinations that can be eliminated from consideration or relegated to low priority. It discusses the first choice, R-32/134a and discusses compositions and considerations for capacity matching, heat transfer, evaporating and condensing temperatures, use of glide, and fractionation. It then presents the findings of experimental evaluations of R-32/134a (30/70) and R-32/125/134a (30/10/60) [a developmental formulation, since modified, of both DuPont Suva(R) AC9000 and ICI Klea(R) 66]. Four figures show the energy efficiency ratios (EERs) and capacity ratios for the two zeotropic blends compared to R-22 at evaporator temperatures from -18 to 15 °C (0-60 °F) and condensing temperatures of 38-60 °C (100-140 °F). The paper discusses chemical reactivity and other compatibility issues, including miscibility with lubricants as well as effects on motor insulation and desiccants, for the pure compounds. It also discusses resultant flammability test conditions and limits when blended with R-125. The authors conclude that refrigerant mixtures with capacities matching that of R-22 also suffer disadvantages. They note that the R-32/125/134a blend is a more desirable match for R-22, but that a spot check in an air conditioner showed significant deterioration in performance associated with pressure drops and heat transfer coefficients. [see RDB4517 for edited version]

S. T. Ro, J. Y. Shin, and Y. S. Chang (Seoul National University, Korea), **Cycle Performance of the Refrigeration System Using Alternatives to R-12 and R-22**, *Heat Pumps in Cold Climates* (proceedings of the Second International Technical Conference, Moncton, NB, Canada, 16-17 August 1993), Caneta Research, Incorporated, Mississauga, ON, Canada, 71-80, January 1994 (10 pages, rdb4885)

M. K. Smith, J. P. Wattelet, and T. A. Newell (University of Illinois at Urbana-Champaign), **A Study of Evaporation Heat Transfer Coefficient Correlations at Low Heat and Mass Fluxes for Pure Refrigerants and Refrigerant Mixtures**, *Heat Transfer with Alternate Refrigerants* (proceedings of the 29th National Heat Transfer Conference, Atlanta, GA, 8-11 August 1993), edited by H. J. Sauer, Jr., and T. H. Kuehn, American Society of Mechanical Engineers (ASME), New York, NY, HTD-243:19-26, 1993 (8 pages with 8 figures, rdb3B18)

This paper presents an average heat transfer correlation for R-12 evaporation for the mass flux range of 25-100 kg/m^2·s (5-20 lb/sf·s) and heat fluxes of 2-10 kW/m^2 (630-3200 Btu/(h·sf)). It also provides local correlations for mixtures of R-22/123 (65/35) and R-22/141b (80/20) for the mass flux ranges of 25-85 and 27-42 kg/m^2·s (5-17 and 6-9 lb/sf·s) and heat fluxes of 1.2-2.8 and 1.0-4.2 kW/m^2 (380-890 and 320-1300 Btu/(h·sf), respectively. These low mass and heat conditions are characterized as predominantly wavy/stratified flow and typical of those found in refrigerator evaporators. A plot contrasts the present work to the flow regimes examined by other researchers, which generally are for higher fluxes. The paper describes a horizontal-tube test stand used to measure heat transfer for neat refrigerants and energy balances performed for a full evaporator for the refrigerant mixtures. Heat transfer coefficients for the latter were found to be approximately 50% lower than predicted coefficients for R-12, for corresponding ranges of mass and heat flux.

Handbook for the Montreal Protocol on Substances That Deplete the Ozone Layer (third edition), United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, August 1993 (176 pages, RDB3C05)

This document contains the complete text of the Montreal Protocol, originally adopted in 1987 as adjusted and amended in June 1990, June 1991, and November 1992. The decisions of the Parties to the Montreal Protocol, that relate to its interpretation, at meetings in Helsinki in (May 1989), London (June 1990), Nairobi (June 1991), Geneva (July 1992), and Copenhagen (November 1992) appear as footnotes to the Articles to which they pertain. The handbook also includes the following appendices: the *Helsinki Declaration on Protection of the Ozone Layer* (2 May 1989); declarations by Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, Liechtenstein, Netherlands, New Zealand, Norway, Sweden, and Switzerland on phase out of CFCs not later than 1997 (June 1990); resolution by represented parties on more stringent measures (June 1990); statements by Austria, Denmark, Germany, Finland, Norway, Sweden, and Switzerland on more stringent measures (June 1991); status of ratification (July 1993, now superseded); list of relevant publications; *Non-compliance Procedure* pursuant to Article 8 of the Protocol; *Indicative List of Measures that Might Be Taken by a Meeting of the Parties in Respect of Non-compliance with the Protocol*; nonconfidential production and consumption data regarding controlled substances; *Terms of Reference for the Multilateral Fund; Terms of Reference of the Executive Committee; Indicative List of Categories of Incremental Costs; Criteria for Projects under the Multilateral Fund; Guidelines for Presentation of Pro-*

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jects and Criteria for Project Approval; names and address of assessment panel chairmen; annotated *Vienna Convention for the Protection of the Ozone Layer*; *Research and Development Observations*; status of ratification of the Vienna Convention (31 July 1993); and the *Rules of Procedure*. The Vienna Convention was adopted in Vienna on 22 March 1985 and entered into force on 22 September 1988. The Montreal Protocol was adopted in Montreal on 16 September 1987 and entered into force on 1 January 1989; the London Amendment was adopted on 29 June 1990 and entered into force on 10 August 1992; the Copenhagen adjustments adopted on 23 November 1992 entered into force on 22 September 1993 and the Copenhagen Amendment will enter into force on 1 January 1994, if at least twenty ratifications are deposited before that date.

July 1993

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Measurement of Viscosity, Density, and Gas Solubility of Refrigerant Blends**, report DOE/CE/23810-20C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1993 (48 pages with 8 figures and 8 tables, available from JMC as RDB3861)

This interim report summarizes progress to measure the viscosity, density, and gas solubility for blends of R-32, R-125, R-134a, R-143a, and R-290 (propane) in lubricants. The specific mixtures include R-32/125 (60/40), R-32/125/134a (30/10/60), R-404A [R-125/143a/134a (44/54/2)], R-32/134a (30/70), R-32/125/290/134a (20/55/-5/20) misidentified in the report as (30/55/5/20), and R-125/143a (45/55). Their miscibilities were determined in five lubricants, including two polyolester (POE) branched acids (Castrol Icematic(R) SW32 and Henkel Emery(R) 2927a), two POE mixed acids (ICI Emkarate(TM) RL 32S, formerly RL 184, and Mobil EAL Arctic(R) 224R), and an alkylbenzene (Shrieve Zerol(R) 150). The last of these is used to examine the aromatic properties of miscibility. R-22 and R-502 also were examined with a mineral oil (Witco Suniso(R) 3GS) for comparison. The viscosities of the first three refrigerant blends will be measured in two of the lubricants as the project continues. The report presents the methods and apparatus used, and provides schematics for an oscillating body viscometer and blend sampling apparatus. Plots relate viscosity to temperature for R-22 and R-502 with mineral oil for -20 to 125 °C (-4 to 257 °F), at pressures of 69-1720 kPa (10-250 psia) and 0-60% refrigerant by weight. Viscosity and pressure for these refrigerant-lubricant mixtures are presented as a modified Daniel Chart. Density also is plotted, as a function of temperature at constant concentration. An appendix provides plots showing the miscibility, partial miscibility, and immiscibility ranges by temperature for -62 to 82 °C (-80 to 180 °F) for combinations of the six blends and five synthetic lubricants. A second appendix presents plots and tabular data for the viscosity and solubility of R-22 in mineral oil selected for -20 to 125 °C (-4 to 257 °F). A third similarly presents data for viscosity, solubility, and fractionation of R-502 in mineral oil for -10 to 125 °C (14 to 257 °F). The report also addresses conflicting findings in measurements by Iowa State University and Spauschus Associates. The report responds to specific questions raised by ARTI regarding concentration determinations, purity of the lubricant, viscosity comparisons for neat lubricant using the oscillating body and Cannon Fenske viscometers, and potential weight measurements stemming from small sample sizes or related oil hang up in the capillary tubes.

D. S. Godwin, G. C. Hourahan, and S. R. Szymurski, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-20, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1993 (44 pages with 6 tables, available from JMC as RDB3863)

This progress report summarizes the goals and status of the Materials Compatibility and Lubricant Research (MCLR) Program, jointly funded under a grant from the Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The 36-month program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) refrigerants. The report introduces a new project to measure thermophysical properties of R-143a and R-152a. It also provides a status update on research to measure the miscibility of lubricants with refrigerants; measure the viscosity, density, and solubility for four azeotropic refrigerant blends to replace R-22 and R-502; and measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures. The report also summarizes three projects to develop accelerated screening and test methods to predict lubricant performance in compressors, the life of motor materials exposed to refrigerant-lubricant mixtures, and chemical and thermal stability of refrigerant-lubricant mixtures. It reviews the progress of a continuing project to collect and facilitate dissemination of data, through development and administration of the ARTI Refrigerant Database. The progress report summarizes seven completed projects to measure thermophysical properties of R-32, R-123, R-124, and R-125; model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502; test the chemical and thermal stability of refrigerant-lubricant mixtures with metals; provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics; and investigate electrohydrodynamic (EHD) enhancement of pool and in tube boiling of alternative refrigerants. The scope of the program, objectives of the individual projects, and significant interim findings are presented. This program summary also identifies reports resulting from the individual projects. Tables summarize significant findings of the individual projects including the miscibility of lubricants with 10 refrigerants; equations of state developed for R-32, R-123, R-124, R-125; and relative elastomer swelling in refrigerants and lubricants.

R. F. Kayser (National Institute of Standards and Technology, NIST), **Thermophysical Properties of HFC-143a and HFC-152a**, report DOE/CE/23810-20A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1993 (22 pages, including 3 tables, available from JMC as RDB4425)

This progress report summarizes experimental measurements to provide highly accurate, thermophysical property data for R-143a and R-152a as well as data fits to modified Benedict-Webb-Rubin (MBWR) equations of state and detailed transport property models. The objective is to fill gaps in existing data and resolve problems and uncertainties that exist in and between such data. The report briefly notes acquisition and characterization of a high-purity sample of R-143a and confirmation of existing data on R-152a. It then summarizes measurements of the liquid density of R-152a at -115 to 127 °C (-175 to 260 °F) in an isochoric PVT apparatus. The resulting temperatures, pressures, and densities are tabulated in both metric (SI) and inch-pound (IP) units of measure. Precise vapor pressure measurements of R-152a for -53 to 0 °C (-63 to 0 °F) in an ebulliometer are described. The resulting data and fits to an Antoine vapor pressure equation are presented. The report mentions continuing work to measure the liquid isochoric heat capacity of R-152a.

T. K. Sheiretov and C. Cusano, **Tribological Evaluation of Compressor Contacts - Retrofitting and Materials Studies**, report TR-46, Air-Conditioning and Refrigeration Center (ACRC), University of Illinois at Urbana-Champaign, Urbana, IL, July 1993 (149 pages, rdb4C41)

lubricants, test methods

Klea[(R)] 32 Preliminary Data Sheet, bulletin 620250201, ICI Klea, Wilmington, DE, July 1993 (8 pages with 1 table, RDB4106)

This bulletin provides summary property data and equations to calculate thermophysical properties for R-32, difluoromethane, in inch-pound (IP) units. The information presented is preliminary; it is based on a combination of measurements and estimation. The bulletin tabulates physical properties including the molecular weight, normal boiling and melting points, corresponding heat of vaporization and density, critical parameters (temperature, pressure, and density), acentric factor, Trouton's constant, and surface tension. It also indicates the latent heat of vaporization, liquid density, and liquid and vapor specific heats, thermal conductivity, and viscosity at 21.1 °C (70 °F). It then presents a Martin-Hou equation of state and extended Antoine equation. The bulletin also provides formulae to calculate the latent heat of vaporization, ideal gas specific heat capacity, saturated liquid enthalpy, and liquid and vapor density, viscosity, and thermal conductivity. ICI's product name for R-32 is Klea[(R)] 32.

June 1993

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 90, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (10 pages with 8 figures and 1 table, available from JMC as RDB3C90)

performance test for R-410 series blend

M. Beatty (National Refrigerants, Incorporated, NRI), **Implementing a Successful Refrigerant Management Program**, paper DE-93-11-1, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):821-824, 1993 (4 pages, RDB3628)

E. Bodio, M. Chorowski, and M. Wilczek (Technical University of Wroclaw, Poland), **Working Parameters of Domestic Refrigerators Filled with Propane-Butane Mixture**, *International Journal of Refrigeration* (IJR), 16(5):353-356, June 1993 (4 pages, rdb7812)

R-290/600

R. G. Doerr, D. Lambert, R. Schafer, and D. Steinke (The Trane Company), **Stability Studies of E-245 Fluoroether, CF_3-CH_2-O-CHF_2**, paper DE-93-20-3, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating,

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and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):1137-1140, 1993 (4 pages with 1 figure and 3 tables, RDB3626)

R-E245fa1 compatibility

M. Döhlinger (Greenpeace Germany, e.V., Germany), **The Success of Hydrocarbons in Domestic Refrigeration: Energy Efficient and Environmentally Friendly**, *Refrigeration and Air-Conditioning Technology Workshop* (proceedings of the 1993 Non-Fluorocarbon Refrigeration and Air-Conditioning Technology Workshop, Breckenridge, CO, 23-25 June 1993), edited by P. J. Lewis and D. M. Counce, report ORNL/6797, Oak Ridge National Laboratory, Oak Ridge, TN, C1-C20, 1994 (20 pages with 9 figures and 9 tables, available from JMC as RDB3633)

R-290, R-600, R-600a, R-290/600a

S. K. Fischer and J. R. Sand (Oak Ridge National Laboratory, ORNL), **Screening Analysis for Chlorine-Free Alternative Refrigerants to Replace R-22 in Air-Conditioning Applications**, paper DE-93-6-1, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):627-635, 1993 (9 pages with 5 figures and 2 tables, RDB3627)

U. J. Jonsson and E. B. Höglund (Luleå University, Sweden), **Determination of Viscosities of Oil-Refrigerant Mixtures at Equilibrium by Means of Film Thickness Measurements**, paper DE-93-20-2, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):1129-1136, 1993 (8 pages with 11 figures and 1 table, RDB3625)

O. Kataoka (Daikin Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 67, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (6 pages with 2 tables, available from JMC as RDB3C67)

performance test for R-410 series blend

O. Kataoka (Daikin Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 68, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 3 figures and 2 tables, available from JMC as RDB3C68)

performance test for R-407 series blend

M. Kurachi (Matsushita Refrigeration Company, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 83, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (6 pages with 1 figure and 3 tables, available from JMC as RDB3C83)

R-32/125/134a (30/10/60) with an unidentified polyolester lubricant compared to R-22 with mineral oil in a room heat pump, with an adjustable-speed scroll compressor, in both the cooling and heating modes

J. W. Linton, W. K. Snelson, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **System Performance of Near Azeotropic Mixtures of R-134a and R-152a**, paper DE-93-9-1 (3732), *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):400-405, 1993 (6 pages with 9 figures, RDB3620)

summarizes laboratory tests of R-134a and two blends of R-134a/152a under controlled conditions in a water-to-water heat pump using an open-drive, reciprocating-piston compressor and counterflow heat exchangers: compares performance characteristics including evaporator capacity, cooling coefficient of performance (COP), refrigerant mass flow, compressor shaft power, compressor efficiency, and overall heat transfer coefficient (HTC) within the evaporator; the tests covered an evaporating temperature range of -15.5 to 9.0 °C (4.1-48.2 °F) with a constant condensing temperature of 51.5 °C (124.7 °F); test results are compared with 12.0 °C (21.6 °F) subcooling and 7.4 °C (13.3 °F) superheat; briefly describes the test facility and the measurement techniques

N. Murata (Mitsubishi Heavy Industries, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 65, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (12 pages with 7 figures and 3 tables, available from JMC as RDB3C65)

performance of R-407 series blend

G. J. O'Neill, **Development of a New Alternative: E-134**, unpublished presentation (*The Global Business Outlook for CFC Alternatives*, Boston, MA, 15-16 June 1993), Hampshire Chemicals Corporation, Nashua, NH, June 1993 (32 pages with 5 figures and 7 tables, RDB5550)

This paper summarizes available data and potential uses for R-E134. It outlines consideration of this chemical and related fluoroethers (including R-E116, R-E125, R-E143, and R-E245) as candidate anesthetics, aerosol propellants, and - with new environmental issues - refrigerants. Two tables summarize key physical properties and compare those of R-E134 and R-114, for which the ether is a potential replacement. The data suggest that R-E134 may offer 40% higher capacity and 5% greater efficiency. A third table compares the characteristics of R-11, R-12, R-22, R-123, R-124, R-134a, R-141b, R-142b, R-E125, R-E134, and R-E143. The paper then reviews toxicity test data for R-E134, with limited comparisons to R-11, R-12, R-21, and R-22. The information includes acute and subchronic inhalation tests as well as Ames assay results for mutagenicity. Limited data are presented for R-E125. The paper then addresses the stability of R-E134, noting that some of the findings reported by others may have been influenced by impurities or conduct of the tests in glass tubes. It points out several fluoroethers that are known to be unstable with glass at elevated temperatures. They include R-E143, an R-E152 isomer [probably R-E152a], R-E161a, and R-E245 [probably R-E245fa1]. The findings of stability tests in steel and Pyrex® glass are tabulated. Four figures show the miscibility limits of R-E134 with polyolester lubricants (CPI Engineering Services developmental lubricants) and a mixture with 5% naphthenic mineral oil. A table summarizes stability tests by York International Corporation of R-E134 and metal catalysts (aluminum, copper, and steel wires) with a mineral oil (unidentified), alkylbenzene (Shrieve Zerol® 300), a polyalkylene glycol (PAG, Union Carbide UCON LB-525), and mixtures of them. The tests showed no changes for exposures at 135 °C (275 °F) for 48 hours and at 149 °C (300 °F). Discoloration, some copper plating, sludge formation, and in two cases tube shattering occurred at 182 °C (360 °F) for 24 or 74 hours. The paper then addresses preparation of R-E134 and outlines the potential markets for it. It also recaps development work by W. R. Grace and Company and its transfer to the Hampshire Chemical Corporation.

M. Ozu (Toshiba Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/-125/134a (30/10/60) and R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 69, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (16 pages with 6 figures and 4 tables, available from JMC as RDB-3C69)

M. Ozu (Toshiba Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60**), Alternative Refrigerants Evaluation Program (AREP) report 70, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (6 pages with 3 tables, available from JMC as RDB-3C70)

performance of R-407 series blend

M. Ozu (Toshiba Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40**), Alternative Refrigerants Evaluation Program (AREP) report 71, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (6 pages with 4 tables, available from JMC as RDB3C71)

performance of R-410 series blend

M. Ozu (Toshiba Corporation, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 82, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 2 figures and 4 tables, available from JMC as RDB3C82)

C. K. Rice (Oak Ridge National Laboratory), **Influence of HX Size and Augmentation on Performance of Mixtures in Air-to-Air Heat Pumps**, paper DE-93-6-4, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):665-679, 1993 (15 pages with 9 figures and 2 tables, rdb3619)

K. Sakaino (Mitsubishi Electric Corporation, Japan), **Compressor Calorimeter Test of Refrigerant R-134a and Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 77, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (10 pages with 4 figures and 2 tables, available from JMC as RDB3C77)

K. S. Sanvordenker (Tecumseh Products Company), **Experimental Evaluation of an R-32/134a Blend as a Near Drop-in Substitute for R-22**, paper DE-93-9-3, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):773-778, 1993 (5 pages with 5 figures and 1 table, RDB3622)

This paper summarizes evaluation of R-32/134a (30/70) as a substitute for R-22 for use in unitary hermetic compressors. It reviews a cooperative industry effort to test new refrigerants, the Alternative Refrigerants Evaluation Program (AREP), and the author's rationale for selecting the R-32/134a blend for testing (see RDB3802). The paper then summarizes calorimeter tests for a nominal 8.8 kW (30,000 Btu/hr), hermetic reciprocating piston compressor. Plots present efficiency and capacity ratios, to compare performance for R-32/134a (30.1/69.9) and R-22, as functions of evaporator and condensing tem-

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peratures. The ranges covered are -26 to 13 °C (-15 to 55 °F) and 32-66 °C (90-150 °F), respectively. The tests were performed using a fully-formulated, polyolester lubricant. The paper notes that above -12 °C (10 °F) evaporator temperature, the efficiencies of the blend slightly exceed those with R-22. Below this temperature, the blend suffers compared to R-22. The capacity is shown to be slightly lower with the blend at almost all conditions plotted, though the same trend in worse comparative performance is evident at low suction temperatures. The paper then discusses materials compatibility considerations. It presents miscibility diagrams for R-32, R-134a, and the R-32/134a blend in polyolester and a solubility plot to compare R-22 in alkylbenzene against R-32/134a in polyolester. Turning to compatibility, the paper notes that R-134a is relatively benign, but that R-32 behaves more like R-22 in softening and blistering magnet wire. A table compares the effects of R-22, R-32, and R-134a on and their absorption by wire enamel. The discussion concludes that the R-32/134a blend is expected to have less or comparable effect than R-22 alone. The paper notes concern with desiccants, since activated alumina will become fully loaded by absorbing polyolester and commercially-available molecular sieves will adsorb R-32. The paper then address flammability considerations. It notes disagreement on classification of the blend, since it could become flammable at low, -20 °C (-4 °F) ambient conditions or if tested above 80 °C (176 °F). The author indicates an urgent need for consensus on acceptable criteria for flammability. The paper concludes that R-32/134a (30/70) is as close as can be expected to a drop-in replacement for R-22, but that its use could be impeded by the definition of, and therefore potential labeling of the blend as, flammable.

M. B. Shiflett, A. Yokozeki, P. R. Reed, and J. P. Gilleard (DuPont Chemicals), **Property and Performance Evaluation of Suva HP Refrigerants as R-502 Alternatives**, *Australian Refrigeration, Air Conditioning and Heating,* 47(6):27-30, June 1993 (14 pages, rdb8937)

introduces R-402A and R-402B, which offer significant reductions in ozone depletion and global warming potentials with essentially the same cooling performance as R-502: describes the them as near-azeotropic blends of R-22, R-125, R-290 (propane) - R-125/290/22; DuPont's product names for the blends are Suva(R) HP80 and HP81

H. W. Sibley (Carrier Corporation), **Compressor Calorimeter Tests of Refrigerant Blends R-32/-125/134a (30/10/60), R-32/134a (25/75), R-125/143a (45/55), and R-32/125 (60/40); and Drop-In Tests of Refrigerant Blends R-32/125/-134a (30/10/60), R-32/134a (25/75), R-125/143a (45/55), and R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 22, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (34 pages with 6 figures and 19 tables, available from JMC as RDB3822)

W. K. Snelson, J. W. Linton, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **Near-Azeotropic Refrigerant Mixtures as Potential Drop-in Substitutes for R-502**, paper 3695, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):60-68, 1993 (9 pages with 17 figures, RDB3636)

describes a series of laboratory tests to compare the performance of two near-azeotropic blends, R-290/22/218 (6/55/39) and (6/74/20) [developmental formulations, since modified, for R-403B and R-403A, respectively], to R-502 for low-temperature refrigeration: tests were carried in a water-to-water heat pump test facility using an open-drive, reciprocating-piston compressor and counterflow heat exchangers: measurements were conducted at condensing temperatures of 43.3 and 54.4 °C (110 and 130 °F); the evaporating temperature was varied over a range of -30 to -15 °C (-22 to -5 °F); superheat was maintained at approximately 5 °C (9 °F), and the inlet temperature to the compressor was maintained 18.3 °C (65 °F); subcooling was held constant at 12 °C (21.6 °F); compressor performance characteristics including shaft power, volumetric efficiency, pressure ratio, and compressor discharge temperature were compared; system performance characteristics were also measured, including evaporator capacity, refrigerant mass flow, and cooling coefficient of performance (COP)

M. W. Spatz and J. Zheng (AlliedSignal Incorporated), **R-22 Alternative Refrigerants: Performance in Unitary Equipment**, paper DE-93-9-4, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):779-785, 1993 (7 pages with 1 figure and 3 tables, RDB3623)

N. Takahasi (Hitachi, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 86, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 2 figures and 3 tables, available from JMC as RDB3C86)

S. Won (University of Ulsan, Korea) and R. K Radermacher (University of Maryland), **R-142b/R-22/R-12 in a Domestic Refrigerator/Freezer**, paper 3701, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):104-108, 1993 (5 pages with 2 figures and 2 tables, RDB4412)

R-22/12/142b, "R-176"

A Research Needs Assessment: Energy Efficient Alternatives to Chlorofluorocarbons, report DOE/ER/30115-H1, U.S. Department of Energy (DOE), Washington, DC, June 1993 (288 pages with 22 figures and 56 table, available from NTIS, RDB3A71)

Heat Transfer and Pressure Drop During Condensation and Evaporation of R-134a/Oil Mixtures in Smooth and Micro-Fin Tubes, research project 630-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1990 - June 1993 (ASH0630)

This project investigated heat transfer and pressure drop for in-tube evaporation and condensation for R-134a for smooth and enhanced tubes. The effects of lubricants also were examined. Existing correlations were evaluated and modified. The contractor for the project was Iowa State University of Science and Technology led by M. B. Pate; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

Participants' Handbook: R-22 Alternative Refrigerants Evaluation Program (AREP), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 7 June 1993 (54 pages with 1 figure and 5 tables, available from JMC as RDB3613)

This document outlines an ARI program to identify and evaluate promising alternatives for R-22 for unitary air conditioners, heat pumps, chillers and refrigeration equipment. This cooperative program seeks to accelerate introduction of alternatives by focusing research efforts and avoiding duplicative work. The document outlines the AREP organization, including its Task Force (chaired by C. J. Tambornino), Technical Committee (chaired by E. B. Muir), and Heat Transfer Project Subcommittee. It identifies cooperating organizations, including the European Committee of Manufacturers of Refrigeration Equipment (CECOMAF), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), National Research Council of Canada (NRCC), and the Electric Power Research Institute (EPRI). EPRI is funding, coordinating, and managing the heat transfer segment, an integral part of the program. The document identifies the nomination process and resultant candidate refrigerants. They include R-32/125 (60/40), R-32/134a (30/70), R-407B [R-32/125/134a (10/70/20)], R-290 (propane), R-134a, R-717 (ammonia), R-32/125/290/134a (20/55/5/20), R-32/125/134a (30/10/60), R-32/134a (25/75), R-32/227ea (35/65), R-125/143a (45/55), R-404A [R-125/143a/134a (44/52/4)], and R-32/125/143a (10/45/45). The last three are of primary interest as potential replacements for R-502, an azeotrope of R-22 and R-115. Procedures and conditions for compressor calorimeter and heat transfer, system simulations, and soft-optimized tests are specified for participants. Related research on toxicity and environmental assessments of the candidate fluids and components will be coordinated and shared. Appendices to this program handbook identify committee members, participating companies, combinations of refrigerants and heat exchanger types to be investigated and equipment categories targeted for soft-optimized testing. This handbook prescribes common terminology, definitions, and report formats and contents to be used. Results of the work will be disseminated via the ARTI Refrigerant Database; an order form is included.

Thermodynamic Properties of Suva(R) HP62 Refrigerant, technical information report T-HP62-ENG (H-49744), DuPont Chemicals, Wilmington, DE, June 1993 (24 pages with 1 figure and 2 tables, RDB3732)

This report provides thermodynamic property data for R-404A, a zeotropic blend of R-125, R-143a, and R-134a - R-125/143a/134a (44/52/4) - in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, specific volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 66 °C (-150 to 150 °F). A set of tables presents specific volume, enthalpy, and entropy data for superheated vapor at constant pressure for 7-3450 kPa (1-500 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-404A is Suva(R) HP62. [see RDB3C04 for update]

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May 1993

A. G. bin-Ujang, N. C. Srivastava, M. S. Ismail, and M. H. bin Saleh (MARA Institute of Technology, Malaysia), **Global Warming Impact Due to CFCs in Refrigerators in Malaysia**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 301-306, 1993 (6 pages with 1 figure and 2 tables, RDB5264)

global warming, TEWI

M. Buschmeier, G. Herres, and D. Gorenflo (Universität Paderborn, Germany), **Prediction of P,V,T,X Data for Mixtures of New Refrigerants by Cubic Equations of State**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 251-262, 1993 (12 pages with 11 figures, RDB5321)

thermodynamic properties of R-22/142b and R-227ea/123 (identified in the paper as R-227/123): equation of state (EOS); thermophysical data

F. de Rossi, R. Mastrullo, and M. Sasso (Università di Napoli "Frederico II", Italy), **R502 Substitution: A Global Evaluation of the Environmental Impact**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 335-341, 1993 (7 pages with 5 figures and 3 tables, RDB5325)

R-22, R-32, R-125, R-32/125 (60/40), R-403A, global warming, TEWI

W. E. Dietrich (McQuay International, then Snyder-General Corporation), **A Positive Outlook for the Future**, *ASHRAE Journal,* 35(5):64-65, May 1993 (2 pages, RDB3605)

This article discusses the benefits of R-134a as a long-term refrigerant, noting that R-22, R-123, and R-134a are no longer alternatives, but the norm in chillers offered today. It notes that hydrochlorofluorocarbon (HCFC) refrigerants, including R-22 and R-123, will be phased out under the Montreal Protocol and the Clean Air Act. It then discusses other advantages of R-134a by operation at positive pressure, such as avoidance of purge requirements, backups to rupture disks, and vacuum prevention systems. The article notes testing that found R-134a to be "essentially nontoxic" and that selection of R-134a by the automotive and appliance industries assures a large market for it, with ample supplies and competitive pricing. The article reviews differences in venting requirements for chlorine-free refrigerants. It briefly outlines safety classifications and requirements, and discusses implications for use of zeotropic blends. The article then reviews retrofit procedures and considerations to convert R-12 and R-500 chillers to R-134a, noting that costs generally will be less expensive than conversion of R-11 equipment to R-123.

S. Devotta and S. Gopichand (National Chemical Laboratory, India), **Derived Thermodynamic Design Data for Refrigeration and Heat Pump Systems Operating on HCFC-123**, *Heat Recovery Systems and CHP,* 13(3):213-218, May 1993 (6 pages, rdb8945)

examines use of R-123 as an alternative to R-11 in air-conditioning, refrigeration and heat pump systems: discusses the theoretical coefficient of performance (COP) in Rankine cycles and the pressure ratios (PR) for heat pumps using R-123; plots the pressure ratio and theoretical as functions of the appropriate temperature for refrigeration and heat pumps systems

Y. Hara (Sanyo Electric Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 74, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (14 pages with 9 figures and 3 tables, available from JMC as RDB3C74)

performance test of R-32/125/134a (30/10/60)

U. Hesse and H. H. Kruse (Forschungszentrum für Kältetechnik und Wärmepumpen GmbH, FKW, Germany), **Alternatives for CFCs and HCFC-22 Based on CO_2**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 317-325, 1993 (9 pages with 7 figures and 3 tables, RDB4333)

R-744 (carbon dioxide), R-744/acetone, R-23/DEGDME

M. Kurachi (Matsushita Refrigeration Company, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (25/75)**, Alternative Refrigerants Evaluation Program (AREP) report 75, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (16 pages with 11 figures and 1 table, available from JMC as RDB3C75)

performance test of R-32/134a (25/75)

M. Kurachi (Matsushita Refrigeration Company, Japan), **Drop-In Test of Refrigerant Blend R-32/-125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 76, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (16 pages with 11 figures and 1 table, available from JMC as RDB3C76)

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Application of 'Natural' Refrigerants**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 55-64, 1993 (10 pages with 3 figures and 1 table, RDB5305)

R-290 (propane), R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), transcritical cycle

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Large Heat Pumps Using CO_2 Refrigerant**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 191-197, 1993 (7 pages with 6 figures, rdb5316)

R-744 (carbon dioxide), transcritical cycle

L. Lucas (International Institute of Refrigeration, IIR, France), **A New Challenge: From the Ozone Layer to the Greenhouse Effect**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 31-43, 1993 (13 pages with 7 figures, RDB5303)

ozone depletion, global warming, refrigerants

C. Madan (Continental Products Incorporated), **R-134a: The Best Alternative for Chillers**, *ASHRAE Journal,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 35(5):58-60, May 1993 (2 pages with 1 figure, RDB3603)

This article briefly reviews efforts by manufacturers to adopt or develop new equipment to use alternative refrigerants. It focuses on use of R-134a, particularly in scroll, screw, and reciprocating-piston compressors. Advantages of the R-134a choice are cited, including its being chlorine free, assured availability because of selection by the automobile industry, reasonable pricing resulting from increased production, and worldwide acceptance. The article discusses advantages and disadvantages of R-134a, noting the suitability of existing chiller components but higher prices than for R-22 due to the larger compressor required. The article describes the cost increment as the right choice, to avoid replacement when hydrochlorofluorocarbon (HCFC) refrigerants become obsolete "in just a few years." The article argues for recommended system changes such as inclusion of a pump-down receiver, built-in refrigerant recovery system, and a pressure relief valve and rupture-disk assembly. The article discusses other considerations noting similarities for R-134a and R-22 in assembly, testing, and installation. It cautions that retrofit of R-22 systems should not be attempted without qualified assistance, and that the conversion may require replacement of compressors, controls, and other components.

H. Madsbøll and G. Mindsen (Dansk Teknologisk Institut, DTI, Denmark), **Energy Saving in Process Cooling by Use of Water as Refrigerant**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 75-85, 1993 (11 pages with 7 figures and 1 table, RDB5307)

R-718 (water)

S. Massien and R. Demke (Dunham-Bush, Incorporated), **Current and Future Refrigerants for Chillers**, *ASHRAE Journal*, 35(5):62-63, May 1993 (2 pages, RDB3604)

This article outlines a rationale for use of R-22 in chillers, noting its low ozone depletion potential (ODP), expected availability for the life of equipment being installed today, and energy efficiency. The article cites studies that show the total global warming of chillers using R-22, R-123, and R-134a to be similar. It discusses both the importance of indirect (energy-related) warming and the fallacy of theoretical efficiencies without regard to other variables. The article notes the long history of R-22 use and reliability of the materials compatibility and safety record garnered. The article then addresses future solutions, including candidate replacements such as R-32, R-125, R-134a, and R-152a among the pure fluids. It also refers to azeotropic blends, noting R-32/125 in particular. It mentions zeotrope consideration. The importance of refrigerant management, including reclaim, is reviewed and the article concludes by noting that the future holds many possibilities, for both refrigerants and the equipment that uses them.

J. Nyvad and F. Elefsen (Dansk Teknologisk Institut, DTI, Denmark), **Energy Efficient Cooling by Use of Cycloid Water Vapor Compressor**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium, 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 67-74, 1993 (8 pages with 5 figures and 1 table, RDB5306)

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R-718 (water), cycloidal compressor principles and construction

H. Ohnishi (Daikin Industries, Limited, Japan), **Drop-In Test of Refrigerant Blends R-32/134a (25/75), R-32/134a (30/70), R-32/134a (40/60), and R-32/125/134a (30/10/60**), Alternative Refrigerants Evaluation Program (AREP) report 66, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (12 pages with 9 tables, available from JMC as RDB3C66)

P. J. Ostman (York International Corporation), **Environmental Solutions for Today's Refrigerant Challenges**, *ASHRAE Journal,* 35(5):70-72, May 1993 (3 pages with 1 figure, RDB3607)

J. R. Parsnow (Carrier Corporation), **The Long-Term Alternative: R-134a in Positive Pressure Chillers**, *ASHRAE Journal,* 35(5):54-56, May 1993 (2 pages with 1 figure, RDB3602)

This article outlines advantages of positive-pressure chillers, with emphasis on near- and long-term use of R-22 and R-134a, respectively. It reviews purge and pressure relief implications for other alternatives, opportunities for integral storage tanks, requirements for code compliance for pressure vessels, and equipment size considerations. The article discusses containment procedures for existing chillers and discusses the transitional nature of hydrochlorofluorocarbons (HCFCs), including both R-22 and R-123. It then outlines considerations for conversion and replacement decisions. The article suggests typical retrofit costs from R-12 or R-500 to R-134a of 26% of replacement costs. The conversion typically results in 8-10% loss in capacity and 1-2% in efficiency for R-12 and minimal capacity and 0.5% efficiency losses for R-500. Modification to impellers and gear sets are mentioned to avoid these losses at an additional 17% or replacement cost. The article concludes that owners and engineers should plan for the refrigerant transition today.

J. Paul (Integral Technologie GmbH, Germany), **Binary Ice - An Alternative Cooling Method**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 87-96, 1993 (10 pages with 4 figures and 7 tables, RDB-5308)

This paper summarizes a cooling method that use an ice slurry, composed of small ice crystals suspended in water, as a coolant in place of chilled water. The slurry may be generated using an indirect process with conventional refrigeration methods. It also may be generated with a direct process, using water under subatmospheric conditions as the refrigerant, identified as "vacuum ice." The paper briefly reviews the German federal Umweltbundesamt (UBA, Authority for the Environment) categorization of refrigerants based on "safe" and "unsafe" environmental properties. Those deemed safe include (R-717) ammonia, R-718 (water), R-729 (air), R-764 (carbon dioxide), and hydrocarbons. A figure shows the conceptual options to provide cooling by combining direct and indirect methods, with and without secondary coolants. The unique properties of the ice slurry are described as combining the advantages of direct expansion (DX) cooling and the simplicity of a brine, secondary coolant system. Moreover, the slurry offers high energetic density due to the latent heat of the ice crystals, but still flows like water. The slurry is described as a Bingham rather than a Newtonian fluid, and the flow as plug flow not exhibiting laminar and turbulent behavior. The means to generate the slurry are described and shown schematically. For the process using water as the refrigerant, ice is formed at the triple point using flash evaporation in an empty shell, used as the evaporator. The paper describes concepts that use both direct and indirect condensation, the former again using an empty shell for the heat exchanger along with a vacuum pump to remove noncondensable gases. The paper compares and tabulates the pipe and storage sizes with the ice slurry, for different ice fractions, against chilled water. It then describes and tabulates key performance parameters for installations for mine cooling, air conditioning, and beverage refrigeration. Integral Technologie GmbH's trade name for the ice slurry system is Binary Ice; Solmecs Flo-Ice Systems offers a similar product that may use different eutectics under the name Flo-Ice.

M. V. Rane and R. K. Radermacher (University of Maryland), **Feasibility Study of a Two-Stage Vapor-Compression Heat Pump with Ammonia/Water Solution Circuits: Experimental Results**, *International Journal of Refrigeration* (IJR), 16(4):258-264, May 1993 (7 pages with 5 figures and 2 tables, RDB4415)

R-717, R-717/718

M. L. Robin (Great Lakes Chemical Corporation), D. Young, and J. Casler (Fike Corporation), **FM-200: Recent Findings**, presentation charts, 1993 Halon Alternatives Technical Working Conference (Albuquerque, NM), Great Lakes Chemical Corporation, West Lafayette, IN, May 1993 (14 pages with 3 figures and 1 table, available from JMC as RDB3727)

thermodynamic properties and uses of R-227ea

K. Sawai (Matsushita Electric Industrial Company Limited, Japan), **Compressor Calorimeter Test of**

Refrigerant Blend R-32/125 (60/40), Alternative Refrigerants Evaluation Program (AREP) report 72, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (10 pages with 4 figures and 2 tables, available from JMC as RDB3C72)

K. Sawai (Matsushita Electric Industrial Company Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 73, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (8 pages with 1 figure and 4 table, available from JMC as RDB3C73)

performance test of R-407 series blend

E. L. Smithart and J. G. Crawford (The Trane Company), **R-123: A Balanced Selection for Low-Pressure Systems**, *ASHRAE Journal,* 35(5):66-69, May 1993 (3 pages with 1 figure, RDB3606)

advantages of R-123 as a refrigerant for chillers with centrifugal (turbo) compressors

M. W. Spatz (AlliedSignal Incorporated), **Alternative Refrigerants for R-22 Chillers**, *ASHRAE Journal,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 35(5):50-52, May 1993 (3 pages with 1 figure, RDB3601)

This article focuses on predicted performance of replacements for R-22 in chillers with reciprocating-piston compressors. It quotes statistics indicating that such chillers account for one third of the installed capacity of chillers and two thirds of annual shipments. The article reviews potential alternatives, noting that the primary replacement candidates are R-134a, R-32/125 (40/60) (marketed as Genetron(R) AZ-20), and R-32/125/134a (30/10/60). Cycle analyses, using the Genesys(TM) program, are described, leading to a finding that R-134a would offer the best coefficient of performance (COP) based on thermodynamic characteristics alone. A sample comparison between R-12 and R-22 is outlined, to show that the former appears favorable based on thermodynamic COP, but the latter is preferred due to superior transport properties and suitability for more compact designs. The article notes that instrument testing of fully optimized systems is required to accurately determine performance for a given refrigerant. One requirement is to adjust the compressor displacement. The article indicates that such tests have not yet been performed with alternative refrigerants in reciprocating chillers. A figure compares the thermodynamic and system performance of the three alternatives to those of R-22 in unitary air conditioners, based on measured and modelled data. Although the thermodynamic efficiency of R-32/125 (40/60) is shown to be the lowest, its system efficiency is the highest. The article discusses the difference, attributing the improvement to better heat transfer, lower pressure drop, and smaller change in saturation temperature for a given pressure drop, all contributing to a lower temperature lift. The article then discusses issues that must be resolved to use the alternatives, including considerations for composition management and potential exploitation of temperature glides with zeotropes. The article concludes that the R-32/125 azeotrope may be the best candidate, offering an 8-10% increase in efficiency without the benefit of system optimization.

R. Tillner-Roth and H. D. Baehr (Universität Hannover, Germany), **An Improved Equation of State for HFC 134a**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 157-165, 1993 (9 pages with 6 figures and 1 table, RDB5312)

thermodynamic properties of R-134a: equation of state (EOS); thermophysical data

F. P. L. M. Vissers (Technical University Delft, The Netherlands), **An Expression for the Excess Gibbs Function of the Liquid R-22/DTG Mixture**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 263-271, 1993 (9 pages with 1 figure and 1 table, RDB5322)

dimethylether tetraethyleneglycol (DTG), R-22/DTG refrigerant/absorbent, absorption systems

K. Watanabe and H. Sato (Keio University, Japan), **Recent Progress on Thermodynamic Property Studies of Alternatives to Replace HCFC-22**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 215-225, 1993 (11 pages with 3 figures and 1 table, RDB5319)

This paper summarizes research performed at Keio University to measure the thermodynamic properties of alternative refrigerants. The paper briefly reviews the phaseout of ozone-depleting substances and the resultant need to select the best hydrofluorocarbon (HFC) refrigerant, to replace R-22. It identifies the binary blends of R-32/125 and R-32/134a as well as ternary blends of R-32/125/134a as candidates. The paper outlines systematic series of measurements and

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analytical studies, including modeling associated with formulations and correlations of different thermodynamic properties. It discusses capabilities including a Burnett apparatus, magnetic densimeter incorporated into a variable volume cell, separate apparatus for isobaric heat capacity measurements in the vapor and liquid phases, a constant-volume apparatus coupled with a sample expansion procedure for PVTx measurements, and a spherical resonator to measure sound velocity. The paper then discusses property measurements for R-32. Plots illustrate the range of measured PVT data and compare the second viral coefficient determined by the authors with those from under studies. A table compares the critical parameters (temperature, pressure, and density) from the subject research with those reported by others. The paper then discuses property measurements for R-125 and R-143a, and compares the former to a published correlation. It briefly cites investigations of R-32/134a and R-32/125 measurements. The paper lists 51 data references, most from studies by the authors and their students.

Genetron(R) AZ-50, technical bulletin #651 (B-525-651), AlliedSignal Incorporated, Morristown, NJ, May 1993 (4 pages with 3 tables, RDB3512)

This bulletin describes an azeotropic blend of R-125 and R-143a, specifically R-125/143a (45/55), designed to replace R-502 in low-temperature commercial refrigeration applications. It provides physical property data, in inch-pound (IP) units, including the chemical formula, molecular weight, atmospheric boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), flammability, and ozone depletion potential. It also indicates the liquid density and specific heats of the liquid and vapor at 26.7 °C (80 °F). It then presents a tabular comparison of performance with R-22 and R-502. The report provides tabular thermodynamic properties (pressure, density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -40 to 71 °C (-40 to 160 °F). Formulae are provided to calculate thermodynamic properties including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. AlliedSignal's product name for R-125/143a is Genetron(R) AZ-50 [the composition was subsequently reformulated from that described in this document.]

April 1993

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-11D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1993 (126 pages, available from JMC as RDB3459)

This document provides bibliographic citations for 692 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately half of these documents. The database identifies sources of specific information on R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. It addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester, and other lubricants. It also references documents on compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes the same citations and abstracts as the report version plus 22 additional citations, for superseded and historical documents, and data summaries for 90 individual refrigerants and blends. It is accompanied by retrieval software to facilitate searches for specific information; the software enables searches for user-selected terms, or combinations of terms. It offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, and a "wildcard" capability to allow entry of word segments. The software also enables printing of selected citations, abstracts, and refrigerant summaries as well as preparation of a document order lists. Both versions of the database include instructions to obtain cited documents or subscriptions for updates to the database. Whereas prior releases of the database have focused primarily on the information needs of manufacturers and researchers, attention is being increased to the requirements of refrigerant users, beginning with this release.

R. C. Cavestri and J. Munk (Imagination Resources, Incorporated, IRI), **Measurement of Viscosity, Density, and Gas Solubility of Refrigerant Blends**, report DOE/CE/23810-11B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1993 (32 pages with 17 figures and 1 table, available from JMC as RDB3418)

This progress report summarizes a project to measure the viscosity, density, and solubility of four refrigerant blends as well as their components using a single polyolester lubricant. The refrigerants include R-32/125 (60/40), R-32/125/134a (10/70/20), R-32/134a (30/70), and R-404A [R-125/143a/134a (44/52/4)]. The report describes examination of four different pentaerythritol polyolesters including two branched acids (Castrol Icematic(R) SW32 and Henkel Emery(R) 2927a) and two mixed acids (ICI Emkarate(TM) RL 32S, formerly RL 184, and Mobil EAL Arctic(R) 224R). The second of the four was chosen for the study based on liquid-liquid miscibility and low influence on refrigerant blend fractionation. An alkylbenzene (Shrieve Zerol(R) 150) was introduced to examine aromatic properties toward miscibility. R-22 and R-502 also were examined with a mineral oil (Witco Suniso(R) 3GS) for comparison. Miscibility plots are provided for the four blends with each of the ester and alkylbenzene lubricants for compositions of 5, 25 and 60% lubricant. A plot relates viscosity to temperature for R-22 and mineral oil for -20 to 125 °C (-4 to 257 °F), at pressures of 69-1720 kPa (10-250 psia) and 0-60% refrigerant by weight. The viscosity and solubility of R-22 with mineral oil are plotted against pressure for the isotherms in the same ranges and for R-502 at 40 and 70 °C (104 and 158 °F).

D. S. Godwin, G. C. Hourahan, and S. R. Szymurski, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-11, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1993 (48 pages with 2 figures and 21 tables, available from JMC as RDB3612)

This progress report summarizes the goals and status of the Materials Compatibility and Lubricant Research (MCLR) Program, jointly funded under a grant from the Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The 36-month program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) refrigerants. The report reviews current projects to measure thermophysical properties, measure the miscibility of lubricants with refrigerants, and provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics. It also outlines projects to measure the viscosity, density, and solubility for four refrigerant blends to replace R-22 and R-502; to measure the viscosity, density, and solubility for 38 refrigerant-lubricant mixtures; and to investigate electrohydrodynamic (EHD) enhancement of pool and in-tube boiling of alternative refrigerants. The report summarizes three projects to develop accelerated screening and test methods to predict lubricant performance in compressors, the life of motor materials exposed to refrigerant-lubricant mixtures, and chemical and thermal stability of refrigerant-lubricant mixtures. It reviews the progress of a continuing project to collect and facilitate dissemination of data, through development and administration of a refrigerant database. It also summarizes two completed projects, to model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502 and to test the chemical and thermal stability of refrigerant-lubricant mixtures with metals. The scope of the program, objectives of the individual projects, and significant interim findings are presented. This program summary also identifies reports resulting from the individual projects. Tables give the equations of state developed for R-32, R-123, R-124, R-125; miscibility results for 10 refrigerants; compatibility concerns with motor materials; and relative elastomer swelling. A series of tables summarize solubility, viscosity, and density equation coefficients for 12 refrigerant-lubricant mixtures; two figures illustrate plots created with these equations.

D. R. Henderson (Spauschus Associates, Incorporated), **Solubility, Viscosity, and Density of Refrigerant-Lubricant Mixtures**, report DOE/CE/-23810-11A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1993 (38 pages with 32 figures and 18 tables, available from JMC as RDB3611)

This interim report presents the findings of a study of solubility, viscosity, and density of refrigerant-lubricant mixtures, generally over 0-100 °C (32-212 °F). It summarizes results for low refrigerant concentrations (70, 80, 90, and 100% lubricant by weight) for the following 12 mixtures: R-12 with ISO 32 and 100 mineral oils (MO); R-22 with ISO 32 MO; R-123 with ISO 32 and 100 MOs; R-123 with ISO 32 and 100 alkylbenzenes (AB); and R-134a with five polyolester (pentaerythritol ester mixed acid) lubricants (POE-MA), ISO 22, two ISO 32s, ISO 68, and ISO 100. Equations and regression coefficients are tabulated for solubility, viscosity (dynamic and kinematic), and density for each mixture. These results also are shown as plots of density versus temperature and as Daniel Charts, showing kinematic viscosity and solubility (expressed as vapor pressure) versus temperature. An appendix summarizes the lubricant purities, including moisture content, total acid number (TAN), and iron and copper contents. A

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second appendix identifies the lubricants, including naphthenic MOs (Witco Suniso(R) 3GS and 5GS), POE-MA (Mobil EAL Arctic(R) 22 and 32; Castrol Icematic(R) SW32, SW68, and SW100), and AB (Shrieve Zerol(R) 150 and 300). The report lists 23 additional refrigerant-lubricant pairs to be studied.

G. C. Hourahan (Air-Conditioning and Refrigeration Institute, ARI), **Planning for the Use of Alternative Refrigerants in Air Conditioning and Refrigeration**, presented at the Seventh Annual Conference (Washington, DC), Defense Fire Protection Association, Alexandria, VA, 29 April 1993 (6 pages with 7 figures and 2 tables, available from JMC as RDB-3502)

This paper illustrates options for equipment planners to alleviate confusion for use of alternative refrigerants in air conditioning and refrigeration. It briefly outlines the phase out of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants as well as the tradeoffs between ozone depletion and global warming among alternatives. It summarizes a study by the Congressional Research Service, which predicts a state of chaos and shortages in late 1995 and subsequent several years. A figure indicates the number of CFC chillers that manufacturers expect to convert or replace before 1993 and in 1993-1995. It addresses new alternatives, concluding that there are "no magic compounds around the corner" and new candidates will require 8-12 years to enter full-scale production. Two figures summarize criteria for selection of alternative refrigerants and chiller options by type and refrigerant. Refrigerant containment, equipment conversion, and equipment replacement options are outlined. Recommendations are noted, including designation of a refrigerant manager and development of a management plan. Two tables summarize estimated refrigerant inventories and service needs by equipment category and alternative refrigerants by applications.

T. Itami (Toshiba Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 12, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (5 pages with 2 tables, available from JMC as RDB3812)

H. Kanno (Mitsubishi Heavy Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 41, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (12 pages with 3 figures and 1 table, available from JMC as RDB3841)

H. Kanno (Mitsubishi Heavy Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 56, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (10 pages with 2 figures and 1 table, available from JMC as RDB3856)

Y. Kiyokawa (Sanyo Electric Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blends R-32/125 (60/40) and R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 35, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (14 pages with 5 figures and 2 tables, available from JMC as RDB3835)

O. Nesje (Norgest Tekniska Högskole, NTH, Norway), **Ammonia in Small and Medium Sized Heat Pumps**, *Heat Pumps for Energy Efficiency and Environmental Progress* (proceedings of the Fourth International Energy Agency (IEA) Heat Pump Conference, Maastricht, The Netherlands, 26-29 April 1993), Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 1993 (rdb4536)

R-717

M. Ohta (Mitsubishi Heavy Industries, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 5, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (5 pages with 2 tables, available from JMC as RDB3805)

Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 12.6 kW cooling (3.6 ton) packaged, air-to-air heat pump using a scroll compressor. R-22 was tested with an alkylbenzene lubricant (ISO viscosity grade 32); the blend was tested with an ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, saturated condensing vapor and liquid conditions, condenser exit, liquid line inlet and exit, inlets to the expansion device and evaporator, saturated evaporating condition, and the evaporator outlet. Data are presented for both the heating and cooling modes. The results show 4 and 1% decreases for the blend in heating capacity and efficiency and 7 and 6% reductions in cooling capacity and efficiency; the latter were lowered to 4 and 2%, respectively, with optimized charge and capillary-tube selection.

M. Ozu (Toshiba Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-**

32/134a (30/70), Alternative Refrigerants Evaluation Program (AREP) report 37, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (12 pages with 3 figures and 1 table, available from JMC as RDB3837)

M. Ozu (Toshiba Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 46, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (10 pages with 4 tables, available from JMC as RDB3846)

S. F. Pearson (Star Refrigeration Limited, UK), **Development of Improved Secondary Refrigerants**, The Institute of Refrigeration, London, UK, 3 April 1993 (rdb5726)

heat transfer fluids (coolants) for indirect (secondary-loop) systems

J. W. Reed, **Environmental Overview: CFC and HCFC Regulatory Update**, *Proceedings of the Fourth International Energy Agency (IEA) Heat Pump Conference* (Maastricht, The Netherlands, 26-29 April 1993), Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 11-19, April 1993 (9 pages, RDB5B23)

regulations on use

S. M. Sami, J. Schnotale (University of Moncton, Canada), and J. G. Smale (DuPont Canada Incorporated, Canada), **A Comparative Performance Study of CFC502, HCFC22 and HFC125**, *International Journal of Energy Research* (IJER), 17(3):-143-151, April 1993 (9 pages with 12 figures, RDB-6741)

drop in performance test of R-125 with comparative measurements for R-22 and R-502 [HCFC/CFC-502] under a range of operating conditions; plots compare the operating parameters of the three refrigerants with both reciprocating piston and scroll compressors; concludes that R-125 degrades performance compared to R-22 as candidate R-502 replacements

D. W. Treadwell (Lennox International, Incorporated), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 62, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (4 pages with 2 tables, available from JMC as RDB3C62; available copy is difficult to read)

The report presents the test conditions and results for laboratory tests of a 10.5 kW (3 ton), split-system, air-to-air heat pump using a hermetic scroll compressor (Copeland ZR34K1PFV) and thermostatic expansion valves. The title indicates that the equipment was soft-optimized for use of R-32/125/134a (30/10/60), though the specific changes are not identified. The report consists of two tables, for the cooling and heating modes, that compare performance with this blend and R-22 at identified, standard rating conditions. All tests were performed using an unidentified ester lubricant. The refrigerant charge amount, total and sensible (cooling mode only) capacities, input power, resultant efficiency, cycling degradation factor, and calculated seasonal performance are presented. Refrigerant temperatures and pressures also are tabulated for compressor suction and discharge; condenser inlet, midpoint, and leaving; expansion device inlet; and evaporator inlet, midpoint, outlet, and leaving conditions. The refrigerant subcooling, superheat, and flow rates also are given. The cooling-mode results indicate 1 and 1% losses in capacity at 35 and 28 °C (95 and 82 °F) "outdoor" ambient temperatures, respectively, with 7 and 1% losses in efficiency; the calculated seasonal efficiency was 3.1% lower with the blend. The heating-mode measurements show a 4% increase and slight decrease in capacities at +8 and -8 °C (47 and 17 °F) with 4 and 6% losses in efficiency; the calculated seasonal efficiency was 7.6% lower with the blend. The compressor discharge pressure was higher in both modes.

DuPont Suva(R) HP Refrigerant Blends: Properties, Uses, Storage, and Handling, bulletin P-HP (H-47122-1), DuPont Chemicals, Wilmington, DE, April 1993 (24 pages with 2 figures and 7 tables, RDB3C02)

This document provides extensive application information for R-402A and R-402B, both blends of R-125, R-290, and R-22 - R-125/290/22 (60/2/38) and R-125/290/22 (38/2/60) respectively. It also addresses R-404A, a blend of R-125, R-143a, and R-134a - R-125/143a/134a (44/52/4). It reviews identifiers, the blend compositions, and potential uses. The bulletin then summarizes physical properties as well as flammability, environmental, and toxicity indices. The bulletin reviews chemical and thermal stability data, including thermal decomposition. A table provides representative data on stability with metals (copper, iron, and aluminum) based on sealed-tube tests of mixtures of R-402B with mineral oil (Witco Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150 TD), and a branched acids polyolester (Castrol Icematic(R) SW32) lubricants. Results also are provided for R-404A with the same lubricants and a mixed acids ester (Mobil EAL Arctic(R) 22). The report reviews compatibility of the refrigerant blends with R-502, noting chemical compatibility but separation difficulty leading to a need for disposal by

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incineration. It then addresses compatibility with elastomers; a tabular summary is provided for five polymers with combinations of the cited lubricants and R-502, R-402B, and R-404A. The compounds tested were polytetrafluoroethylene (PTFE, DuPont Teflon(R) in commercial grade sheet from Tex-O-Lon Manufacturing), Buna N nitrile butadiene (NBR, Parker Seal), hydrogenated NBR (HNBR, Parker Seal N1195), chloroprene (CR, Precision Rubber neoprene W), and EPDM (Kirkhill Rubber). Compatibility data also are discussed for polyethylene terephthalate (PET, DuPont Mylar(R) film), polyesterimide motor wire with amide-imide overcoating, and Dacron/Mylar/Dacron(R) lead wire (Belden) as well as for molecular sieve desiccants (UOP 4A-XH-5 and XH-9). Miscibility is summarized for R-502 and the three zeotropes with mineral oil, alkylbenzene, and polyolester lubricants. Safety data are then presented including a review of inhalation toxicity, cardiac sensitization, responses to spills or leaks, skin and eye contact, and flammability. Monitors and leak detection are discussed as are storage, handling, and shipping. The bulletin concludes with discussion of recovery, reclamation, recycling, and disposal. DuPont's product names for R-402A, R-402B, and R-404A are Suva(R) HP80, Suva(R) HP81, and Suva(R) HP62 respectively. [see RDB4503 for update]

Klea Blend 60, Replacement for R502, technical note CP/30364/34051/2Ed/13/493, ICI Chemicals and Polymers Limited, Runcorn, Cheshire, UK, April 1993 (6 pages with 2 tables, RDB3729)

This document describes a ternary, zeotropic blend of R-32, R-125, and R-134a (R-32/125/134a), developed as a replacement for R-502. The technical note summarizes the phase out of chlorofluorocarbon (CFC) refrigerants, the need for alternatives to R-502, and ICI's search for likely replacements. It then compares the boiling points, atmospheric lifetimes, ozone depletion potentials (ODPs) and global warming potential (GWPs) of R-22, R-32, R-125, R-134a, R-502, and the R-32/125/134a blend. It also provides a theoretical performance comparison between R-502 and the blend. The document then discusses the flammability and toxicity of both the blend and its components, noting that the composition was designed to be nonflammable despite the R-32 content. The bulletin also discusses handling and leakage and states that composition changes are anticipated to be less serious than had been expected. It discusses appropriate lubricants, with focus on the ICI Emkarate(R) family of synthetic, neopentyl polyolesters. Several documents are cited as available or under preparation to provide thermophysical properties, flammability specifics, blend design information, handing and storage advice, and retrofit guidance. ICI's product name for the R-32/125/134a blend discussed is Klea(R) Blend 60.

March 1993

R. S. Agarwal and A. F. Waleed (Indian Institute of Technology, India), **Transport Properties of R22-DMF Mixtures**, *Energy Conversion and Management,* 34(3):223-229, March 1993 (7 pages, rdb8963)

presents estimates for the transport properties of mixtures of R-22 with dimethyl formamide (DMF), R-22/DMF, over a wide range of temperatures and compositions; predicts density, viscosity, thermal conductivity, specific heat, surface tension, and thermal diffusivity using estimation methods; describes the correlations, developed to express each of these properties as a function of temperature and composition, to facilitate design of vapor-absorption systems

M. H. Blatt (Electric Power Research Institute, EPRI), **Electric Chillers: Cost-Effective Choice for the Future**, *Heating/Piping/Air Conditioning Engineering* (HPAC), 65(3):75-82, March 1993 (6 pages with 4 figures and 2 tables, RDB3412)

discusses impacts of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) phaseout; examines the comparative environmental impacts of electric vapor-compression and gas-fired absorption cycle chillers

B. Carter, P. Dexter, E. B. Muir, and S. G. Sundaresan (Copeland Corporation), **Compressor Calorimeter Test of Refrigerant Blends R-32/125 (60/40), R-32/134a (25/75), R-32/134a (30/70), R-32/125/134a (10/70/20), and R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 29, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (50 pages with 13 figures and 24 tables, available from JMC as RDB3829)

R-32/125 (60/40), R-32/134a (25/75), R-32/134a (30/70), R-407B, and R-32/125/134a (30/10/60)

B. Carter, P. Dexter, E. B. Muir, and S. G. Sundaresan (Copeland Corporation), **Compressor Calorimeter Test of Refrigerant R-134a and Refrigerant Blends R-32/125 (60/40), R-32/134a (25/75), R-32/134a (30/70), R-32/125/134a (10/70/20)** [R-407B]**, and R-32/125/134a (30/10/60**), Alternative Refrigerants Evaluation Program (AREP) report 30, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (62 pages with 17 figures and 31 tables, available from JMC as RDB-3830)

R-134a, R-32/125 (60/40), R-32/134a (25/75), R-32/134a (30/70), R-407B, and R-32/125/134a (30/10/60)

B. Carter, S. Kulkarni, E. B. Muir, and S. G. Sundaresan (Copeland Corporation), **Compressor Calorimeter Test of Refrigerant Blends R-125/143a/-134a (44/52/4), R-125/143a (45/55), and R-32/-125/143a (10/45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 53, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (36 pages with 9 figures and 15 tables, available from JMC as RDB3853)

R-404A, R-125/143a (45/55), and R-32/125/143a (10/45/55)

C. Cusano (University of Illinois at Urbana-Champaign), **Accelerated Screening Methods for Predicting Lubricant Performance in Refrigerant Compressors**, report DOE/CE/23810-11C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, March 1993 (16 pages with 1 table, available from JMC as RDB4732)

This interim report introduces a research project to recommend a bench tester for screening lubricants for air-conditioning and refrigeration compressors. The report outlines a proposed program of specimen testing to serve as a basis for the recommendation. It progresses from a literature search and manufacturer consultations to testing of selected contact geometries for representative materials. The report then summarizes the literature search performed and lists identified references in an appendix. It also summarizes manufacturer visits and general observations derived from them. It focuses on the tribological components used, critical contact pairs, general lubrication requirements, and test methods. The report then outlines a test program for evaluation of a high pressure tribometer (HPT). Approximate operating and environmental conditions are tabulated for these tests.

K. E. Hickman (York International Corporation), **Refrigerants After CFCs - What Are the Choices**, *Technical Papers of the 15th Annual Meeting* (Vancouver, BC, Canada, 21-24 March 1993), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, March 1993 (30 pages with 2 figures and 2 tables, RDB3409)

This paper reviews refrigerants to replace R-12, R-22, and R-502. It summarizes the phase out schedule of the Montreal Protocol and identifies alternative refrigerants that are available. The paper addresses R-134a, R-401 (R-22/152a/124) blends, R-152a/227ea (80/20), and R-134a/152a (85/15) as alternatives for R-12 as well as R-402A and R-402B (both R-125/290/22 blends), R-403A and R-403B (both R-290/22/218 blends), and R-22 as alternatives for R-502. It then discusses longer-range options, specifically those under investigation in the Alternative Refrigerants Evaluation Program (AREP). They include R-32/125 (60/40), R-32/134a (25/75) and (30/70), R-407B [(10/70/20)] and R-32/125/134a (30/10/60), R-32/125/290/134a (20/55/5/20), R-32/227ea (35/65), R-134a, R-290 (propane), and R-717 (ammonia) as R-22 replacements and R-125/143a (45/55), R-404A [R-125/143a/134a (44/52/4)], and R-32/125/143a (10/45/45) as replacements for R-502. Two tables summarize near term and longer range alternatives and identify their compositions, characteristics, and for some potential applications. The paper outlines ongoing research of these fluids, including determination of properties and investigation of materials compatibility. It suggests potential changes in equipment design, particularly for zeotropes, for the new fluids. They include considerations for temperature glides, influences of composition change on heat transfer, counterflow heat exchangers, composition maintenance in charging and servicing, and requirements for testing and field diagnosis. Two figures illustrate the temperature glide for zeotropes. The paper then surveys requirements and complexities for service including prohibitions against venting, labeling needs, and composition maintenance for blends. It briefly mentions considerations for retrofit conversions. The paper concludes that new refrigerants are likely to be more expensive than those they replace, design emphasis is required for charge reduction and leak avoidance, and that work is needed to examine changes to improve performance with refrigerant blends. It also notes that propane and ammonia are likely to receive fresh consideration in the turmoil created by changes.

A. T. Lim (Inter-City Products Corporation), **Drop-In Test of Refrigerant Blends R-32/125/134a (10/-70/20), R-32/125/290/134a (20/55/5/20), and R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 24, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (8 pages with 5 tables, available from JMC as RDB3824)

performance tests of R-407B, R-32/125/290/134a (20/55/5/20), and R-32/125/134a (30/10/60) without system optimization

K. Mumpower (Bristol Compressors, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 54, Air-Condi-

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tioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (28 pages with 4 figures and 12 tables, available from JMC as RDB3854)

J. Pettersen and G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **A New Efficient and Environmentally Benign Systems for Automobile Air Conditioning**, paper 931129 (Vehicle Thermal Management Systems Conference, Columbus, OH, March 1993), Society of Automotive Engineers (SAE), Warrendale, PA, 1993 (rdb5652)

R-744, carbon dioxide

K. S. Sanvordenker (Tecumseh Products Company), **Compressor Calorimeter Test of Refrigerant Blends R-32/134a (30/70), R-32/134a (25/75), and R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 32, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (14 pages with 7 tables, available from JMC as RDB3832)

This report summarizes calorimeter test results for a nominal 8.8 kW (30,000 Btu/hr), hermetic reciprocating piston compressor (Tecumseh model AW5530F). Tabular data are provided to compare the capacity and efficiency for R-22, R-32/134a (30/70), R-32/134a (25/75) and R-32/125/134a (30/10/60) as functions of evaporator and condensing temperatures. The ranges covered are -15 to 13 °C (5 to 55 °F) and 32-66 °C (90-150 °F), respectively. The last two blends were tested to supplement earlier data (see RDB3802), based on indications that R-32/134a (30/70) might be flammable. The tests were performed with the same compressor and lubricant, a fully-formulated, polyolester (Mobil EAL Arctic(R) 322 R, ISO viscosity grade 22). Four tables compare the measured capacity and efficiency of each blend to that with R-22 and to compare the two R-32/134a blends to each other. These tables show the blend capacities to be slightly lower and efficiencies slightly higher, compared to R-22, for common application conditions of air-conditioners and heat pumps. The composition shift from R-32/134a (30/70) to (25/75) yields consistent further drops in capacity. The author deems the 25/75 blend as not even a near drop in substitute, since it would require redesign of the compressor. The ternary blend shows a persistent improvement in both capacity and efficiency compared to R-22, and is described as deserving more attention as a substitute for R-22. An addendum tabulates refrigerant conditions for the condenser, evaporator, subcooled liquid, and compressor inlet, calculated for each blend with NIST REFPROP 3.04a.

G. D. Short and T. E. Rajewski (CPI Engineering Services, Incorporated), **Lubricants for Use With Highly Fluorinated Refrigerants,** *Technical Papers of the 15th Annual Meeting* (21-24 March 1993, Vancouver, BC, Canada), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 139-169 as misnumbered, March 1993 (31 pages with 4 figures and 6 tables, RDB3410)

This paper provides an update on lubricants for use with hydrofluorocarbon (HFC) refrigerants and HFC blends. It also summarizes evaluations of several synthetic lubricants and the tests necessary to insure that a lubricant will provide expected durability and performance with refrigerants. The paper identifies near-term alternatives for common chlorofluorocarbon (CFC) refrigerants, and provides tabular summaries of both candidate refrigerants and recommended lubricant types for use with R-22, R-23, R-123, and R-134a. The paper describes the derivation, applications, characteristics, and experience with several lubricants. They include polyolester (POEs), polyalkylene glycols (PAGs), modified PAGs, diesters, PAG esters, carbonates, fluoroethers, fluorosilicones, and alkylbenzenes. Tables provide recommended viscosity ranges for different compressor types, refrigerant-lubricant miscibility data for R-22 and replacement candidates, lubricity findings (based on Falex pin and v-block tests) for ester lubricants and mineral oil with steel on steel, and the effects of additives on lubricant stability. The paper discusses miscibility, viscosity dilution, lubricity tests, chemical and thermal stability, and compatibility of refrigerant-lubricant combinations with other materials. Four figures illustrate the viscosity-temperature-pressure relations for R-22 with a 32 ISO alkylbenzene, R-134a with a 68 ISO PAG, R-134a with a 68 ISO POE, and R-134a and R-12 with a 46 ISO POE. The paper briefly cites findings with retrofits and field experience of PAGs and POEs, and notes that neither are suitable for use with R-717 (ammonia). The paper concludes that POEs appear to be the choice for HFCs and dialkylbenzenes with HCFC-123 and HFC/HCFC blends. It notes that POEs are preferred over PAGs for retrofit due to their miscibility and their compatibility with residual chlorine.

A. M. Smith, M. C. Beggs, and B. D. Greig (Castrol Limited), **Experience of Retrofitting Automotive Air-Conditioning from CFC-12 to HFC-134a**, paper 930292 (SAE International Congress and Exposition, Detroit, MI, 1-5 March 1993), Society of Automotive Engineers (SAE), Warrendale, PA, March 1993 (8 pages with 1 figure and 4 tables, RDB3504)

This paper describes the development of and presents a procedure for retrofit of mobile air conditioners. The conversion addressed is from

R-12 and mineral oil to use of R-134a and a polyolester (POE) based lubricant, Castrol Icematic(R) SW100. The paper reviews requirements for retrofit lubricants for R-134a, covering miscibility, thermal and hydrolytic stability, lubricating properties, and compatibility with elastomers. Miscibility is discussed in terms of matching that for conventional mineral oil systems, including the influences of residual mineral oil. Sealed-tube tests with copper, steel, and aluminum coupons in refrigerant-lubricant systems were performed; no reactions or copper plating were observed. The tests were repeated with added moisture, to provide an indication of hydrolytic stability. Copper plating was observed with both high moisture levels and an additive-free lubricant, but not with the fully-formulated POE and 300 ppm moisture. A Turbine Oxidation Stability Test (TOST, based on DIN 51587) to demonstrate the effectiveness of the hydrolytic stabilizer is summarized. Falex pin and v-block tests with refrigerant gas bubbled through the lubricant are described. Whereas mineral oil alone is indicated to be a poor lubricant, its performance improves with R-12; the reverse is noted for the POE, which is a good lubricant alone and is compromised by inclusion of R-134a. The lower performance is attributed to a combination of factors, including reduction in viscosity and increased cooling. The brief description of compatibility testing notes significant variation within generic elastomer groups, and points to the need to test elastomers from specific suppliers. The paper outlines field trial experience, from January 1990, initially using three different compressor types (Sanden SD 508, Diesel Kiki DKS - York, and Seiko Seiki SS170). Initial results based on use of polyalkylene glycol (PAG) lubricants are briefly outlined, including discussion of one failed o-ring attributed to incompatibility between the fluoroelastomer (DuPont Viton(R)) and R-134a. One of the test systems was lost in an unrelated incident; the other two were refit with the POE and the tests continued. Early retrofit procedures, and their limitations, are discussed. Mention is made of a test of more than 50 vehicles using a procedure that removes less than 75% of the mineral oil. No failures have occurred, though poor performance under idling conditions is noted and attributed to the higher latent heat of R-134a compared to R-12. An attachment details and a figure shows the sequence of a recommended retrofit procedure.

Refrigerant Reclin(R) 23, product bulletin AFK2043E/035, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, March 1993 (12 pages with 6 figures and 7 tables, RDB4774)

This bulletin provides data for R-23 along with comparative data for R-13 and R-503 [R-23/13 (40.1/59.9)] in metric (SI) units of measure. The introduction describes R-23 as an alternative for R-13 and R-503 for low-temperature refrigeration. It outlines the environmental impetus to phase out R-13 and R-503 and typical uses for these refrigerants. They include applications with evaporating temperatures of -110 to -60 °C (-166 to -76 °F) such as laboratory cryostats, test facilities, and equipment for gas separation and process technologies. Such applications use cascaded equipment with R-22 or R-134a for the high stage. The bulletin reviews thermodynamic selection criteria. Four plots compare the compression ratios, compressor discharge temperatures, volumetric refrigerating effect, and coefficient of performance for R-13, R-23, and R-503 for -110 to -60 °C (-110 to -76 °F). These data also are tabulated. The bulletin then discusses lubricants, noting that only fully synthetic lubricants are suitable, since mineral oils and semisynthetic oils do not have adequate miscibility with R-13, R-23, and R-503 in their usual application temperature range. It suggests that polyalkylbenzene with solubizers, silicates (Bayer Fluisil(R) S 55 K), polysiloxanes (Bayer Baysilone(R)), or low viscosity esters (DEA Mineralöl Triton SEZ 22) may be suitable. A miscibility diagram is provided for R-23 with an ester from Deutsche Shell AG. Oil-free labyrinth piston compressors also offer solutions. The bulletin provides elastomer swell data for R-13 and R-23 with chloroprene (CR, Neoprene(R) GN), nitrile (NBR, Perbunan(R) N), styrene-butadiene (SBR, Buna(R) S), polysulfide (Thiokol(R)), natural (NR), butyl (IIR), chlorosulfonated polyethylene (CSM, Hypalon(R) 40), and fluorinated (FPM, DuPont Viton(R) A) rubbers. A table provides physical property information including the chemical formula and name, molecular mass, normal boiling and freezing points, critical parameters (temperature, pressure, and density), and latent heat of vaporization. It also gives the surface tension, vapor dielectric constant, and liquid viscosity, thermal conductivity, specific heat, and density at selected temperatures. The bulletin discusses differences in evaporator sizing for R-13, R-23, and R-503. Three tables then provide saturated property data for these refrigerants. The thermodynamic data include pressure; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover the ranges of -130 °C (266 °F) to the critical points. The bulletin concludes with a pressure-enthalpy (Mollier) diagram for R-23 based on a Benedict-Webb-Rubin (BWR) equation of state. Hoechst Chemical's product name for R-23 is Reclin(R) 23.

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February 1993

J. M. Calm (Engineering Consultant), **Global Warming Impacts of Chillers**, *Heating/Piping/Air Conditioning* (HPAC), 65(2):28-39, February 1993 (9 pages with 9 figures and 1 table, available from JMC as RDB3304)

This paper summarizes a study of comparative impacts of chillers on global warming, including both direct (chemical) and indirect (energy-related) effects. It summarizes refrigerant options for chillers and uses of alternative refrigerants to replace chlorofluorocarbons (CFCs). It then reviews the greenhouse gas impacts of refrigerant emissions, and compares them to other warming sources. It discusses both global warming potential (GWP) values and their variation with the integration time horizon (ITH) selected for analysis. GWPs are plotted for CFC and alternative refrigerants and as a function of ITH. The paper then summarizes prior analyses of chiller warming impacts, and introduces a recent study performed for EPRI. It summarizes information used to calculate historical and projected carbon dioxide factor (CDF) values, ratios of carbon dioxide amount produced per unit of energy used. The paper outlines regional variations in fuels used to generate electricity as well as generation and load profiles. It presents calculated warming findings on both a national and regional bases, noting that the regional data can be extrapolated to impacts for other locations or countries with similar generation mixes. The paper concludes that once high-GWP CFCs are eliminated, global warming will be more readily influenced through efficiency improvement and emission reduction than by refrigerant substitutions. It reaffirms the findings of prior studies that indirect effect dominates over direct, including the combined impacts leakage, service, and ultimate disposal losses. It also notes that direct effect is equivalent to less than a 0.1 to 1.1% change in efficiency, depending on the refrigerant used, once service and disposal losses are reduced and CFCs eliminated. Three figures show comparative warming on a national and regional basis for chillers using R-11, R-12, R-22, R-123, and R-134a as well as direct-fired, absorption chillers (double-effect, water/lithium-bromide). A final plot shows the progressive reduction in total equivalent warming impact (TEWI) for R-11 and R-123 for 1985-1995 based on emission reductions and efficiency improvements.

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-8G, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, February 1993 (106 pages, available from JMC as RDB3205)

This document provides bibliographic citations for 572 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Abstracts that emphasize the content, materials addressed, and key conclusions are provided for approximately half of these documents. The database identifies sources of specific information on R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-245ca, R-290 (propane), R-600 (butane), R-600a (isobutane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. It addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester, and other lubricants. It also references documents addressing compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits. The database is available in a computerized version and as a listing in report form. The computerized version of the database includes the same citations and abstracts as the report version plus summaries for 53 individual refrigerants and blends. It is accompanied by retrieval software to facilitate searches for specific information; the software enables searches for user-selected terms, or combinations of terms. It offers several automated features to simplify searches including optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, and a "wildcard" capability to allow entry of word segments. The software also enables printing of selected citations and abstracts as well as preparation of a document order lists. Both versions of the database include instructions to obtain cited documents or subscriptions for updates to the database.

R. E. Cawley (The Trane Company), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 17, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1993 (12 pages with 7 figures and 2 tables, available from JMC as RDB3817)

performance test for R-410 series blend

S. Devotta, S. Gopichand, and V. R. Pendyala (National Chemical Laboratory, India), **Assessment of HFCs, Fluorinated Ethers and Amines as Alternatives to CFC-12**, *International Journal of Refrigeration* (IJR), 16(2):84-90, February 1993 (7 pages, RDB4126)

H. T. Gilkey (Energy Consultant), **Refrigerant Management**, *Heating/Piping/Air Conditioning Engineering* (HPAC), 66(1);78-82 and 85-87, February 1993 (8 pages with 2 figures and 1 table, RDB4304)

This article outlines strategies to prolong equipment life through refrigerant conservation and reclamation and through conversion to alternative refrigerants. It cites the phaseout schedules for chlorofluorocarbon (CFC) refrigerants and consequent need to develop a refrigerant management program. The article outlines options to retain, convert, or replace systems and cites considerations in selecting among them. It also cites statistics on the inventory of existing equipment and then reviews steps to develop a management plan. The three key actions are identified as designating a corporate and/or facility refrigerant manager, conducting an inventory of equipment and refrigerants, and developing a plan for refrigerant conservation and utilization. The article explains these steps and refrigerant recovery options, including simple recovery, recycling, and reclaim. It also explains the terminology and designations being introduced for new refrigerants. The author concludes that the opportunity to implement effective refrigerant management is just about gone based on the phaseout schedule for CFCs.

H. Jürgensen (AEG Hausgeräte AG, Germany), **Messungen an Haushaltskühlgeräten mit brennbaren Kältemitteln** [Measurements of Residential Refrigerators with Flammable Refrigerants], *DKV Jahrestagung* [Proceedings of the DKV Annual Meeting] (Bremen, Germany, 17 November 1992), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 19(II/2):177-192, 1992; republished in *Die Kälte- und Klimatechnik,* Germany, 46(2):84-94, February 1993 (16 pages with 5 figures and 5 tables, in German, RDB3108)

R-290, propane, R-600, butane, R-601, isobutane, hydrocarbon blends

D. L. Klug (DuPont Chemicals), **Near- and Long-Term Alternatives for Hydrochlorofluorocarbon 22 (HCFC-22)**, paper 1.2, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 9-14, February 1993 (6 pages with 3 figures and 1 table, RDB3307)

K. Koike (Ebara Corporation, Japan), **HCFC-123 Centrifugal Refrigeration Machine**, paper 4.3, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 67-76, February 1993 (10 pages with 7 figures and 3 tables, RDB3315)

R-123

M. Masuda (Sharp Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 59, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1993 (6 pages with 4 figures and 2 tables, available from JMC as RDB3C59)

R-22 with mineral oil (Witco Suniso(R) 4GDID), R-32/134a (30/70) with an unidentified ester lubricant; room air conditioner/heat pump, rotary rolling-piston compressor

A. Meyer (DKK Scharfenstein GmbH, Germany), **The Success of Hydrocarbons in Domestic Refrigeration**, *International Journal of Refrigeration* (IJR), 16(2):343-363, February 1993; republished in *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 281-291, 1993 (20/11 pages with 4 figures and 1 table, preprint available from JMC as RDB3226)

R-290, R-600a, R-290/600a (50/50), refrigerators, refrigerator/freezers

G. Mozzon and P. Sansalvadore (Aspera-Whirlpool SpA, Italy), **Reliability of Hermetic Compressors for R-134a Appliances**, paper 4.4, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 77-82, February 1993 (6 pages with 2 figures and 6 tables, RDB3316)

Y. Natsume (Nippondenso Company, Limited), **Refrigerating Machine Lubricants for New Refrigerants**, paper 2.1, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 21-26, February 1993 (6 pages with 11 figures and 1 table, RDB3309)

K. S. Sanvordenker (Tecumseh Products Company**), Materials Compatibility Concerns for Refrigerator-Freezers - A Historic Perspective and a Look to the Future**, paper 3.2, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 39-44, February 1993 (8 pages with 2 tables, preprint available from JMC as RDB3116)

The paper traces compatibility concerns for refrigerator-freezers, from historic use of R-764

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(sulfur dioxide) and R-40 (methyl chloride) to present use of R-12. Sludge deposition with oils led to an oil-free, belt-driven model, using R-764, as early as 1913. R-764 achieved 90% penetration around 1925, but was limited to open-drive compressors. The driving force for hermetic systems was the problem of leaks, particularly with sulfur dioxide. Identification of an appropriate lubricant led to introduction of hermetic compressors. The initial solution was a highly refined mineral oil, referred to as white oil. The paper reviews introduction of R-40 in the 1930s, in both open and hermetic compressors, reaching a peak of 20% penetration. It avoided subatmospheric operation, thereby eliminating introduction of air and moisture. The required compressor displacement was smaller, discharge temperatures much lower, and compatibility with mineral oils higher; but it was flammable and toxic. Incompatibility with aluminum, particularly in dry systems, led to demise of R-40 use. R-12 came in as the successor fluid in the late 1930s, though the paper also cites early use of R-21 and R-114. R-12 became dominant because of its thermodynamic properties, positive pressure operation, full miscibility with mineral oils, and compatibility with metals and other materials of construction. Compatibility problems resulted later, in seeking smaller compressors and associated increases in discharge temperatures. The paper briefly outlines the resolution of these problems. It then turns to recent environmental concerns with chlorofluorocarbon refrigerants, and introduction of R-134a. Compatibility issues are discussed, with emphasis on lubricant interactions. Tables are included to summarize the effects of temperature and metals (steel, copper, and aluminum) on decomposition for both polyalkylene glycol (PAG) and polyolester (POE) lubricants. The role of metal passivation is outlined, particularly for POEs with steel. Chemical reactivity, miscibility, solubility, lubricity, suitability with motor materials, and contaminant issues are reviewed. The paper cites consideration of R-152a, particularly in developing countries, and future refrigerant candidates. Compatibility is indicated as manageable with R-152a, partly based on experience with R-500 of which it is a component; flammability is cited as a concern. The paper concludes by noting the role of the Materials Compatibility and Lubricant Research (MCLR) Program.

N. D. Smith (U.S. Environmental Protection Agency, EPA), K. Ratanaphruks, M. W. Tufts, and A. S. Ng (Acurex Environmental Corporation), **R-245ca: A Potential Far-Term Alternative for R-11**, *ASHRAE Journal,* 35(2):19-23, February 1993 (5 pages with 3 tables, RDB3301)

This article summarizes tests and modeling of R-245ca, a candidate refrigerant to eventually replace R-11 and R-123. Thermophysical properties measurements are described. The results and findings of performance modeling are compared to data for R-11 and R-123; the efficiency of R-245ca is indicated to be 3-4% lower than for R-11. Flammability measurements based on the ASTM E681-85 procedure are described. The flammability was found to be sensitive both to the presence of moisture and the ignition source. Lower and upper flammability limits (LFL and UFL) of 7.0-14.4% are reported at 30 °C (84 °F) for 43.5% relative humidity; the fluid was nonflammable in dry air. Tests of miscibility with two unidentified polyolester (POE) lubricants are discussed, indicating complete miscibility, insensitive to moisture content, for -30 to 125 °C (-22 to 257 °F) for concentrations of 10, 20, and 30% lubricant by weight. Sealed tube tests to gauge compatibility with aluminum, copper, valve steel, fluoroelastomer (DuPont Viton(R)), nitrile butyl rubber (Buna(TM) N), neoprene, DuPont Nomex(R), and DuPont Mylar(R) are described. Observations, results of gas chromatography and infrared spectrometry, acidity, weight change, and swell are summarized. The paper indicates that R-245ca with a POE lubricant is compatible with the metals tested, Mylar, Viton; possibly compatible with Buna N and Nomex; and incompatible with neoprene. As a chlorine- and bromine-free compound, R-245ca is expected to have an ozone depletion potential (ODP) of zero. Its atmospheric lifetime was estimated as 6.4 years by measuring its reaction rate with atmospheric hydroxyl radicals; its global warming potential (GWP) was estimated to be one-third that of R-134a. Very preliminary testing of acute inhalation toxicity tests are outlined; no signs of concern were identified at a concentration level of 993 ppm. The paper concludes that R-245ca has been shown to be a good candidate for replacement of R-11 or R-123 in the far-term.

N. D. Smith, **Thermophysical Properties of HFE-125**, Environmental Research Brief EPA-600/S-93-001, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, February 1993 (4 pages with 4 tables, available from JMC as RDB-3404)

This synopsis summarizes properties of R-E125 (pentafluorodimethyl ether), a potential alternative refrigerant for low-temperature applications. Tables, in both inch-pound (IP) and metric (SI) units provide the freezing and boiling points, critical properties, heat of vaporization, and liquid specific heat capacity. Measured liquid densities are given at eight temperatures from 10-61 °C (50-142 °F) and vapor pressures for -104 to 81 °C (-156 to 177 °F). Calculated liquid and vapor density as well as heat of vaporization are tabulated for -55 to 81 °C (-66 to 177 °F) and the equations used are provided. The methods used and estimated accuracy are indicated.

S. G. Sundaresan (Copeland Corporation), **Commercial Refrigeration: The Challenge and the Issues Regarding the Retrofit and New Equipment**, paper 4.2, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 57-66, February 1993 (6 pages with 1 figure and 6 tables, available from JMC as RDB3314)

service history, control and system components, cleanout procedures, refrigerant selection, lubricant selection, moisture control, composition control, comparison of R-12 and R-502 alternatives

T. Takaichi (Showa Denko K.K., Japan**), Current Status of R&D for CFC Alternatives**, paper 1.1, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 3-8, February 1993 (6 pages with 5 figures and 4 tables, RDB3306)

The paper briefly surveys research and development efforts to identify alternatives for chlorofluorocarbon (CFC) refrigerants. It recaps the introduction of CFCs, discovery of their ozone depletion role, and both measured concentrations in the atmosphere and ozone decline. It then reviews the 1992 revisions to the Montreal Protocol, international production of CFCs and R-22, and 1991 CFC consumption by application in Japan. The paper discusses interest in hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) alternatives and provides a tabular summary of candidate fluids. A figure indicates the chemical paths to produce the primary alternative fluorocarbons. It then reviews the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) and outlines the five programs underway. It also summarizes efforts under the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) to assess candidate HCFCs and HFCs. It mentions a five-year cooperative program by the Japanese Research Institute of Innovative Technology for the Earth (RITE), Ministry of International Trade and Industry (MITI), New Energy Development Organization (NEDO), National Chemistry Laboratory for Industry (NCLI), and ten chemical producers to develop a new generation refrigerant. This "third generation" fluid would be ozone safe, have low global warming effect, and have a new molecular structure consisting of oxygen and other elements in addition to carbon, fluorine, and hydrogen. While this paper does not address any of these subjects in depth, it provides a sweeping overview of efforts to introduce alternative refrigerants.

N. Tanaka (Mitsubishi Electric Corporation, Japan), **Trends of Alternative Refrigerants**, paper 4.1, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 51-56, February 1993 (6 pages with 5 figures and 2 tables, RDB3313)

S. Uemura (Daikin Industries, Limited, Japan), **Basic Requirements and Future Solutions of Air-Conditioning Units with Alternative Refrigerants - 1**, paper 5.2, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 89-94, February 1993 (6 pages with 9 figures and 6 tables, RDB3317)

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Basic Requirements and Future Solutions of Air-Conditioning Units with Alternative Refrigerants - 2**, paper 5.3, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 95-100, February 1993 (6 pages with 6 figures and 4 tables, RDB3318)

Genetron(R) 134a, technical bulletin B-525-645, AlliedSignal Incorporated, Morristown, NJ, February 1993, May 1993, and September 1993 (4 pages with 3 tables, RDB3453)

This bulletin supplies information on R-134a, described as a replacement for R-12 in automobile air conditioning; residential, commercial and industrial refrigeration; and in certain centrifugal chiller applications. It provides physical property data, in inch-pound (IP) units, including the chemical formula, molecular weight, atmospheric boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), flammability, and ozone depletion potential. It also indicates the liquid density and specific heats of the liquid and vapor at 30 °C (86 °F). It then presents a tabular comparison of performance for R-12, R-22, and

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R-134a. The report provides tabular thermodynamic properties (pressure, density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -29 to 71 °C (-20 to 160 °F). Formulae are provided to calculate thermodynamic properties including vapor pressure, liquid density, and ideal gas heat capacity correlations. Coefficients are presented for a Martin-Hou equation of state. AlliedSignal's product name for R-134a is Genetron(R) 134a.

Klea Blend 66, Replacement for HCFC 22, technical note CP/30356/31112/2Ed/33/353, ICI Chemicals and Polymers Limited, Runcorn, Cheshire, UK, February 1993 (6 pages with 2 tables, RDB3730)

This document describes a ternary, zeotropic blend of R-32, R-125, and R-134a (R-32/125/134a), developed as a replacement for R-22. The technical note summarizes the phase out of chlorofluorocarbon (CFC) and eventually also of hydrochlorofluorocarbon (HCFC) refrigerants, the need for alternatives to R-22, and ICI's search for likely replacements. It then compares the boiling points, atmospheric lifetimes, ozone depletion potentials (ODPs) and global warming potential (GWPs) of R-22, R-32, and the R-32/125/134a blend. It also provides a theoretical performance comparison between R-22 and the blend. The document then discusses the flammability and toxicity of both the blend and its components, noting that the composition was designed to be nonflammable despite the R-32 content. The bulletin also discusses handling and leakage and states that composition changes are anticipated to be less serious than had been expected. It discusses appropriate lubricants, with focus on the ICI Emkarate(R) family of synthetic, neopentyl polyolesters. Several documents are cited as available or under preparation to provide thermophysical properties, flammability specifics, blend design information, handling and storage advice, and retrofit guidance. ICI's product name for the R-32/125/134a blend discussed is Klea(R) Blend 66 [subsequently reformulated].

Materials Compatibility and Lubricant Research Presentation Slides, report DOE/CE/23810-9, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, February 1993 (98 pages, available from JMC as RDB3206)

This report contains prints of the charts used by five researchers for a seminar on *Materials Compatibility and Lubricant Research* as part of the 1993 American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Winter Meeting, held in Chicago in January 1993. This session was sponsored by ASHRAE Technical Committees 3.2 (Refrigerant System Chemistry), 3.3 (Contaminant Control in Refrigerating Systems), and 3.4 (Lubrication). The presentations included were by D. F. Huttenlocher (Spauschus Associates, Incorporated) on "*Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures with Metals*," S. C. Zoz (Iowa State University of Science and Technology) on "*Miscibility of Lubricants with Refrigerants*," G. R. Harried (The University of Akron) on "*Compatibility of Refrigerants and Lubricants with Elastomers*," R. C. Cavestri (Imagination Resources, Incorporated, IRI) on "*Compatibility of Refrigerants and Lubricants with Plastics*," and R. G. Doerr (The Trane Company) on "*Compatibility of Refrigerants and Lubricants with Motor Materials*." The research projects covered are funded by ARTI under a grant from the U.S. Department of Energy. (Presentation slides are not reviewed by ASHRAE except for commercialism; no endorsement should be inferred.)

Report of the ARI Delegation to Japan on Alternative Refrigerants, report DOE/CE/23810-12, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1993 (20 pages including 2 appendices, available from JMC as RDB3401)

This document reports on a trip, by an ARI delegation, to exchange information on alternative refrigerants and to review methods to screen alternatives to chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Five representatives traveled to Japan to participate in the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility. They subsequently visited seven manufacturers and the Ministry of International Trade and Industry (MITI). Techniques for materials compatibility screening, lubricant testing, and flammability studies were of specific interest. This report provides an overview of Japanese phase-out strategies, identifies research into alternative refrigerants and lubricants for them, and reviews the screening methods used. It discusses the status of retrofits and system design. The conference agenda and lists of both the ARI delegates and companies visited are provided in appendices. The report notes that the leading replacement refrigerant is R-134a. Efforts with hydrochlorofluorocarbon (HCFC) alternatives are limited since companies expect to move away from such fluids by the year 2000. R-32/134a (30/70) is considered a candidate to replace R-22, though the Japanese view this zeotrope as not flammable, unlike in the U.S., based on testing under different conditions. More than 50 compounds have been synthesized and are under investigation as alternatives for R-502. Polyolester (POE) lubricants are the prime focus for hydrofluorocarbons (HFCs), except in automotive air conditioning where polyalkylene glycols (PAGs) are used. The report discusses specific fluids, lubricants, test procedures, and regulatory actions and expectations for several application areas. Observations regarding use of absorption chillers as alternatives, government incentives, CFC taxes, safety standards, and a CFC destruction technology also are mentioned.

January 1993

J. C. Bare (U.S. Environmental Protection Agency, EPA), **Simulation of Performance of Chlorine Free Fluorinated Ethers and Fluorinated Hydrocarbons to Replace CFC-11 and CFC-114 in Chillers**, paper 3661, *Transactions* (Winter Meeting, Chicago, IL, January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(1):397-407, 1993 (11 pages with 4 figures and 4 tables, RDB-3407)

R-11 and R-114 alternatives

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Compatibility of Refrigerants and Lubricants with Plastics**, report DOE/CE/23810-8E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1993 (76 pages with 1 figure and 58 tables, available from JMC as RDB3203; type on page A-2 is small and may be difficult to read)

This interim report summarizes progress to provide compatibility information on engineering plastics with alternative refrigerants and suitable lubricants. A narrative summary outlines the work methods used, including modifications to standard or planned test procedures, and notes significant findings. A table provides the manufacturer specifications and actual conditions for molding 23 plastic materials. They include acetal (DuPont Delrin(R) II 11500), acrylonitrile-butadiene-styrene terpolymer (ABS, GE Cycolac(R) GPM4700), liquid crystal polymer (LCP, Amoco Xydar(R) MG450), phenolic (Hooker Durez(R) 153), poly(aryletheretherketone) (PEEK, ICI Victrex(TM) PEEK 450G), polyamide nylon 6/6 (DuPont Zytel(R) 101), polyamideimide (Amoco Torlon(R) 4203L and 4301), polyaryletherketone (PAEK, BASF Ultrapek(R)), polyarylsulfone (Amoco Radel(R) A-200), poybutylene terephthalate (PBT, GE Valox(R) 325PBT), polycarbonate (GE Lexan(R) 161), polyetherimide (GE Ultem(R) 1000), modified polyetherimide (GE Ultem(R) CRS5001), polyethylene terephthalate (PET, DuPont Rynite(R) 530), polyimide thermoset (DuPont Vespel(R) DF and DF-ISO), modified polyphenylene oxide (PPE, GE Noryl(R) 731), polyphenylene sulfide (PPS, GE Supec(TM) G401), polyphthalamide (Amoco Amodel(R) AD-1000 HS), polypropylene (Himont Profax(TM) 6331 NW), polytetrafluoroethylene (PTFE, DuPont Teflon(R)), and polyvinylidene fluoride (Atochem Kynar(R) 720). Seven tables summarize the changes for immersions in lubricants, including mineral oil (BVA R015), alkylbenzene (Shrieve Zerol(R)150), polypropylene glycol butyl monoether (ICI Emkarox(R) VG32), polypropylene glycol diol (Dow P-425), and a modified polyglycol (AlliedSignal BRL-150), pentaerythritol ester mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244), and pentaerythritol ester branched acid (Henkel Emery(R) 2927-A). Seven tables summarize changes in the plastics following immersions in the lubricants, each at 60 and 100 °C (140 and 212 °F). Observations of particulates, cracking, crazing, softening, and color change are presented. Quantitative data are provided for dimensional (length, width, and thickness) and weight changes. Ten tables summarize corresponding changes following exposures to R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, and R-152a. The refrigerant immersions were at room temperature and 60 °C (140 °F) for 14 days. Three tables summarize the creep modulus of the plastics at 10-300 hours for immersions in R-22, R-134a, and R-152a with branched acid polyolester. 36 tables summarize physical changes and tensile-property changes following exposures to refrigerant lubricant mixtures. All of the plastics were affected by the lubricants; mineral oil and alkylbenzene caused the greatest effects. The refrigerants generally resulted in softening or weight change; hydrofluorocarbons (HFCs) had the least impact. The report documents several combinations that failed at ambient conditions or are likely to fail at elevated temperatures.

R. G. Doerr, S. A. Kujak, and T. D. Waite (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials**, report DOE/CE/-23810-8C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1993 (62 pages with 42 tables, available from JMC as RDB3614)

This interim report summarizes progress to provide compatibility information for 24 motor materials, commonly used in hermetic compressors, with refrigerants and refrigerant-lubricant combinations. The report briefly outlines findings previously reported and then presents new results. The findings are tabulated for exposures at 127 °C (260 °F) to 17 refrigerant-lubricant combinations. R-22 was tested with mineral oil (Witco Suniso(R) 3GS). R-124, R-142b,

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and R-152a were tested with alkylbenzene (Shrieve Zerol(R) 150). R-134a was tested with a polyolester (POE) mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244); and R-32, R-125, R-134, R-134a, R-143a, and R-245ca with a POE branched acid (Henkel Emery(R) 2927 ISO 32). R-32, R-125, and R-134a were tested with a polyalkylene glycol (PAG) butyl monoether (ICI Emkarox(R) VG32); R-125 and R-134a with a modified PAG (AlliedSignal BRL-150); and R-134a with a PAG diol (Dow Chemical P425). Data are provided both after 500 hour exposures and after a subsequent air bake for 24 hours at 150 °C (302 °F), to remove absorbed refrigerant. The effects of heat alone were gauged by similar exposure to nitrogen (R-728). Weight change is reported for exposed disks of six varnishes including two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and waterborne epoxy (Schenectady Isopoxy(R) 800). Bond strength is compared to unexposed values for dipped coats of each varnish on three magnet wires. The magnet wire specimens included a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a modified polyester base overcoated with polyamide-imide and epoxy saturated glass (Phelps Dodge Armored Poly-Thermaleze Daglass 2000), and polyesterimide overcoated with polyamide-imide (Phelps Dodge/Schenectady Chemical). Burnout resistance and dielectric strength are compared to unexposed values for each varnish on each of the magnet wires and also to unvarnished specimens. Weight, tensile strength, elongation, and dielectric strength are compared to unexposed values for six sheet insulations (Westinghouse Nomex-Mylar-Nomex(R), Westinghouse Dacron-Mylar-Dacron(R), DuPont Mylar(R) MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228). Weight change is tabulated for Insulations Sales Nomex(R), Mylar(R), and Nomex-Mylar(R) spiral wrapped sleeving insulation. Changes in weight and dielectric strength are presented for A. O. Smith Dacron-Mylar-Dacron(R) and Dacron-Teflon-Dacron(R) lead wire insulations. Weight and breaking load changes are supplied for woven glass tape (Carolina Narrow), heat shrinkable braided polyester tape (Electrolock), glass-acrylic tape (Essex Permacel P247), and polyester tie cord (Ludlow Textiles). The report concludes that the refrigerant-lubricant combinations tested appeared to have less effect than pure refrigerants on motor materials, with the exception of the tapes. No evidence of insulation degradation due to desorption of refrigerant were observed in the presence of lubricants.

The primary issues noted as of concern were delamination of the sheet insulation by the PAG diol lubricant and decreased strength of the tapes. Precipitation of extracted solid polyester materials was observed with the mineral oil. No evidence of polyester precipitate was observed with the synthetic lubricants, suggesting that sticking valves and clogged capillaries may be less of a problem with the new lubricants. The results suggest that the new synthetic lubricants will present few compatibility problems with motor materials. This indication is based on comparison of observed effects to those for R22 with mineral oil, which generally showed greater impact, and consideration of the documented history of their reliability.

P. A. Domanski and D. A. Didion (National Institute of Standards and Technology, NIST), **Thermodynamic Evaluation of R-22 Alternative Refrigerants and Refrigerant Mixtures**, paper DE-93-6-2, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(2):636-648, 1993 (13 pages with 18 figures and 3 tables, RDB3617)

This paper evaluates performance of candidate refrigerants to replace R-22, including R-32/125 (60/40), R-407B [R-32/125/134a (10/70/20)], R-32/125/134a (30/10/60), R-32/125/290/134a (20/55/5/20), R-32/134a (25/75), R-32/134a (30/70), R-32/227ea (35/65), R-134a, and R-290 (propane). The analyses are based on a semi-theoretical model, CYCLE-11, with cross-flow heat transfer in the evaporator and condenser. Thermodynamic properties were calculated using the Carnahan-Starling-DeSantis (CSD) equation of state. The conditions examined approximate outdoor rating conditions for residential heat pumps, namely 27.8 and 35 °C (82 and 95 °F) for cooling and -8.3 and 8.3 °C (17 and 47 °F). Calculated volumetric capacities, coefficients of performance (COPs), pressure lift, and compressor discharge temperatures and pressures are plotted. The analyses are presented for "drop-in" conditions (constant heat exchangers), constant heat exchanger loading, and with addition of a liquid-suction heat exchanger. Summary fluid properties and results for the constant exchanger loading cases are tabulated. They indicate efficiency losses of 1-16% for the R-22 alternatives. Corresponding changes in volumetric capacity range from 31% lower to 55% higher. The paper notes, however, that these findings would change with consideration of differences in transport properties. The paper abstractly discusses the influence of critical temperature on performance and unavoidable trade off between COP and volumetric capacity. It also reviews the impacts of heat capacity, liquid thermal conductivity, and liquid viscosity; neither these transport properties nor toxicity and flammability were otherwise addressed. An appendix describes the CYCLE-11 model. [See RDB3305 for a more complete summary, from which this paper was extracted.]

G. J. Epstein and S. P. Manwell (Xenergy Incorporated), **Environmental Tradeoffs Between CFCs and Alternative Refrigerants**, *ASHRAE Journal,* 35(1):38-44, January 1993 (7 pages with 1 figure and 5 tables, RDB3225)

G. R. Hamed and R. H. Seiple (University of Akron), **Compatibility of Refrigerants and Lubricants with Elastomers**, report DOE/CE/23810-8D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1993 (310 pages with 32 figures and 100 tables, available from JMC as RDB3202)

This interim report summarizes swell measurements for 95 elastomeric gasket and seal materials in refrigerants and lubricants. Swell behavior was determined using weight and in-situ diameter measurements for the refrigerants and diameter and thickness measurements for the lubricants. The refrigerants include both hydrochlorofluorocarbons (HCFCs R-22, R-123, R-124, and R-142b) and hydrofluorocarbons (HFCs R-32, R-125, R-134, R-134a, R-143a, and R-152a). The lubricants include a mineral oil (Witco Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150), and three polyalkylene glycols (PAGs), namely a polypropylene glycol butyl monoether (ICI Emkarox(R)), a polypropylene glycol diol (Dow P425), and a modified polyglycol (AlliedSignal BRL-150). Two polyolester (POE) lubricants also are included, namely a pentaerythritol ester branched acid (Henkel Emery(R) 2927-A) and a pentaerythritol ester mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244). An appendix identifies the elastomer formulations, which include polyisoprene (Natsyn 2200), polychloroprene (Neoprene W), isobutyl isoprene (Polysar Butyl), bromobutyl (Polysar X2), chlorobutyl 1068, styrene butadiene rubber (SBR 1502 and Stereon 730A and 840A), nitrile (Chemigum N206, N300, N615B, and N917), hydrogenated nitrile (Polysar Tomac A3850 and A4555), fluoroelastomers (DuPont Viton(R) A, B, and GF), KEL-F 3700, epichlorohydrin (Hydrin H-65, C-65, and T-75), silicones (SE-33(VMQ), SE-436U, SE-565U, SE-3808U, and LS-63U), thermoplastics (Santoprene 201-87, 201-73, 203-40, and 203-50, Geolast 701-87, 701-80, and 703-40, and Hytrel EPDM 4056, 5526, G6356, and 7246), FA and ST polysulfide rubber, polyurethanes (Airthane PET-95A, PET-60D, Cyanaprene A-8, D-55, Millathane 76 and E-34), chlorosulfonated polyethylenes (Hypalon 20, 40, and 4085), EPM (Vistalon 404 and 707), ethylene acrylics (Vamac G and B-124), chlorinated polyethylenes (Dow CM0136 and 4211P), and ethylene propylene diene (EPDM rubbers Royalene 552, 525, and 359). Another appendix identifies ten gasket materials supplied by ARTI including filled chloroprene (Precision Rubber 2167), acrylonitrile (Precision Rubber 7507), neoprene (Garlock 2930), non-asbestos (Armstrong N-8092, Specialty Paperboard NI-2085G, Victopac 69, and Klinger C-4401), nitrile-aramid (Specialty Paperboard 2099), fluorocarbon (Parker V747-75), and neoprene (Greene Tweed 956). The physical properties of the samples were tabulated prior to exposures. 17 figures summarize the diameter change for exposures in the individual refrigerants and lubricants. 95 tables present data on swell after immersions of 1, 3, and 14 days, weight change after 14 days, diameter and weight after removal, and shore hardness after 1 day of drying. The test methodology and apparatus also are described. R-123 generally resulted in the greatest swelling, but EPDM/PP/TPE, butyl rubber/PP TPE, and several vendor-supplied compositions swelled little in this refrigerant. R-134 and R-134a caused much less swelling, except with fluoroelastomers and fluorosilicone elastomers. Some vendor compositions are identified that resisted swelling in all refrigerants and lubricants tested. The HFCs generally gave much less swelling than the HCFCs, though the fluoroelastomers and fluorosilicones exhibit high swelling in them. Some of the industry-supplied samples resisted swelling in all refrigerants. Several compositions were identified that resisted swelling in the lubricants as well. 17 refrigerant-lubricant systems are identified, and pressure calibration curves are provided, for an ongoing second phase of the project. 25 selected elastomers will be tested in Phase II. Completion is expected in April 1993, contingent on the availability of R-32 for testing.

D. R. Henderson (Spauschus Associates, Incorporated), **Solubility, Viscosity, and Density of Refrigerant-Lubricant Mixtures**, report DOE/CE/-23810-8F, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1993 (20 pages with 8 figures and 9 tables, available from JMC as RDB3207)

This interim report presents results of measurements to determine the solubility (pressure), viscosity, and density of refrigerant-lubricant mixtures. It summarizes initial findings for low refrigerant concentrations (70, 80, 90, and 100% lubricant by weight) for R-12 and R-22 with ISO 32 mineral oil (Witco Suniso(R) 3GS) and R-134a with ISO 32 pentaerythritol ester mixed acid (Mobil EAL Arctic(R) 32) for 0-100 °C (32-212 °F).

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The data have been reduced to engineering form and are presented as Daniel Charts. Scatter diagrams, overlain with curve fits, are provided for R-12 with mineral oil. These diagrams illustrate both the quality of data and rationale for the manner chosen to represent the data. The regression equations and correlation statistics are reported. Viscosity, pressure, and density data are represented by Walther, quadratic polynomial, and linear equations, respectively. Measured data are tabulated for each of the fluids. The report outlines work performed for the project, lists the refrigerant-lubricant pairs to be studied along with associated temperature ranges, and summarizes the data reduction. 35 mixtures will ultimately be tested over selected ranges of composition and temperature.

G. C. Hourahan and S. R. Szymurski, **Materials Compatibility and Lubricants Research on CFC Refrigerant Substitutes**, report DOE/CE/23810-8, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1993 (38 pages with 12 figures and 9 tables, available from JMC as RDB3204)

This progress report summarizes the goals and status of the Materials Compatibility and Lubricant Research (MCLR) Program, jointly funded under a grant from the Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The 36-month program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) refrigerants. The report reviews projects to measure thermophysical properties, model the performance and key operating parameters of 12 potential alternatives for R-22 and R-502, test the chemical and thermal stability of refrigerant-lubricant mixtures with metals, and measure the miscibility of lubricants with refrigerants. It outlines projects to provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics. The report identifies the objectives and contractors for three new projects to develop accelerated screening and test methods to predict lubricant performance in compressors, the life of motor materials exposed to refrigerant-lubricant mixtures, and chemical and thermal stability of refrigerant-lubricant mixtures. Other projects introduced will measure the viscosity, density, and solubility for refrigerant blends in selected lubricants, electrohydrodynamic (EHD) enhancement of heat exchangers for alternative refrigerants, and the compatibility of desiccants with refrigerants and lubricants. An ongoing project to collect and facilitate dissemination of data, through development and administration of a refrigerant database, is cited. The scope of the program, objectives of the individual projects, and significant interim findings are presented. This program summary also identifies reports resulting from the individual projects, including three final reports on *Theoretical Evaluations of R-22 Alternative Fluids, Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures with Metals, and Miscibility of Lubricants with Refrigerants.* Eight figures summarize progress in measuring thermophysical properties of R-32, R-123, R-124, and R-125. Three figures provide Daniel and density plots for R-12 and R-22 with mineral oil and R-134a with pentaerythritol ester mixed acid. A table summarizes measured elastomer swelling in refrigerants and lubricants.

O. Kataoka (Daikin Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 38, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (12 pages with 4 figures and 1 table, available from JMC as RDB3838)

O. Kataoka (Daikin Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 39, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (12 pages with 4 figures and 1 table, available from JMC as RDB3839)

R. F. Kayser (National Institute of Standards and Technology, NIST), **Thermophysical Properties**, report DOE/CE/23810-8A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1993 (102 pages, including 13 figures and 32 tables, available from JMC as RDB3201)

This progress report provides an update on a project to provide highly accurate, selected thermophysical properties data for R-32, R-123, R-124, and R-125. The report summarizes the work completed in the fourth quarter of a 15-month project and includes plots showing the ranges of measured data, deviations from correlations, and comparisons with earlier data. Preliminary tables are appended, in both metric (SI) and inch-pound (IP) units. They relate Burnett measurements of density and pressure to temperature for the vapor phase and vibrating densimeter measurements for the liquid phase for R-32. Burnett and ebulliometric vapor-pressure data are tabulated and extrapolated to provide saturated vapor and liquid densities. Adiabatic calorimeter measurements at constant volume are presented for the liquid and two-phase regions. Measurements of thermal conductivity have been delayed by a failure, not yet analyzed, due to corrosion of leads in the transient hot-wire apparatus. Supercritical data, therefore, are not tabulated pending verification and completion, though a preliminary plot is included. Density and pressure measurements versus temperature also are provided for R-124 and R-125 for the liquid phase. Measured pressure and density data also are tabulated for R-125 for compressed liquid, and a range of isochores. Ebulliometric vapor-pressure measurements and fits to Antoine equations are given for both R-124 and R-125. Isochoric PVT measurements and both liquid and two-phase heat capacity are tabulated for R-123. Progress in fitting the data to modified Benedict-Webb-Rubin (MBWR) equations of state for R-125, both as part of related research and the present project, is cited. Progress on a 32-term MBWR equation, based on analysis of thermal conductivity data for R-123, also is described.

K. Kim, U. C. Spindler (University of Maryland), D. Jung (Inha University, Korea), and R. K. Radermacher (University of Maryland), **R-22/152a Mixtures and Cyclopropane (R-C270) as Substitutes for R-12 in Single-Evaporator Refrigerators: Simulation and Experiments**, paper CH-93-20-2, *Transactions* (Winter Meeting, Chicago, IL, January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(1):1439-1446, 1993 (8 pages with 4 figures and 3 tables, RDB3114)

Y. Kiyokawa (Sanyo Electric Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 44, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (10 pages with 2 figures and 4 tables, available from JMC as RDB3844)

G. Lorentzen and J. Pettersen (Norgest Tekniska Högskole, NTH, Norway), **A New, Efficient and Environmentally Benign System for Car Air Conditioning**, *International Journal of Refrigeration* (IJR), 16(1):4-12, January 1993 (9 pages, rdb5452)

R-744 (carbon dioxide), transcritical cycle

A. Meyer (DKK Scharfenstein GmbH, Germany), **Der FCKW-frei Kühlschrank der FORON Hausgeräte GmbH - ein Beitrag für eine bessere Umwelt** [The CFC-Free Refrigerator from FORON Hausgeräte GmbH - A Contribution for a Better Environment], *Luft- und Kältetechnik*, Germany, 3-4, January 1993 (2 pages, in German, rdb5715)

R-290, R-600a, R-290/600a (50/50), refrigerators, refrigerator/freezers

Y. Morikawa (Matsushita Electric Industrial Company Limited, Japan), **Procedure and Report Format for Compressor Calorimeter Tests Performed by JRAIA Member Companies**, Alternative Refrigerants Evaluation Program (AREP) report 34, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (22 pages with 1 figure and 7 tables, available from JMC as RDB3834)

This document outlines uniform test procedures used for compressor calorimeter tests for the Japanese Alternative Refrigerants Evaluation Program (JAREP). The procedures were developed and the cooperative program is conducted by the Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), in coordination with the U.S. Air-Conditioning and Refrigeration Institute's (ARI's) Alternative Refrigerants Evaluation Program (AREP). The procedure addresses refrigerant blends. It prescribes test conditions (evaporator, condenser, and ambient temperatures as well as superheat and subcooling) for air-conditioning and heat pump applications. It also specifies test conditions (evaporator, condenser, and ambient temperatures as well as suction temperature and subcooling) for medium- and low-temperature applications. The procedure indicates test requirements to measure input power, for the power supply, for verification of blend compositions, and for data presentation. It identifies reference data to be taken with R-22 or R-502, selection of lubricants, and procedures for azeotropes. A single figure illustrates the temperatures points defined by the procedure. Appendices tabulate thermodynamic property data for R-32/134a (30/70) and R-32/125 (60/40). NIST REFPROP version 3 is identified for data for R-125/143a (45/55) and R-404A [R-125/143a/134a (44/52/4)]. The report provides data forms to report general and compressor information as well as the findings. A final table indicates the specific tests and refrigerants to be performed by participating companies. They include Daikin, Hitachi, Kobe Steel, Mayekawa, Matsushita, Matsushita Refrigeration, Mitsubishi Electric, Mitsubishi Heavy, Sanden, Sanyo, Sharp, and Toshiba.

N. Murata (Mitsubishi Heavy Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 64, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 1 figure and 3 tables, available from JMC as RDB3C64)

R. K. Radermacher and D. Jung (University of Maryland), **Theoretical Analysis of Replacement Refrigerants for R22 for Residential Uses**, paper 3654, *Transactions* (Winter Meeting, Chicago, IL, 23-27 January 1993), American Society of Heating,

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Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(1):333-343, 1993 (11 pages with 7 figures and 1 table, RDB4413)

This paper examines the need for and candidate replacements for R-22. The simulation programs and data used for the study are summarized. Hydrofluorocarbon (HFC) refrigerants R-32, R-125, R-134, R-134a, R-143a, and R-152a and hydrochlorofluorocarbon (HCFC) R-124 were selected for analyses. Results are presented for R-32/124 (30/70), R-32/134 (30/70), R-32/134a (30/70), R-32/152a (40/60), R-125/152a (20/80), R-143a/124 (30/70), and R-143a/152a (10/90). Results also are provided for three ternary blends, investigated to reduce flammability, namely R-32/152a/124 (20/20/60), R-32/152a/134 (30/-40/30), and R-32/134a/152a (40/10/50). Coefficients of performance (COPs) are tabulated and both the COPs and seasonal performance factors (SPFs) are plotted. Three figures illustrate the cooling COPs and volumetric capacities of binary mixtures of R-32/124, R-32/134, R-32/134a, R-32/152a, R-125/124, R-125/134a, R-125/152a, R-143a/124, R-143a/134a, and R-143a/152a as functions of composition. The paper also reviews the design modifications considered, with emphasis on concentration management, by a short distillation column, and use of counterflow heat exchangers. The direct (refrigerant emission) and indirect (energy related) global warming impacts of selected blends are contrasted to those with R-22 in a plot. The paper concludes that refrigerant mixtures can replace R-22 without loss in efficiency, and that gains are possible with use of counterflow heat exchangers and capacity modification by composition shifting. Both the ozone depletion and global warming impacts can be reduced by the blends examined.

C. K. Rice and J. R. Sand (Oak Ridge National Laboratory, ORNL), **Compressor Calorimeter Performance of Refrigerant Blends - Comparative Methods and Results for a Refrigerator Freezer Application**, paper CH-93-20-3, *Transactions* (Winter Meeting, Chicago, IL, January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(1):-1447-1466, 1993 (20 pages with 7 figures and 5 tables, RDB3115)

K. Sakaino (Mitsubishi Electric Corporation, Japan), **Compressor Calorimeter Test of Refrigerant R-134a and Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 42, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (34 pages with 17 figures and 9 tables, available from JMC as RDB3842)

K. Sakuma (Mitsubishi Electric Corporation, Japan), **Drop-In Test of Refrigerant R-134a and Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 48, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (28 pages with 4 figures and 18 tables, available from JMC as RDB3848)

J. R. Sand, E. A. Vineyard, and V. D. Baxter (Oak Ridge National Laboratory, ORNL), **Laboratory Evaluation of an Ozone-Safe Nonazeotropic Refrigerant Mixture in a Lorenz-Meutzner Refrigerator Freezer Design,** paper CH-93-20-4, *Transactions* (Winter Meeting, Chicago, IL, January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 99(1):1467-1481, 1993 (14 pages with 8 figures and 12 tables, RDB2412)

summarizes laboratory tests of a domestic refrigerator-freezer (RF) incorporating a Lorenz-Meutzner circuit design with R-32/124 (15/85) to increase the thermodynamic efficiency with zeotropic blends: comparisons the performance to reference data measured for before modification to the Lorenz-Meutzner design and for the modified circuit operating with R-12; describes the circuiting and component changes resulting from initial testing; presents computer modeling and compressor calorimeter results for R-12 and the blend used; concludes that the modifications yielded approximately 3% increase in efficiency, but that modeled results and steady-state data suggest potential for improvements of approximately 15%; suggests that the larger, predicted improvements are not realized due to poor heat transfer and refrigerant circuiting arrangements; includes discussion by C. Weng (Revco Scientific) and M. Kempiak (Admiral Company)

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 36, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (12 pages with 3 figures and 1 table, available from JMC as RDB3836)

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 45, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (10 pages with 1 figure and 5 tables, available from JMC as RDB3845)

performance test

H. Yasuda (Hitachi, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 40, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (12 pages with 1 figure and 2 tables, available from JMC as RDB3840)

This report summarizes calorimeter tests of R-32/134a (30/70) in a 1-10 kW (0.3-2.8 ton) rotary, rolling-piston compressor and in a 2.5-25 kW (0.7-7.1 ton) scroll compressor using an unidentified polyolester (POE) lubricant. The charge and lubricant quantities, motor characteristics, and test conditions are indicated. A table presents evaporator and condenser temperatures and pressures along with compressor speed and discharge temperature. The capacity, input, and efficiency are tabulated relative to an undescribed base performance, presumed to be that with R-22. The efficiencies and capacities are indicated to be approximately 3-6% and 7-12% lower, respectively, for the rotary compressor and 10% lower to 1% higher and 5-13% lower, respectively, for the scroll compressor. A schematic shows the calorimeter arrangement and instrumentation.

DuPont Suva® HP Refrigerant Blends: Properties, Uses, Storage, and Handling, bulletin P-HP (H-47122), DuPont Chemicals, Wilmington, DE, January 1993 (24 pages with 2 figures and 7 tables, RDB3442)

This document provides extensive application information for R-402A and R-402B, both blends of R-125, R-290, and R-22 - R-125/290/22 (60/2/38) and R-125/290/22 (38/2/60) respectively. It also addresses R-404A, a blend of R-125, R-143a, and R-134a - R-125/143a/134a (44/52/4). It reviews identifiers, the blend compositions, and potential uses. The bulletin then summarizes physical properties as well as flammability, environmental, and toxicity indices. The bulletin reviews chemical and thermal stability data, including thermal decomposition. A table provides representative data on stability with metals (copper, iron, and aluminum) based on sealed-tube tests of mixtures of R-402B with mineral oil (Witco Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150 TD), and a branched acids polyolester (Castrol Icematic(R) SW32) lubricants. Results also are provided for R-404A with the same lubricants and a mixed acids ester (Mobil EAL Arctic(R) 22). The report reviews compatibility of the refrigerant blends with R-502, noting chemical compatibility but separation difficulty leading to a need for disposal by incineration. It then addresses compatibility with elastomers; a tabular summary is provided for five polymers with combinations of the cited lubricants and R-502, R-402B, and R-404A. The compounds tested were polytetrafluoroethylene (PTFE, DuPont Teflon(R) in commercial grade sheet from Tex-O-Lon Manufacturing), Buna N nitrile butadiene (NBR, Parker Seal), hydrogenated NBR (HNBR, Parker Seal N1195), chloroprene (CR, Precision Rubber neoprene W), and EPDM (Kirkhill Rubber). Compatibility data also are discussed for polyethylene terephthalate (PET, DuPont Mylar(R) film), polyesterimide motor wire with amide-imide overcoating, and Dacron/Mylar/Dacron(R) lead wire (Belden) as well as for molecular sieve desiccants (UOP 4A-XH-5 and XH-9). Miscibility is summarized for R-502 and the three zeotropes with mineral oil, alkylbenzene, and polyolester lubricants. Safety data are then presented including a review of inhalation toxicity, cardiac sensitization, responses to spills or leaks, skin and eye contact, and flammability. Monitors and leak detection are discussed as are storage, handling, and shipping. The bulletin concludes with discussion of recovery, reclamation, recycling, and disposal. DuPont's product names for R-402A, R-402B, and R-404A are Suva(R) HP80, Suva(R) HP81, and Suva(R) HP62 respectively. [see RDB3C02 for update]

Genetron(R) AZ-20, technical bulletin #652 (B-525-652), AlliedSignal Incorporated, Morristown, NJ, January 1993 and reissued May 1993 (4 pages with 3 tables, RDB3219)

This bulletin describes a patented azeotropic blend of R-32 and R-125, specifically R-32/125 (60/40), designed to replace R-22 in residential air-conditioning systems. It provides physical property data, in inch-pound (IP) units, including the chemical formula, molecular weight, atmospheric boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), flammability, and ozone depletion potential. It also indicates the liquid density and specific heats of the liquid and vapor at 26.7 °C (80 °F). It then presents a tabular comparison of performance with R-22, R-32, R-125, and R-502. The report provides tabular thermodynamic properties (pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -29 to 71 °C (-20 to 160 °F). Formulae are provided to calculate thermodynamic properties including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. AlliedSignal's product name for R-32/125 is Genetron(R) AZ-20 [the composition was subsequently reformulated from that described in this document.]

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Genetron(R) AZ-50, technical bulletin 525-651, AlliedSignal Incorporated, Morristown, NJ, January 1993 (4 pages with 3 tables, RDB3222)

This bulletin describes an azeotropic blend of R-125 and R-143a, specifically R-125/143a (45/55), designed to replace R-502 in low-temperature commercial refrigeration applications. It provides physical property data, in inch-pound (IP) units, including the chemical formula, molecular weight, atmospheric boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), flammability, and ozone depletion potential. It also indicates the liquid density and specific heats of the liquid and vapor at 26.7 °C (80 °F). It then presents a tabular comparison of performance with R-22 and R-502. The report provides tabular thermodynamic properties (pressure, density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -40 to 71 °C (-40 to 160 °F). Formulae are provided to calculate thermodynamic properties including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. AlliedSignal's product name for R-125/143a is Genetron(R) AZ-50 [the composition was subsequently reformulated from that described in this document.]

Retrofit Guidelines for Suva(R) HP81, document ART-15 (H-47763), DuPont Chemicals, Wilmington, DE, January 1993 (10 pages with 2 tables, available from JMC as RDB3446) [see RDB4506 for update]

R-402B

1993 (month not indicated)

A. Abdul-Razzak, M. Shoukri, and J-S. Chang (McMaster University, Canada), **Literature Review on Measurement of Two-Phase Refrigerant Liquid-Vapor Mass Flow Rate**, interim report for 722-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1993 (rdb4684)

refrigerant mass-flow rate, instrumentation

E. M. Clark (DuPont Chemicals) and M. O. McLinden (National Institute of Standards and Technology, NIST), **Refrigerants**, *ASHRAE Handbook - Fundamentals* (published in separate editions with inch-pound and SI metric units), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, chapter 16, 16.1-16.10, 1993 (10 pages with 2 figures and 14 tables, RDB3A79)

This chapter summarizes information on common refrigerants, including designations, physical and electrical properties, performance, safety data, leak detection methods, and effects on construction materials. The refrigerants addressed include R-10, R-11, R-12, R-12B1, R-12B2, R-13, R-13B1, R-14, R-20, R-21, R-22, R-22B1, R-23, R-30, R-31, R-32, R-40, R-41, R-50, R-110, R-111, R-112, R-112a, R-113, R-113a, R-114, R-114a, R-114B2, R-115, R-116, R-120, R-123, R-123a, R-124, R-124a, R-125, R-133a, R-134a, R-140a, R-141b, R-142b, R-143a, R-150a, R-152a, R-160, R-170, R-216ca, R-218, R-245cb, R-290, R-C316, R-C317, R-C318, R-400, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-600, R-600a, R-610, R-611, R-620, R-630, R-631, R-702, R-704, R-717, R-718, R-720, R-728, R-732, R-740, R-744, R-744A, R-764, R-1112a, R-1113, R-1114, R-1120, R-1130, R-1132a, R-1140, R-1141, R-1150, and R-1270. Molecular mass, normal (atmospheric) boiling point, freezing point, critical properties (temperature, pressure, and specific volume), and liquid refractive index are tabulated for most of these fluids. Dielectric constants, volume resistivity, velocity of sound, latent heat of vaporization, comparative performance, effects of temperature on performance, and safety classifications are presented for the more common fluids. Swell data are tabulated for R-11, R-12, R-13, R-13B1, R-21, R-22, R-30, R-40, R-113, R-114, R-502, and R-600 for eight elastomers. They include nitrile butyl rubber (Buna(TM) N), butadiene styrene (Buna(TM) S, GR-S), Butyl(TM) (GR-1), natural rubber, neoprene GN, polysulfide rubber (Thiokol(R) FA), fluoroelastomer (DuPont Viton(R) B), and silicone. Diffusion data are tabulated for water, R-12, and R-22 through neoprene, Buna N, synthetic rubber (DuPont Hypalon(R) 40), Butyl, Viton, polyethylene, and natural rubber. Mass density, specific heat, and viscosity are plotted for water/lithium bromide solutions (for absorption cycles) as functions of the mass fraction of lithium bromide.

S. W. Crown, **An Experimental Study of Thermal Performance of R-134a and Refrigerant Blends in an Air Conditioning System**, PhD dissertation, Iowa State University of Science and Technology, Ames, IA, 1993 (rdb6338)

performance comparison of R-134a and refrigerant to R-12

F. de Rossi, R. Mastrullo (Università di Napoli "Frederico II", Italy), and P. Mazzei (Università degli Studi di Salerno, Italy), **Exergetic and Thermodynamic Comparison of R12 and R134a as Vapour-Compression Refrigeration Working Fluids**, *International Journal of Refrigeration* (IJR), 16(3):156-160, 1993 (5 pages, rdb8507)

R-12, R-134a, efficiency, thermodynamic properties, thermophysical data

R. Döring (Fachhochschule Münster, Germany), H. Buchwald, and C. von Eynatten (Solvay Fluor und Derivate GmbH, Germany), **Gemische aus R134a und R23, pvTx-Messungen sowie Ergebnisse weiterer experimenteller und theoretischer Untersuchungen** [Mixtures of R-134a and R-23, pvTx Measurements along with Results of Further Experimental and Theoretical Investigations], *DKV-Tagungsberichte*, Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 20(II.2):65 ff, 1993 (in German, rdb8C12)

pressure, volume, temperature, and concentration data and analyses for R-23/134a blends

D. A. Fisher (E. I. duPont de Nemours and Company, USA) and P. M. Midgley (M&D Consulting, Germany), **The Production and Release to the Atmosphere of CFCs 113, 114, and 115**, *Atmospheric Environment, 27*A(2):271-276, 1993 (6 pages, RDB5503)

R-113, R-114, R-115, production and emission data

J. Franklin, **The Atmospheric Degradation and Impact of 1,1,1,2-Tetrafluoroethane (Hydrofluorocarbon 134a)**, *Chemosphere*, 27(8):1565-1601, 1993 (37 pages, rdb65B2)

refrigerant decomposition, atmospheric reactions

B. Frehn, **Propan als Arbeitsmittel für Wärmepumpen - die beste Alternative zu R22** [Propane as Working Fluid for Heat Pumps - the Best Alternative for R-22], *Ki Klima-Kälte-Heizung*, Germany, 10:402-405, 1993 (4 pages in German, rdb8369)

R-290

E. Granryd and Å. Melinder (Kungliga Tekniska Högskolan, KTH, Sweden), **Köldbärare för indirekta Kyl- och Värmepumpsystem** [Refrigerants for Indirect Refrigeration and Heat Pump Systems], Scan Ref, Stockholm, Sweden, (6):29-34, 1993 (6 pages, rdb5329)

alternative refrigerants

T. Hackenseller and C. Jurisch, **Die Untersuchung von Hochtemperatur-Kompressions-Wärmepumpen mit dem Arbeitsmedium Wasser** [Examination of High-Temperature Vapor-Compression Heat Pumps Using Water as the Working Fluid], *Fortschritt-Berichte VDI*, VDI-Verlag, Düsseldorf, Germany, 19(71), 1993 (in German, rdb5A15)

R-718

J. C. Holste (Texas A&M University), **Thermodynamic Properties of Refrigerants R-125 and R-141b**, final report for 654-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1993 (rdb4A54)

measured thermodynamic properties of R-125 and R-141b; thermophysical data

T. Hozumi, H. Sato, and K. Watanabe (Keio University, Japan), **Ideal Gas Heat Capacities for Four Kinds of HFC Refrigerants**, *Proceedings of the 1993 Annual Conference,* Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 9-12, 1993 (4 pages, rdb8246)

thermophysical properties

International Union of Pure and Applied Chemistry (IUPAC) Commission on Atomic Weights and Isotopic Abundances, **Atomic Weights of the Elements 1991**, *Journal of Physical and Chemical Reference Data*, 22(6):1571-1584, 1993 (14 pages, rdb4567)

definitive atomic weights used to calculate the molecular mass of refrigerants

M. Jelinek, N. C. Daltrophe, and I. Borde (Ben-Gurion University of the Negev, Israel), **Prediction of Thermophysical Properties of CFC-Free Refrigerants**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 199-206, 1993 (8 pages with 6 tables, RDB5317)

R-32, R-124, R-134a, thermodynamic data, specific volume, enthalpy, entropy

M. O. McLinden (National Institute of Standards and Technology, NIST) and S. G. Penoncello (University of Idaho), **Refrigerant Properties**, *ASHRAE Handbook - Fundamentals* (published in separate editions with inch-pound and SI metric units), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, chapter 17, 17.1-17.86, 1993 (86 pages, RDB3A80)

This chapter provides pressure-enthalpy (Mollier) diagrams and tabulates thermodynamic and thermophysical properties for R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-32, R-50 (methane), R-113, R-114, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-152a, R-170 (ethane), R-290 (propane), R-500, R-502, R-503, R-600 (butane), R-600a (isobutane), R-702 (normal hydrogen), R-702p (parahydrogen), R-704 (helium), R-717 (ammonia), R-718 (water/steam), R-720 (neon), R-728 (nitrogen), R-729 (air), R-732 (oxygen), R-740 (argon), R-744 (carbon dioxide), R-1150 (ethylene), and R-1270 (propylene). The tabular data include temperature, pressure, vapor volume, liquid density, enthalpy, entropy, specific heat, specific heat ratio, velocity of

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sound, viscosity, thermal conductivity, and surface tension. An enthalpy-concentration diagram and tabular data for the specific volume at saturation are presented for ammonia/water for absorption cycles. Enthalpy equilibrium and concentration diagrams are similarly provided for water/lithium bromide solutions.

W. M. Meylan and P. H. Howard, **Computer Estimation of the Atmospheric Gas-Phase Reaction Rate of Organic Compounds with Hydroxyl Radicals and Ozone**, *Chemosphere*, 26(12):2293-2299, 1993 (7 pages, rdb5960)

refrigerant decomposition, atmospheric reactions, lifetime

P. M. Midgley (M&D Consulting, Germany) and D. A. Fisher (E. I. duPont de Nemours and Company, USA), **The Production and Release to the Atmosphere of Chlorodifluoromethane (HCFC 22)**, *Atmospheric Environment*, 27A(14):2215-2223, 1993 (9 pages with 5 figures and 5 tables, RDB5507)

R-22, production and emission data

F. G. Oberender, **Refrigerant and Refrigeration Oil Trends**, *Lubrication*, Texaco Publications, 79(3):1-16, 1993 (16 pages, RDB6372)

lubricants

S. G. Penoncello, R. T. Jacobsen, R. C. Williams, and E. W. Lemmon (University of Idaho), **Comparisons of Equations of State for HFC-134a and HCFC-123**, report for IEA HPC Annex 18 (also identified as Center for Applied Thermodynamic Studies, CATS, report 93-3), International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, 1993 (52 pages with 55 tables, rdb5850)

R-123, R-134a, thermodynamic properties, thermophysical data

R. A. Perkins, L. J. Van Poolen, J. B. Howley, and M. L. Huber, **Thermal Conductivity of 2-Chloro-1,1,1,2-tetrafluoroethane (R-124)**, unpublished paper, National Institute of Standards and Technology (NIST), Boulder, CO, 1993 (rdb3924)

R-124, transport properties, thermophysical data (see RDB2801)

J. Pettersen and G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Eine neue, effiziente und umweltfreundliche Pkw-Klimaanlage mit CO_2 als Kältetechnik** [A New Efficient and Environmentally Friendly Systems for Automobile Air Conditioning with Carbon Dioxide as the Cooling Means], *Luft- und Kältetechnik*, Germany, (3):105-111, 1993 (7 pages in German, rdb4149)

R-744, carbon dioxide

V. G. Skripka et al., **Vapor-Liquid Equilibrium of Binary Systems of Natural Gas Components at Low Temperatures**, *Gazovaja Promyslennost'*, publication date unknown - circa 1993 (in Russian, rdb5716)

thermodynamic properties, R-50, R-290, R-600a, and R-290/600a blends: thermophysical data [referenced in RDB5705]

G. A. Sturrock, P. G. Simmonds, G. Nickless, and D. Zweip, *Journal of Chromatography*, 648:423-431, 1993 (9 pages, rdb5212)

gas chromatography of various chlorofluorocarbons (CFCs)

N. Tengblad, **Resultat från prov med liten luft-luft värmepump med propan/gasol som köldmedium** [Results from Tests on a Small Air-to-Air Heat Pump with Propane/Gasol as Working Medium], report REFR/R-93/12-Se, Kungliga Tekniska Högskolan [Royal Institute of Technology] (KTH), Stockholm, Sweden, 1993 (in Swedish, rdb5722)

R-290

R. Tillner-Roth and H. D. Baehr (Universität Hannover, Germany), **Measurements of p,rho,T Properties in the Liquid, Near Critical and Supercritical Regions of 1,1,1,2-Tetrafluoroethane (R134a) and 1,1-Difluoroethane (R152a)**, *Journal of Chemical Thermodynamics*, 25:277-292, 1993 (8 pages, rdb4408)

thermodynamic properties of R-134a and R-152a: pressure, density, temperature, thermophysical data

W. Wagner and A. Pruß, **International Equations for the Saturation Properties of Ordinary Water Substance. Revised According to the International Temperature Scale of 1990 (Addendum to 16:1893, 1987)**, *Journal of Physical and Chemical Reference Data*, 22(3):783-787, 1993 (5 pages, rdb-7B33)

R-718 (water), thermodynamic properties, thermophysical data, equation of state (EOS)

H-W. Xiang, **Theoretical Studies on the Equations of Thermophysical Properties of Fluids and Experimental Measurements of Vapor Pressure of R32 and PVTx of R32/R152a**, MS thesis, Xi'an Jiaotong University, China, 1993 (in Chinese, rdb8948)

thermodynamic properties of R-32 and R-32/152a; thermophysical data

1993-1994 Research Plan, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1 January 1993 (40 pages, RDB3118)

This list of prospective research subjects identifies 238 proposed projects, 72 designated as priority status. The projects are grouped into nine project classifications, based on approved funding guidelines. Projects relating to refrigerants fall in several of these categories, including the highest priority topic, *Environmentally-Safe Materials (CFC, etc)*. The research areas were proposed by ASHRAE Technical Committees, Task Groups, and other committees; they were prioritized by ASHRAE's Research and Technical Committee. The highest priority group *(three stars)* includes research of *"Thermophysical Properties of Alternative Refrigerants*." The next classification includes "*Cascade Refrigeration System to Replace CFC and HCFC Refrigerants Below -60 °F*" [-51 °C]. The *one-star* priority group includes development of "*A Uniform Equation of State for Alternatives to CFC Refrigerants*." It also includes *"Dispersion of Ammonia Plumes in the Atmosphere*" and research to "*Develop Solubility and Viscosity Data for Various Oil-Refrigerant Mixtures at High Discharge Temperatures and Pressures*." Among nonpriority projects are those addressing "*Mixtures of Alternative Refrigerants and Lubricating Oils - Properties and Effects on Heat Transfer*," "*Develop Corrosion Data with Materials of Construction and New Refrigerant-Lubricants at Various Moisture Levels*," "*Develop Refrigerant-Lubricant-Desiccant Moisture Equilibrium Data with New HFC Refrigerants and Relevant Lubricants,"* and *"Measurement of R-22 and Alternative Refrigerant Leakage Rates from Open-Shaft Compressors*." Further projects will examine *"Double-Walled Heat Exchangers for Class 2 Refrigerants," "Heat and Mass Transfer Additives in Aqua Ammonia Systems," "Impacts of Lubricants on the Segregation of Nonazeotropic Refrigerant Mixtures," "Impacts of Lubricants on the Segregation or Fractionation of Refrigerant Mixtures*." This plan summarizes anticipated funding and procedures for implementing the research identified; it replaces versions published for preceding years [see RDB2426].

1992 Annual Report, Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Washington, DC, 1993 (12 pages, RDB3609)

Analytical Procedures for ARI Standard 700-93, Appendix 93 to ARI Standard 700, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1993 (176 pages with 40 figures and 40 tables, available from ARI for $75.00, RDB4943)

This document identifies definitive test procedures to determine the quality of new, reclaimed, and/or repackaged refrigerants for use in new and existing refrigeration equipment. These procedures are identified as referee methods; users must be able to demonstrate that the results of alternative test procedures employed are equivalent. Information is provided on the sensitivity, precision, and accuracy of each method. The tests covered are for determination of acidity, water (moisture) by Karl Fischer coulometric titration, high boiling residue by volumetric and/or gravimetric measurement, visual particulate residue, chloride content by silver chloride precipitation, and noncondensable gas content by gas chromatography (GC). The document also identifies GC procedures to determine the purity, and for blends the compositions, of R-11, R-12, R-13, R-22, R-23, R-32, R-113, R-114, R-123, R-124, R-125, R-134a, R-143a, R-401 series blends (R-22/152a/124), R-402 series blends (R-125/-290/22), R-500, R-502, and R-503.

Revision of the ASHRAE 'Thermophysical Properties of Refrigerants', research project 558-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, December 1987 - 1993 (ASH0558)

The objective of this project was to update a standard reference on refrigerant properties. The work comprised a literature search, data analysis, development of empirical or semi-empirical property equations, and preparation of tables. The fluids addressed included R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-50 (methane), R-113, R-114, R-115, R-142b, R-152a, R-170 (ethane), R-290 (propane), R-C318, R-500, R-502, R-503, R-600 (butane), R-600a (isobutane), R-702 (hydrogen), R-702p (para-hydrogen), R-704 (helium), R-717 (ammonia), R-718 (water), R-720 (neon), R-728 (nitrogen), R-729 (air), R-732 (oxygen), R-740 (argon), R-744 (carbon dioxide), R-1150 (ethene), and R-1270 (propene). The contractor was Purdue University, led by P. E. Liley and P. D. Desai; it was sponsored by ASHRAE Technical Committee 3.1, *Refrigerants and Brines.*

Specifications for Fluorocarbon and Other Refrigerants, standard 700-93, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1993 (12 pages with 1 table, available from ARI for $15.00, RDB4942)

This standard specifies acceptable levels of contaminants for fluorocarbon and other refrigerants, regardless of source (new, reclaimed, and/or repackaged). It is intended for the guidance of manufacturers, refrigerant reclaimers, repackagers, distributors, installers, servicemen, contractors, and consumers. It identifies purity requirements and determination procedures for acceptance or rejection of refrigerants, for both new and existing refrigeration and air-conditioning products. These refrigerants include R-

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11, R-12, R-13, R-22, R-23, R-32, R-113, R-114, R-123, R-124, R-125, R-134a, R-143a, R-22/-152a/124 (53/13/34) [R-401A], R-22/152a/124 (61/11/28) [R-401B], R-125/290/22 (60/2/38) [R-402A], R-125/290/22 (38/2/60) [R-402B], R-500, R-502, and R-503. It provides for characterization of refrigerants by gas chromatography and boiling point or boiling point range. It also addresses water (moisture), chloride, acidity, high boiling residue, particulates and solids, non-condensables, and impurities including other refrigerants. The standard outlines procedures of sampling, purity determination, and reporting. A table lists the physical properties and maximum contaminant levels for covered refrigerants. It addresses the boiling point, typical isomer content (including R-113a in R-113, R-114a in R-114, R-123a in R-123, R-124a in R-124, R-134 in R-134a, and R-143 in R-143a), and the cited impurities. An appendix, published separately, describes the test procedures to be used.

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A. Advani (Safeway Incorporated), **Alternate Refrigerants and Energy Savings in Supermarkets**, *ASHRAE Journal,* 34(12):40-42, December 1992 (3 pages with 4 figures, RDB3224)

alternative refrigerants, commercial refrigeration

J. Barnhart, **An Experimental Investigation of Flow Patterns and Liquid Entrainment in a Horizontal Tube Evaporator**, PhD thesis (Department of Mechanical Engineering), University of Illinois, December 1992 (rdb3B49)

R. E. Cawley (The Trane Company), **Compressor Calorimeter Test of Refrigerant Blend R-32/-125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 19, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 4 December 1992 (14 pages with 8 figures and 2 tables, available from JMC as RDB3819; table 2 contains type that is small and may be difficult to read)

performance test for R-407 series blend

R. E. Cawley (The Trane Company), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (25/75)**, Alternative Refrigerants Evaluation Program (AREP) report 20, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 4 December 1992 (14 pages with 8 figures and 2 tables, available from JMC as RDB3820; table 2 contains type that is small and may be difficult to read)

J. Chen and G. G. Haselden (University of Leeds, UK), **Mixed Refrigerants for Air Conditioning and Heat Pumping**, *Proceedings of the Institute of Refrigeration*, 89:3-1 - 3-10, 3 December 1992 (10 pages with 7 figures and 3 tables, RDB5811)

R-22/142b, zeotropic blends, performance, cost implications, balanced-thrust modulating float valve

P. R. Glamm and E. F. Keuper (The Trane Company), **Drop-In Test of Refrigerant R-134a and Refrigerant Blends R-32/125/134a (24/16/60), R-32/134a (30/70), and R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 16, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1992 (14 pages with 6 tables, available from JMC as RDB3816)

J. P. Soley (Unidad Hermética, S.A., Spain), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 23, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1992 (10 pages with 6 tables, available from JMC as RDB3823)

G. B. Wetzel (McQuay International, then Snyder-General Corporation), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 27, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1992 (14 pages with 7 tables, available from JMC as RDB3827)

Pilot Survey of Refrigerant Use and Emissions from Retail Food Stores, research project 691-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1991 - December 1992 (ASH0691)

The contractor for the project was the Radian Corporation, led by T. J. Nelson; it was sponsored by the ASHRAE Task Group on *Halocarbon Emissions*

Thermodynamic Properties of Refrigerants 125 and 141b, research project 654-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1990 - December 1992 (ASH0654)

This study determined the liquid densities, vapor densities, vapor pressures, PVT properties, enthalpy, entropy, specific heat, and sound velocities of R-125. Vapor specific heat and PVT were determined for R-141b. Critical temperatures and pressures also were determined for each substance. The contractor for the project was Texas A&M University led by J. C. Holste; it was sponsored by ASHRAE Technical Committee 3.1, *Refrigerants and Brines.*

November 1992

J. Allcott (McQuay International, then McQuay Refrigeration of SnyderGeneral Corporation, UK), **HFC-134a and Centrifugal Compressors**, *CFC Alternatives: User Experience and Update,* Institution of Mechanical Engineers and The Institute of Refrigeration, London, UK, 11 November 1992 (9 pages with 4 figures and 5 tables, RDB3336)

R-134a

M. Buschmeier, W. Künstler, G. Herres, and D. Gorenflo (Universität Paderborn, Germany), **Phasengleichgewicht und Dichte der Stoffsysteme R22/R142b sowie R227/R123** [Phase Equilibria and Densities of R-22/142b and R-227ea/123 Blends], *DKV-Tagungsberichte* (Bremen, Germany, November 1992), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 19:99-120, 1992 (rdb5494)

thermodynamic properties of R-22/142b and R-227ea/123 (identified in the paper as R-227/123): equation of state (EOS); thermophysical data

D. J. G. Butler (Building Research Establishment, UK), **Summary of Trials with New Refrigerants in Air Conditioning**, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and The Institute of Refrigeration, London, UK, 11 November 1992 (10 pages with 2 figures and 3 tables, RDB3334)

alternative refrigerants, performance

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-4E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, November 1992 (94 pages, available from JMC as RDB2B04)

This superseded document provides bibliographic citations for 530 publications that may be useful in research and design of air-conditioning and refrigeration equipment. Abstracts that emphasize the content, materials addressed, and key conclusions are provided for approximately half of these documents. The database identifies sources of specific information on R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-245ca, R-290 (propane), R-600 (butane), R-717 (ammonia), ethers, and others as well as azeotropic and zeotropic blends of these fluids. It addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), ester, and other lubricants. It also references documents addressing compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits. The database is available in a computerized version, to facilitate searches for specific information, and as a listing in report form. Ordering instructions for both versions of the database, as well as for documents and software cited in it, are included.

N. E. Carpenter (ICI Chemicals and Polymers, Limited), **An Overview: Options for the Supply of Alternative Refrigerants**, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and The Institute of Refrigeration, London, UK, 11 November 1992 (12 pages with 9 tables, RDB3329)

J. L. Cox (Rheem Manufacturing Company), **Drop in Test of Refrigerant Blend R-32/134a (25/75)**, Alternative Refrigerants Evaluation Program (AREP) report 25, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, November 1992 (6 pages with 3 tables, available from JMC as RDB3825)

S. C. Ericson, S. K. Chaturvedi, S. Boregowda (U.S. Navy), **Prediction of Refrigerant Properties and Heat Pump Cycle Thermal Performance Using Several Equations of State**, *Recent Research in Heat Pump Design, Analysis, and Application* (Winter Annual Meeting, Anaheim, CA, 8 November 1992), American Society of Mechanical Engineers (ASME), AES-28:53-60, 1992 (8 pages, rdb7366)

presents a methodology, employing several equations of state (EOSs), for performance analysis of vapor-compression cycles for heat pumps: discusses five approaches employing the Redlich-Kwong (RK), Peng-Robinson (PR), and Carnahan-Starling-DeSantis (CSD) EOSs to predict thermodynamic properties for R-22 and R-152a; concludes that use of the PR EOS and the Reidel equation for vapor pressure yields the best results while calculations with the RK equation deviated the most from published property data, especially for liquid properties; describes a computational procedure to analyze a basic heat pump cycle

H. T. Haukås (Norgest Tekniska Högskole, NTH, Norway), **Practical Performance of Alternatives to R-12 and R-502 in Refrigerators and Freezers**, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and The Institute of Refrigeration, London, UK, 11 November 1992 (7 pages with 9 figures and 2 tables, RDB3333)

R. D. Heap (Shipowners Refrigerated Cargo Research Association, UK), **Practical Application of Alternative Refrigerants in Refrigerated Trans-**

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port, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and The Institute of Refrigeration, London, UK, 11 November 1992 (7 pages with 3 tables, RDB3332)

H. Jürgensen (AEG Hausgeräte AG, Germany), **Messungen an Haushaltskühlgeräten mit brennbaren Kältemitteln** [Measurements of Residential Refrigerators with Flammable Refrigerants], presentation charts, *DKV Jahrestagung* [DKV Annual Meeting] (Bremen, Germany, 17 November 1992), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 1992 (18 pages, in German, RDB3109)

R-290, propane, R-600, butane, R-601, isobutane, hydrocarbon blends

M. A. Palmer (W. S. Atkins Limited, UK), **Better Ways of Using Ammonia**, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and The Institute of Refrigeration, London, UK, 11 November 1992 (4 pages with 4 figures, RDB3335)

S. G. Sundaresan (Copeland Corporation), **Aspects of Lubrication, Fractionation, and Reliability of Compressors with New Refrigerants for Commercial Refrigeration**, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and The Institute of Refrigeration, London, UK, 11 November 1992 (12 pages with 1 figure and 7 tables, available from JMC as RDB3330)

This paper presents findings of an evaluation of candidate refrigerants to replace R-12 and R-502 in commercial refrigeration. The R-12 alternatives discussed include R-134a, R-22/152a/124 (52/15/33) (a developmental version of DuPont Suva(R) MP39), and R-22/152a/124 (60/13/27) (a developmental version of Suva MP66). The R-502 alternatives include R-143a/22 (composition unspecified, a developmental version Atochem Forane(R) FX10), R-32/125/143a (10/-45/45) (a developmental version of Forane FX40), R-404A [R-125/143a/134a (44/52/4) marketed as Forane FX70 and as Suva HP62], R-402A [R-125/290/22 (60/2/38) marketed as Suva HP80], R-290/22/218 (6/55/39) (a developmental version of Rhône-Poulenc Isceon 69L), R-32/125/134a (30/40/30) (a developmental version of ICI Klea(R) 60), and R-125/143a (45/55) (a developmental version of AlliedSignal Genetron(R) AZ-50). The lubricants addressed include formulated alkylbenzene and polyolesters, though only the latter was considered for the chlorine-free refrigerants. The paper discusses and tabulates environmental and performance data for the refrigerant candidates. It then discusses selection criteria for lubricants, both for new equipment and retrofit; two tables summarize the lubricants selected. The paper then addresses fractionation. A figure illustrates the change in composition and a table lists the effects on pressure, capacity, efficiency, and discharge temperature with HP62, as a vapor leak progresses. Another table gives the composition changes, capacity and efficiency ratios, and discharge temperature differences at compressor inlet for a near azeotrope. A final table, indicates the change in composition for four blends for liquid removal from a tank from 90 to 10% full.

J. Wang, Z-G. Liu, L-C. Tan, and J-M. Yin (Xi'an Jiaotong University, China), **Measurements of the Vapor-Liquid Coexistence Curve in the Critical Region for Refrigerant Mixture R152a/R22**, *Preprints of the 11th Symposium on Thermophysical Properties* (Boulder, CO, 23-27 June 1991), American Society of Mechanical Engineers (ASME), New York, NY, 1991; republished in *Fluid Phase Equilibria*, 80(4):203-211, 30 November 1992 (9 pages, rdb8961)

measurements of the vapor-liquid coexistence curve in the critical region for R-22/152a (20/80), (50/50), and (80/20) by observation of meniscus disappearance at the vapor-liquid interface within an optical cell: reports 31 data points for saturated vapor and liquid in the critical region at 99-112 °C (210-233 °F); determines the critical temperatures and densities and critical locus of temperature-density; correlates the critical temperature and density to composition R-22/152a blends

DuPont HFC-134a: Properties, Uses, Storage, and Handling, bulletin P134a (H-45945), DuPont Chemicals, Wilmington, DE, November 1992 (32 pages with 10 figures and 20 tables, available from JMC as RDB3439)

This document provides extensive application information for R-134a. It reviews identifiers and potential uses, shows an infrared spectrum for laboratory analyses, compares theoretical performance to R-12, and summarizes physical properties as well as flammability, environmental, and toxicity indices. Plots of solubility in water, pressure-temperature relationships, and vapor thermal conductivity are included. Pressure-enthalpy diagrams, in both inch-pound (IP) and metric (SI) units, are provided. The bulletin reviews chemical and thermal stability data, including thermal decomposition, stability with metals and refrigeration lubricants, stability with foam chemicals, and concerns if mixed with R-12. It then addresses compatibility with plastics, elastomers, desiccants, and refrigeration lubricants. A table summarizes compatibility with plastics including ABS polymer (Kralastic(R)), acetal (DuPont Delrin(R)), acrylic (Lucite(R)), cellulosic (Ethocel(R)), epoxy, polytetrafluoroethylene (PTFE, DuPont Teflon(R)), ETFE (Tefzel(R)), PVDF, ionomer (Surlyn(R)), nylon 6/6 polyamide (DuPont Zytel(R)), polyarylate (Arylon(R)), polycarbonate (Tuffak(R)), polybutylene terephthalate (PBT, GE Valox(R)), polyethylene terephthalate (PET, DuPont Rynite(R)), polyetherimide (GE Ultem(R)), polyethylene-HD (Alathon(R)), polyphenylene oxide (PPE, GE Noryl(R)), polyphenylene sulfide (Ryton(R)), polypropylene, polystyrene (Styron(R)), polysulfone (Polysufone(R)), and polyvinyl chloride (PVC and CPVC). Tabular summaries also are provided for R-134a compatibility with a urethane rubber (Uniroyal Adiprene(R) L), Buna N, Buna S, butyl rubber, synthetic rubber (DuPont Hypalon(R) 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel(R)), silicone rubber, polysulfide rubber (Thiokol(R) FA), and fluoroelastomer (DuPont Viton(R) A). These summaries indicate changes in length, weight, Shore A hardness, elasticity, and appearance after exposures at 25 and 80 °C (77 and 176 °F). A table summarizes permeation through elastomeric hoses made of nylon, Hypalon 48, and two nitriles with identified liners, reinforcement, and covers. Solubility data are provided for R-134a in unidentified naphthenic mineral oil, dialkylbenzene, alkylbenzene, polyalkylene glycol (PAG), and ester lubricants. Safety data are then presented including a review of inhalation toxicity, cardiac sensitization, responses to spills or leaks, and skin and eye contact. Flammability data and recommended practices for leak testing, bulk delivery, storage, charging, and recovery are reviewed. Monitors and leak detection are discussed as are storage, handling, and shipping. The bulletin concludes with discussion of recovery, reclamation, recycling, and disposal.

Participants' Handbook: R-22 Alternative Refrigerants Evaluation Program (AREP), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 2 November 1992 (44 pages, available from JMC as RDB2B03)

This document outlines an ARI program to evaluate candidate alternatives for R-22 and R-502, the latter an azeotrope of R-22 and R-115, for unitary air conditioners, heat pumps, chillers, refrigeration equipment, and ice-making machines. This cooperative program seeks to accelerate introduction of alternatives by focusing research efforts and avoiding duplicative work. The document outlines the AREP organization, including is Task Force (chaired by D. M. Goldberg), Technical Committee (chaired by E. B. Muir), and Heat Transfer Subcommittee. It identifies cooperating organization, including the European Committee of Manufacturers of Refrigeration Equipment (CECOMAF) and the Electric Power Research Institute (EPRI). EPRI is funding, coordinating, and managing the heat transfer segment, an integral part of the program. The document identifies the nomination process and resultant candidate refrigerants, which have changed since the prior version of this document. They include R-32/125 (60/40), R-32/134a (30/70), R-32/125/134a (10/70/20), R-290 (propane), R-134a, R-717 (ammonia), R32/125/290/134a (20/55/5/20), R-32/125/134a (30/10/60), R-32/134a (25/75), R-32/227ea (35/65), R-125/143a (45/55), R-404A [R-125/143a/134a (44/52/4)], and R-32/125/143a (10/45/45). The last three are of primary interest as potential replacements for R-502. Procedures and conditions for compressor calorimeter and heat transfer test are specified for participants. Results of the work will be disseminated via the Refrigerant Database. Related research on toxicity and environmental assessments of the candidate fluids and components will be coordinated and shared. Appendices to this program handbook identify committee members, participation commitments, international organizations conducting similar research, and pertinent combinations of refrigerants and heat exchanger types. This handbook prescribes common terminology and definitions to be used as well as formats and contents to be provided for the program.

Retrofit Guidelines for Suva(R) HP80, document ART-9 (H-45947), DuPont Chemicals, Wilmington, DE, November 1992 (8 pages with 1 table, available from JMC as RDB3445) [see RDB4506 for update]

R-402A

October 1992

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials**, report DOE/CE/23810-4B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1992 (36 pages with 43 tables, available from JMC as RDB-2B01)

This interim report summarizes progress to provide compatibility information for motor materials (for hermetic compressors) in refrigerants and refrigerant-lubricant combinations. Tabular findings are reported for exposures to R-22, R-123, R-124, R-134, R-134a, R-142b, and R-152a at 90 °C (194 °F); to R-32, R-125, and R-143a at 60 °C (140 °F); and to nitrogen (R-728) at both temperatures, as a reference. Tests of dielectric strength, burnout resistance, and bond strength have not been completed yet for R-134; future tests are planned for R-245ca. Data are provided both after 500 hour exposures and after a subsequent air bake for 24 hours at 150 °C (302 °F), to remove absorbed refrigerant. Bond strength, burnout resistance, and dielectric strength are compared to the unexposed values for three magnet wires, both uncoated and pre-pared with six varnishes. The wire specimens included an ester base with amide-imide overcoat (Phelps Dodge Armored Poly-Thermaleze 2000), Dacron(R)/glass served wire (Phelps Dodge Armored Poly-Thermaleze Daglass 2000), and ester-imide overcoated with amideimide (Phelps Dodge/Schenectady Chemical). The varnishes tested include two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). Weight change also is reported for exposed disks of the six varnishes. Weight, tensile strength, elongation, and dielectric strength are compared to unexposed values for six sheet insulations (Westinghouse Nomex-Mylar-Nomex(R), Westing-house Dacron-Mylar-Dacron(R), DuPont Mylar(R) MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228). Weight change is tabulated for Insulations Sales Nomex(R), Mylar(R), and Nomex-Mylar(R) spiral-wrapped sleeving insulation. Changes in weight and dielectric strength are presented for A. O. Smith Dacron-Mylar-Dacron(R) and Dacron-Teflon-Dacron(R) lead wire insulations. Weight and breaking load changes are supplied for woven glass tape (Carolina Narrow), heat shrinkable braided polyester tape (Electrolock), glass-acrylic tape (Essex Permacel P247), and polyester tie cord (Ludlow Textiles). A final table compares gas chromatographic analyses of the refrigerants before and after 500 hr exposures. The report concludes that R-123 exhibited higher absorption and extraction than the other refrigerants tested. The most severe effect of refrigerants on motor materials was caused by high absorption followed by rapid desorption at higher temperatures. R-22 caused the most damage in this case; based on the excellent reliability history of this refrigerant with many of the materials tested, compatibility with the other refrigerants is highly probable. Final judgments should be postponed until studies are completed for the refrigerant-lubricant mixtures.

G. R. Hamed and R. H. Seiple (University of Akron), **Compatibility of Refrigerants and Lubricants with Elastomers**, report DOE/CE/23810-4C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1992 (148 pages with 17 figures and 95 tables including addendum 1, available from JMC as RDB2A12)

This superseded interim report summarizes swell measurements for 95 elastomers in refrigerants and lubricants. Swell behavior was determined using weight and in situ diameter measurements for the refrigerants and diameter and thickness measurements for the lubricants. The refrigerants include both hydrochlorofluorocarbons (HCFCs R-22, R-123, R-124, and R-142b) and hydrofluorocarbons (HFCs R-32, R-125, R-134, R-134a, R-143a, R-152a). The lubricants include a mineral oil (Witco Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150), and three polyalkylene glycols (PAGs), namely a polypropylene glycol butyl monoether (ICI Emkarox(R)), a polypropylene glycol diol (Dow P425), and a modified polyglycol (AlliedSignal BRL-150). Two polyolester (POE) lubricants also are included, namely a pentaerythritol ester branched acid (Henkel Emery(R) 2927-A) and a pentaerythritol ester mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244). Appropriately cured elastomers, encompassing both general purpose and specialty rubbers, were tested. Gum and black-filled compounds were included, as were some thermoplastic elastomers (TPEs). A series of figures summarize the diameter changes. Swell data also are tabulated, for exposures of 1, 3, and 14 days; weight change is tabulated after 14 days. The elastomers tested include polyisoprene, neoprene, butyl, bromobutyl, SBR/styrene, nitrile, hydrogenated nitrile, fluoroelastomer, fluorochloroelastomer, epichloro-hydrin (homopolymer, ethylene oxide copolymer, and terpolymers), dimethyl silicone rubber, methylphenylvinylsilozane rubber, silicone rubber, fluorosilicone, EPDM/PP/TPE, nitrile/PP/TPR, chlorosulfonated polyethylene, ethylene/propylene copolymer (EPM), ethylene/acrylic elastomer, chlorinated polyethylene, EPDM, butyl rubber, chloroprene, and ACN compound. The test methodology and apparatus are described in an appendix. The report indicates that filled compositions swelled less than corresponding unfilled ones in all cases. R-123 generally resulted in the greatest swelling, but EPDM/PP/TPE, butyl rubber/PP TPE, and several vendor-supplied compositions swelled little in this refrigerant. R-134 and R-134a caused much less swelling in general, with the exception of with fluoroelastomers and fluorosilicone elastomers. Some vendor compositions are identified that resisted swelling in all refrigerants and lubricants tested. R-143a, the least acidic of the refrigerants tested, gave the least swelling overall. Some compositions shrunk, suggesting that the swellant was removing a component, probably plasticizer, from the elastomer.

G. C. Hourahan and S. R. Szymurski, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-4, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1992 (16 pages with 10 tables, available from JMC as RDB2B02)

This progress report summarizes the goals and status of the Materials Compatibility and Lubricant Research (MCLR) Program, jointly funded under a grant from the Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The 36-month program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) refrigerants. The program comprises projects to measure thermophysical properties, model the performance and key operating parameters of nine potential alternatives for R-22, test the chemical and thermal stability of refrigerant-lubricant mixtures with metals, and measure the miscibility of lubricants with refrigerants. Three projects are providing information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics. An eighth project collects and facilitates dissemination of data through development and administration of a refrigerant database. The second phase of the project commenced in October 1992 and will continue through September 1994. The scope of the program, objectives of the individual projects, and significant interim findings are presented. This program summary also identifies reports resulting from the individual projects, including three new final reports on *Theoretical Evaluations of R-22 Alternative Fluids, Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures with Metals,* and *Miscibility of Lubricants with Refrigerants.* Ten tables summarize the miscibility of alternative refrigerants in seven tested lubricants.

R. F. Kayser (National Institute of Standards and Technology, NIST), **Thermophysical Properties**, report DOE/CE/23810-4A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1992 (222 pages, including a 104-page report with 8 figures and 23 tables, and 4 appended draft papers, available from JMC as RDB2C01)

This progress report provides an update on a project to provide highly accurate, selected thermophysical properties data for R-32, R-123, R-124, and R-125. Pressure-temperature and density-pressure relations are plotted for R-32 based on measurements using a Burnett apparatus. Pressure-volume-temperature relations, determined with a vibrating-tube apparatus and extrapolations, also are plotted. Deviations to measured data, generally within ±0.1% are plotted and skeleton density data are tabulated. PVT and experimental liquid heat capacity data are tabulated for the 284-340 K (51-153 °F). Transient hot-wire measurements of thermal conductivity for 300-340 K (80-160 °F) are presented and viscosity measurements are described. A virial equation and coefficients for the ideal-gas heat capacity of R-124 is summarized. The speed of sound, ideal-gas heat capacity, and acoustic virial coefficients are tabulated for R-125 for 250-400 K (-10 to 260 °F). Pressure-temperature and molar heat capacity data are plotted and PVT and heat capacity data are tabulated for R-125. Finally, thermal conductivity data are tabulated for R-123, based on transient hot-wire measurements. Further data are summarized in four appended draft papers entitled *Coexisting Densities, Vapor Pressures, and Critical Densities of Refrigerants R-32 and R-152a at 300 to 385 K; Coexisting Densities and Vapor Pressures of Refrigerants R-22, R-134a, and R-124 at 300 to 395 K; Critical Densities and Coexisting Density Data: Application to Refrigerants R-22, R-134a, and R-124;* and *Measurements of the Viscosities of Saturated and Compressed Fluid 1-Chloro-1,2,2,2-tetrafluoroethane (R-124) and Pentafluoroethane (R-125) at Temperatures Between 120 and 420 K.*

M. B. Pate, S. C. Zoz, and L. J. Berkenbosch (Iowa State University of Science and Technology), **Miscibility of Lubricants with Refrigerants (Phase I)**, report DOE/CE/23810-6, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1992 (64 pages with 1 figure and 82 tables, available from JMC as RDB3503)

This report summarizes the data obtained from an investigation of miscibility of lubricants with refrigerants. Experiments are being performed in two phases, namely screening tests and preparation of miscibility plots. Qualitative miscibility observations are tabulated for R-32, R-125, R-134, R-134a, R-142b, and R-143a with four lubricants. They include two pentaerythritol esters, a mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244) and a branched acid (Castrol Icematic(R) SW32), and for two polyalkylene glycols (PAGs), a polypropylene glycol diol (Dow P425) and a polypropylene glycol butyl monoether (ICI Emkarox(R) VG32). These tests were performed for three lubricant concentrations over a temperature range of -50 to 60 °C (-58 to 140 °F) for R-32, R-125, R-134, and R-143a. The range was extended to 90 °C (194 °F) for R-134a and R-142b. R-22, R-123, R-124, and R-152a will be tested later. The refrigerant concentrations varied due to the method of charg-

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ing the test cells, but future tests will provide data at nominal concentrations of 10, 50, and 95% by weight for all of the combinations. Composition changes as the density of the vapor decreases and the vapor volume increases are discussed. Minor problems with leakage and corrections are described. Summary observations are provided for each refrigerant-lubricant combination.

N. D. Smith, **Thermophysical Properties of HFC-236ea**, Environmental Research Brief EPA-600/S-92-066, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, October 1992 (5 pages with 5 tables, available from JMC as RDB-3403)

This synopsis summarizes properties of R-236ea (1,1,1,2,3,3-hexafluoropropane), a potential alternative for R-114. It notes that the thermophysical properties of the fluids closely match, and that modeling indicates acceptable performance. The efficiency of R-236ea is indicated as within 1% of that of R-114. Tables, in both inch-pound (IP) and metric (SI) units provide the freezing and boiling points, critical properties, heat of vaporization, and liquid specific heat capacity. Measured liquid densities are given at eight temperatures from 2-95 °C (35-202 °F) and vapor pressures for -14 to 141 °C (8-286 °F). Calculated liquid and vapor density as well as heat of vaporization are tabulated for -14 to 141 °C (8-286 °F) and the equations used are provided. The ideal gas heat capacity is similarly provided for 27-327 °C (80-620 °F). The methods used and estimated accuracy are indicated.

Heat Pumps, An Opportunity for Reducing the Greenhouse Effect, report HPC-BR1, International Energy Agency (IEA) Heat Pump Centre (HPC), Sittard, The Netherlands, October 1992 (12 pages, available from the HPC, RDB3724)

global warming, greenhouse gases, environmental impact

Heat Transfer and Fluid Flow in a Finned-Tube Flooded Evaporator, research project 392-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, phases I and II: January 1986 - January 1989, phase III: September 1989 - October 1992 (ASH0392)

The objective of this project was to develop data to improve designs of flooded evaporators. Heat transfer coefficients were measured for different finned-tube geometries. The first two phases entailed a literature search and addressed modeling and simulation, respectively. Phase III collected and analyzed data on pool and forced-convection boiling. The contractor was Pennsylvania State University, led by R. L. Webb and C. Pais; it was sponsored by ASHRAE Technical Committee 8.5, *Liquid to Refrigerant Heat Exchangers*. [see RDB2404 and RDB2405 for findings]

Measurement of Solubility, Viscosity, and Density of Synthetic Lubricants in HFC-134a Mixtures, research project 716-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1991 -October 1992 (ASH0716)

This project involved measurement of physical property data for solutions of R-134a with miscible and partially miscible synthetic lubricants. It specifically addressed gas solubility (refrigerant concentration), density, and viscosity of R-134a/lubricant mixtures. The pressures and temperatures for these determinations ranged from 70 to 3450 kPa (10-500 psia) and -25 to 125 °C (-13 to 257 °F). The contractor for the project was Imagination Resources, Incorporated (IRI), led by R. C. Cavestri; it was sponsored by Technical Committees 3.4, *Lubrication*, and 8.1, *Positive Displacement Compressors*.

Pressure-Enthalpy Graphs for the Alternative Refrigerants R-32, R-123, R-125, R-134a, and R-141b, research project 743-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1992 - October 1992 (ASH0743)

The contractor for the project was the University of Idaho, led by S. G. Penoncello; it was sponsored by ASHRAE Technical Committee 3.1, *Refrigerants and Brines.*

Refrigerant R-176, information packet, Arctic Chill, Incorporated, Sterling, VA, October 1992 (30 pages, available from JMC as RDB2A20)

This set of documents includes product data on R-22/12/142b (25/15/60), a zeotropic ternary blend, marketed as "R-176" [this designation does not conform to the numbering system in ASHRAE Standard 34-1992]. The data include limited physical, thermodynamic, and flammability properties as well as descriptions, measured results, and testimonials from field retrofits. The documents also provide general information on the environmental impacts of refrigerants as well as recommended retrofit procedures to use "R-176".

Suva(R) 123 (Suva Centri-LP, HCFC-123) in Chillers, document ART-2 (H-42443), DuPont Chemicals, Wilmington, DE, October 1992 (8 pages with 6 tables, available from JMC as RDB4504)

This bulletin discusses use of R-123 in new and retrofit chillers. It briefly introduces R-123 as one of the alternatives to replace chlorofluorocarbon (CFC) refrigerants. A table compares the boiling point, flammability, exposure limit, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP) for R-11 and R-123. The bulletin identifies general considerations for chiller conversions, indicating that alternative refrigerants cannot simply be "dropped into" systems designed for CFCs. Comparative ranges are provided for capacity, coefficient of performance (COP), evaporator and condenser pressures, and discharge temperature for R-123 relative to R-11. The usual changes in capacity and COP are indicated as -5 to -20% and 0 to -5%, respectively. The bulletin then outlines chemical compatibility considerations, and illustrates differences with a table comparing R-11 and R-123 compatibility with plastics, after exposures at 24 and 54 °C (75 and 130 °F). They include linear polyethylene (DuPont Alathon(R) 7150), polypropylene (Alathon(R) 9140), acetal resin (DuPont Delrin(R)), ABS polymer (USS Chemicals Krylastic(R)), polycarbonate (General Electric Lexan(R)), methyl-methacrylate (DuPont Lucite(R)), polyvinyl chloride (PVC), polystyrene (Dow Chemical Styron(R)), fluoropolymer resin (DuPont Teflon(R) TFE), and nylon (DuPont Zytel(R) 101). A separate table provides compatibility data with elastomers, including urethane (Uniroyal Adiprene(R) C), hydrocarbon rubber (DuPont Nordel(R)), natural rubber, butyl rubber, Buna N and S, neoprene W, fluoroelastomer (DuPont Viton(R) A), polysulfide (Morton Thiokol(R) FA), silicone, and chlorosulfonated polyethylene (DuPont Hypalon(R) 48). The bulletin also discusses lubricants, noting that those currently used with R-11 are fully miscible with R-123 for expected conditions. It cites stability tests with metals, including steel 1010, copper, and aluminum; the tabulated findings show that R-123 is more stable than R-11. The bulletin then reviews recommended handling and operating procedures, specifically addressing storage, charging, maintenance, sampling, leaks, and spills. The bulletin outlines factors for chiller retrofit from R-11 to R-123. It notes that requirements may range from a minimum effort, such as lubricant replacement, to significant changes, such as replacing gears, impellers, or materials of construction. The document then describes a retrofit program, with major equipment manufacturers, to convert DuPont's large chillers from CFCs to alternative refrigerants. It reviews field experience with three case histories, the first involving retrofit of a 1670 kW (475 ton), York open-drive chiller converted to R-123 in September 1988. Monitoring and refrigerant and lubricant sampling are described, along with measurements of machine room concentrations. Typical concentrations of 1 ppm - even during refrigerant removal and recharging - are indicated, with spikes of approximately 8 ppm when making or breaking hose connections. Two other machines at the same site were converted in May/June 1990. The second case history involved conversion of a 3517 kW (1000 ton), Carrier chiller in February 1988. Tests showed 18% loss in capacity, restored with replacement of the impellers at a tradeoff of 13% in efficiency. Measured exposure levels of 1-2 ppm are noted, with spikes as high as 20 ppm during maintenance. A 2110 kW (600 ton), Trane hermetic chiller conversion in October 1990 also is summarized. Although field data were not then available, the capacity was predicted to remain unchanged and the efficiency to drop slightly. Normal machine room concentrations of 1-2 ppm were found. DuPont's product names for R-123 in chillers are Suva(R) 123 and Suva(R) Centri-LP.

Suva(R) 134a (Suva Cold MP, HFC-134a) in Chillers, document ART-3 (H-42444), DuPont Chemicals, Wilmington, DE, October 1992 (6 pages with 5 tables, RDB3443)

This bulletin discusses use of R-134a in new and retrofit chillers. It briefly introduces R-134a as one of the alternatives to replace chlorofluorocarbon (CFC) refrigerants. A table compares the boiling point, flammability, exposure limit, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP) for R-12 and R-134a. The bulletin identifies general considerations for chiller conversions, indicating that alternative refrigerants cannot simply be "dropped into" systems designed for CFCs. Comparative ranges are provided for capacity, coefficient of performance (COP), evaporator and condenser pressures, and discharge temperature for R-134a relative to R-12. The usual changes in capacity and COP are indicated as -10 to +2% and -8 to +2%, respectively. The bulletin then outlines and tabulates chemical compatibility considerations, and illustrates differences with a table comparing R-12 and R-134a compatibility with elastomers after exposures at 25 and 80 °C (77 and 176 °F). They include urethane (Uniroyal Adiprene(R) C), Buna N and S, butyl rubber, chlorosulfonated polyethylene (DuPont Hypalon(R) 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel(R)), silicone, polysulfide (Morton Thiokol(R) FA), and fluoroelastomer (DuPont Viton(R) A). The bulletin also discusses lubricants and contrasts polyalkylene glycol (PAG) and polyolester (POE) synthetics to mineral oils (MO). A table indicates the temperature ranges from -50 to 93 °C (-58 to 200 °F) for solubility of R-134a in

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naphthenic and paraffinic MO, alkylbenzene and dialkylbenzene, two PAGs, and four POEs. The bulletin outlines factors for chiller retrofit from R-12 and R-500 to R-134a. It notes that requirements may range from a minimum effort, such as lubricant replacement, to significant changes, such as replacing gears, impellers, or materials of construction. The document describes a retrofit program, with major equipment manufacturers, to convert DuPont's large chillers from CFCs to alternative refrigerants. It then reviews field experience with a 2462 kW (700 ton) York International TurboPak(R) centrifugal chiller, converted to R-134a and an unidentified 300 SUS PAG lubricant in November 1989. Subsequent inspections and a second retrofitting of the drive gear, in the spring of 1990, are described, indicating satisfactory operation with a decrease in efficiency of up to 7% and an increase in capacity of up to 9%. The document also discusses conversion of a Carrier open drive, R-12 chiller rated at 4224 kW (1200 ton) to R-134a with a PAG in December 1990; the gear set was changed in the spring of 1991. A maintenance problem with the lubricant oil pump and slight wear in the compressor journal bearings were found. While the cause was not ascertained, the lubricant was changed to a POE, indicated as less sensitive to residual chlorides. A third case history involved a 10,560 kW (3000 ton) open drive, York R-500 chiller with naphthenic MO. It was converted to R-134a with a POE in April 1991; preliminary testing confirmed that a gear change was not needed. The bulletin mentions flushing with R-11 for the first two retrofits and with POE for the third. It also indicates that monitoring is continuing. DuPont's product names for R-134a in chillers are Suva(R) 134a and Suva(R) Cold MP. [see RDB4509 for update]

September 1992

D. Arnaud, S. Macaudiere, J. C. Tanguy (Elf Atochem S.A., France), and P. F. Radice (Elf Atochem North America), **Properties of Blends Which Can Be Used as R-502 Substitutes in Refrigeration**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 105-114, September 1992 (10 pages with 3 figures and 6 tables, RDB2A06)

FX-10, FX-20, FX-21, FX-30, FX-40, FX-50, FX-71

S. C. Bhaduri (Indian Institute of Technology, India), **Thermodynamic Criterion for Selection of Refrigerant-Absorbent Pairs for Vapor Absorption Refrigeration System**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 83-98, September 1992 (16 pages with 5 figures and 1 table, RDB2A04)

J. M. Calm (Engineering Consultant), **Refrigerant Database**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 55-72, September 1992 (8 pages with 4 figures, available from JMC as RDB2907)

This paper reviews the history of the Refrigerant Database, including initial efforts by the Air-Conditioning and Refrigeration Institute (ARI) and National Institute of Standards and Technology (NIST). The database currently is sponsored by the Air-Conditioning and Refrigeration Technology Institute (ARTI), as part of the Materials Compatibility and Lubricant Research (MCLR) Program, under a grant from the U.S. Department of Energy (DOE). The paper outlines the contents and focus of the database, and describes the search and retrieval functions available in a computerized version. Sample searches are illustrated along with the results obtained. Options to specify search terms are summarized; they include topical prompts, combinations of search criteria (using Boolean logical operators), and chained searches to refine or broaden earlier searches. The procedures to obtain the database and documents cited by it are indicated.

T. W. Dekleva, R. Yost (ICI Americas, Incorporated), S. Corr, R. D. Gregson, G. Tompsett (ICI Chemicals and Polymers, Limited), T. Nishizawa, and Y. Obata (ICI Japan), **Investigations into the Potential Effects of Process Chemicals and Materials on the Long-Term Performance of Home Appliances**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 29 September 1992 (17 pages with 4 figures and 7 tables, RDB2913)

T. W. Dekleva, S. H. Colmery (ICI Americas, Incorporated), J. Bresnahan (ICI Australia Operations Pty Limited), S. Corr, and A. Lindley (ICI Chemicals and Polymers, Limited), **Retrofitting Mobile Air-Conditioning Systems with HFC-134a - An Update**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 697-706, September 1992 (10 pages with 1 table, RDB2914)

This paper focuses on procedures and system performance for retrofit of mobile air air-conditioning (MAC) systems with R-134a. The paper outlines the need for retrofit, pointing to the hundreds of millions of vehicles that use R-12 and anticipated shortfall to meet service needs after recycling and recovery. The paper briefly notes activities underway to prepare guidelines for refrigerants, procedures, and fittings; qualify suitable lubricants; and identify acceptable practices. ICI is pursuing ester lubricants, but the paper notes that others are investigating use of polyalkylene glycols (PAGs). The paper reviews a number of retrofit procedures and the labor requirements for them. Two categories are contrasted, with and without flushing to remove mineral oil. The paper reviews the time and impacts of R-12 recovery, system flushing, removal and draining of the compressor, addition of lubricant, system reassembly, evacuation, and recharging with R-134a. Specific flushing agents including per- and tri-chloroethylene (PCE and TCE), are discussed. Fleet trials to gauge the performance and compressor durability consequences of retrofit, with different procedures and compressor types, are reviewed; these tests are underway in Australia, the United States, and elsewhere. R-134a may require 10-20% extra condenser capacity at idle conditions or high ambient temperatures. No performance penalties have been associated with flushing or not flushing. The paper concludes that R-134a combined with ester lubricants appears to offer acceptable levels of performance and systems compatibility, but more work is required.

R. G. Doerr, D. Lambert, R. Schafer, and D. Steinke (The Trane Company), **Stability and Compatibility Studies of R-245ca, $CHF_2CF_2CH_2F$, A Potential Low-Pressure Refrigerant**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 147-152, September 1992 (6 pages with 1 figure and 4 tables, available from JMC as RDB2A10)

This paper reviews the selection of R-245 isomers as low-pressure refrigerant candidates. This series offers the highest number of hydrogen atoms without becoming flammable and, therefore, the best potential among fluoropropanes. R-245ca was selected for further examination, based on performance modeling and its reported synthesis. Slightly lower efficiency is expected compared to R-123. Physical and chemical properties are tabulated for R-11, R-123, R-134a, and R-245ca for comparison. R-245ca is expected to be nontoxic, and it is indicated to be very similar to R-11 in terms of molecular weight, boiling point, and critical temperature. Its ozone depletion potential (ODP) is zero, but its 5.5 year atmospheric lifetime leads to a global warming potential (GWP) higher than for R-123 but lower than for R-134a. [Newer data indicate an atmospheric lifetime of 7.0 years.] The paper summarizes stability and compatibility studies. Sealed-tube tests, with and without lubricants, indicate that R-245ca is extremely stable; no evidence of decomposition was noted after 500 hours at 175 °C (347 °F). Parr bomb compatibility tests with electric motor materials and elastomers showed lower refrigerant absorption than for R-11 and R-123. The compatibility of R-245ca was found to be very similar to R-134a toward both motor materials and elastomers; no degradation was found for the materials tested. They included varnishes, slot liners, DuPont Mylar(R) sheet and tape, Dacron-Mylar-Dacron(R) and DuPont Nomex(R) wedges, DuPont Dacron(R) tape and cord, and reinforced tape. The varnishes tested included solvent epoxy (P. D. George Sterling(R) U-475 EH), 100% solids epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). Weight, volume, and hardness change results are tabulated for a proprietary, chloroprene, and nitrile elastomers. The results suggest further investigation of R-245ca as a potential refrigerant. Commercialization is not expected for a number of years pending flammability, toxicity, and other testing as well as development of a competitive manufacturing process. [see RDB2A11 for presentation charts]

R. G. Doerr, D. Lambert, R. Schafer, and D. Steinke (The Trane Company), **Stability and Compatibility Studies of R-245ca, $CHF_2CF_2CH_2F$, A Potential Low-Pressure Refrigerant**, presentation charts (International CFC and Halon Alternatives Conference, Washington, DC), September 1992 (4 pages, available from JMC as RDB2A11)

This presentation reviews the selection of R-245 isomers as low-pressure refrigerant candidates. This series offers the highest number of hydrogen atoms without becoming flammable and, therefore, the best potential among fluoropropanes. R-245ca was selected for further examination, based on performance modeling and its reported synthesis. Slightly lower efficiency is expected compared to R-123. Physical and chemical properties are tabulated for R-11, R-123, R-134a, and R-245ca for comparison. R-245ca is expected to be nontoxic, and it is indicated to be very similar to R-11 in terms of molecular weight, boiling point, and critical temperature. Its ozone depletion potential (ODP) is zero, but its 5.5 year atmospheric lifetime leads to a global warming potential (GWP) higher than for R-123 but lower than for R-134a. [Newer data indicate an atmospheric lifetime of 7.0 years.] The presentation summarizes stability and compatibility studies. Sealed-tube tests, with and without lubricants, indicate that R-245ca is extremely stable; no evidence of decomposition was noted after 500 hours at 175 °C (347 °F). Parr bomb compatibility tests with

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electric motor materials and elastomers showed lower refrigerant absorption than for R-11 and R-123. The compatibility of R-245ca was found to be very similar to R-134a toward both motor materials and elastomers; no degradation was found for the materials tested. They included varnishes, slot liners, DuPont Mylar(R) sheet and tape, Dacron-Mylar-Dacron(R) and DuPont Nomex(R) wedges, DuPont Dacron(R) tape and cord, and reinforced tape. The varnishes tested included solvent epoxy (P. D. George Sterling(R) U-475 EH), 100% solids epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). Weight, volume, and hardness change results are tabulated for a proprietary, chloroprene, and nitrile elastomers. The results suggest further investigation of R-245ca as a potential refrigerant. Commercialization is not expected for a number of years pending flammability, toxicity, and other testing as well as development of a competitive manufacturing process. [see RDB2A10 for text]

V. Z. Geller and M. E. Paulaitis (University of Delaware), **The Calculation and Prediction of Transport Properties for New Refrigerants and Blends in Refrigeration Application**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 115-124, September 1992 (10 pages with 6 figures and 3 tables, RDB2A07)

thermal conductivity and viscosity

P. V. Gilli, H. Halozan, and W. Stretcher, **The Impact of Heat Pumps on the Greenhouse Effect**, report HPC-AR1, International Energy Agency (IEA) Heat Pump Centre (HPC), Sittard, The Netherlands, September 1992 (158 pages, available from the HPC for NLG 80.00, rdb3723)

B. D. Greig (Castrol Limited), **Formulated Polyol Ester Lubricants with HFC-134a: The Role of Additives and Conversion of Existing CFC-12 Plant to HFC-134a**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 135-145, September 1992 (11 pages with 3 figures and 3 tables, RDB2A09)

R-12, R-134a, polyolester

G. C. Hourahan and D. S. Godwin (Air-Conditioning and Refrigeration Institute, ARI), **ARI's R-22 Alternative Refrigerants Evaluation Program (AREP)**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 55-64, September 1992 (10 pages with 3 figures and 3 tables, available from JMC as RDB2906)

This paper summarizes a program to evaluate candidate fluids to replace R-22, establish test protocols to evaluate them, conduct the tests, and present the results. The overall objective is to perform a broad screening of alternative candidates, while eliminating unnecessary duplication of work and wasting of limited resources. The paper outlines the AREP organization, including its Task Force (chaired by D. M. Goldberg) and Technical Committee (chaired by E. B. Muir); both their members and participating international organizations are named. The document reviews considerations for ten candidates selected for initial examination from nearly 30 nominations. They include R-32/125 (60/40), R-32/134a (25/75), R-407B [R-32/125/134a (10/70/20)], R-290 (propane), R-134a, R-717 (ammonia), R-32/125/290/134a (20/55/5/20), R-32/125/134a (30/10/60), R-125/143a (45/55), and R-125/143a/-134a (45/50/5); the list notes changes in selected blend compositions from earlier AREP documents. The last two are of primary interest as potential replacements for R-502. Procedures and conditions for compressor calorimeter and heat transfer test are outlined. The Electric Power Research Institute (EPRI) is funding the heat transfer segment. Planned drop-in tests, system simulations, and system tests are outlined. Results of the work will be disseminated through technical publications and through the Refrigerant Database. A Gantt chart shows the schedule for introduction of R-22 replacements. Additional figures indicate the AREP testing plan and detail the heat transfer testing protocol.

H. M. Hughes (AlliedSignal Incorporated), **Non-Ozone Depleting Refrigerants for Centrifugal Compressors**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 41-46, September 1992 (6 pages with 4 figures, RDB2A01)

This paper reviews the characteristics sought in a replacement for R-11 and R-123, as well as reasons for their widespread use and the long-term need for a replacement. R-245ca, with a boiling point of 25.5 °C (79.9 °F) and a molecular mass of 134.0, is identified as a candidate. It is reported to be nonflammable and have a global warming potential (GWP) comparable to that of R-134a. The paper presents the results of cycle comparisons based on modeling. These results include figures comparing the capacity and coefficient of performance (COP) for R-11, R-123, and R-245ca. An investigation of multistage systems is outlined. The results, excluding interstage losses, indicate that R-245ca matches R-11's efficiency with three stages and becomes more efficient with four or more. Moreover, anticipation of better heat transfer characteristics is noted, based on the higher molecular weight of R-245ca. Little is known of the toxicity of this fluid, though most HFCs tend to have low toxicity. Potential obstacles such as lubricant identification and materials compatibility are discussed.

K. Kawamura (Mayekawa Manufacturing Company, Limited, Japan), **Drop-in Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 14, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (2 pages with 1 table, available from JMC as RDB3814)

S. N. Kondepudi (Drexel University), **Experimental Investigation of R-22 Replacement Refrigerants in a Split-System Residential Air Conditioner**, report EPA/430/R-92/007, U.S. Environmental Protection Agency (EPA), Washington, DC, September 1992 (30 pages with 4 figures and 12 tables, RDB-2B09)

This report summarizes capacity and efficiency tests of five zeotropic blends in a Lennox, 2 ton, split-system air conditioner. The refrigerants included three mixtures of R-32 and R-134a, with 20, 30, and 40% R-32 by mass, and two of R-32 and R-152a, with 30 and 40% R-32. The five blends were selected as candidate R-22 replacements based on prior studies. Testing was performed by ETL Testing Laboratories, and confirmed by independent tests by Lennox Industries; both were performed in accordance with standard rating test procedures. The fluids were tested under near "drop-in" conditions, without equipment modification except for substitution of a manual expansion device and replacement of the refrigerant and lubricant. An unidentified polyolester lubricant was used. The report summarizes the need for R-22 alternatives, candidates identified in prior and ongoing studies, testing and equipment details, and measured results. It also compares the findings to simulations. Measured capacity and efficiency fell below simulated results, but the test system had not been optimized for the alternative refrigerants. The blends tested generally showed steady-state efficiency to be within 2% of that of R-22, but offered lower capacity. R-32/134a (40/60) was identified as a promising retrofit fluid since it yielded steady state efficiency and capacity 1% higher than R-22, though the seasonal performance (SEER) was 1% lower.

S. Madigan (Danfoss), **Compressor Manufacturer's Experiences with R-134a Applications**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 153-155, September 1992 (3 pages with 4 figures and 1 table, available from JMC as RDB2A14)

This paper outlines factors requiring attention when substituting R-134a for R-12 in systems with capillary tubes and Danfoss LBP compressors. Pressure-enthalpy diagrams show that the latent heat of vaporization is significantly higher for R-134a than for R-12, requiring lower mass flow for the same capacity. A table compares the enthalpy and design parameters for the two fluids. The paper notes that capillary tubes must be reselected with the refrigerant change to adapt for the differences in pressure and mass and volume flow. Compatibility is noted as good with substitution of polyolester lubricants, to account for miscibility; valve coking is not anticipated. The dependence on a filter drier, with Union Carbide XH7 recommended as the desiccant, is outlined based on the moisture content of the lubricant and the difficulty of drying it. A set of housekeeping rules is outlined.

K. Matsuo (Hitachi, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 6, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3806)

Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 2.7 kW cooling (3/4 ton) air-to-air, room heat pump using a variable-speed, rotary rolling-piston compressor. R-22 was tested with ISO viscosity grade 56 mineral oil; the blend was tested with an ISO viscosity grade 32 ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, condenser exit, inlets to the expansion device and evaporator, and the evaporator outlet. Data are presented for both the heating and cooling modes. The results show 8 and 3% decreases for the blend in heating capacity and efficiency at the same speeds and 6% reductions in cooling capacity and efficiency. With speed increases of 8% for heating and 12% for cooling, to restore the capacities with the blend, the efficiencies were reduced by 10 and 12% in the heating and cooling modes, respectively, compared to the R-22 reference.

K. Matsuo (Hitachi, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 8, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3808)

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Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 7.0 kW cooling (2 ton) air-to-air, packaged heat pump using a scroll compressor. R-22 was tested with a mineral oil; the blend was tested with an unidentified ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the suction line and compressor shell outlets, condenser inlet, saturated vapor and liquid states in the condenser, condenser and liquid line exits, expansion device outlet, evaporator inlet, saturated vapor state in the evaporator, and the evaporator outlet. Data are presented for both the heating and cooling modes. The results show 3 and 6% decreases for the blend in heating capacity and efficiency and 1 and 2% reductions in cooling capacity and efficiency, respectively.

K. Matsuo (Hitachi, Limited, Japan), **Drop-In Test of Refrigerant Blend R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 7, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3807)

Two tables summarize tests to compare performance of R-22 and R-134a through drop-in tests in a 3.1 kW cooling (0.9 ton) air-to-air, room heat pump using a variable-speed, rotary rolling-piston compressor. R-22 was tested with an ISO viscosity grade 56 mineral oil; R-134a was tested with an ISO viscosity grade 15 ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, condenser exit, expansion device inlets and outlets, and evaporator inlets and outlets. Data are presented for both the heating and cooling modes. The results with R-134a show a 33% capacity decrease and 14% efficiency increase in the heating mode, at the same speeds, and 25% capacity decrease and 20% efficiency increase in the cooling mode. With speed increases of 33% for heating and 64% for cooling, to partially restore the capacities with R-134a, the four corresponding changes were decreases of 6, 6, 12, and 27%, respectively.

J. T. McMullan, N. J. Hewitt, A. J. Masson, and N. E. Murphy (University of Ulster, UK), **The Influence on Oil Viscosity and Refrigerant Quality on Evaporator Performance**, *International Journal of Energy Research* (IJER), 16(7):567-581, September 1992 (15 pages with 20 figures and 1 table, RDB-4C22)

effects of compressor lubricants on performance and specifically the degradations from reduced heat transfer and increased pressure drop in the evaporator: tests on R-12 with two solvent-refined, naphthenic mineral oils (MO, Shell Clavus 32 and 68) and an alkylated benzene and solvent extracted MO (Shell SD) at concentrations of 0, 1, and 3% m/m on the tube-side of shell-and-tube evaporators; shows that the addition of oil changes the two-phase flow regime inside the evaporator; use of a low viscosity oil yields better results for a stratified flow regime and inferior results for annular flow; concludes that the performance degradation can be minimized by selecting a low viscosity lubricant if the oil fraction is small or a high viscosity oil if the fraction is high

J. J. Meyer and J. M. Saiz Jabardo, **An Ultrasonic Device for Measuring the Oil Concentration in Flowing Liquid Refrigerant**, report TR-24, Air-Conditioning and Refrigeration Center (ACRC), University of Illinois at Urbana-Champaign, Urbana, IL, September 1992 (10 pages, RDB5443)

Y. Morikawa (Matsushita Electric Industrial Company Limited, Japan), **Procedure and Report Format for Drop-In Tests Performed by JRAIA Member Companies**, Alternative Refrigerants Evaluation Program (AREP) report 60, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (14 pages with 2 figures and 4 tables, available from JMC as RDB3C60)

This document outlines uniform test procedures to be used for drop-in performance tests for the Japanese Alternative Refrigerants Evaluation Program (JAREP). The procedures were developed and the cooperative program is conducted by the Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), in coordination with the U.S. Air-Conditioning and Refrigeration Institute's (ARI's) Alternative Refrigerants Evaluation Program (AREP). The procedure addresses three replacement candidates for R-22 including R-32/125 (60/40), R-32/134a (30/70), and R-134a. It identifies three systems for testing, including a 1 HP "room air conditioner (RAC)" (split-system heat pump with inverter-driven hermetic rotary, rolling-piston compressor), a 3-5 HP "packaged air conditioner (PAC)" (split-system heat pump with hermetic scroll compressor), and a 40 HP chiller (shell-and-tube heat exchangers with a screw compressor). Photographs are provided to illustrate the first two system types. The report then identifies the participating companies and specific systems and refrigerants to be tested. The companies include Daikin, Hitachi, Mayekawa (Mycom), Matsushita (Panasonic), Mitsubishi Heavy, Sanyo, and Toshiba. The report specifies indoor and outdoor dry and wet bulb temperatures for testing, based on the JIS C9612-1989 test standard for RACs. It also prescribes use of thermophysical property data from Daikin Industries for calculations, with compositions verified by gas chromatography. It identifies 5 test points to be measured in the refrigeration cycle and three to be calculated. Tables are provided to report both heating and cooling performance data, including reporting of performance relative to that with R-22, as a reference.

T. Nagai (Sanyo Electric Company. Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 13, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3813)

performance test R-410 series blend

M. L. Robin, Y. Iikubo (Great Lakes Chemical Corporation), G. de Souza Damasceno, J. N. Dubrouillet, V. W. Goldschmidt, and D. R. Tree (Purdue University), **Performance of Alternative Refrigerants: Refrigerator-Freezer Energy Testing with HFC-152a / HFC-227ea Mixtures**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 99-104, September 1992 (6 pages with 2 tables, RDB2A05)

This paper presents measured performance data for blends of R-152a and R-227ea tested in an unmodified home refrigerator. Physical and thermodynamic properties as well as flammability data and ozone depletion potentials (ODPs) are tabulated for R-12, R-152a, and R-227ea for comparison. The energy measurements were based on ANSI/AHAM Standard HRF-1-1988, with an increased number of thermocouples. An unidentified polyolester (POE) was used as the lubricant for the R-152a/227ea mixtures. R-152a/227ea (80/20) offered slightly reduced energy consumption and 50/50 and 20/80 mixtures increased energy consumption by 4.3%. The paper concludes that the R-152a/227ea blends may offer significantly improved performance compared to R-12 in an optimized system. Recommendations are provided for further work.

K. S. Sanvordenker (Tecumseh Products Company), **Compressor Manufacturer's R-134a Applications**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 157-164, September 1992 (8 pages with 3 figures and 3 tables containing corrections to the copy in the proceedings, available from JMC as RDB2901)

This paper highlights the efforts of a compressor manufacturer to implement research data into R-134a applications for hermetic units. Comparative capacity and performance data, based on calorimeter tests, are tabulated for compressors representative of those used in refrigerator/freezer applications. The capacity is approximately 10% lower with R-134a at rating conditions, but the efficiency stays the same. Further data show that the relative capacities and efficiencies of R-12 and R-134a may be lower or higher depending on the application conditions. Sound levels are plotted for traditional R-12 and redesigned, high-efficiency R-134a compressors; the overall sound level is lower for the latter. Materials compatibility issues are reviewed, noting the advantages and acceptance of polyolester (POE) lubricants as the consensus selection for R-134a. The paper discusses lubricant stability, chemical reactivity, miscibility, solubility, and lubricity. A plot compares the solubility of R-12 and R-134a in two POEs to R-12 in mineral oil. The discussion suggests that a bigger motor, with a small potential penalty in efficiency, may be required for R-134a due to the impact on equalization pressure and the required starting torque. A need is noted for new test methods for lubricity. The impacts on motor insulation and uncertainties regarding contaminants are covered briefly. The paper concludes that there are no technical barriers to conversion from R-12 to R-134a, but that information dissemination and the cost of the refrigerant and lubricant remain factors in the rate of conversion.

S. R. Szymurski (Air-Conditioning and Refrigeration Technology Institute, ARTI), **Materials Compatibility and Lubricant Research on CFC-Refrigerant Substitutes - Research Update**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 73-82, September 1992 (10 pages, RDB2A03)

This paper provides an update on the goals and status of the Materials Compatibility and Lubricant Research (MCLR) Program, jointly funded under a grant from the Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program addresses critical research to accelerate the introduction of substitutes for chlorofluorocarbon (CFC) refrigerants. The program comprises projects to measure thermophysical properties, test the chemical and thermal stability of refrigerant-lubricant mixtures with metals, and measure the miscibility of lubricants with refrigerants. One project is modeling the performance and key operating parameters of alternatives for R-22. Three projects will provide information on the compatibility of refrigerants and lubricants with

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motor materials, elastomers, and engineering plastics. An eighth project collects and facilitates dissemination of data through development and administration of a refrigerant database. The scope of the program, objectives of the projects, and significant preliminary findings are presented.

S. Uemura (Daikin Industries, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 10, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3810)

Two tables summarize tests to compare performance of R-22 and R-32/125 (60/40) through drop-in tests in a 2.7 kW cooling (3/4 ton) air-to-air, room heat pump with a variable-speed, rotary rolling-piston compressor. R-22 was tested with a mineral oil; the blend was tested with an ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser exit, liquid line inlet, and the evaporator inlet and outlet. Data are presented for both the cooling and heating modes. With a speed adjustment (to 77% of the R-22 reference case) to match capacity, the cooling efficiency dropped by 18% with the blend; a further speed reduction (to 73% of the reference) yielded a 4% loss in capacity and 16% increase in efficiency, both relative to the reference case. With a speed adjustment (to 73% of the R-22 reference case) to match capacity, the heating efficiency dropped by 5% with the blend; a further speed reduction (to 64% of the reference) yielded a 10% loss in capacity and 3% increase in efficiency, both relative to the reference case. Corresponding changes in superheating and subcooling are noted.

S. Uemura (Daikin Industries, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 9, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3809)

Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 7.6 kW cooling (2.1 ton) air-to-air, packaged heat pump using a scroll compressor. R-22 was tested with a mineral oil; the blend was tested with an ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, condenser and liquid line exits, evaporator inlet, and the evaporator outlet. Data are presented for both the heating and cooling modes. The results for the blend show a 3% decrease to a 1% gain in capacity, depending on superheating and subcooling, and corresponding 2 and 1% efficiency increases in the heating mode. The results also show a 1% decrease to 1% gain in capacity, again depending on superheating and subcooling, and corresponding 3% gain and 1% loss in efficiency in the cooling mode.

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 11, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3811)

Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 2.5 kW cooling (3/4 ton) air-to-air, room heat pump with a variable-speed, rotary rolling-piston compressor. R-22 was tested with an unidentified synthetic lubricant; the blend was tested with an ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, saturated vapor and liquid states in the condenser, condenser exit, liquid line inlet, expansion device inlet, evaporator inlet, saturated vapor state in the evaporator, and the evaporator outlet. Data are presented for both the cooling and heating modes. With an unspecified speed adjustment to match capacity, the cooling efficiency dropped 6% with the blend; other (unspecified) adjustments yielded a 1% increase in capacity at 6% loss in efficiency or 3% loss in capacity and efficiency. Set to match heating capacity, the efficiency dropped less than 1% with the blend. Other, unspecified adjustments yielded a 3% increase in capacity at 3% loss in efficiency or 1% loss in capacity and negligible drop in efficiency.

Alternative Fluorocarbons Environmental Acceptability Study, program description, AFEAS, Washington, DC, September 1992 (4 pages with 1 figure and 1 table, available from JMC as RDB2A21)

This leaflet introduces the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), initiated in December 1988. The program was formed to assess the potential impacts of chlorofluorocarbon (CFC) refrigerant alternatives on the environment. AFEAS is a cooperative research effort sponsored by 12 leading chemical producers. Results were presented at the United Nations Environment Programme (UNEP) meeting in Nairobi in August 1989, and were incorporated as an appendix to the *Scientific Assessment under the Montreal Protocol on Substances that Deplete the Ozone Layer*. Further research, in a three-year, $6 million program, seeks to identify and help resolve uncertainties regarding potential environmental effects of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). A second objective is to stimulate prompt dissemination of scientific information to the research community, government decision makers, affected industries, and the public. A table lists potential alternatives to CFCs, including HCFCs R-22, R-123, R-124, R-141b, R-142b, R-225ca, and R-225cb, as transitional substances, and HFCs R-32, R-125, R-134a, and R-152a. The summary notes that scientific studies show that use of HCFCs and HFCs to replace CFCs will reduce the amount of atmospheric chlorine. These alternatives will break down, in the lower atmosphere, into products that will not contribute to either acid deposition or ozone pollution. Some of the HCFCs and HFCs can be expected to form trifluoroacetyl halides that will dissolve in water to form trifluoroacetic acid. While the concentrations are so low that adverse effects are unlikely, this issue is being investigated further. A figure contrasts the minor direct (chemical emission related) and larger indirect (energy related) contributions to total equivalent warming impact (TEWI) for a representative refrigerator. A study of global warming, co-funded with the U.S. Department of Energy, indicates that HCFCs and HFCs provide substantial improvements in energy efficiency over CFCs in many applications.

Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) Summaries, AFEAS, Washington, DC, September 1992 (20 pages with 6 figures and 1 table, available from JMC as RDB2A22)

This series of nine leaflets presents key AFEAS objectives and findings. A summary of *Atmospheric Fluorocarbons and Stratospheric Ozone* reviews the mechanisms of stratospheric ozone depletion and provides values for ozone depletion potentials (ODPs). It also illustrates how substitution of hydrochlorofluorocarbons (HCFCs) for chlorofluorocarbons (CFCs) reduces chlorine in the atmosphere. The illustration further shows that use of HCFCs for a limited time will not delay return of atmospheric chlorine to pre-1970s levels. A sheet on *UV-B Radiation Measurements* discusses the importance of the ozone layer in shielding ultraviolet B (UV-B) radiation in sunlight as well as efforts to monitor and observed trends of incoming UV-B intensity. A leaflet on *The Next Few Years* addresses the effect of HCFCs on peak chlorine loading and the misleading consequences of using time-dependent ODPs. A review of the *Breakdown Products of Alternatives* outlines the mechanisms and consequences of HCFC and hydrofluorocarbon (HFC) breakdown. It notes that they decompose readily in the lower atmosphere, that the ultimate breakdown products are acidic compounds that are washed out in rain, that the acidic concentrations are so low as to have no appreciable effect, and that the alternatives do not contribute to photochemical smog formation in urban areas. A further summary of the *Environmental Fate of Trifluoroacetyl Halides* addresses the atmospheric breakdown of R-123, R-124, and R-134a, ultimately forming trifluoroacetate ion (TFA) in surface waters. While no impact is anticipated, further study is underway. A synopsis of the *Relative Contributions of Greenhouse Gas Emissions to Climate Forcing* discusses radiative forcing, a parameter used to perturb the heat balance in modeling of the earth-atmosphere system. It outlines understanding and uncertainties associated with GWP values, atmospheric persistence of greenhouse gas emissions, and the quantitative influence of *integration time horizon* (ITH) on analyses of impacts. A table provides estimates for the atmospheric lifetimes and GWP values for 20, 100, and 500 yr ITH. A sheet on *Total Global Warming Impact* compares the Total Equivalent Warming Impacts (TEWIs) of alternative technologies and fluids. It notes that a not-in-kind (NIK) refrigerant option, with more than a 1% increase in energy use, would have a larger total warming impact than HCFC and HFC options. A *Glossary of Terms* defines terminology for discussion of the atmospheric effects of alternative fluorocarbons. The last sheet briefly outlines the history and activities of both AFEAS and the companion Programme for Alternative Fluorocarbon Toxicity Testing (PAFT).

Programme for Alternative Fluorocarbon Toxicity Testing, program description, PAFT, Bristol, United Kingdom, September 1992 (4 pages with 1 table, available from JMC as RDB2A23)

This leaflet introduces the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), initiated in December 1987. The program is designed to expedite the development of toxicology data for possible substitute fluorocarbons to replace chlorofluorocarbons (CFCs), or more broadly halogenated fluoroalkanes, that may be catalyzing a decrease in stratospheric ozone levels. PAFT is a cooperative research effort sponsored by 15 of the leading CFC producers from nine countries. Five PAFT program sec-

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tors are identified including PAFT I to address R-123 and R-134a, PAFT II for R-141b, PAFT III for R-124 and R-125, PAFT IV for R-225ca and R-225cb, and PAFT V for R-32. The leaflet summarizes program objectives and schedules. It notes that there are more than 100 individual toxicology tests in the program, at a cost of $3-5 million per compound. It also indicates that more than a dozen testing laboratories in Europe, Japan, and the United States are performing tests, the results of which will be published in peer-reviewed journals and presented at scientific conferences. The program comprehensively addresses acute, sub-chronic, developmental and chronic toxicity/carcinogenicity studies, genotoxicity, and environmental toxicology studies.

Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries, PAFT, Bristol, United Kingdom, September 1992 (16 pages, available from JMC as RDB2A24)

Eight data sheets summarize the status and findings of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). They address *HCFC-123 in Comparison with CFC-11, HFC-134a in Comparison with CFC-12, HCFC-141b in Comparison with CFC-11, HCFC-124 in Comparison with CFC-114, HFC-125 in Comparison with CFC-115, HCFC-225ca and HCFC-225cb, HFC-32,* and a *Glossary of Terms*. The summaries outline studies of acute toxicity (short term exposures to high concentrations, such as accidental leakages), genotoxicity (effects on genetic material, an early screen for possible carcinogenic activity), sub-chronic toxicity (repeated exposure to determine any overall toxicological effect), reproductive and developmental toxicity (teratology, assessment of the effects on the reproductive system and of the potential for causing birth defects), chronic toxicity/-carcinogenicity (lifetime testing to assess late-in-life toxicity or increased evidence of cancer), and ecotoxicity (assessment of potential to affect living organisms in the environment). Interim results and program plans are summarized for R-32, R-123, R-124, R-125, R-134a, R-141b, R-124, R-125, R-225ca, and R-225cb. Testing is in the final phase for R-123 and complete for R-134a. The results indicate that they are safe for use in refrigeration and air-conditioning applications, and for R-134a in other proposed industrial applications, provided that recommended normal hygiene practices are observed. No current findings preclude use of R-32, R-124, R-125, and R-141b in general industrial uses, again provided that recommended normal hygiene practices are observed. Further studies are being planned and conducted to address findings for R-225ca and R-225cb, though the acute toxicity was found to be low for both isomers.

August 1992

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-3G, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 8 August 1992 (74 pages, available from JMC as RDB2810)

This superseded document provides bibliographic citations for 425 publications that may be useful in research and design of air-conditioning and refrigeration equipment. Abstracts that emphasize the content, materials addressed, and key conclusions are provided for approximately half of these documents. [Please see RDB2B04 for update and a more complete abstract.]

D. G. Gehring, D. J. Barsotti, and H. E. Gibbon (DuPont Chemicals), **Chlorofluorocarbons Alternatives Analysis, Part II: The Determination of HCFC-141b Purity by Gas Chromatography**, *Journal of Chromatographic Science*, 30:301-305, August 1992 (5 pages with 2 figures and 2 tables, limited copies available from JMC as RDB3A57)

R-141b

K. S. Sanvordenker (Tecumseh Products Company), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 2, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, August 1992 (22 pages with 10 figures and 4 tables, available from JMC as RDB3802)

This report summarizes calorimeter test results for a nominal 8.8 kW (30,000 Btu/hr), hermetic reciprocating piston compressor (Tecumseh model AW5530F). Plots present efficiency and capacity ratios, to compare performance for R-32/134a (30.1 /69.9) and R-22, as functions of evaporator and condensing temperatures. The ranges covered are -26 to 13 °C (-15 to 55 °F) and 32-66 °C (90-150 °F), respectively. The tests were performed using a fully-formulated, polyolester lubricant (Mobil EAL Arctic(R) 322 R, ISO viscosity grade 22). Tables and plots summarize the compressor performance (capacity, input power, current draw, mass flow, and efficiency) and coefficients per ARI standard 540-91. The report notes that above -12 °C (10 °F) evaporator temperature, the efficiencies of the blend exceed those with R-22 by less than 5%. Below this temperature, the blend suffers compared to R-22. The effect is described as real, because the compression ratios are significantly higher, but exaggerated, because there may be large errors in measurements at these conditions. The capacity is shown to be slightly lower with the blend at almost all conditions plotted. The report also notes that the same gain in efficiency was not found for a different compressor, using thermodynamic data from a separate source (NIST REFPROP 3.04a versus DuPont Chemicals data), though the trends are the same. (also see RDB3622)

Retrofit Guidelines for Suva(R) MP39 and Suva(R) MP66, document ART-5 (H-42446), DuPont Chemicals, Wilmington, DE, August 1992 (10 pages with 4 tables, available from JMC as RDB3444) [see RDB4505 for update]

R-401A and R-401B

Workplace Guidelines for Suva(R) Centri-LP (HCFC-123) in Refrigeration and Air Conditioning Applications, document AS-4 (H-42438), DuPont Chemicals, Wilmington, DE, August 1992 (10 pages with 2 tables, RDB3908)

This bulletin presents recommended workplace guidelines for use of R-123 in refrigeration equipment. It is based on new toxicity information resulting from toxicity testing, including findings of retinal atrophy and benign (nonmalignant) tumor development late in the lifetime of test animals. The bulletin notes that DuPont reacted by revising its recommended Acceptable Exposure Limit (AEL) from 100 ppm to 10 ppm, but that concentrations of 1-3 ppm were routine in monitored installations. The document then discusses health and safety practices for R-123 addressing uses, health protection including monitoring and use of respirators, and safety. It outlines recommendations for storage, handling, and use. An appendix tabulates breakthrough times for R-123 in organic vapor cartridges for respirators for 100 and 500 ppm challenges at 50 and 80% relative humidity. A second appendix suggests actions based on measured machinery room concentrations. A third appendix discusses R-123 monitoring procedures. [see RDB4C50 for update]

July 1992

D. Arnaud, L. Niveau, and S. Wosinski (Atochem Groupe Elf Aquitaine), **Comparison of Thermophysical Properties of HFC 125, 32, and 143a**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:375-383, July 1992 (9 pages with 4 figures and 4 tables, available from JMC as RDB2820)

This paper provides property data for R-32, R-125, and R-143a. These data are provided to predict the properties of their mixtures as replacements for R-502, an azeotrope containing R-22 and R-115. Critical properties, solubility, flammability, ozone depletion potential (ODP), and global warming potential (GWP) are compared for the three hydrofluorocarbons (HFCs) to those of R-502. Transport properties, including thermal conductivity, viscosity, surface tension, and specific heat are similarly compared. Tabular data are provided for compatibility with polychloroprene (neoprene), nitrile butyl rubber (NBR), and polyethylene chlorosulfone (DuPont Hypalon(R)) elastomers. Miscibility also is compared for R-502 and the three HFCs with unidentified naphthenic mineral oil and neopentyl polyester and alkylbenzene lubricants in 80% and 5% lubricant concentrations. A series of plots provide the vapor pressure, saturated liquid density, liquid viscosity, and liquid thermal conductivity for -60 to 60 °C (-76 to 140 °F). The paper reviews the design changes required, but concludes that only few adaptations will be needed for either retrofit or new uses of these fluids.

M. Barret and Y. Candau (Université Paris XII - Val de Marne, France), **Thermodynamic Properties Computation of Two Possible Substitute Refrigerants: R143a (1,1,1-Trifluoroethane) and R125 (Pentafluoroethane)**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:433-442, July 1992 (10 pages with 3 figures and 7 tables, RDB2826)

thermodynamic properties of R-125 and R-143a: Martin-Hou (MH) equations of state (EOS); Mollier diagrams; thermophysical data

K. Beermann and H. H. Kruse (Universität Hannover, Germany), **Experiences with the Refrigerant R-134a as a 'Drop-In' Replacement in a Large Water-Water Heat Pump**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:211-219, July 1992 (9 pages with 4 figures and 4 tables, RDB2723)

performance tests for R-134a

B. Bella, A. Cavallini, G. A. Longo, and L. Rossetto (Università di Padova, Italy), **Pure Refrigerant Condensation on a Single Integral Finned Tube: Vapor Velocity Effects**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette,

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IN, 1:177-186, July 1992 (10 pages with 7 figures and 2 tables, RDB2719)

heat transfer

D. B. Bivens and A. Yokozeki (DuPont Chemicals), **Heat Transfer of Refrigerant Mixtures**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:141-148, July 1992 (8 pages with 5 figures and 1 table, RDB2715)

blends, heat transfer

R. Camporese, B. Boldrin, M. Scattolini (Consiglio Nazionale della Ricerche, CNR, Italy), and G. Cortella (Università di Udine, Italy), **Improvement of R-134a Performance by Addition of R-290**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:45-52, July 1992 (8 pages with 9 figures and 3 tables, RDB2712)

R-290/134a

L. Canren, Y. Zhao, and M. Yitai (Tianjin University, China), **Investigation of Using the Ternary Mixture as the Alternative for R-12**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:661-667, July 1992 (7 pages with 3 figures and 2 tables, RDB2841)

zeotropic blends

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Compatibility of Refrigerants and Lubricants with Plastics**, report DOE/CE/23810-3F, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1992 (26 pages with 18 tables, available from JMC as RDB2807; type on page A-1 is small and may be difficult to read)

This interim report summarizes progress to provide compatibility information on engineering plastics with alternative refrigerants and suitable lubricants. Two tables provide the molding specifications, molding conditions, and physical properties of 23 plastic materials. They include acetal (DuPont Delrin(R) II 11500), acrylonitrile-butadiene-styrene terpolymer (ABS, GE Cycolac(R) GPM4700), liquid crystal polymer (LCP, Amoco Xydar(R) MG450), phenolic (Hooker Durez(R) 153), poly(aryletheretherketone) (PEEK, ICI Victrex(TM) PEEK 450G), polyamide nylon 6/6 (DuPont Zytel(R) 101), polyamide-imide (Amoco Torlon(R) 4203L and 4301), polyaryletherketone (PAEK, BASF Ultrapek(R)), polyarylsulfone (Amoco Radel(R) A-200), polybutylene terephthalate (PBT, GE Valox(R) 325PBT), polycarbonate (GE Lexan(R) 161), polyetherimide (GE Ultem(R) 1000), modified polyetherimide (GE Ultem(R) CRS5001), polyethylene terephthalate (PET, DuPont Rynite(R) 530), polyimide (DuPont Vespel(R) DF and DF-ISO), modified polyphenylene oxide (PPE, GE Noryl(R) 731), polyphenylene sulfide (PPS, GE Supec(TM) G401), polyphthalamide (Amoco Amodel(R) AD1000HS), polypropylene (Himont Profax(TM) 6331NW), polytetrafluoroethylene (PTFE, DuPont Teflon(R)), and polyvinylidene fluoride (Atochem Kynar(R) 720). Seven tables summarize the changes for immersions in lubricants, including BVA R015, alkylbenzene (Shrieve Zerol(R) 150), a pentaerythritol ester mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244), a pentaerythritol ester branched acid (Henkel Emery(R) 2927a ISO 32), a polypropylene glycol butyl monoether (ICI Emkarox(R) VG32), a polypropylene glycol diol (Dow P425), and a modified polyglycol (AlliedSignal BRL-150). Nine tables summarize changes following exposures to R-22, R-32, R-123, R-124, R-134, R-134a, R-142b, R-143a, and R-152a. Observations of particulates, cracking, crazing, softening, and color change are presented. Quantitative data are provided for dimensional (length, width, and thickness) and weight changes. The lubricant immersions at 60 and 100 °C (140 and 212 °F) for 14 days are complete. All of the plastics were affected by the lubricants; mineral oil and alkylbenzene caused the greatest effect. Ambient immersion studies are complete for nine of ten refrigerants at 60 °C (140 °F). All of the refrigerants had some impact, generally softening or weight change; hydrofluorocarbons (HFCs) have the least impact. The report documents several combinations that failed at ambient conditions or are likely to fail at elevated temperatures. Test plans for subsequent work, including creep rupture tests, are outlined.

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Compatibility of Refrigerants and Lubricants with Plastics**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:689, July 1992 (1 page, available from JMC as RDB2816)

This synopsis outlines the objectives and approach for a study to provide compatibility information on engineering plastics with alternative refrigerants and suitable lubricants. The plastics, refrigerants, and lubricants to be tested are identified.

S. W. Crown, H. N. Shapiro, M. B. Pate (Iowa State University of Science and Technology), **A Com-**

parison Study of the Thermal Performance of R-12 and R-134a, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:187-196, July 1992 (10 pages with 11 figures and 2 tables, RDB2720)

This paper compares the performance of a 10 kW (3 ton) refrigeration system with R-134a to R-12. The equipment tested, instrumentation, and test conditions are described. Both the capacity and coefficient of performance (COP) are plotted as functions of the condenser water temperature for representative evaporator temperatures. COP and capacity ratios for R-134a to R-12 are similarly plotted with varying R-134a charges. System performance was shown to be less sensitive to the charge for R-12. Experimental results show that R-134a yielded higher efficiency and cooling capacity for almost all tests, especially with subcooling of 5.6-7.5 °C (10-15 °F). COPS are compared to pressure ratios for the two refrigerants, leading to a conclusion that the system can operate at a higher pressure ratio with R-134a and yet have a higher COP than with R-12. The effects of operating conditions are presented in detail.

S. Devotta and S. Gopichand (National Chemical Laboratory, India), **Comparative Assessment of Some Flammable Refrigerants as Alternatives to CFC-12**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:249-257, July 1992 (9 pages with 4 figures and 1 table, available from JMC as RDB2727)

This paper reviews the need for assessment of flammable refrigerants and the implications of using such fluids as alternatives to R-12. Because of the complexities and potential adverse findings in qualifying alternative refrigerants, there may not be adequate time for developed countries to fully evaluate new fluids. Developing countries such as India and China, which are self-reliant in the manufacture of refrigerants and equipment, are short of funds and cannot afford to introduce transition fluids, such as HCFCs and possibly HFCs, and then change again. Global environmental concern requires that flammable fluids also be considered, some of which were used in the past even in home refrigerators. Flammability is considered to pose a lower risk than toxicity. The paper reviews the theoretical performance and flammability of R-142b, R-152a, R-C270 (cyclopropane), R-290 (propane), R-600 (butane), R-600a (isobutane). The pressure ratios, specific compressor displacements, theoretical efficiency, and specific shaft power are plotted for these refrigerants as functions of the evaporating temperature for a range of -35 to 5 °C (-31 to 41 °F) for a 50 °C (122 °F) condensing temperature. The performance, flammability and environmental data, and fundamental properties are tabulated and compared to those of R-12. Means to reduce leaks and charge quantities are discussed as ways to reduce the risks. R-C270 would require smaller compressors and may offer superior performance. R-152a may be preferred based on its lower flammability and experience with it.

R. G. Doerr, R. H. Ernst, F. Howard, S. A. Kujak, D. Lambert, R. Schafer, and D. Steinke (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:691-692, July 1992 (2 pages, available from JMC as RDB2817)

This synopsis outlines the objectives and approach for a study to provide compatibility information on 24 representative motor materials with 11 refrigerants and 17 refrigerant-lubricant combinations. The materials (including magnet wires, varnishes, sheet insulation, slot liners, phase separators, insulation, tapes, and tie cords), refrigerants, and lubricants to be tested are identified.

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials**, report DOE/CE/23810-3D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1992 (20 pages with 43 tables, available from JMC as RDB2804)

This interim report summarizes progress to provide compatibility information for motor materials (for hermetic compressors) in refrigerants and refrigerant-lubricant combinations. Tabular findings are reported for exposures at 90 °C (194 °F) to R-22, R-123, and R-134a and to nitrogen at 127 °C (260 °F). Data are provided both after 500 hour exposures and after a subsequent air bake for 24 hours at 150 °C (302 °F), to drive off absorbed refrigerant. Dielectric strength, burnout time, bond strength, and qualitative flexibility are compared to the unexposed values for three magnet wires. The specimens included six varnishes and an uncoated specimen for magnet wire with an amide-imide overcoat (Phelps Dodge Armored Poly-Thermaleze 2000), Daglass served wire (Phelps Dodge Armored Poly-Thermaleze Daglass 2000), and ester-imide overcoated with amide-imide (Phelps Dodge / Schenectady Chemical). Weight change also is reported for six exposed varnish disks. The varnishes tested

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include two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). Flexibility of the varnish is suggested as important, due to the tendency of the end turns of motor windings to move in startup and operation of motors. The enamel could be removed from the wire by flexing, due to low flexibility of some varnishes and strong bonding to the insulation. Preliminary observations are presented on the role of refrigerant absorption and desorption when heated. Rapid desorption could result in structural breakdown of varnishes and other materials. Tensile strength, weight change, and elongation are compared to the unexposed values for six sheet insulations including Westinghouse Nomex-Mylar-Nomex(R), Westinghouse Dacron-Mylar-Dacron(R), DuPont Mylar(R) MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228. Weight change comparisons are tabulated for Insulations Sales Nomex(R), Mylar(R), and Nomex-Mylar(R) sleeving materials. Heat degradation of polyethylene terephthalate (PET) insulation was observed, especially with residual moisture and butyl cellosolve evolved from Isopoxy(R) 800 varnish. Changes in weight and dielectric strength are presented for A. O. Smith Dacron-Mylar-Dacron(R) and Dacron-Teflon-Dacron(R) lead wire insulation. Weight and breaking load changes are supplied for Carolina Narrow woven glass tape, Electrolock heat shrinkable braided polyester tape, Essex Permacel P247 glass-acrylic tape, and Ludlow Textiles polyester tie cord. HCFC refrigerants, and R-22 in particular, appear to have a greater effect than HFCs on motor materials. Based on historical reliability of motors with R-22, reliable use is anticipated with HFCs. The report indicates that the project is progressing on schedule and test completion is anticipated by the end of 1992.

C. L. Gage (U.S. Environmental Protection Agency, EPA) and G. S. Kazachki (Acurex Environmental Corporation), **Predictions of Azeotropes Formed from Fluorinated Ether, Ethane, and Propane Azeotropes**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:611-619, July 1992 (9 pages with 6 figures and 3 tables, RDB2836)

D. G. Gehring, D. J. Barsotti, and H. E. Gibbon (DuPont Chemicals), **Chlorofluorocarbons Alternatives Analysis, Part I: The Determination of HFC-134a Purity by Gas Chromatography**, *Journal of Chromatographic Science*, 30:280-284, July 1992 (5 pages with 3 figures and 2 tables, RDB3A56)

R-134a

K. D. Gerdsmeyer (Danfoss GmbH, Germany), **R-134a in Small Commercial Refrigeration Systems: Some Practical Aspects**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:197-202, July 1992 (10 pages with 4 figures, RDB2721)

This paper present findings with R-134a in commercial refrigeration equipment for evaporating temperatures of -15 to 15 °C (5-59 °F) with small hermetic compressors (with displacements volumes up to 20 cm^3, 1.2 in^3). Emphasis is placed on beverage coolers, cooling units for electronics, commercial refrigerators, and heat pump water heaters (HPWHs). Cooling capacities are plotted for R-12 and R-134a based on calorimetric tests of a compressor, showing that the capacity of R-12 and R-134a are similar, but slightly greater for R-12 at low evaporating temperatures and for R-134a at high temperatures. Coefficients of performance (COP) are similarly plotted, showing no penalty with R-134a in compressors optimized for R-12. Tests of a HPWH showed reduced operating time with R-134a due to its higher capacity. More favorable results with systems optimized for R-134a are suggested. The relative miscibility of mineral oil in R-12 and esters in R-134a are discussed, noting higher concern with design for oil return for the latter. The paper notes that new ester lubricants have the advantage of being biodegradable. Moisture implications and the need for higher drying with ester lubricants are discussed. Residual chlorine from retrofits leads to increased wear with R-134a and esters. The paper argues against conversion from R-12 to R-134a for small refrigeration systems, but concludes that R-134a can be successfully used in new systems.

G. H. Goble (Peoples Welding Supply, Incorporated), **A Drop-In CFC-12 Replacement for Automotive Air Conditioning**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:607-609, July 1992 (3 pages, available from JMC as RDB2835)

This paper presents a ternary zeotropic blend, proposed as a transition fluid, to replace R-12 in automotive air conditioners. The blend is R-22/600a/142b (55/8/37), which offers an ozone depletion potential of 0.05 and compatibility with mineral oils. It has been tested in approximately

150 vehicles, two since August 1990. Only one failure has resulted, but it was not attributed to the refrigerant change. Colder air delivery than for R-12 was found; the condensing temperature is higher, though still low enough to prevent refrigerant-oil breakdown. The isobutane content makes the blend miscible in standard mineral oils, including Witco Suniso(R) 3GS and 5GS naphthenic oils and Virginia KMP 150 paraffinic oil. The flammability, both as compounded and after fractionation from leakage, is reviewed. Testing of a silane-based, desiccant and sealant additive are described to reduce refrigerant leaks. The paper notes that the blend composition can be customized for hot climates. [The blend addressed is a developmental version of GHG, later reformulated to R-22/600a/142b (55/4/41), R-406A.]

L. R. Grzyll and C. F. Parish (Mainstream Engineering Corporation), **An Innovative Approach for the Screening and Development of CFC Alternatives**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:415-424, July 1992 (10 pages with 6 figures and 4 tables, RDB2824)

G. R. Hamed and R. H. Seiple (University of Akron), **Compatibility of Refrigerants and Lubricants with Elastomers**, report DOE/CE/23810-3E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1992 (102 pages with 31 figures and 60 tables, available from JMC as RDB-2805)

This interim report summarizes swell measurements for approximately half of the 94 elastomers being tested in refrigerants and lubricants. Swell behavior was determined using weight and in situ diameter measurements for the refrigerants and diameter and thickness measurements for the lubricants. The refrigerants include both hydrochlorofluorocarbons (HCFCs R-22, R-123, R-124, and R-142b) and hydrofluorocarbons (HFCs R-32, R-125, R-134, R-134a, R-143a, R-152a). The lubricants include an unidentified mineral oil, alkylbenzene, three polyalkylene glycols (PAGs: a polypropylene glycol butyl monoether, a polypropylene glycol diol, and a modified polyglycol), and both a branched acid and a mixed acid pentaerythritol ester (PE). Appropriately cured elastomers, encompassing both general purpose and specialty rubbers, were tested. Gum and black-filled compounds were tested, as were some thermoplastic elastomers (TPEs). Compositions containing carbon black had reduced swelling compared to their unfilled counterparts. Among the HCFCs, R-123 generally resulted in the highest swelling, although an EPDM/PP TPE, butyl rubber/PP TPE, and a fiber-filled neoprene were quite resistant to it. Some compositions shrunk, suggesting that the swellant was removing a component,, probably plasticizer, from the elastomer. All the HFCs resulted in substantially lower swelling than the HCFCs. R-143a, the least acidic of the refrigerants tested, gave the least swelling overall. A series of figures summarize the diameter changes. Swell data also are tabulated, for exposures of 1, 3, and 14 days; weight change is tabulated after 14 days. The elastomers tested include polyisoprene, neoprene, butyl, bromobutyl, SBR/styrene, nitrile, hydrogenated nitrile, fluoroelastomer, fluorochloroelastomer, epichlorohydrin (homopolymer, ethylene oxide copolymer, and terpolymers), dimethyl silicone rubber, methylphenylvinylsilozane rubber, silicone rubber, fluorosilicone, EPDM/PP/TPE, nitrite/PP/TPR, chlorosulfonated PE, ethylene/propylene copolymer (EPM), ethylene/acrylic elastomer, chlorinated PE, EPDM, butyl rubber, chloroprene, and ACN compound. [see RDB2806 for supplemental data]

G. R. Hamed and R. H. Seiple (University of Akron), **Compatibility of Refrigerants and Lubricants with Elastomers - Supplement**, supplement to report DOE/CE/23810-3E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1992 (144 pages with 135 figures and 2 tables, available from JMC as RDB2806)

This supplement provides gas chromatograms and results for the refrigerant specimens, FTIR data (infrared absorbance) for the refrigerants and lubricants, and thermogravimetric analyses (TGA) and oscillating disk rheometer (ODR) plots for the elastomers tested. See RDB2805 for further information.

D. F. Huttenlocher (Spauschus Associates, Incorporated), **Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures with Metals**, report DOE/CE/23810-3B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 10 July 1992 (64 pages with 37 figures and 24 tables, available from JMC as RDB2802)

This interim report presents stability data, based on sealed tube tests, for mixtures of refrigerants and lubricants in the presence of a valve steel strip. Tabular results are presented for R-22 with mineral oil, R-124 with alkylbenzene, R-134a with three pentaerythritol esters (PEs), R-142b with alkylbenzene; R-143a with PE branched acid, and R-152a with alkylbenzene. Partial results are provided for eight additional refrigerant-lubricant mixtures, including those containing R-11, R-32, R-123, R-125, and R-134. The information provided includes visual observations on the aged sealed tubes and gas chromatographic analyses on their vapor-phase contents. Chloride ion contents are provided for hydrochlorofluorocarbon (HCFC) containing mixtures and fluoride ion contents for hydrofluorocarbon (HFC) mixtures. Total acid number values and infrared analyses are presented for mixtures containing ester lubricants. The mineral oils tested were Witco Suniso(R) 3GS (ISO 32) and Freezene Naphthenic Heavy white oil (ISO 46). The alkylbenzene was Shrieve Zerol(R) 150. The polyalkylene glycols (PAGs) included ICI Emkarox(R) polypropylene glycol butyl monoether (ISO 32) and Dow Chemical P245 polypropylene glycol diol (ISO 22). The pentaerythritol esters (PEs) included Castrol Icematic(R) SW32 branched acid, ICI Emkarate(TM) RL mixed acids, and Henkel Emery(R) 4078X (2928 ISO 100) 100 cSt. Most of the tests were repeated at three temperature levels, namely 150, 175, and 200 °C (221, 302, and 347 °F); additional tests were performed at 105 °C (221 °F) when indicated. The preliminary findings indicate that the HFCs tested are very stable and did not undergo measurable chemical reactions or thermal decomposition, even in the presence of lubricants. The high-viscosity ester is the only lubricant that showed significant signs of instability, based on decarboxylation of the ester molecule, especially at 200 °C (347 °F). All of the HCFCs tested, possibly excepting R-22, are less stable than the HFCs. Except for R-123, however, they are no more reactive than R-12 under equivalent test conditions. While R-123 is significantly more reactive, it offers a stability improvement by a factor of ten over R-11.

P. E. Hansen (Danfoss-Flensburg GmbH, Germany) and L. Finsen (Danfoss A/S, Denmark), **Lifetime and Reliability of Small Hermetic Compressors Using a Ternary Blend HCFC-22/HFC-152a/HCFC-124**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:641-649, July 1992 (9 pages with 6 figures and 2 tables, RDB2839)

R-22/152a/124, R-401 series

D. F. Huttenlocher (Spauschus Associates, Incorporated), **Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures with Metals**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:679, July 1992 (1 page, available from JMC as RDB2813)

R. F. Kayser (National Institute of Standards and Technology, NIST), **Thermophysical Properties**, report DOE/CE/23810-3A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1992 (54 pages including a 6 page report and 2 appended draft papers, available from JMC as RDB2801)

This progress report provides an update on a project to provide highly accurate, selected, thermophysical properties data for R-32, R-123, R-124, and R-125. The thermodynamic data also will be fit to modified Benedict-Webb-Rubin (MBWR) and improved Carnahan-Starling-DeSantis (CSD), or Carnahan-Starling-DeSantis-Morrison (CSDM), equations of state for each fluid. The CSDM equation takes into account the effects of the dipole moment to improve modeling of blends of very polar fluids, such as R-32/134a. Viscosity and thermal conductivity data for R-32 and thermal conductivity data for R-123 will be correlated for use in transport property models. Measurements in this reporting period have focused on the PVT behavior, isochoric heat capacity, and transport properties of R-32 and on the thermal conductivity of R-123. Measurements for R-32, based on Burnett apparatus, are described. A draft paper entitled "Ebulliometric Measurement of the Vapor Pressure of Difluoromethane (R-32)," submitted to the *Journal of Chemical and Engineering Data*, is appended. Measurements of the molar heat capacity using an adiabatic calorimeter, of thermal conductivity using a low temperature transient hot-wire instrument, and shear viscosity using a torsional quartz crystal viscometer are outlined. The pressure and liquid densities of R-32/134a and R-32/152a were determined at the bubble points of these mixtures in a related project. The thermal conductivity of R-124 was measured in the liquid and vapor phases, and a draft paper entitled "Thermal Conductivity of 2-Chloro-1,1,1,2-Tetrafluoroethane (R-124)," submitted to the *International Journal of Thermophysics*, also is appended. Thermal conductivity measurements of R-125 in the vapor, liquid, and supercritical phases are outlined as are viscosity measurements for both R-124 and R-125. The thermal conductivity measurements of R-123, using low and high-temperature transient hot-wire instruments, also are described. The agreement between newly acquired property data are compared to those resulting from other identified investigations, generally indicating more complete and much more precise findings.

G. S. Kazachki (Acurex Environmental Corporation) and C. L. Gage (U.S. Environmental Protection Agency, EPA), **Thermodynamic Evaluation of Predicted Fluorinated Ether, Ethane, and Propane Azeotropes**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants,* edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:595-605, July 1992 (11 pages with 10 figures and 4 tables, RDB2834)

This paper summarizes thermodynamic analyses of seven predicted azeotropes of fluorinated ethers, ethanes, and propanes. They include R-E125/C270, R-E125/134a, R-E143a/134, R-134a/E143a, R-E143a/152a, R-134/245cb, and R-245cb/227ea. Their performance was evaluated using basic thermophysical property data and the results used to rank the azeotropes among other refrigerants.

T. S. Kim, J. Y. Shin, S-D. Chang, M. S. Kim, and S. T. Ro (Seoul National University, Korea), **Cycle Performance and Heat Transfer Characteristics of a Heat Pump Using R-22/142b Refrigerant Mixtures**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants,* edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:53-62, July 1992 (10 pages with 14 figures, RDB2713)

H. H. Kruse and F. Rinne (Universität Hannover, Germany), **Performance and Leakage Investigations of Refrigeration and Air-Conditioning Systems Using Refrigerant Mixtures as Working Fluids**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants,* edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:621-630, July 1992 (10 pages with 10 figures, available from JMC as RDB2837)

J-Y. Lin and M. B. Pate (Iowa State University of Science and Technology), **A Thermal Conductivity Prediction Method for Refrigerant Mixtures in the Liquid Phase**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:365-374, July 1992 (10 pages with 8 figures and 1 table, RDB2819)

J. W. Linton, W. K. Snelson, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **The Potential of HFC-134a and HFC-152a to Replace CFC-12 in Medium Temperature Heat Pump Applications**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants,* edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:203-209, July 1992 (7 pages with 8 figures, RDB2722)

R-134a, R-152a

M. S. Menzer (Air-Conditioning and Refrigeration Technology Institute, ARTI), **ARTI Preliminary Results of Materials Exposed to Refrigerants and Lubricants**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:677, July 1992 (1 page, available from JMC as RDB2812)

This synopsis introduces the Materials Compatibility and Lubricant Research (MCLR) Program, an effort to investigate the properties and compatibilities of alternative refrigerants. The goal of this program is to accelerate commercialization of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) substitutes in air-conditioning and refrigeration applications. The funding and program management are indicated. Seven research projects exceeding $1.2 million in total are identified for the first phase. The program includes projects to measure thermodynamic and heat transport properties of refrigerants, test the chemical and thermal stability of refrigerant-lubricant mixtures with metals, and measure the miscibility of refrigerants and lubricants. Three additional projects will provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics. The seventh project facilitates dissemination of data through development and administration of a refrigerant database. The second phase also is introduced. It includes projects to measure the solubility and viscosity of refrigerant-lubricant mixtures, their compatibility with desiccants, and development of screening and test methods. This summary serves as a preface for five presentations from the program.

J. Pannock, D. A. Didion (National Institute of Standards and Technology, NIST), and R. K. Radermacher (University of Maryland), **Performance Evaluation of Chlorine-Free Zeotropic Refrigerant Mixtures in Heat Pumps - Computer Study and Tests**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:25-34, July 1992 (10 pages with 8 figures and 2 tables, RDB2710)

M. B. Pate, S. C. Zoz, and L. J. Berkenbosch (Iowa State University of Science and Technology), **Miscibility of Lubricants with Refrigerants**, report DOE/CE/23810-3C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1992 (22 pages with 24 tables, available from JMC as RDB2803)

This progress report summarizes the status and initial data obtained from an investigation of miscibility of lubricants with refrigerants. Experiments are being performed in two phases, namely screening tests and preparation of mis-

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cibility plots. Qualitative miscibility observations are tabulated for R-32, R-125, R-134, R-134a, R-142b, and R-143a with four lubricants. They include two pentaerythritol esters, a mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244) and a branched acid (Castrol Icematic(R) SW32), and for two polyalkylene glycols (PAGs), a polypropylene glycol diol (Dow P425) and a polypropylene glycol butyl monoether (ICI Emkarox(R) VG32). These tests were performed for three lubricant concentrations over a temperature range of -50 to 60 °C (-58 to 140 °F) for R-32, R-125, R-134, and R-143a. The range was extended to 90 °C (194 °F) for R-134a and R-142b. R-22, R-123, R-124, and R-152a will be tested later. The refrigerant concentrations varied due to the method of charging the test cells, but future tests will provide data at nominal concentrations of 10, 50, and 95% by weight for all of the combinations. Composition changes as the density of the vapor decreases and the vapor volume increases are discussed. Minor problems with leakage and corrections are described. Summary observations are provided for each refrigerant-lubricant combination.

M. B. Pate, S. C. Zoz, and L. J. Berkenbosch (Iowa State University of Science and Technology), **Miscibility of Lubricants with Refrigerants**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:681-686, July 1992 (6 pages with 4 figures and 2 tables, available from JMC as RDB2814)

N. D. T. Rohatgi and H. O. Spauschus (Spauschus Associates, Incorporated), **Method for Determining Flexural Property Changes of Polymeric Materials upon Accelerated Aging in Refrigerant-Lubricant Mixtures**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:395-403, July 1992 (9 pages with 6 figures and 6 tables, available from JMC as RDB2822)

This paper describes a test method to determine changes in flexural properties of small samples of polymeric materials after aging in refrigerants and/or lubricants. The method uses linear stress versus strain curves and calculated flexural modulus of materials. Changes after thermal aging are used to indicate whether a material becomes more flexible (due to absorption of liquid lubricant or refrigerant-lubricant mixture) or less flexible (due to possible extraction of material from the polymeric matrix by the liquid phase). The effects of aging time and temperature also are addressed. The procedure provides quantitative measurements which, along with visual observations, linear swelling and changes in hardness, are necessary to interpret compatibility results from sealed-tube tests. Results are reported for glass-reinforced nylon 6/6, flexible nylon alloy, plasticized nylon copolymers, and polyamide 1212 in R-12 with mineral oil and in R-134a with an unidentified polyalkylene glycol (PAG) lubricant. Density, Shore durometer D hardness, flexural modulus, visual observations, and dimensional changes are tabulated. Stress versus strain curves are plotted both before and after aging.

P. Rohlin (Kungliga Tekniska Högskolan, KTH, Sweden), **Coefficients of Performance and Local Heat Transfer Coefficients for Flow Boiling Inside Horizontal Tubes with Nonazeotropic Refrigerant Mixtures in a Small Exhaust Air Heat Pump**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:157-166, July 1992 (10 pages with 8 figures and 1 table, RDB2717)

Test results are presented for three refrigerant blends in an exhaust-air heat pump, with a heating capacity of 1050-1450 W (3600-4950 Btu/hr). Such heat pumps are used, widely in Sweden, to recover heat from exhaust air to heat service hot water, particularly for large multifamily residential buildings. Heating coefficients of performance (COPs), capacities, and local heat transfer coefficients in the evaporator are compared to those for R-12. Data for R-22/-152a/124 (36/24/40) and two blends of R-22/142b (45/55 and 60/40) are plotted and discussed. The experiments indicate that use of these zeotropic mixtures can increase both the COP and capacity despite a large reduction in the local heat transfer coefficient. The reduction is large with the binary mixtures and is compounded by suppression in nucleate boiling, also observed by other referenced investigations. Both the experimental apparatus and analytical methods used are described.

S. M. Sami, J. Schnotale (University of Moncton, Canada), and J. G. Smale (DuPont Canada, Incorporated), **An Experimental Investigation of Ternary Blends Performance Proposed as Substitutes for CFC-12**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:651-660, July 1992 (10 pages with 9 figures, RDB2840)

R. H. Seiple and G. R. Hamed (University of Akron), **Compatibility of Refrigerants and Lubricants with Elastomers** in *Proceedings of the 1992 Inter-*

national Refrigeration Conference - Energy Efficiency and New Refrigerants, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:687-688, July 1992 (2 pages, available from JMC as RDB2815)

This synopsis outlines the objectives and approach for a study to provide information on the compatibility and change of properties for 84 elastomers, used as seals, and hoses in refrigeration systems. The materials to be tested, refrigerants, lubricants, and methods are identified.

M. B. Shiflett, A. Yokozeki, and P. R. Reed (DuPont Chemicals), **Property and Performance Evaluation of 'SUVA' HP Refrigerants as R-502 Alternatives**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:15-24, July 1992 (10 pages with 10 figures and 2 tables, RDB-2709)

M. B. Shiflett, A. Yokozeki, and D. B. Bivens (DuPont Chemicals), **Refrigerant Mixtures as HCFC-22 Alternatives**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:35-44, July 1992 (10 pages with 8 figures and 2 tables, RDB2711)

R. R. Singh, H. T. Pham, and I. R. Shankland (AlliedSignal Incorporated), **Some Issues in the Use of Refrigerant Mixtures**, presented at the 1992 International Refrigeration Conference (Purdue University, West Lafayette, IN, July 1992), published in *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 455-463, July 1994 (9 pages with 11 figures, RDB-4861)

This paper summarizes an investigation of segregation of R-32/134a (30/70), proposed as an alternative for R-22, into is components. The paper briefly cites the benefits of zeotropic refrigerant blends and introduces preferential fractionation based on differences in vapor pressure. It notes that the vapor phase composition is enriched in the more volatile component, compared to the liquid phase, so the more volatile component is lost faster in a vapor leak. The paper discusses the implications for performance, flammability, and recharging. Leakage was simulated with a variable vapor leak. Plots illustrate the dependence of measured capacity, efficiency, and temperature glide on composition. A second series contrasts the vapor and liquid compositions to the flame limit to the fraction of lost charge at -20 and 40.2 °C (-4 and 104 °F). Three final plots show the capacity and corrected capacity for 10 and 20% leak rates at -20 °C (-4 °F) with one to five recharges. The paper reports that fractionation depends on the temperature, can result in potentially flammable vapors, and that continual loss in capacity will occur with recharging if the losses exceed 10%.

L. Snitkjær and F. K. Eggert (Danfoss-Flensburg GmbH, Germany), **Use of a Ternary Blend in Existing Domestic CFC-12 Appliances**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:631-640, July 1992 (10 pages with 5 figures and 4 tables, RDB2838)

M. W. Spatz and J. Zheng (AlliedSignal Incorporated), **Performance of Alternative Refrigerants in Heat Pumps and Air Conditioners**, presented at the 1992 International Refrigeration Conference (Purdue University, West Lafayette, IN, July 1992), published in *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 465-475, July 1994 (11 pages with 3 figures and 4 tables, RDB4862)

performance tests of R-134a, R-152a, R-32/125 (60/40), R-32/134a (25/75)

K. E. Starner, **Summary of Pool Boiling Test Results for R-134a, R-22, and R-12 with Oils**, York International Corporation, York, PA, 22 July 1992 (1 page, available from JMC as RDB2808)

This document summarizes tests to compare heat transfer characteristics of R-12, R-22, and R-134a, with and without lubricants, for Wolverine Turbo-B(R) enhanced-surface tubes. Turbo-B(R) tube is enhanced on both the inside and outside surfaces to increase the overall heat transfer coefficient; its primary use is as a boiling tube for evaporators in chillers. Quantitative results are presented for a heat flux of 17.3 kW/m^2 (5500 Btu/h·ft^2) for nominal 19 mm (3/4") outside-diameter tubes in a 60 cm (2'), 8-tube bundle at 4.4 °C (40 °F). Differences are presented between the wall temperature and the refrigerant saturation temperature at the measured pressure. Results are compared between refrigerant-lubricant mixtures, with 1.5% mineral oil by volume, and those for pure refrigerants. Additional data are provided for R-134a with miscible lubricants, including an unidentified polyalkylene glycol (PAG) and ester. For pure refrigerants, the measured temperature difference is 0.14 °C (0.25 °F) lower for R-22 and 0.06 °C (0.1 °F) higher for R-12 compared to that for R-134a. The document reports penalties, com-

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pared to pure refrigerants, of 0.53, 0.31, 2.78, 0.19, and 0.33 °C (0.95, 0.55, 5.00, 0.35, and 0.60 °F) for mixtures with 1.5% lubricant for R-12 with mineral oil, R-22 with mineral oil, R-134a with mineral oil (nonmiscible), R-134a with PAG, and R-134a with ester, respectively. Additional penalties of 0.17 and 0.39 °C (0.30 and 0.70 °F) are reported for mixtures of 0.08 and 0.15% mineral oil with 1.5% ester-based lubricant above that for the refrigerant-ester mixture alone.

S. G. Sundaresan (Copeland Corporation), **Near Azeotrope Refrigerants to Replace R-502 in Commercial Refrigeration**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:1-13, July 1992 (13 pages with 11 figures and 7 tables, RDB2708)

alternative refrigerants, blends

S. R. Szymurski, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-3, Air-Conditioning and Refrigeration Technology Institute (ARTI) , Arlington, VA, July 1992 (13 pages, available from JMC as RDB2809)

This progress report summarizes the goals and status of the Materials Compatibility and Lubricant Research (MCLR) Program, jointly funded under a grant from the Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program addresses critical research to accelerate the introduction of substitutes for chlorofluorocarbon (CFC) refrigerants. The program comprises projects to measure thermophysical properties, test the chemical and thermal stability of refrigerant-lubricant mixtures with metals, and measure the miscibility of lubricants with refrigerants. One project is modeling the performance and key operating parameters of alternatives for R-22. Three projects will provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics. An eighth project collects and facilitates dissemination of data through development and administration of a refrigerant database. The scope of the program, objectives of the projects, and significant preliminary findings are presented. [see RDB2B02 for update]

S. Uemura, S. Inagaki, N. Kobayashi, T. Teraoka, and M. Noguchi (Daikin Industries, Limited), **Characteristics of HFC Refrigerants**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:385-394, July 1992 (10 pages with 13 figures and 5 tables, available from JMC as RDB2821)

K. Watanabe, H. Sato, and Z-Y. Qian (Keio University, Japan), **Thermodynamic Properties of New Refrigerants - HFC-32 and HFC-125**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:443-452, July 1992 (10 pages with 9 figures, RDB2827)

R-32, R-125

L. A. Weber (National Institute of Standards and Technology, NIST), **Criteria for Establishing Accurate Vapor Pressure Curves**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:463-471, July 1992 (9 pages); republished in *International Journal of Refrigeration* (IJR), 17(2):117-122, February 1994 (6 pages with 4 figures, available from JMC as RDB2829)

This paper uses standard thermodynamic relationships to demonstrate the accuracy of new vapor pressure measurements. Calculated, liquid-phase, heat capacities, based on data for R-123 and R-134a, are compared to published, experimental values. The paper describes and schematically illustrates a comparative ebulliometer apparatus used to measure vapor pressures. It contrasts the measured data to those obtained by others, noting that the new vapor pressure data tend to be systematically lower than published values. It suggests that the deviations may derive from presence of a volatile impurity (air) in samples used in static measurements, overcome by the dynamic approach of the apparatus described. The paper presents relations, based on thermodynamic principles, to confirm assertion of volatile impurities and to select the most reliable vapor pressure curves. It then discusses plots of heat capacity deviations. The paper concludes that discrepancies between precise vapor pressure data, from different laboratories, can be explained by assumption of impurities, probably air. It notes that very small concentrations of air can have relatively large effects, which can affect calculated thermodynamic properties.

L. A. Weber (National Institute of Standards and Technology, NIST), **Thermophysical Properties of Some Selected Alternative Refrigerants**, presentation at the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference (Purdue University, West Lafayette, IN, July 1990); published in the *Proceedings of the 1992 International Refrigeration Conference - Energy Effi-*

ciency and New Refrigerants, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:703-712, July 1992 (10 pages with 8 figures and 1 table, available from JMC as RDB0908)

Paper summarizes research on thermophysical properties for R-123, R-125, R-134, R-134a, and R-141b as well as properties obtained for R-E134. It describes measurements of the gas and liquid-phase PVT, vapor pressure, surface tension, index of refraction, dielectric constant, gas-phase speed of sound, critical parameters and materials compatibility.

X. Xu and D. Clodic (École des Mines de Paris, France), **Exergy Analysis on a Vapor-Compression Refrigerating System Using R12, R134a, and R290 as Refrigerants**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:231-240, July 1992 (10 pages with 3 figures and 8 tables, RDB2725)

R-12, R-134a, and R-290

M. Yitai, W. Jie, Y. Zhao, W. Huaixin, and L. Canren (Tianjin University, China), **Investigation of Using Nonazeotropic Refrigerant Mixture as the Replacement of R-12**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:669-676, July 1992 (8 pages with 6 figures and 3 tables, RDB2842)

M-S. Zhu, L-Z. Han, Z-Z. Lin (Tsinghua University, China), B. Lu, D. Liu, and L. Yang (Beijing Snow Flake Electrical Appliance Group Corporation, China), **Experimental Researches on Domestic Refrigerators Using HFC-134a as Refrigerant**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:241-247, July 1992 (7 pages with 1 figure and 5 tables, RDB2726)

Safety Code for Mechanical Refrigeration, ASHRAE Standard 15-1992, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, July 1992 (RDB2910)

This voluntary, consensus standard specifies reasonable safeguards of life, limb, health, and property; defines practices that are inconsistent with safety, and prescribes safety standards. It applies to mechanical refrigerating systems and heat pumps used in identified occupancies as well as to components replaced after adoption. The purpose is to promote the safe design, construction, and operation of covered systems. This standard is widely cited and either incorporated by reference or directly quoted in construction codes. It prescribes the maximum quantities of individual refrigerants that may be used for specific building occupancies as well as component, equipment, and installation requirements. Minimum safety devices, marking, and tests also are specified. This version supersedes ANSI/ASHRAE Standard 15-1989, including its addendum (ANSI/ASHRAE Standard 15a-1991) and earlier editions.

June 1992

P. K. Bansal, T. Dutto, and B. Hivet, **Performance Evaluation of Environmentally Benign Refrigerants in Heat Pumps: A Simulation Study**, *International Journal of Refrigeration* (IJR), 15(6):340-348, June 1992 (19 pages, rdb2C03)

alternative refrigerants, efficiencies

J. C. Conklin and E. A. Vineyard (Oak Ridge National Laboratory, ORNL), **Flow Boiling Enhancement of R-22 and a Nonazeotropic Mixture Using Perforated Foils**, paper BA-92-4-3, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 98(2):402-410, 1992 (9 pages with 12 figures, RDB-2611)

heat transfer

S. K. Fischer (Oak Ridge National Laboratory, ORNL), **An Analytical Screening of Alternatives for R-502 in Low-Temperature Refrigerating Applications**, paper 3617, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 98(2):188-203, 1992 (15 pages with 9 figures and 11 tables, RDB-2602)

N. S. Gupte (Carrier Corporation) and R. L. Webb (Pennsylvania State University), **Convective Vaporization of Refrigerants in Tube Banks**, paper BA-92-4-4, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 98(2):411-424, 1992 (14 pages with 27 figures and 2 tables, RDB2607)

heat transfer

E. Korfitsen and A. Christensen, **New Ammonia Technology for Heat Pumps**, *Proceedings of the International Symposium on Refrigeration, Energy, and the Environment* (Trondheim, Norway, 22-24 June 1992), Norgest Tekniska Högskole (NTH), Trondheim, Norway), 165-177, 1992 (13 pages, RDB4344)

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R-717

G. Lorentzen and J. Pettersen (Norgest Tekniska Högskole, NTH, Norway), **New Possibilities for Non CFC Refrigeration**, *Proceedings of the International Symposium on Refrigeration, Energy, and the Environment* (Trondheim, Norway, 22-24 June 1992), Norgest Tekniska Högskole (NTH), Trondheim, Norway), 147-163, 1992 (17 pages, rdb5436)

alternative refrigerants, "natural" refrigerants

P. Nekså (Norgest Tekniska Högskole, NTH, Norway), **The Transcritical Vapor Compression Cycle - Its Potential in Heat Pump Processes**, *Proceedings of the International Symposium on Refrigeration, Energy, and the Environment* (Trondheim, Norway, 22-24 June 1992), Norgest Tekniska Högskole (NTH), Trondheim, Norway, 1992 (RDB-5497)

R-744 (carbon dioxide), transcritical cycle

J. Ogata, Y. Iwafuji, Y. Shimada (Mitsubishi Heavy Industries, Limited, Japan), and T. Yamazaki (Tokyo Electric Power Company, Japan), **Boiling Heat Transfer Enhancement in Tube-Bundle Evaporators Utilizing Electric Field Effects**, paper BA-92-5-2, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 98(2):435-444, 1992 (10 pages with 10 figures and 3 tables, RDB2609)

R. J. Rose (University of Maryland), D. Jung (Inha University, Korea) and R. K. Radermacher (University of Maryland), **Testing of Domestic Two-Evaporator Refrigerators with Zeotropic Refrigerant Mixtures**, paper 3620, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 98(2):216-226, 1992 (10 pages with 7 figures and 3 tables, RDB2605)

S. M. Sami, J. Schnotale (University of Moncton, New Brunswick, Canada), and J. G. Smale (DuPont Canada, Incorporated), **Prediction of the Heat Transfer Characteristics of R-22/152a/114 and R-22/152a/124**, paper 3602, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 98(2):51-58, 1992 (8 pages with 10 figures and 1 table, RDB2601)

A. Yabe, T. Taketani (Mechanical Engineering Laboratory, Japan), H. Maki, K. Takahashi, and Y. Nakadai (University of Tokyo, Japan), **Experimental Study of Electrohydrodynamically (EHD) Enhanced Evaporator for Nonazeotropic Mixtures**, paper BA-92-5-4, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 98(2):455-461, 1992 (7 pages with 10 figures, RDB2610)

Participants' Handbook: R-22 Alternative Refrigerants Evaluation Program (AREP), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 10 June 1992 (46 pages, available from JMC as RDB2620)

This superseded document outlines an ARI program to evaluate candidate alternatives for R-22 and R-502, the latter an azeotrope of R-22 and R-115, for unitary air conditioners, heat pumps, chillers, refrigeration equipment, and ice-making machines. This cooperative program seeks to accelerate introduction of alternatives by focusing research efforts and avoiding duplicative work. The document outlines the AREP organization, including its Task Force (chaired by D. M. Goldberg), Technical Committee (chaired by E. B. Muir), and Heat Transfer Subcommittee. It identifies cooperating organization, including the European Committee of Manufacturers of Refrigeration Equipment (CECOMAF) and the Electric Power Research Institute (EPRI). EPRI is funding, coordinating, and managing the heat transfer segment, an integral part of the program. The document identifies the nomination process and resultant candidate refrigerants. They include R-32/125 (60/40), R-32/134a (30/70), R-32/125/-134a (10/70/20), R-290 (propane), R-134a, R-717 (ammonia), R-32/125/290/134a (20/55/5/20), R-32/125/134a (30/10/60), R-125/143a (45/55), and R-125/143a/134a (40/45/15). The last two are of primary interest as potential replacements for R-502. Procedures and conditions for compressor calorimeter and heat transfer test are specified for participants. Results of the work will be disseminated via the Refrigerant Database. Related research on toxicity and environmental assessments of the candidate fluids and components will be coordinated and shared. Appendices to this program handbook identify committee members, participation commitments, international organizations conducting similar research, and pertinent combinations of refrigerants and heat exchanger types. A statement of work for an EPRI request for proposals (RFP 3412-50), for the heat transfer studies, also is appended.

The Impact of Heat Pumps on the Greenhouse Effect, report HPC-ASR1, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, June 1992 (64 pages, RDB2C08)

This report summarizes analyses to determine how different types of heat pumps can contribute to reduction of global warming. It focuses on heating-only heat pumps for space and service-water heating. Some discussion is included of dual-mode (heating and cooling) and cooling-only devices. The report reviews the international status of heat pump use, the environmental concerns with stratospheric ozone depletion and global warming, and activities in selected countries to address these issues. The analyses were based on separate studies conducted in member countries of the IEA and by various international organizations. Of the 41 national studies, 32 examine heat pump roles in reducing emissions of greenhouse gases. Eight address heat pumps relative to reductions in electricity or fossil-fuel use. One examines the effects of alternative technologies on heat pump energy use and greenhouse gas emissions. The report reviews the efficiency levels of different types of heat pumps, opportunities to reduce carbon dioxide emissions, and direct warming effects resulting from emissions of working fluids or methane fuel. The report concludes that the greatest reduction in warming impact can be achieved by changing to working fluids with a lower global warming potential. Additional reductions can be achieved by reducing losses during equipment operation, through use of hermetic designs and recycling of fluids upon retirement. The report notes that sealing is essential for reliability and because working fluids are frequently flammable and/or toxic. Addressing the future of heat pumps, the report notes the need to optimize the full energy system including improvement of power plant efficiency and use of cogeneration-based power production.

May 1992

J. M. Calm (Engineering Consultant), **Alternative Refrigerants: Challenges and Opportunities**, *Heating/Piping/Air Conditioning* (HPAC), 64(5):38-49, May 1992 (8 pages with 5 figures and 1 table, available from JMC as RDB2621)

This article reviews the status and options available for refrigerants in chillers, with emphasis on use of R-22, R-123, R-134a, R-717 (ammonia), and absorption cycles. The efficiency, global-warming potential (GWP), ozone-depletion potential (ODP), flammability, toxicity, and cost of refrigerants are discussed; quantitative data are tabulated. A figure shows the capacity ranges and types of equipment available by refrigerant. Comparative ODP, GWP, efficiency, and capacity are plotted for R-123 and R-11, R-134a and R-12, and R-134a and R-500. Cost projections (with excise taxes) are plotted for the refrigerants reviewed. Options are discussed for existing equipment, including continued use, retrofit, and replacement. Safety and other considerations are reviewed for the alternative refrigerants. The paper concludes that good options are available provided that sound engineering is used.

E. A. Groll and H. H. Kruse (Universität Hannover, Germany), **Kompressionskältemaschine mit Lösungskreislauf für umweltverträgliche Kältemittel** [Vapor-Compression Refrigeration Machine with a Solution Circuit for Environmentally Friendly Refrigerants], *DKV-Forschungsberichte* [Research Report] 35, Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, May 1992 (in German, rdb5725)

M. Jelinek, N. C. Daltrophe, and I. Borde (Ben-Gurion University of the Negev, Israel), **Prediction of Thermophysical Properties on Few Alternative CFC-Free Refrigerants**, *Proceedings of the 24th Israel Conference on Mechanical Engineering*, 3.1.1-1 - 3.1.1-3, May 1992 (3 pages, rdb5454)

thermodynamic data

H. H. Kruse and E. A. Groll (Universität Hannover, Germany), **Untersuchung alternativer Anlagenschaltungen und Arbeitsstoffe zur Lösung des FCKW-Ozon-Problems** [Examination of Alternative Cycles and Working Materials to Solve the CFC/Ozone-Depletion Problem], final report 01ZH89C1, Bundesminister für Forschung und Technolgie (BMFT) [Federal Ministry of Research and Technology], Bonn, Germany, May 1992 (in German, rdb5499)

alternative cycles and refrigerants, environmental protection

A. D. Nickens, G. F. Brunner, and D. L. Hamilton (U.S. Navy), **Navy Investigations of HFC-134a as a Replacement for CFC-12 in Shipboard Applications**, *Naval Engineers Journal*, 98-103, May 1992 (6 pages with 4 figures and 4 tables, available from JMC as RDB2706)

This article reviews research and development efforts by the U.S. Navy to qualify R-134a as the retrofit replacement refrigerant for R-12 and for future air-conditioning applications on ships and submarines. The article recaps fleet use of R-12 for air-conditioning and refrigeration, compares the properties of R-134a to those of R-12, and outlines the Navy's review of toxicity data and risk affects. Unique considerations for submarine use are summarized, including potential interactions with life-support and contaminant removal systems, in the event of refrigerant leaks. These systems include burners to oxidize carbon monoxide and hydrogen as well as carbon

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dioxide scrubbers. The article reviews tests of R-134a in 25 and 80 ton shipboard air-conditioning plants. Initial retrofit tests using R-134a with a polyalkylene glycol (PAG) lubricant resulted in 5% improvements in both capacity and efficiency. Inspection after 5100 hours of operation, however, revealed extensive copper plating and severe damage to one piston, wrist pin, and connecting rod. Damage to other parts, including a chipped oil ring, worn piston rings, and broken or collapsed suction valve springs also were noted. These findings led to a judgment that PAG lubricants are unsatisfactory for shipboard reciprocating-piston compressors for air conditioning. While a molecular-sieve drier had been used for a portion of the cited tests, initial operation was without a drier. The paper reviews a subsequent test of an 80 ton plant with R-134a and a proprietary polyolester (POE) lubricant, provided by the Carrier Corporation. A lubricant analysis after two hours of operation revealed approximately 15% residual mineral oil, which was reduced to approximately 3% after a second oil change. Cooling capacity increased by 1% and efficiency dropped by 2% using R-134a. Although minor copper plating was evident after 2000 hours of operation, particularly on the suction valves, no measurable decomposition was detected in the R-134a. No wear was found on any component to date, and the extended operation test is continuing. Onboard demonstration and fleet retrofit plans are summarized.

M. L. Robin, **Halon Alternatives: Recent Technical Progress**, unpublished presentation, 1992 Halon Alternatives Technical Working Conference (Albuquerque, NM), Great Lakes Chemical Corporation, West Lafayette, IN, May 1992 (22 pages with 3 figures and 11 tables, available - missing page 1 - from JMC as RDB3726)

R-227ea, thermodynamic properties

K. P. Tyagi (Bharat Heavy Electrical Corporation, India), **Methylamine-Sodium Thiocyanate Vapour Absorption Refrigeration**, *Heat Recovery Systems and CHP*, 12(3):283-287, May 1992 (5 pages, rdb-8964)

summarizes a performance analysis of the methylamine-sodium thiocyanate - as refrigerant-absorbent - vapor-absorption refrigeration system; provides polynomial equations to estimate the thermodynamic properties of the working pair; compares the thermal efficiency of this system to that of ammonia-water (R-717/718) and ammonia-sodium thiocyanate absorption cycles; concludes that the methylamine-sodium thiocyanate pair offers the highest coefficient of performance (COP) of the three

April 1992

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-2G, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 30 April 1992 (56 pages, RDB2434)

This superseded document provides bibliographic citations for 336 publications that may be useful in research and design of air-conditioning and refrigeration equipment. Abstracts, emphasizing the content, materials addressed, and key conclusions, are provided for approximately half of these documents. [Please see RDB2810 for update and a more complete abstract.]

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Compatibility of Refrigerants and Lubricants with Plastics**, report DOE/CE/23810-2F, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1992 (12 pages with 5 figures, available from JMC as RDB2420)

This superseded interim report summarizes progress to provide compatibility information on engineering plastics with alternative refrigerants and suitable lubricants. The status of test specimen procurement and preparation is outlined. The report also addresses experimental methods and modifications to test procedures for the planned work. Solubility plots are included for R-22, R-32, R-134a, and R-152a at 20 and 60 °C (68 and 140 °F) in polyolester (EXP0621 ISO 32); both refrigerant-lubricant viscosity and refrigerant concentration are shown. The solubility data are needed to maintain the refrigerant concentration in the test apparatus that will be used. The plastics that will be tested include polyimide (DuPont Vespel(R) DF and DF-ISO), tetrafluoroethylene (TFE, DuPont Teflon(R)), BASF Ultrapek, Victrex PEEK 45G 300, Radel A-200, DuPont Delrin(R) II 11500, acetal resin (DuPont Rynite(R) 530), DuPont Zytel(R) 101, polycarbonate resin (GE Lexan(R) 161), GE Noryl(R) 731, polyetherimide (GE Ultem(R) 1000), ABS resin (GE Cycolac(R) GPM4700), polyphenylene sulfide (PPS, GE Supec(TM) G401), Kynar 720, Xydar MG350, polyamide-imide (Torlon 4301 and 4203L), Plenco 04485, polybutylene terephthalate (PBT, GE Valox(R) 325), and Profax 6331 NW. These plastics will be tested with R-22, R-32, R-123, R-124, R-125, R-134a, R-142b, R-143a, R-152a, and R-E134.

R. G. Doerr, S. A. Kujak, and R. Schafer (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials**, report DOE/CE/-23810-2D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 13 April 1992

(11 pages with 7 tables, available from JMC as RDB2418)

This superseded interim report introduces a project, and summarizes procedural steps, to provide compatibility information for 24 motor materials (for hermetic compressors) in 11 refrigerants and 17 refrigerant-lubricant combinations. The report summarizes progress to procure necessary materials and equipment, prepare test specimens, analyze the refrigerants and lubricants to be used, test the thermal stability of the refrigerant-lubricant systems at 127°C (260 °F), and prepare for data collection and analysis. The magnet wires obtained for evaluation include modified polyester over coated with polyamide imide, modified polyester overcoated with polyamide imide and epoxy saturated glass, and polyester imide over coated with polyamide imide. The varnishes tested include two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy 800). Sheet insulation, slot liner, and phase separator materials include Nomex-Mylar-Nomex(R), Dacron-Mylar-Dacron(R), DuPont Mylar(R) MO, DuPont-Nomex(R) 410, Nomex(R) Mica 418, and Melinex(R) 228. Sleeving insulations to be tested are Nomex(R), DuPont Mylar(R), and Nomex-Mylar(R). Lead wire insulations include Dacron-Mylar-Dacron(R) and Dacron-Teflon-Mylar-Dacron(R). Heat cleaned glass, heat shrinkable braided polyester, and Permacel P247 glass acrylic tapes as well as polyester tie cords also will be examined. The refrigerants to be tested will include R-22, R-32, R-123, R-124, R-125, R-134a, R-142b, R-143a, and R-152a; efforts are underway to obtain R-E134 and identify an HFC alternative for R-11. Moisture and purity data are provided for the refrigerants received. The lubricants to be tested include a mineral oil (Witco Suniso(R) 3GS), an alkylbenzene (Shrieve Zerol(R) 150), and two polyalkylene glycols(PAGs), namely a modified polyglycol(AlliedSignal BRL-150) and a polypropylene glycol diol (Dow P425). Three esters will be tested, namely a polypropylene glycol butyl monoether (ICI Emkarox(R) VG32), a pentaerythritol ester branched acid (Henkel Emery(R) 2927 ISO 32), and a pentaerythritol ester mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244).

S. K. Fischer, P. J. Hughes, and P. D. Fairchild (Oak Ridge National Laboratory, ORNL), **Global Warming Implications of Replacing CFCs**, *ASHRAE Journal*, 34(4):14-19, April 1992 (8 pages with 3 figures and 2 tables, reprint available from JMC as RDB3969)

This article summarizes an assessment (see RDB2432) of the total equivalent warming impact (TEWI) of options to replace chlorofluorocarbons (CFCs). It briefly recaps the transition in refrigerants, in response to ozone depletion and the emerging issue of global warming. It reviews quantification of both global warming potentials (GWPs) and warming associated with related energy use. The article outlines and illustrates calculations of TEWI, summarizing a comparison for a refrigerator/freezer with replacement of the CFC refrigerant and blowing agent. It lists a range of applications addressed, among them air conditioning, refrigeration, and insulation blowing. Tables present both GWP values for common refrigerants and alternatives - for 20, 100, and 500 year integration time horizons - and comparative warming findings for representative applications. The article concludes that the greatest opportunities for not-in-kind technologies, as alternatives to use of refrigerants of concern, may be for applications for which substantial direct-effect (emission-related) warming remain. It notes that constraints on hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) alternatives could be counterproductive from a global warming point of view. A change of only 2-5% in efficiency would have greater impact on TEWI than eliminating their direct-effect. The article identifies the importance of addressing the needs of developing countries and treating the matter as a global issue.

E. A. Groll and H. H. Kruse (Universität Hannover, Germany), **Kompressionskältemaschine mit Lösungskreislauf für umweltverträgliche Kältemittel - R23/DEGDME und CO_2/Aceton** [Vapor-Compression Refrigeration Machine with a Solution Circuit for Environmentally Friendly Refrigerants – R-23/-DEGDME and R-744/Acetone], *Kältetechnik-Klimatisierung*, Germany, 45:206-218, April 1992 (13 pages in German, rdb4534)

G. R. Hamed and R. H. Seiple (University of Akron), **Compatibility of Refrigerants and Lubricants with Elastomers**, report DOE/CE/23810-2E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1992 (16 pages with 11 figures and 1 table, available from JMC as RDB2419)

This superseded interim report introduces a project, and summarizes procedural steps, to provide compatibility information for approximately 94 elastomeric materials in ten refrigerants and suitable lubricants. In situ swell (diameter change) as well as weight and volume changes following immersion will be measured. Property changes will be determined for selected elastomers in a subsequent phase, The report summarizes efforts to obtain and prepare

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test specimens. Oscillating disk rheometer (ODR) plots are provided for 11 compounds including three formulations of polyisoprene, two of neoprene, two of SBR 1502, and four of EPDM. Moisture content measurements are reported for samples of Dow P425, ICI Emkarate(TM) RL 22H, formerly RL 244, Witco Suniso(R) 3GS, Henkel Emery(R) 2927 ISO 32, Shrieve Zerol(R), and ICI Emkarox(R) VG32 lubricants. The moisture levels found were higher than expected.

R. F. Kayser (National Institute of Standards and Technology, NIST), **Thermophysical Properties**, report DOE/CE/23810-2A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1992 (9 pages with 4 figures, available from JMC as RDB2511)

This interim report introduces a project to provide highly accurate, selected thermophysical properties data for R-32, R-123, R-124, and R-125. The thermodynamic data also will be fit to modified Benedict-Webb-Rubin (MBWR) and improved Carnahan-Starling-DeSantis (CSD), or Carnahan-Starling-DeSantis-Morrison (CSDM), equations of state for each fluid. The CSDM equation takes into account the effects of the dipole moment to improve modeling of blends of very polar fluids, such as R-32/134a. Viscosity and thermal conductivity data for R-32 and thermal conductivity data for R-123 will be correlated for use in transport property models. Measurements in this reporting period have focused on the PVT behavior and vapor pressure of R-32, thermal conductivity of R-123, and speed of sound in R-124. Plots compare the measured and calculated vapor pressure data for R-32 and measured thermal conductivity of R-123 with similar data from prior studies by other researchers. The report also summarizes ongoing property measurements and modeling for the same fluids in companion research.

M. B. Pate, S. C. Zoz, and L. J. Berkenbosch (Iowa State University of Science and Technology), **Miscibility of Lubricants with Refrigerants**, report DOE/CE/23810-2C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1992 (8 pages with 4 tables, available from JMC as RDB2417)

This interim report summarizes progress for an investigation of miscibility of lubricants with refrigerants. Qualitative miscibility observations are tabulated for R-134a with two polyalkylene glycols (PAGs), namely a polypropylene glycol butyl monoether (ICI Emkarox(R) VG32) and a polypropylene glycol diol (Dow P425). Results also are given for a pentaerythritol ester branched acid (Castrol Icematic(R) SW32) and for a pentaerythritol ester mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244). These tests were performed at nominal lubricant concentrations of 10, 50, and 95% over a temperature range of -50 to 90 °C (-58 to 162 °F). Of those tested, Emkarox(R) VG32 remained fully miscible for the full range of concentrations and temperatures tested. Procedures to charge the refrigerant and lubricant into test cells and a method to quantify immiscibility, based on visual observations, were developed. The experimental apparatus being used was modified for the project and additional unidentified refrigerants and lubricants were ordered. The report discusses problems encountered with the procedures used and identifies changes to reduce the probability of test cell ruptures.

M. L. Robin, **Thermodynamic Properties of Halogenated Fire Extinguishing Agents**, paper FLUO-40, 203rd National Meeting of the American Chemical Society (San Francisco), reprint by Great Lakes Chemical Corporation, West Lafayette, IN, April 1992 (22 pages with 4 figures and 12 tables, available from JMC as RDB3725)

This paper presents the thermodynamic properties of R-22B1 (bromodifluoromethane) and R-227ea (1,1,1,2,3,3,3-heptafluoropropane). Both are under consideration as fire suppressants and the latter also is being considered as a refrigerant. The paper summarizes thermodynamic data for them along with coefficients for the Carnahan-Starling-DeSantis (CSD) equation of state. CSD coefficients also are presented for R-13B1 and R-12B1. A table summarizes physical properties of the four compounds, including their molecular weights, melting and boiling temperatures, and critical parameters (temperature, pressure, and density). Correlations are presented for vapor pressure and temperature and for liquid volume and temperature for R-22B1 and R-227ea. Tabular properties and enthalpy-pressure diagrams are provided for the four fluids. Great Lakes Chemical Corporation's product names for R-22B1 and R-227ea are FM-100 and FM-200, respectively.

Number Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34-1992, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1992 (16 pages with 1 figure and 5 tables, RDB2909)

This voluntary, consensus standard describes a shorthand way of naming refrigerants and classifies them according to potential hazards. It is intended to establish a simple means of referring to common refrigerants, instead of using the chemical name, formula, or trade name. It also establishes a uniform system for assigning unambiguous reference numbers, composition-designating prefixes for refrigerants, and safety classifications based on toxicity and flammability. This standard is widely cited in construction codes and provides the classifications used in ASHRAE Standard 15-1992, *Safety Code for Mechanical Refrigeration*, to specify safety requirements for refrigerant use. This version supersedes ANSI/ASHRAE Standard 34-1989 and earlier editions.

March 1992

S. K. Fischer (Oak Ridge National Laboratory, ORNL) and M. McFarland (DuPont Chemicals), **Alternatives to CFCs and Global Warming: A Systems Approach to Evaluating Net Contributions**, *MRS Bulletin*, Materials Research Society, XVII(3):39-42, March 1992 (4 pages with 2 figures and 1 table, RDB2413)

TEWI

J. Gallagher, M. O. McLinden, G. Morrison, M. L. Huber, and J. Ely, **NIST Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database (REFPROP)**, NIST Standard Reference Database (SRD) 23 version 3.0, National Institute of Standards and Technology, Gaithersburg, MD, March 1992 (software and documentation available from NIST, RDB2430)

Version 3.00 of REFPROP calculates properties for 26 pure refrigerants, as well mixtures of up to five of them. A method to estimate binary interaction parameters is provided for those pairs of fluids for which measurements are not available. The refrigerants include R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-23, R-113, R-114, R-115, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143, R-143a, R-152a, R-218, R-290 (propane), R-C270 (cyclopropane), R-C318, and R-E134. Fourteen thermodynamic properties can be calculated, in user-selected units of measurement. This update replaces version 2.0 (see RDB1105).

D. F. Huttenlocher (Spauschus Associates, Incorporated), **Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures with Metals**, report DOE/CE/23810-2B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 31 March 1992 (28 pages with 11 figures and 12 tables, available from JMC as RDB2416)

This interim report summarizes stability data, based on sealed tube tests, for mixtures of refrigerants and lubricants in the presence of a valve steel strip. Tabular results are presented for R-123 with mineral oil at 105, 150, and 175 °C (221, 302, and 347 °F). The findings indicate that prolonged exposures to temperatures exceeding approximately 150 °C (302 °F) lead to rapid chemical deterioration, yielding R-133a and R-143a as decomposition products. Preliminary data, for tests at 150 and 175 °C (302, and 347 °F), are presented for R-22 with a mineral oil (Witco Suniso(R) 3GS), R-124 and R-142b with an alkylbenzene (Zerol(R) 150), and R-32, R-125, R-134a, and R-143a with pentaerythritol ester branched acid (Castrol Icematic(R) SW32). Preliminary results also are presented for R-134a with a higher-viscosity pentaerythritol ester (Henkel Emery(R) 2928 ISO 100). The information provided includes visual observations, chemical analyses, and gas chromatograms with summary data indicating the fraction of refrigerant that reacted. The preliminary results suggest that the seven refrigerant-lubricant systems are very stable at the temperatures tested, and that further testing is needed to define the upper temperature limits.

S. M. Miner (Engineering Consultant), **An Appraisal of Ammonia as an Alternative Refrigerant in Light of the CFC and GWP Situation**, *Technical Papers of the 14th Annual Meeting* (22-25 March 1992, Miami, FL), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 231-250, March 1992 (20 pages with 4 figures and 5 tables, RDB2912)

This paper reviews the history of R-717 (ammonia) refrigeration and the impediments - real and perceived - to its broader use. Safety issues and environmental benefits associated with ammonia are identified. Current developments and research efforts related to ammonia use are summarized. The paper then outlines several applications of ammonia as examples and concludes with sources of further information.

N. D. Smith, **New Chemical Alternatives for CFCs and HCFCs**, Environmental Research Brief EPA-600/F-92-012, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, 24 March 1992 (2 pages with 2 tables, available from JMC as RDB3405)

This summary outlines efforts to identify alternative refrigerants. It mentions a panel, convened to assess the potential for finding suitable alternative chemicals. It discusses the trade-offs, in replacing one or more chlorine or bromine atoms in familiar refrigerants with hydrogen, between desired environmental characteristics and flammability, toxicity, and loss in efficiency. It reviews a search and cooperatively funded project, with the Electric Power Research Institute (EPRI), at Clemson University and the University of Tennessee. The goals were to synthesize and determine relevant physical properties of numerous fluorinated propanes, butanes, and ethers. Chemical formulae and normal boiling points are tabulated for 34 compounds considered. 11 are identified for further characterization; their chemical names and the refrigerants they might replace are tabulated. Additional testing of these 11 candidates is continuing. This research includes determination of atmospheric stability and tests of acute inhalation toxicity, materials compatibility, vapor thermal conductivity, and refrigeration performance. The 11 selected chemicals include nine hydrofluorocarbons (HFCs), namely R-227ca, R-227ea, R-236cb, R-236ea, R-236fa, R-245ca, R-245cb, R-245fa, and R-254cb. They also include two fluoroethers, R-E125 and R-E143a.

ARI Research Plan, Air-Conditioning and Refrigeration Institute, Arlington, VA, 10 March 1992 (58 pages, available from JMC as RDB0C01)

This plan documents research needs for air-conditioning and refrigeration, with primary focus on refrigerants, energy conservation, and building environment. It provides industry guidance for public-sector research organizations and sponsors. It also may be useful to individual companies in planning proprietary research and development or cooperative programs. A specific plan for materials compatibility and lubricant research, the basis for the Air-Conditioning and Refrigeration Technology Institute (ARTI) Materials Compatibility and Lubricant Research (MCLR) Program, is included as an appendix. A second appendix provides a series of charts, to show the status of alternative refrigerants and projections for their commercialization. The charts also list announced production plants. Charts are included for R-32, R-123, R-124, R-125, R-134a, R-142b, R-143a, R-152a, and R-E134. A third appendix provides elaborations for selected research recommendations including objectives, rationale, suggested approaches, and estimated or recommended budgets and time requirements. This version updates and replaces those published on 6 November 1989, 30 April 1990, 19 December 1990, and 25 September 1991.

February 1992

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-1G, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 28 February 1992 (42 pages, RDB2415)

This superseded document provides bibliographic citations for 244 publications that may be useful in research and design of air-conditioning and refrigeration equipment. Abstracts, emphasizing the content, materials addressed, and key conclusions, are provided for approximately a third of these documents. [Please see RDB2434 for update and a more complete abstract.]

J. J. Grebner and R. R. Crawford, **The Effects of Oil on the Thermodynamic Properties of Dichlorodifluoromethane (R12) and Tetrafluoroethane (R134a)**, report TR-13, Air-Conditioning and Refrigeration Center (ACRC), University of Illinois at Urbana-Champaign, Urbana, IL, February 1992 (113 pages, rdb4B73)

R-12, R-134a, properties of refrigerant-lubricant mixtures, thermophysical data

R. W. James and J. S. Missenden, **The Use of Propane in Domestic Refrigerators**, *International Journal of Refrigeration* (IJR), 15(2):95-100, February 1992 (6 pages, RDB4240)

R-290

N. Kagawa (National Defense Academy, Japan), H. Ikeda, H. Kawano, M. Uematsu, and K. Watanabe (Keio University, Japan), **Thermodynamic State Surface and Cycle Analysis for Refrigerant 22 Plus Refrigerant 114 System**, *JSME International Journal (series II: Fluids Engineering, Heat Transfer, Power, Combustion, and Thermophysical Properties)*, Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, 35(1):116-123, February 1992 (8 pages, available from ASME in the Americas and from Maruzen Company, Limited, elsewhere, rdb8967)

presents an equation of state (EOS) coupled with empirical mixing rules for R-22/114 developed to enable cycle analyses with this zeotropic blend: the EOS was formulated with available measurements of pressure, volume, temperature, and composition data; it is expressed as a Helmholtz equation as a function of temperature, density and composition, and is effective for a range of temperatures from -23 to 227 °C (-10 to 440 °F) for pressures up to 10 MPa (1450 psia), which corresponds to the density range up to the critical value; the cycle analysis of the heat pump and refrigeration systems indicate that R-22/114 is promising for industrial heat pumps or air-conditioning and heat pump water heaters (HPWH); predicted changes in composition were confirmed by testing [see RDB3868 for Japanese version of this paper]

M. B. Shiflett, A. Yokozeki, and P. R. Reed (DuPont Chemicals), **Near-Azeotropic Refrigerants as Alternatives for R-502**, *ASHRAE Journal*, 34(12):24-28, February 1992 (5 pages with 2 figures and 3 tables, RDB3302)

replacements for R-502, zeotropic blends

A. Yamada, Y. Sonoda, and Y. Arakawa, **Development of an Automotive Air Conditioning System Using the HFC-134a Refrigerant**, paper 920216 (SAE International Congress and Exposition, Detroit, MI), Society of Automotive Engineers (SAE), Warrendale, PA, February 1992 (rdb4B03)

R-134a, mobile air-conditioning (MAC) systems

Dampftaflen für Frigen 12, 22, 502 / Refrigerant Tables for Frigen 12, 22, 502, product bulletin AFK2074D/E, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, February 1992 (44 pages with 7 tables, in English and German, RDB4773)

This bulletin provides thermodynamic property data for R-12, R-22, and R-502 in metric (SI) units of measure. An introduction summarizes the units used, provides conversion factors from metric to inch-pound (IP) units, and outlines the reference states and adjustments for other selections. A table then summarizes basic physical data, including the chemical formula and name, molecular mass, normal boiling point, freezing point, critical parameters (temperature, pressure, and density), and latent heat of vaporization. It also gives the surface tension, liquid density, specific heat ratio, water solubility, refractive index, relative dielectric strength, and vapor and liquid dielectric constants at selected temperatures. Three tables then provide saturated property data including pressure; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover R-12 from -60 to 112.0 °C (-76 to 233.6 °F), R-22 from -100 to 96.18 °C (-148 to 205.1 °F), and R-502 from -65 to 82.16 °C (-85 to 179.9 °F); the upper limits are the critical temperatures. Three additional tables give the specific volume, enthalpy, and entropy for superheated vapor for R-12 from -40 to 74 °C (-40 to 165 °F), R-22 from -60 to 62 °C (-76 to 144 °F), and R-502 from -60 to 62 °C (-76 to 144 °F). Hoechst Chemical's product names for R-12, R-22, and R-502 are Frigen(R) 12, 22, and 502.

January 1992

X. He, U. C. Spindler, D. Jung, and R. K. Radermacher (University of Maryland), **Investigation of R-22/R142b Mixture as a Substitute for R-12 in Single-Evaporator Domestic Refrigerators**, paper 3557, *Transactions* (Winter Meeting, Anaheim, CA, January 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 98(1):150-159, 1992 (10 pages with 10 figures and 1 table, RDB2340)

R-22/142

J. W. Linton, W. K. Snelson, and P. F. Hearty (National Research Council, Canada, NRCC), **Effect of Condenser Liquid Subcooling on System Performance for Refrigerants CFC-12, HFC-134a, and HFC-152a**, paper 3558, *Transactions* (Winter Meeting, Anaheim, CA, 25-29 January 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 98(1):160-166, 1992 (7 pages with 12 figures and 1 table, RDB4432)

R-12, R-134a, R-152a

V. Nowack and F. Steimle (Universität Essen), **Thermophysical Properties of New Working Fluid Systems for Absorption Processes**, *International Journal of Refrigeration* (IJR), 15(1):10-15, January 1992 (6 pages, RDB7641)

thermodynamic data, thermophysical properties

S. F. Pearson (Star Refrigeration Limited, UK), **The Development of a Drop-In Replacement for R-502**, paper 92.4, *Proceedings of the Institute of Refrigeration*, London, UK, January 1992 (9 pages with 15 figures and 1 table, RDB2306)

This paper describes the development, performance testing, flammability considerations, charging, and separation of two ternary zeotropes, R-403A and R-403B, developed as replacements for R-502. Both are blends of R-22, R-218 (octafluoropropane), and R-290 (propane). R-403B, which contains 39% R-218, results in marginally lower discharge temperatures; R-403A, which contains 20% R-218, offers discharge temperatures between those of R-502 and R-22. These R-290/22/218 mixtures are nonflammable and of low toxicity. They exhibit ozone depletion potentials (ODPs) of 0.037 and 0.028 and nearly the same refrigerating effect as R-502. Measured coefficients of performance (COPs) with these blends were higher than for R-502 under comparable conditions. The paper describes the choice of components, including initial consideration of blends containing R-125 and R-1270. The test rig, results, and effects of diffusion and replacement of lost refrigerants also are discussed. Extensive international field testing is mentioned, but not described.

K. S. Sanvordenker (Tecumseh Products Company), **R-152a versus R-134a in Domestic Refrigerator-Freezer - Energy Advantage or Energy Penalty!**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants,* edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 1:259-263, July 1992 (5 pages with 4 tables, RDB-2728)

This paper presents new laboratory data for R-12, R-134a, and R-152a in domestic refrigerator-

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freezer applications. It responds to assertions and reported findings that R-152a would offer higher efficiency, noting an error in the published thermodynamic data used. The paper reviews reports of R-152a advantages and implications. It also provides capacity and efficiency data, based on calorimeter tests, for six compressors for R-12, R-134a, and R-152a with a polyolester lubricant. These tests were run at -23 °C (-10 °F) evaporator temperature and both 43 and 54°C (110 and 130 °F) condenser temperatures. The test method, ASHRAE Standard 23, and associated peculiarities are reviewed. R-152a consistently yielded a 10% lower capacity than R-134a, which in turn showed a 10% drop compared to R-12. The energy efficiencies were nearly the same at the higher condensing temperature, but R-152a suffered a 6.5% penalty at the more representative lower condensing temperature. The data are briefly related to analyses by other investigators, which corroborate the findings. The paper concludes that use of R-152a instead of R-134a may yield a significant energy penalty rather than advantage.

S. R. Szymurski, **Materials Compatibility and Lubricants Research on CFC-Refrigerant Substitutes**, report DOE/CE/23810-1, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1992 (6 pages, available from JMC as RDB2414)

This interim report summarizes the progress of the Materials Compatibility and Lubricant Research (MCLR) Program. It is jointly funded under a grant from the Department of Energy and cost sharing by the air-conditioning and refrigeration industry. The program addresses refrigerant and lubricant properties, materials compatibility, and lubricants for alternative refrigerants. The program comprises projects to measure thermophysical properties, test the chemical and thermal stability of refrigerant-lubricant mixtures with metals, and measure the miscibility of lubricants with refrigerants. Three projects will provide information on the compatibility of refrigerants and lubricants with motor materials, elastomers, and engineering plastics. A seventh project will collect and facilitate dissemination of data through development and administration of a refrigerant database. The scope of the program, objectives of the seven initial projects, and highlights of the first quarter are presented. The primary effort focused on solicitation, evaluation, and negotiation of proposals for the cited projects. A grant proposal for the second phase was completed and submitted to the DOE. [see RDB2809 and RDB2B02 for update]

1992-1993 Research Plan, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1 January 1992 (25 pages, RDB2426)

This list of prospective research subjects identifies 182 high-priority projects, grouped into eight project classifications based on approved funding guidelines. Projects relating to refrigerants fall in several of these categories, including the highest priority topic, *Environmentally-Safe Materials (CFC, etc.)*. The research areas were proposed by ASHRAE Technical Committees, Task Groups, and other committees; they were prioritized by ASHRAE's Research and Technical Committee. The highest priority group (*three stars*) includes research of thermophysical properties of R-123, R-125, R-134a, and R-141b, as well as measurement of two-phase refrigerant liquid-vapor mass flow rates. The next classification includes real-time determination of the lubricant concentration dissolved in alternative refrigerants, evaluation of leak detection methods for non-CFC refrigerants, and flow regime mapping of R-134a/lubricant mixtures in smooth and internally enhanced tubes. It also includes experimental determination of heat transfer with R-134a and R-22 refrigerants in water-cooled condensers and direct-expansion water coolers using brazed plate heat exchangers. The *one-star* priority group includes research of alternatives to replace R-22 and R-502, development of a uniform equation of state for alternative refrigerants, and determination of properties and heat transfer effects for mixtures of alternative refrigerants and lubricants. Research of ammonia (R-717) dispersion in the atmosphere also is included. This plan summarizes anticipated funding and procedures for implementing the research identified; it replaces the versions published for preceding years.

Decomposition of HCFC-123 and HCFC-141b in Foam Blowing Applications, Society of the Plastics Industry (SPI) and Polyurethane Insulation Manufacturers Association (PIMA), Washington, DC, January 1992 (rdb6864)

decomposition processes and products for two fluorochemicals used as blowing agents, R-123 (also used as a refrigerant) and R-141b

1992 (month not indicated)

D. L. Albritton (National Oceanic and Atmospheric Administration, NOAA), R. Monastersky (Science News), J. A. Eddy (Consortium for International Earth Science Information Network), J. M. Hall (NOAA), and E. Shea (NOAA), **Reports to the Nation on our Changing Planet: Our Ozone Shield**, report 2, University Corporation for Atmospheric Research (UCAR) Office for Interdisciplinary Earth

Studies (OIES), Boulder, CO, fall 1992 (24 pages with 9 figures, RDB3747)

explains in simple terms the quest to understand the earth's ozone layer and the debate among governments over how to best protect it: addresses the functions of the stratospheric ozone layer, the balance between continuous ozone production and destruction, and recognition of human activities that are altering the protective layer; outlines the history and research of stratospheric ozone changes, the Montreal Protocol, and the phenomenon described as the "ozone hole"; lists unanswered questions that are the subject of ongoing research

M. A. Anisimov, S. B. Kiselev, J. V. Sengers, and S. Tang (University of Maryland), **Crossover Approach to Global Critical Phenomena in Fluids**, *Physica A*, 188:487-525, 1992 (139 pages, rdb9509)

equation of state (EOS), critical point

J. F. Chen, **The Use of Mixed Refrigerant to Save Power in Air Conditioning and Heat Pumps**, PhD thesis, University of Leeds, UK, 1992 (rdb5812)

zeotropic blends, performance

Z. H. Chen, R. Y. Li, and H. L. Yu**, Research on Domestic Refrigerator/Freezer with CFC Alternative Refrigerant**, Shanghai Institute of Mechanical Engineering, China, 1992 (rdb6332)

S. Devotta and S. Gopichand (National Chemical Laboratory, India), **Theoretical Assessments of HFC-134a and Alternatives to CFC-12 as Working Fluids for Heat Pumps**, *Applied Energy*, 41(4):285-299, 1992 (15 pages, rdb3516)

R-12, R-134a

S. Devotta and S. Gopichand (National Chemical Laboratory, India), **Comparative Assessment of HFC-134a and Some Refrigerants as Alternatives to CFC-12**, *International Journal of Refrigeration* (IJR), 15(2):112-118, 1992 (7 pages, rdb4127)

R-12, R-134a

D. G. Friend, M. L. Huber, and J. S. Gallagher (National Institute of Standards and Technology, NIST), **Thermophysical Property Computer Packages from NIST**, *Computerized Thermophysical Property Packages*, American Society of Mechanical Engineers (ASME), New York, NY, HTD-225:13-18, 1992 (6 pages with 11 tables, available from JMC as RDB3713)

thermophysical property data

E. Hahne and A. Noworyta, **Calculation of the Heat Transfer Coefficients for Nucleate Boiling in Binary Mixtures of Refrigerant-Oil,** *International Communications in Heat and Mass Transfer*, (1):417-429, circa 1992 (13 pages, rdb4742)

K. Inoue and A. Iwamoto (Nippon Oil Company, Limited, Japan), **Mutual Solubility of HFC-134a (1,1,1,2-Tetrafluoroethane) and Synthetic Ester Base Stocks**, *Sekiyu Gakkaishi*, Japan, 35(1):76-83, 1992 (8 pages, RDB4B18)

R-134a, polyolester (POE) lubricants

Intergovernmental Panel on Climate Change (IPCC), **Climate Change 1992 - the IPCC Scientific Assessment**, edited by J. T. Houghton, B. A. Callander, and S. K. Varney (Meteorological Office, UK), IPCC Secretariat, World Meteorological Organization (WMO), Geneva, Switzerland, 1992; republished by the Cambridge University Press, Cambridge, UK, 1992 (200 pages, rdb3959)

global warming, greenhouse gases, environmental impact

Intergovernmental Panel on Climate Change (IPCC), **Climate Change 1992 - The Supplementary Report to the IPCC Scientific Assessment**, IPCC Secretariat, World Meteorological Organization (WMO), Geneva, Switzerland, 1992; republished by the Cambridge University Press, Cambridge, UK, 1992 (199 pages, rdb3970)

global warming, greenhouse gases, environmental impact

P. M. Kesselman and V. P. Zhelezny (Odessa State Academy of Refrigeration, Ukraine then USSR), **Full Investigations of Thermophysical Properties of Ozone-Safe Refrigerants**, *Refrigeration Equipment*, (11-12):16-18, 1992 (3 pages probably in Russian, rdb6C28)

thermodynamic properties, thermophysical data

H. H. Kruse (Universität Hannover, Germany), **Development Trends of Future Replacements for Refrigerants R-502 and R-22 for Food Refrigeration at Low Temperatures**, *DKV-Statusbericht* [Status Report], Deutsche Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 11:1-45, 1992 (45 pages, RDB5B31)

R-22 and R-502 alternatives

H. H. Kruse (Universität Hannover, Germany), **Trends to the Substitution of Refrigerant R22**, *DKV-Statusbericht* [Status Report], Deutsche Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 10:1-4, 1992 (4 pages, rdb5959)

R-22 alternatives

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J. Landé, **Praktiska prov med olika köldmedier i en brinevatten värmepump** [Experience from Practical Laboratory Tests with Different Refrigerants in a Brine-to-Water Heat Pump], Trita Report REFR/R-92/8-Se, Kungliga Tekniska Högskolan [Royal Institute of Technology] (KTH), Stockholm, Sweden, 1992 (in Swedish, rdb4512)

performance

D. R. Lovley and J. C. Woodward, **Consumption of Freons CFC-11 and CFC-12 by Anaerobic Sediments and Soils**, *Environmental Science and Technology*, 26(5):925-929, 1992 (5 pages, rdb7230)

refrigerant decomposition, destruction, fate, environmental impacts

Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Saturated-Liquid Densities and Bubble-Point Pressures of the Binary System HCFC-22 + HCFC-142b**, *High Temperatures - High Pressures*, 24(4):435-442, 1992 (8 pages, rdb8943)

provides thermodynamic property measurements for R-22/142b (20/80), (40/60), (60/40), and (80/20) for 7-127 °C (44-260 °F): presents 46 saturated-liquid densities and bubble-point pressures measured with a magnetic densimeter coupled to a variable-volume cell; discusses a Hankinson-Brobst-Thomson (HBT) equation for the measurements; also discusses a Peng-Robinson (PR) equation of state (EOS) for the measured vapor-liquid equilibria (VLE) properties

M. McFarland (DuPont Chemicals), **Investigations of the Environmental Acceptability of Fluorocarbon Alternatives to Chlorofluorocarbons**, *Proceedings of the National Academy of Science* (NAS), Washington, DC, 89:807-811, 1992 (5 pages, rdb3130)

environmental impacts of hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) alternatives

D. Miyatani, K. Shinoda, T. Nakamura, M. Ohta, and K. Yasuda, *Chem. Letters*, 795-798, 1992 (4 pages, rdb5253)

decomposition of R-12 over iron catalyst

S. Morikawa (Asahi Glass Company, Limited, Japan), **Recent Development of CFC Alternatives**, Catalysis Society of Japan, 34(7):458-463, 1992 (6 pages, rdb3325)

A. Nilsson, **Greenhouse Earth**, John Wiley and Sons Limited, Chichester, UK, 1992 (rdb5962)

greenhouse effect, global warming, refrigerants

J. S. Panek, **Evaporation Heat Transfer and Pressure Drop in Ozone-Safe Refrigerants and Refrigerant Oil Mixtures**, MS thesis (Department of Mechanical Engineering), University of Illinois at Urbana-Champaign, 1992 (rdb3B51)

J. Pannock, **Performance of Refrigerant Mixtures in Heat Pumps**, doctoral dissertation, Department of Mechanical Engineering, University of Maryland, College Park, MD, 1992 (rdb4879)

U. Plöcker (Technische Universität Berlin, Germany), **Berechnung von Hochdruck-Phasengleichgewichten mit einer Korrespondenzmethode unter besonderer Berücksichtigung asymmetrischer Gemische** [Calculation of High-Pressure Phase Equilibria by Means of a Correspondence Method Under Special Consideration of Asymmetric Mixtures], translation of doctoral dissertation, Oak Ridge National Laboratory, Oak Ridge, TN, undated circa 1992 (in German, rdb3343)

see RDB3342 for original language version

E. Preisegger and R. Henrici (Hoechst Aktiengesellschaft, Germany), **Refrigerant 134a: The First Step Into a New Age of Refrigerants**, *International Journal of Refrigeration* (IJR), 15(6):326-331, 1992 (6 pages, rdb6373)

R-134a

J. R. Sand, S. K. Fischer (Oak Ridge National Laboratory, ORNL), and J. A. Jones (Jet Propulsion Laboratory, JPL, California Institute of Technology), **Experimentally Determined and Estimated CSD and LKP Interaction Coefficients for Ozone-Safe Refrigerant Mixtures**, review draft for publication in the *International Journal of Refrigeration* (IJR), circa 1992 (RDB2336)

Estimates of interaction coefficients (ICs) are provided for binary refrigerant blends for both the Carnahan-Starling-Desantis (CSD) and Lee-Kesler-Plöcker (LKP) equations of state (EOS). These IC values characterize the non-ideal behavior of mixtures, and are useful in calculating thermodynamic properties. The estimates were determined by least-squares fits of the CSD and LKP equations to previously measured, saturated vapor pressure (bubble point) data. 71 mixtures of 8 different refrigerants in 18 binary combinations were analyzed. The combinations included R-12/152a, R-22/124, R-22/134, R-22/134a, R-22/142b, R-22/152a, R-23/22, R-23/134a, R-124/142b, R-134/124, R-134/142b, R-134a/124, R-134a/134, R-134a/142b, R-134a/152a, R-152a/124, R-152a/134, and R-152a/142b. The paper describes the use of IC values, experimental apparatus used to measure the data, presents the resulting ICs, and discusses variances found with previously de-

termined values. Good agreement was found for several known blends, but poor agreement resulted for the well characterized R-22/142b blend; further experimental verification is recommended. Comparisons between experimental ICs and those calculated from physical properties or critical constants of the components suggest that refinement of the property calculation algorithms may be desirable. [see RDB4130 for published version]

N. Shafaghian, **The Influence of Lubricating Oil on the Performance of Refrigeration Systems Using Refrigerant R22**, D.Phil. thesis, University of Ulster, Coleraine, Northern Ireland, UK, 1992 (rdb8445)

lubricant influences on heat transfer; R-22; refrigerant-lubricant (RL) properties

G. Shi, **Radiative Forcing and Greenhouse Effect Due to the Atmospheric Trace Gases**, *Science China*, series B, 35(2):217-229, 1992 (13 pages, rdb5965)

greenhouse effect, global warming potential (GWP)

A. T. Sousa, P. Sousa Fialho, C. A. Nieto de Castro, R. Tufeu, and B. Le Neindre (Universidade de Lisboa, Portugal), **Density of HCFC-142b and Its Mixture with HCFC-22**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 80:213-225, 1992 (13 pages, rdb7106)

thermodynamic properties of R-142b and R-22/-142b blends; thermophysical data

K. Stephan and R. Krauss (Universität Stuttgart, Germany), **Regulated CFCs and their Alternatives**, *Proceedings of the Symposium on Solid Sorption Refrigeration,* International Institute of Refrigeration (IIR), Paris, France, 32-43, 1992; republished in *Heat Recovery Systems and CHP*, 13(4):373-381 (12/8 pages, rdb5275)

alternative refrigerants

Y. Takaishi, H. Nakagawa, and K. Oguchi (Kanagawa Institute of Technology, Japan), **Vapor Pressure of the Solutions of HFC-134a and Ester Oil**, *Proceedings of the Third Asian Thermophysical Properties Conference* (Beijing, People's Republic of China), 321-326, 1992 (6 pages, rdb5434)

R-134a, polyolester (POE), solubility

T. Tamatsu, H. Sato, and K. Watanabe (Keio University, Japan), **PVTx Properties of Binary 1,1-Difluoroethane + 1,1,2,2-Tetrafluoroethane**, *Journal of Chemical and Engineering Data*, 37:512-515, 1992 (4 pages, rdb5476)

thermodynamic properties of R-152a/134 blends; thermophysical data

T. Tamatsu, H. Sato, and K. Watanabe (Keio University, Japan), **Determination of Virial Coefficients for Refrigerant Mixture HFC-152a (1,1-Difluoroethane) + HFC-134 (1,1,2,2-Tetrafluoroethane)**, *Proceedings of the Third Asian Thermophysical Properties Conference* (Beijing, People's Republic of China), 334-339, 1992 (6 pages, rdb-5479)

thermodynamic properties of R-152a/134 blends; thermophysical data

L. Tan, Z. Zhao, and Y. Duan (Xi'an Jiaotong University, China), **Bubble-Point and Dew-Point Equation for Binary Refrigerant Mixture R22-R142b**, *High Temperatures - High Pressures*, 24(4):449-454, 1992 (6 pages, rdb8942)

presents bubble-point and dew-point equations. as functions of either temperature or pressure, for R-22/142b; also proposes a modified Rackett equation for calculation of the bubble-point volume; indicates that the rms errors in the calculations of the bubble-point temperature, dew point temperature, and bubble-point volume are 1.093%, 0.947%, and 1.120%, respectively

R. Tillner-Roth and H. D. Baehr (Universität Hannover, Germany), **Burnett Measurements and Correlations of Gas Phase (P,rho,T) Data of 1,1,1,2-Tetrafluoroethane (R134a) and 1,1-Difluoroethane (R152a)**, *Journal of Chemical Thermodynamics*, 24:413-424, 1992 (12 pages, rdb4409)

R-134a and R-152a thermodynamic properties, thermophysical data

R. P. Wayne, C. E. Canosa-Mas, A. C. Heard, and A. D. Parr, **On Discrepancies Between Different Laboratory Measurements of Kinetic Parameters for the Reaction of Hydroxyl Radical with Halocarbons**, *Atmospheric Environment*, 26A:2371-2379, 1992 (9 pages, rdb7104)

alternative refrigerants, lifetime, atmospheric reactions

J. V. Widiatmo, Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Liquid Densities and Vapor Pressures of HCFC-225ca and HCFC-225cb**, *Fluid Phase Equilibria*, 80:227-238, 1992 (12 pages, rdb5472)

thermodynamic properties of R-225ca and R-225cb: thermophysical data

H. Wirbser, G. Bräuning, J. Gürtner, and G. Ernst (Universität Karlsruhe, Germany), **Flow Calorimetric Specific Heat Capacities of CF_3CHFCF_3 (R227) - a New Working Fluid in Energy Technics - at Pressures up to 15 MPa and Tempera-**

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tures between 253 K and 423 K, *Journal of Chemical Thermodynamics*, 24:761-772, 1992 (12 pages, rdb3A20)

thermodynamic properties of R-227ea; thermophysical data up to 15 MPa (2200 psia)

L. Zhigang, L. Xianding, Y. Jianmin, T. Zhoufang, J. Pingkun (Xi'an Jiao Tong University, China), C. Zhehua, L. Dairu, R. Mingzhi, Z. Fan, and W. Hong (Sha'an Xi Refrigerator Factory, China), **Application of HFC-152a/HCFC-22 Blends in Domestic Refrigerators**, publication unknown, circa 1992 (7 pages with 3 tables, partially illegible and incomplete copy available from JMC as RDB2514)

This paper documents a study of substitutes for R-12 in refrigerators. Analytical data are tabulated for ozone depletion potential, global warming potential, condensing pressure, evaporating pressure, pressure ratio, compressor discharge temperature, capacity, and coefficient of performance (COP) for nine pure refrigerants. They include R-12, R-22, R-123, R-124, R-125, R-134a, R-142b, R-143a, and R-152a. Based on both capacity and COP, only R-134a and R-152a were found suitable, and R-134a was rejected on the basis of lower efficiency. The paper concludes that the blend of R-22/152a is more promising than pure R-152a. This finding is based on tests that show that addition of small amounts of R-22 to R-152a can reduce its flammability, but still result in a vapor pressure curve (vapor pressure and temperature relation) similar to that of R-12. Tests of a selected refrigerator using three different compressors are summarized to compare the performance of R-12 with two compositions of R-22/152a. The blend requires a change in magnet wire for the motors in hermetic compressors, but suitable enamels have been identified.

M-S. Zhu, Y-D. Fu, and L-Z. Han (Tsinghua University, China), **An Experimental Study of PVT Properties of CFC Alternative HFC-134a**, *Fluid Phase Equilibria*, 80:149-156, 1992 (8 pages with 2 figures and 3 tables, RDB4B42)

measurements of the thermodynamic properties of R-134a using a Burnett method: describes the three-chamber apparatus used; tabulates 42 measurements of pressure-volume-temperature (PVT) data and compares the results to published data from other studies; identifies the work as the first set of reliable PVT data for R-134a taken in China; thermophysical data

1992-1993 Threshold Limit Values for Chemical Substances in the Work Environment, *1992-1993 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, The American Conference of Government Industrial Hygienists (ACGIH), Cincinnati, OH, 1-56 and notes, 1992 (55 of 142 pages with 2 tables and 4 appendices, available from ACGIH for $6.00, RDB3901)

This book provides data for use as guidelines or recommendations in the control of potential hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document also lists intended changes and provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter.

Assignment of Refrigerant Container Colors, ARI Guideline N-1992, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1992 (8 pages, with 1 table, available from ARI for $15.00, RDB3101)

This guideline sets color standards for containers for existing, new, and reclaimed refrigerants. It further provides a means by which ARI can assign colors as new refrigerants are introduced, and maintains a record of those assigned and available. The guideline also recommends a container color (light green grey) for refrigerants that are not produced in sufficient quantities to qualify for individual colors. While color coding is not intended as a substitute for reading cylinder labels and markings, the guideline facilitates distinction among refrigerant containers by content. Four groups are identified, namely those for liquids at 20 °C (68 °F) normally packaged in drums, low-pressure fluids, high pressure fluids, and flammable (red band) refrigerants or mixtures. A table summarizes color assignments and corresponding color matching data. Refrigerants with assigned colors include R-11 (orange), R-12 (white), R-13 (light blue, sky), R-13B1 (pinkish-red, coral), R-14 (yellow-brown, mustard), R-22 (light green), R-23 (light blue grey), R-113 (dark purple, violet), R-114 (dark blue, navy), R-116 (dark grey, battleship), R-123 (light blue grey), R-134a (light blue, sky), R-500 (yellow), R-502 (light purple, lavender), and R-503 (blue-green, aqua).

Chemical Kinetics and Photochemical Data for Use in Stratospheric Modeling, report 92-20, Jet Propulsion Laboratory (JPL), California Institute of Technology, 1992 (rdb5847)

alternative refrigerants, lifetime, atmospheric reactions

Greenfreeze, the World's First CFC- and HFC-Free Refrigerators, Greenpeace Germany, e.V., Hamburg, Germany, undated circa 1992 (12 pages with 1 table, RDB3634)

Reducing Emission of Fully Halogenated Chlorofluorocarbon (CFC) Refrigerants in Refrigeration and Air-Conditioning Equipment Applications, ASHRAE Guideline 3-1990 plus addendum ASHRAE Guideline 3a-1992, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1990 and 1992 (30 pages with 5 tables, RDB2911)

This guideline covers all refrigeration and air-conditioning equipment and systems that use fully halogenated CFC refrigerants. It recommends practices and procedures to reduce inadvertent release of CFC refrigerants during manufacture, installation, testing, operation, maintenance, and disposal of refrigeration and air-conditioning equipment and systems. It also covers refrigerant recovery, recycling, reclaim, and disposal.

The Impact of Ozone-Layer Depletion, document 7, Global Environment Monitoring System (GEMS), United Nations Environment Programme (UNEP), Nairobi, Kenya, 1992 (40 pages with 17 figures and 1 table, available from JMC as RDB2704)

This report is one in a series that summarize scientific and engineering assessments for those without technical qualifications. It deals with the effects of ozone depletion on human health and the environment, and outlines ways of reducing damage to the ozone layer. This publication reviews the scientific background for ozone depletion, including observations of the Antarctic ozone hole, mid-latitude ozone-layer depletion, and Arctic ozone-layer depletion. It then addresses the effects of ultraviolet radiation - specifically the UV-B wavelengths - on immune systems, skin cancer, and increasing eye damage. It also discusses impacts on the oceans and aquatic ecosystems, land plants, air pollution, and damage to materials. The document then discusses ozone-friendly technologies for refrigeration, air conditioning, and other uses. It stresses the importance of global cooperation and the need for recycling and destruction of chlorofluorocarbons (CFCs) and halons. The report discusses future policy options and lists several information sources.

Safety of Suva(R) Refrigerants, document AS-1 (H-27350-2), DuPont Chemicals, Wilmington, DE, undated circa 1992 (6 pages with 1 table, RDB3451)

This bulletin reviews considerations for safe use of refrigerants by providing answers to common questions. It outlines the introduction of alternative refrigerants and associated testing. It briefly reviews the collaborative Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) and individual programs for specific refrigerants. The document discusses the flammability of R-123, R-124, and R-134a, noting that they are neither flammable nor explosive, but can become so when mixed with gases that are. The document notes that mixtures of R-134a with more than 60% air (by volume) can become flammable at raised pressures and temperatures. It counsels against use of refrigerant-air mixtures for leak testing. The document then addresses inhalation toxicity and the potential for suffocation. It explains the DuPont Acceptable Exposure Limit (AEL), a time weighted average concentration usually for eight hours, to which nearly all workers may be repeatedly exposed without adverse effects. The document discusses symptoms of exposure above the AEL, cardiac sensitization, asphyxiation, the DuPont Emergency Exposure Limit (EEL), measures for safety, and detection by odor. It goes on to address special requirements for R-123 and offers guidance in the event of a large spill or leak. The chemical formulae, boiling points, AELs, and EELs are tabulated for R-123, R-124, and R-134a. The bulletin provides general advice on skin and eye contact with refrigerants, frostbite, pressure hazards, handling and disposal of cylinders, brazing or welding of pipes in air-conditioning and refrigeration systems, and decomposition. It concludes with specific cautions. The document identifies related bulletins that may be helpful and recommends familiarization with the Material Safety Data Sheet (MSDS) provided for the refrigerant to be used. DuPont's product names for R-123 and R-124 are Suva(R) Centri-LP and Suva(R) Chill-LP, respectively; it identifies R-134a as both Suva(R) Cold-MP and Suva(R) Trans A/C. [see RDB4C48 for update]

Sax's Dangerous Properties of Industrial Materials (eighth edition), edited by R. J. Lewis, Sr. (revision of publication by N. I. Sax), Van Nostrand Reinhold Publishers, New York, NY, 1992 (rdb5160)

widely cited reference for flammability, toxicity, and other safety data

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1991

December 1991

J. L. Adcock, S. B. Mathur, W. A. Van Hook, H. Q. Huang, M. Narkhede, and B-H. Wang (University of Tennessee), **Fluorinated Ethers - A New Series of CFC Substitutes**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 386-395, 1991 (10 pages with 6 tables, RDB2255)

fluoroether refrigerants

T. Atwood (AlliedSignal Incorporated), **HFC-32 ... Part of the 'New Math' of Refrigerants**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December, 1991), Alliance for Responsible CFC Policy, Arlington, VA, 432-441, December 1991 (10 pages, RDB6323)

R-32

T. Atwood and J. Zheng (AlliedSignal Incorporated). **Cascade Refrigeration Systems: The HFC-23 Solution**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 442-450, 1991 (9 pages with 3 figures and 2 tables, RDB4561)

R-13, R-23, R-503

J. C. Bare (U.S. Environmental Protection Agency, EPA), **Program to Determine Performance of Fluorinated Propanes and Fluorinated Ethers in a Compressor Calorimeter**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December, 1991), Alliance for Responsible CFC Policy, Arlington, VA, 418-427, December 1991 (10 pages, RDB6327)

HFC and HFE refrigerants, performance

A. L. Beyerlein, D. D. DesMarteau, S. H. Hwang (Clemson University), N. D. Smith (Environmental Protection Agency, EPA), and P. Joyner (Electric Power Research Institute, EPRI), **Physical Property Data on Fluorinated Propanes and Butanes as CFC and HCFC Alternatives**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 396-405, December 1991 (10 pages with 5 tables, RDB2256)

J. C. Conklin (Oak Ridge National Laboratory, ORNL) and E. Granryd (Kungliga Tekniska Högskolan, KTH, Sweden), **Thermal Performance Analysis for Heat Exchangers Having a Variable Overall Heat Transfer Coefficient**, paper 91-WA-NE-7 (ASME Winter Annual Meeting, Atlanta, GA), American Society of Mechanical Engineers (ASME), New York, NY, December 1991 (6 pages with 5 figures and 4 tables, RDB2341)

heat transfer

D. D. DesMarteau, A. L. Beyerlein, S. H. Hwang, Y. Shen, S. Li, R. Mendonca, K. Naik (Clemson University), N. D. Smith (Environmental Protection Agency, EPA), and P. Joyner (Electric Power Research Institute, EPRI), **Selection and Synthesis of Fluorinated Propanes and Butanes as CFC and HCFC Alternatives**, unpublished presentation, International CFC and Halon Alternatives Conference (Baltimore, MD, 3-5 December 1991), U.S. Environmental Protection Agency, Research Triangle Park, NC, 1991 (rdb2264)

This paper estimates the annual quantity of R-22 required internationally for unitary equipment through the year 2000. Based on its properties, including efficiency, low cost, and safety, R-22 is the most widely used refrigerant. The paper estimates its 1990 use as 160 million kg (352 million lbs), of which 14% was used for equipment other than unitary (e.g., existing and new chillers). For the unitary portion, 24% was used in new products and 76% to service existing equipment. Two parametric scenarios are presented: (1) 3, 5, and 7% growth in demand for unitary products with no change in service practices, and (2) recovery increasing to 40, 60, or 80 %/yr by 2000. Based on assumptions for usage in room air-conditioners, duct-free split systems, ducted systems, and commercial unitary systems, the paper projects a range of 77-149 million kg (169-327 million lbs), depending on recovery levels, to be required in 2000 at the 5% annual new-product growth rate.

R. G. Doerr, R. Schafer, D. Lambert, and D. Steinke (The Trane Company), **Stability Studies of E-245 Fluoroether $CF_3CH_2OCHF_2$**, presentation at the International CFC; and Halon Alternatives Conference (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 1991 (4 pages with 14 charts, available from JMC as RDB-2811)

These presentation charts summarize an investigation into the use of R-E245fa1, a proposed low-pressure refrigerant for centrifugal chillers. The charts summarize properties of this fluid and sealed-tube tests to determine its stability. Tests in glass tubes, both with and without an unidentified oil, resulted in violent explosions. Tests of R-123 and R-E245fa1 with copper and iron coupons in Parr bombs are presented, indicating stable results. Repetition of the R-E245fa1 tests with copper, iron, and glass coupons led to reactions. Analyses of the pressure build-up as well as a gas chromatogram and quantitative analysis of the reaction products are presented. Further tests with glass are outlined to examine the role of water, air, oxygen, and peroxide. The charts note that R-E245fa1 can react autocatalytically with glass to produce high pressures, hydrogen fluoride, and 2,2,2-trifluoroethyl ether (a convulsant). This reaction is accelerated by air (oxygen) and peroxide. The fraction of R-E245fa1 remaining after exposures at 121 °C (250 °F) for 14 days are tabulated to indicate the effects of various materials. They included elastomers, motor materials, copper, iron, water, glass-like materials. Tests with copper, iron, and aluminum at 166 and 177 °C (330 and 350 °F) also are presented. R-E245fa1 was found to be unstable with fiberglass motor materials.

R. E. Ertinger (Carrier Corporation), **HCFC-22: Requirements for Unitary Products**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 340-347, 1991 (8 pages with 3 figures, RDB2257)

future demand for R-22

S. K. Fischer, P. J. Hughes, P. D. Fairchild (Oak Ridge National Laboratory, ORNL), C. L. Kusik, J. T. Dieckmann, E. M. McMahon, and N. Hobday (Arthur D. Little, Incorporated, ADL), **Energy and Global Warming Impacts of CFC Alternative Technologies**, Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) and U.S. Department of Energy (DOE), Washington, DC, December 1991 (602 pages with 98 figures and 40 tables plus supporting figures and tables in appendices, RDB2432)

This report documents detailed analyses of global warming for options to replace chlorofluorocarbons (CFCs) in energy-related applications. The study addressed both direct and indirect effects, namely greenhouse gas impacts of chemical emissions and carbon dioxide emissions from associated energy use. The report compares impacts, for alternative technologies, on the basis of total equivalent warming impact (TEWI). Domestic refrigerator-freezers, commercial refrigeration, commercial chillers, residential and commercial unitary heating and cooling equipment, automobile air conditioning, building insulation, and solvents for metal and electronic cleaning were examined on an international basis. The refrigerants addressed for household refrigeration included R-12, R-134a, R-22/152a/-124, R-22/142b; absorption and Stirling cycles also were assessed. R-12, R-22, R-134a, R-502, and R-717 (ammonia) were examined for commercial refrigeration. R-11, R-12, R-22, R-123, R-134a, and R-717 were addressed for commercial air conditioning along with water-lithium bromide absorption cycles. R-22, R-134a, and ammonia-water absorption were analyzed for unitary air conditioners. R-12, R-134a, R-152a, R-290 (propane), and R-22/152a/124 were evaluated for automotive air conditioning along with Brayton and Stirling cycles.

L-Z. Han, M-S. Zhu, and Z-Z. Lin (Tsinghua University, China), **Experimental Study on Blend HCFC-22/HFC-152a as a Refrigerant in Refrigerator**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 494-501, 1991 (8 pages with 4 figures and 1 table, RDB2311)

R-22/152a

N. J. Hewitt, J. T. McMullan, N. E. Murphy, and N. Shafaghian (University of Ulster, UK), **A Solubility Equation for R22-Oil Mixtures**, *International Journal of Energy Research* (IJER), 15(9):763-768, December 1991 (6 pages with 5 figures and 3 tables, RDB4C21)

solubility of R-22 in paraffinic mineral oil (MO) expressed as a Bambach-style formula; refrigerant-lubricant (RL) properties

S. T. Jolley, **The Performance of Synthetic Ester Lubricants in Mobile Air-Conditioning Systems**, unpublished presentation at the Society of Automotive Engineers (SAE) Passenger Car Meeting and Exposition (Nashville, TN, 16-19 September 1991); unpublished presentation repeated at the International CFC and Halon Alternatives Conference (Baltimore, MD, 3-5 December 1991); Lubrizol Corporation, Wickliffe, OH, 1991 (14 pages with 3 figures and 6 tables, available from JMC as RDB-2C07)

The publication reviews polyolester chemistry and the reactions of alcohol and carboxylic acid to produce them. The variety of lubricants that can be produced from neopentylglycol (NPG), glycerine (GLY), trimethylolpropane (TMP) and pentaerythritol (PER) polyols (alcohols with multiple hydroxyl reaction sites) is illustrated. A table demonstrates the influence of the alcohol type on viscosity and miscibility using the same carboxylic acid. A second table shows that when similar lubricants, with the same viscosity are prepared, differences occur in miscibility with R-134a. GLY and NPG fluids exhibit the poorest and highest solubility, respectively. Tabulated results of sealed-tube tests of R-134a and lubricant in the presence of iron, copper, and aluminum show high thermal stability for a number of polyolesters, generally superior to

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that of R-12 with mineral oil. The more reactive systems tended to be those with high water content or residual carboxylic acid. Data are presented on the same refrigerant-lubricant pairs with addition of controlled amounts of water, to examine hydrolytic stability. Resultant increases in acid number are discussed, but caveated that higher acid levels might occur with additives instead of the base lubricants tested. A figure summarizes elastomer swell for mineral oil as well as NPG, TMP, and PER esters for NBR, H-NBR, EPDM, nitrile, neoprene, and Butyl; the paper notes that further testing is needed. It then discusses miscibility with mineral oil, a concern for retrofit of automobile air conditioners with R-134a and esters. TMP and PER esters are indicated to be fully compatible with both residual R-12 and mineral oil. Compressor tests are summarized, to address the influence of viscosity on durability and the role of unidentified additives. The paper indicates that equivalent performance to R-12 and mineral oil can be obtained with polyolesters and appropriate additive packages. The paper concludes that polyolesters appear ideal for use in automobile air conditioner systems, and that they can be tailored for specific needs.

B. D. Joyner, **Refrigerants 69-S and 69-L, 'Drop-in' Replacements for R-502**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 1991 (RDB2303)

R-403A, R-403B

S. Komatsuzaki, Y. Homma, K. Kawashima, and Y. Itoh (Hitachi Limited, Japan), **Polyalkylene Glycol as Lubricant for HFC-134a Compressors**, *Lubrication Engineering*, 47(12):1018-1025, December 1991 (8 pages, rdb2212)

R-134a, PAG

R. L. Powell (ICI Chemicals and Polymers, Limited), **Long Term Replacements for R-22 and R-502: The Next Challenge**, unpublished presentation (International CFC and Halon Alternatives Conference, Baltimore, MD, 3-5 December 1991), ICI Americas Incorporated, New Castle, DE, USA, December 1991 (16 pages with 4 figures and 3 tables, RDB2519)

This paper identifies a number of candidates to replace R-22 and R-502, and describes the advantages and disadvantages of each. Options addressed include R-32, R-125, R-134a, R-143a, R-152a, as well as nine binary and ten ternary blends of them. Candidate selection was limited to fluorocarbons because they offer the low boiling points needed for refrigeration, including the temperatures needed for frozen-food storage. Chlorinated compounds are excluded because of their potential for ozone depletion. Perfluorocarbons, such as R-218, were deemed unlikely since their high fluorine content, and resultant long atmospheric lifetimes, are expected to lead to high direct global warming potentials (GWPs). Property similarity to the fluids being replaced, to minimize equipment development requirements, and avoidance of subatmospheric operation were further goals. Flammability and toxicity limited some choices, such as R-290 (propane) and R-717 (ammonia). The paper describes avoidance of high GWPs, flammable ranges, discharge superheat, and fractionation potential in leakage. It also cites the goal of maintaining, or improving, efficiency to further narrow the list of candidates. The paper recommends mixtures of R-32 and R-134a as the preferred solutions; it notes that their blends may be modified by addition of R-125, to suppress the flammability of R-32 and reduce discharge temperatures.

R. K. Radermacher and D. Jung (University of Maryland), **Theoretical Analysis of Replacement Refrigerants for R-22 for Residential Uses**, report EPA/400/1-91/041, U.S. Environmental Protection Agency (EPA), Washington, DC, December 1991 (77 pages with 10 figures and 10 tables, available from JMC as RDB2509)

This report examines the need and candidate replacements for R-22. The simulation programs (HAC1 for single fluids and binary mixtures and HACT1 for ternary mixtures) and data used for the study are summarized. Hydrofluorocarbon (HFC) refrigerants R-32, R-125, R-134, R-134a, R-143a, and R-152a and hydrochlorofluorocarbon (HCFC) R-124 were selected for analyses. Results are presented for R-32/124, R-32/134, R-32/134a, R-32/152a, R-125/124, R-125/134a, R-125/152a, R-143a/124, R-143a/134a, and R-143a/152a. Results also are provided for three ternary blends, investigated to reduce flammability, namely R-32/152a/124, R-32/152a/134, and R-32/134a/-152a. Coefficients of performance (COPs) and seasonal performance factors (SPFs) were calculated. The report also reviews the design modifications considered and discusses requirements for future research. No single-component refrigerant was found acceptable as a substitute, but binary and ternary blends appear promising. The ternary mixture of R-32/152a/124 showed the best performance, with a COP increase of 13.7% over R-22. Chlorine-free R-32/152a/134 yielded a 12.6% increase, but no manufacturer has indicated intent to produce R-134. R-32/134a shows an improvement of 6% and may not be flammable since it contains 70% R-134a.

The report notes that significant design changes, such as use of counter-flow heat exchangers, will be necessary to achieve these gains. A caveat indicates that the ranking of substitutes may change, due to the influence of transport properties and other variables not considered. (This report replaces the published draft, see RDB1134.)

W. R. Rhodes (U.S. Environmental Protection Agency, EPA), **Stratospheric Ozone Protection: An EPA Engineering Perspective**, *Journal of the Air and Waste Management Association*, 41(12):1579-1584, December 1991 (6 pages with 2 tables, available from JMC as RDB2707)

D. R. Riffe (Americold / White Consolidated Industries, Incorporated) and T. W. Dekleva (ICI Americas, Incorporated), **Effects of Lubricants on the Energy Efficiency of R-134a in Home Appliances**, unpublished presentation (International CFC and Halon Alternatives Conference, Baltimore, MD, 3-5 December 1991), ICI Americas Incorporated, Wilmington, DE, 1991 (RDB5123)

literature survey, mineral oil (MO), polyolester (POE), polyalkylene glycol (PAG), compressor losses, effects of solubility and viscosity

F. Rinne and H. H. Kruse (Universität Hannover, Germany), **Anlagentechnische Untersuchungen mit dem Kältemittelgemisch R23/R152a** [Equipment Test of the R-23/152a Refrigerant Mixture], *Ki Klima-Kälte-Heizung*, 19(12):505-509, December 1991 (5 pages, in German, RDB4530)

performance, R-23/152a

J. R. Sand, S. K. Fischer (Oak Ridge National Laboratory, ORNL), and P. A. Joyner (Electric Power Research Institute, EPRI), **Modeled Performance of Nonchlorinated Substitutes for CFC-11 and CFC-12 in Centrifugal Chillers**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 406-415, 1991 (10 pages with 2 tables, RDB2260)

P. Sanvi, N. Genet, F. Espinoux, and G. Bardy (Elf Centre de Recherche de Solaize, France), **Lubrication for HFC-134a Compressor in Home Appliances**, unpublished presentation (International CFC and Halon Alternatives Conference, Baltimore, MD, 3-5 December 1991), Elf Atochem S.A., Paris - La Défense, France, December 1991 (rdb6326)

R-134a, lubricants

M. W. Spatz (AlliedSignal Incorporated), **Performance of Alternative Refrigerants from a System's Perspective**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 352-361, 1991 (10 pages with 5 figures and 3 tables, RDB2253)

The modeled coefficients of performance (COPs), capacities, and discharge temperatures for a representative 11 kW (3 ton) air-to-air heat pump are presented for R-22, R-32/125 (60/40), R-134a, and R-152a - all HFCs. The analyses were made with a modified version of the Oak Ridge National Laboratory (ORNL) Mark III Heat Pump System Design Model. Calculated COPs are tabulated both with simple replacement of R-22 and with reoptimization of the expansion device, heat exchangers, and tubing sizes. Calculations based on a simple (saturated) thermodynamic cycle indicate 8% lower, 1% lower, and 4% higher efficiency for R-32/125, R-134a, and R-152a, respectively, compared to R-22. The magnitude of these differences shrink when subcooling and superheating are introduced. With reoptimization, the differences range from -0.3 to 3.2% for a system optimized for both the heating and cooling modes and -0.9 to 0.6% for cooling only, depending on the refrigerant. The paper, therefore, concludes that while these three alternative refrigerants could be used without significant energy penalty, other factors need to be addressed. The approximately 50% higher condensing pressure of R-32/125 could increase costs. Changes in compressor displacement, increased for R-134a and decreased for R-32/125, also effect system costs. The flammability of R-152a would either eliminate it from consideration or impact costs by requiring additional safety controls.

D. W. Treadwell (Lennox Industries Incorporated), **Application of Propane (R-290) to a Single Packaged Unitary Air-Conditioning Product**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 348-351, 1991 (4 pages with 1 table, available from JMC as RDB2261)

This paper discusses the safety considerations and two tests of propane (R-290) as a refrigerant in a single-package, unitary air conditioner. Advantages cited include lower discharge temperature and pressure compared to R-22, both favorable to compressor life, as well as higher efficiency (by 1-2%) and materials compatibility. The low cost, availability, and favorable environmental attributes (no ozone-depletion potential and near zero global warming potential) are contrasted to its flammability. The paper estimates the charge quantity required to be less than half that of R-22, and concludes that the probability of reaching the lower flammability limit in a house - under identified leak assumptions - is remote. The paper indicates that the

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potential risks should be evaluated in light of the environmental and other advantages.

E. A. Vineyard (Oak Ridge National Laboratory, ORNL), L. Roke and F. Hallet, **Overview of CFC Replacement Issues for Household Refrigeration**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December, 1991), Alliance for Responsible CFC Policy, Arlington, VA, 310-316, December 1991 (7 pages with 2 tables, RDB2C09)

N. Xu, J. Yao, Y. Wang, J. Shi, and B. C-Y. Lu (Nanjing Institute of Chemical Technology, China), **Vapor-Liquid Equilibria of Five Binary Systems Containing R-22**, *Fluid Phase Equilibria*, 69:261-270, 10 December 1991 (10 pages, RDB5B66)

measurements of the isothermal vapor-liquid equilibrium (VLE) values and modified, volume-translated, Peng-Robinson (PR) equations of state (EOSs) for binary blends of R-22: these mixtures include R-10 (tetrachloromethane), ethanol, 1-hexane, cyclohexane, and 2-propanol; describes the high-pressure static apparatus used to determine the VLE data for 70-127 °C (158-260 °F)

M-S. Zhu, L-Z. Han, and Z-Z. Lin (Tsinghua University, China), **Researches of CFC Alternatives in Tsinghua University**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 484-493, 1991 (10 pages with 6 tables, RDB2312)

Alternative Fluorocarbons Environmental Acceptability Study, program description, AFEAS, Washington, DC, December 1991 (4 pages with 1 figure and 1 table, available from JMC as RDB2105)

This leaflet introduces the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), initiated in December 1988. The program was formed to assess the potential impacts of chlorofluorocarbon (CFC) refrigerant alternatives on the environment. AFEAS is a cooperative research effort sponsored by 12 leading chemical producers. Results were presented at the United Nations Environment Programme (UNEP) meeting in Nairobi in August 1989, and were incorporated as an appendix to the *Scientific Assessment* under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. Further research seeks to identify and help resolve uncertainties regarding potential environmental effects of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). A second objective is to stimulate prompt dissemination of scientific information to the research community, government decision makers, affected industries, and the public. A table lists potential alternatives to CFCs, including HCFCs R-22, R-123, R-124, R-141b, R-142b, R-225ca, and R-225cb and HFCs R-32, R-125, R-134a, and R-152a. A figure contrasts the direct (chemical emission related) and indirect (energy related) contributions to total equivalent warming impact (TEWI) for a representative refrigerator.

Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) Summaries, AFEAS, Washington, DC, December 1991 (14 pages with 5 figures and 1 table, available from JMC as RDB2106)

This series of seven leaflets presents key AFEAS objectives and findings. A summary of *Atmospheric Fluorocarbons and Stratospheric Ozone* reviews the mechanisms of stratospheric ozone depletion and provides values for ozone depletion potentials (ODPs). It also illustrates how substitution of hydrochlorofluorocarbons (HCFCs) for chlorofluorocarbons (CFCs) reduces chlorine in the atmosphere. A sheet on *UV-B Radiation Measurements* discusses the importance of the ozone layer in shielding ultraviolet-B (UV-B) radiation in sunlight as well as efforts to monitor and long-term trends of incoming UV-B intensity. A summary of *Alternative Fluorocarbons and Global Warming* compares the global warming potentials (GWPs) of CFCs to those of HCFCs and hydrofluorocarbons (HFCs). It also contrasts the calculated warming effects of these compounds to other greenhouse gases, including carbon dioxide, methane, and nitrous oxide. A synopsis of the *Relative Contributions of Greenhouse Gas Emissions to Climate Forcing* discusses radiative forcing, factors that can perturb the heat balance of the earth-atmosphere system. It outlines understanding and uncertainties associated with GWP values, atmospheric persistence of greenhouse gas emissions, and the quantitative influence of *integration time horizon* (ITH) on analyses of impacts. A review of the *Breakdown Products of Alternatives* outlines the mechanisms and consequences of HCFC and HFC breakdown, including the potential impacts of degradation products. A table provides estimates for the atmospheric lifetimes and GWP values for 20, 100, and 500 yr ITH. A *Glossary of Terms* explains key terminology for discussion of the atmospheric effects of alternative fluorocarbons. The last sheet briefly outlines the history and activities of both AFEAS and the companion Programme for Alternative Fluorocarbon Toxicity Testing (PAFT).

Development of an Advanced Refrigerant for Compression Heat Pump, Research Institute of

Innovative Technology for the Earth (RITE), Japan, December 1991 (rdb3326)

background to examination of hydrofluoroether (HFE) refrigerants that led to selection of R-E245cb1 [$CH_3OCF_2CF_3$], R-E347mmy1 [CH_3O-$CF(CF_3)_2$ and $CF_3CF(OCH_3)CF_3$], R-E347mcc3 [$CH_3OCF_2CF_2CF_3$] as candidates

Programme for Alternative Fluorocarbon Toxicity Testing, program description, PAFT, Bristol, United Kingdom, December 1991 (4 pages with 1 figure and 1 table, available from JMC as RDB2107)

This leaflet introduces the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), initiated in December 1987. The program is designed to expedite the development of toxicology data for possible substitute fluorocarbons to replace chlorofluorocarbons (CFCs), or more broadly halogenated fluoroalkanes, that may be catalyzing a decrease in stratospheric ozone levels. PAFT is a cooperative research effort sponsored by 15 of the leading CFC producers from nine countries. Four PAFT program sectors are identified including PAFT I to address R-123 and R-134a, PAFT II for R-141b, PAFT III for R-124 and R-125, and PAFT IV for R-225ca and R-225cb. The leaflet summarizes program objectives and schedules. It notes that there are nearly 100 individual toxicology tests in the program, at a cost of $3-5 million per compound. It also indicates that more than a dozen testing laboratories in Europe, Japan, and the United States are performing tests, the results of which will be published in peer-reviewed journals and presented at scientific conferences. The program comprehensively addresses acute, subchronic, developmental and chronic toxicity/carcinogenicity studies, and environmental studies.

Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries, PAFT, Bristol, United Kingdom, December 1991 (10 pages, available from JMC as RDB2108)

Five data sheets summarize the status and findings of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). They address *HCFC-123 in Comparison with CFC-11, HFC-134a in Comparison with CFC-12, HCFC-141b in Comparison with CFC-11, Other PAFT Programs* (HCFC-124 and HFC-125 compared to CFC-114 and CFC-115, respectively), and a *Glossary of Terms*. The summaries outline studies of acute toxicity (short-term exposures to high concentrations, such as accidental leakages), genotoxicity (effects on genetic material, an early screen for possible carcinogenic activity), subchronic toxicity (repeated exposure to determine any overall toxicological effect), developmental toxicity (teratology, assessment of the potential for causing birth defects), and chronic toxicity/carcinogenicity (lifetime testing to assess late-in-life toxicity or increased evidence of cancer). Interim results and program plans are summarized for R-123, R-134a, R-141b, R-124, and R-125. The results available to date indicate that applications testing can proceed with R-123, provided that close attention is paid to exposure levels. Similarly, no findings preclude use of R-134a and R-141b in general industrial uses, provided that recommended normal hygiene practices are observed.

Refrigeration Systems Program Summary, report DOE/CH10093-120, U.S. Department of Energy (DOE), Washington, DC, December 1991 (24 pages, available from NTIS as GPO #573122/40020 at price code A03, RDB2263)

This document summarizes results, current activities, and objectives of the U.S. Department of Energy (DOE) for research of refrigerators, air conditioners, heat pumps, chillers, and supermarket systems. Key activities include investigation of alternative refrigerants and refrigeration cycles, developing advanced technologies for future air-conditioning and refrigeration equipment designs, and developing advanced insulation for appliances. The program structure and opportunities for collaboration with industry are outlined.

Report of the Refrigeration, Air Conditioning, and Heat Pumps Technical Options Committee for the 1991 Assessment, chaired by L. J. M. Kuijpers, *Technical Progress on Protecting the Ozone Layer*, report RWR-570-LK-91423-al, United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, December 1991 (298 pages with 12 figures and 42 tables, RDB2318)

This report is one of six prepared to assess the status of technologies impacted by the Montreal Protocol and to assess whether the control measures of the Protocol are sufficient to meet the goals of reducing ozone depletion. It is based on a review of the current state of knowledge on technical, scientific, environmental, and economic issues related to stratospheric ozone protection. The Technical Options Committee (TOC) examined options and trends for achieving compliance and assembled projections for refrigerant uses. The report was prepared, pursuant to Article 6 of the Protocol, by an international panel representing 90 firms, organizations, or agencies and 19 countries. It addresses the Protocol and reassessment procedure, refrigerants, domestic refrigeration (including refrigerators and other appliances), commercial refrigeration, cold storage and food processing, industrial refrigeration, air condi-

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tioning and heat pumps, chillers, transport refrigeration and air conditioning, mobile air conditioning, heating-only heat pumps and heat recovery, refrigerant conservation, developing countries aspects, and information dissemination and research coordination.

November 1991

S. Kussi, **Polyethers as Base Fluids to Formulate High Performance Lubricants**, *Lubrication Engineering*, 47(11):926-933, November 1991 (8 pages, rdb6913)

chemistry of polyalkylene glycol (PAG) lubricants

J. Paul (Integral Technologie GmbH, Germany), **Wasser als Kältemittel: III** [Water as a Refrigerant: Part III], *Bericht über die Kälte-Klima-Tagung* [Proceedings of the Refrigeration and Air-Conditioning Conference] (Berlin, Germany, November 1991), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 18:, 1991 (in German, rdb4A70)

R-718

A. Schelling, H. H. Kausch, and A. C. Roulin, **Friction Behavior of Polyetherketone Under Dry Reciprocating Movement**, *Wear*, Switzerland, 151(1):129-142, 30 November 1991 (14 pages, rdb-4C37)

PEK

M-S. Zhu, L-Z. Han, Z-Z. Lin, L. Li, and Y-D. Fu (Tsinghua University, China), **Experimental Study on Interim Substitute Refrigerant in Refrigerator**, *Proceedings of the Far East Conference on Environmental Quality* (Hong Kong, 5-8 November 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA pages 181-184, 1991 (4 pages with 9 figures and 1 table, rdb5612)

examination of use of R-500 as an interim replacement for R-12; concludes that R-500 offers higher capacity than R-12 for the same conditions and optimized charges, that energy use with the two refrigerants is nearly the same, and that R-500 can be used to replace R-12 without changing the lubricant or "great modification" of the system

October 1991

M. C. Adams (University of Utah Research Institute), J. J. Beall (Calpine Corporation), S. L. Enedy (Northern California Power Agency), and P. N. Hirtz (Thermochem, Incorporated), **The Application of Halogenated Alkanes as Vapor-Phase Tracers: A Field Test in the Southeast Geysers**, *Transactions*, Geothermal Resources Council, 15:457-463, October 1991 (7 pages with 8 figures, RDB8B30)

field test of R-12 and R-13 to map flow paths in hydrogeological studies; notes that R-12 displayed significant decay in the geothermal field, but that R-13 showed little or none; also notes that the R-12 decay was reduced for some conditions, possibly movement outside an oxidized zone surrounding the injection well or other geochemical conditions

D. B. Bivens (DuPont Chemicals), **Heat Pumps – R-22 and Beyond,** *Proceedings: Meeting Customer Needs with Heat Pumps - 1991* (Dallas, TX, October 1991), report TR-101944, Electric Power Research Institute (EPRI), Palo Alto, CA, 6-1 - 6-6, December 1992 (6 pages with 2 tables, RDB3B03)

This paper examines three options for heat pumps if R-22 ceases to be available. The first two are Stirling or Vuilleumier cycles (using helium) or sorption technologies such as absorption, adsorption, and chemi-sorption (using ammonia with water, salt, carbon, or zeolites or lithium bromide/water). They are dismissed as requiring development and demonstration to achieve system lifetimes comparable to vapor-compression systems, at equal or lower purchase and operating costs. The paper then presents 12 candidates to replace R-22, including (in order of increasing boiling point) R-23, R-41, R-116, R-32, R-125, R-143a, R-290 (propane) boiling at lower temperatures than R-22, and R-161, R-218, R-717 (ammonia), R-134a, and R-152a above. Boiling points, atmospheric lifetimes, ozone depletion potentials (ODPs) and global warming potentials (GWP) are tabulated for them. Most are flammable, have high global warming potentials, or are toxic, leaving R-134a and R-125 as the primary candidates. The paper discusses tradeoffs to use these fluids, including loss of efficiency and capacity or increases in equipment size. It then presents a tabular summary of performance, compressor discharge pressure and temperatures, and temperature glide for six of the fluids, for blends with R-32, and for propane blended with a secondary fluid. The paper concludes that if R-22 is not available, heat pump systems will continue to be based on vapor-compression technology, but with chlorine-free working fluids. It notes that several blends containing R-32 are under investigation. It suggests that the optimal blend will result from cooperative development between refrigerant and equipment manufacturers.

P. D. Fairchild and S. K. Fischer (Oak Ridge National Laboratory, ORNL), **Global Warming and End-Use Efficiency Implications of Replacing CFCs**, *Proceedings: Meeting Customer Needs with Heat Pumps - 1991* (Dallas, TX, October 1991), report TR-101944, Electric Power Research Institute (EPRI), Palo Alto, CA, 7-1 - 7-14, December 1992 (14 pages with 9 figures, RDB3B04)

A. K. Grebenkov et al., **Experimental Research of Heat Conductivity of R134a Both in the Liquid and in the Gas Phases**, *The Cold is to the National Economy* (proceedings of the All Union Science-Technical Conference), LTIHP, USSR, October 1991 (rdb5448)

R-134a, transport properties, thermophysical data, thermal conductivity

J. E. Korleski (E. I. duPont de Nemours and Company), **The Performance of PET Motor Insulation in CFC-Free Refrigerant Systems**, *Proceedings of the 20th Electrical Electronics Insulation Conference and Electrical Manufacturing and Coil Winding Conference* (EEIC/ICWA, Boston, MA, 7-10 October 1991), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 190, 1991 (RDB3C15)

The rapid conversion to chlorofluorocarbon (CFC) free refrigerants has prompted reexamination of the performance of polyethylene terephthalate (PET) insulating materials in the presence of the new refrigerant-lubricant systems. Several PET motor films were subjected to sealed-tube aging tests in the presence of CFC-free refrigerants and lubricants. The effects of the type of lubricant, level of moisture, temperature, and time on the physical properties of the motor films were examined. The factors which dominate the motor film's performance were considered. The performance of the films in sealed-tube tests was compared to their performance in other aging tests, such as hydrolytic stability, thermal aging at 160 °C (320 °F), and oligomer extraction, to obtain a correlation of the later test's relative predictive value.

J. W. Linton and W. K. Snelson (National Research Council, Canada, NRCC), **A New Environmentally Acceptable High-Temperature Heat Pump**, *Proceedings: Meeting Customer Needs with Heat Pumps - 1991* (Dallas, TX, October 1991), report TR-101944, Electric Power Research Institute (EPRI), Palo Alto, CA, 55-1 - 55-15, December 1992 (14 pages with 9 figures, RDB3B05)

R-123

Handbook for the Montreal Protocol on Substances That Deplete the Ozone Layer (second edition), United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, October 1991 (104 pages including 2 page errata, available from JMC as RDB2702)

This document contains the complete text of the Montreal Protocol, originally adopted in 1987 as adjusted and amended in June 1990 and further amended in June 1991. The decisions of the Parties to the Montreal Protocol, that relate to its interpretation, at meetings in Helsinki in (May 1989), London (June 1990), and Nairobi (June 1991) appear as footnotes to the Articles to which they pertain. The handbook also includes the following appendices: the *Helsinki Declaration on Protection of the Ozone Layer* (2 May 1989); declarations by Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, Liechtenstein, Netherlands, New Zealand, Norway, Sweden, and Switzerland on phase out of CFCs not later than 1997 (June 1990); resolution by represented parties on more stringent measures (June 1990); statements by Austria, Denmark, Germany, Finland, Norway, Sweden, and Switzerland on more stringent measures (June 1991); status of ratification (September 1991, now superseded); list of relevant publications; nonconfidential production and consumption data regarding controlled substances; *Criteria for Projects under the Multilateral Fund*; names and address of assessment panel chairmen; annotated *Vienna Convention for the Protection of the Ozone Layer*; status of ratification of the Vienna Convention (September 1991; now superseded); and the *Rules of Procedure*. The Vienna Convention was adopted in Vienna on 22 March 1985 and entered into force on 22 September 1988. The Montreal Protocol was adopted in Montreal on 16 September 1987 and entered into force on 1 January 1989; the Amendment was adopted in London on 29 June 1990 and entered into force on 10 August 1992. (see RDB3C05 for update)

September 1991

S. Corr, E. Goodwin, R. D. Gregson, A. Halse, A. Lindley (ICI Chemicals and Polymers, Limited), S. H. Colmery, T. W. Dekleva, and R. Yost (ICI Americas, Incorporated), **Retrofitting Mobile Air-Conditioning Systems with HFC-134a**, seminar presentation at the Society of Automotive Engineers (SAE) Passenger Car Meeting and Exposition (Nashville, TN), ICI Americas Incorporated, New Castle, DE, USA, 18 September 1991 (22 pages with 27 charts, RDB2618)

This document provides the charts and text for a presentation on retrofit of mobile air air-conditioning (MAC) systems. The need for a service refrigerant, after market logistics, and requirements of the Clean Air Act Amendments of 1990

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are introduced. The reasons for selecting R-134a as a retrofit refrigerant are discussed. Retrofit solutions may lie between simple replacement of the refrigerant and lubricant and the need to flush the system and also replace certain components. The rationale for esters as the lubricant is presented. Ten ester candidates are summarized and data are provided on viscosity, miscibility, and wear tests. Compatibility findings are presented for EPDM, HNBR, neoprene, nitrile, nylon, and fluoroelastomer (DuPont Viton(R)) with mineral oil, a polyalkylene glycol (PAG), an end-capped PAG, and an ester. Mutual compatibility and thermal stability data are discussed for the lubricants. A finding on chlorinated impurities (e.g., residual R-12 or flushing solvents) is reviewed, indicating that its nature is more important than its concentration. Sealed-tube test results are reviewed for R-12 and R-134a with mineral oil, PAG, and ester lubricants with contaminants. The data include changes in color, viscosity, acid number, and metal content as well as copper plating and metal impacts; no detrimental effects from residual R-12 and mineral oil were observed with R-134a and the esters. Hydrolytic stability tests point to greater stability with polyolesters than PAGs. The stability analyses and a compressor test program are outlined.

Limiting Net Greenhouse Gas Emissions in the United States, Energy Responses (Report to the Congress of the United States), edited by R. A. Bradley, E. C. Watts, and E. R. Williams, report DOE/PE-0101 volume II, U.S. Department of Energy, Washington, DC, September 1991 (552 pages with 187 figures and 243 tables, available from NTIS, RDB4210)

climate change, environmental impacts, global warming

August 1991

M. Arnemann and H. H. Kruse (Universität Hannover, Germany), **Liquid Viscosities of the Nonazeotropic Binary Refrigerant Mixtures of R22/R114, R22/R152a, and R22/R142b: Measurement and Calculations**, paper 41, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, 11:379-383, August 1991 (5 pages with 4 figures and 6 tables, rdb4A45)

thermodynamic properties of R-22/114, R-22/-142b, and R-22/152a: zeotropic blends; thermophysical data

C. Baroncini, G. Giuliani, M. Pacetti, and F. Polonara (Università degli Studi di Ancona, Italy), **Experimental Vapor Pressures and P-v-T Properties of Refrigerants R123 and R124**, paper 76, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, 11:648-652, 1991 (5 pages with 5 figures and 4 tables, RDB5458)

vapor pressure and PVT behavior of R-123 and R-124; thermodynamic properties, thermophysical data

B. Boldrin, G. Minotto, G. Panozzo, L. Rebellato, B. Toniolo, G. Varotto (Instituto per la Tecnica del Freddo del CNR, Italy), and A. Bertocco (Truck Frigo, Italy), **Propane as an Alternative Refrigerant in Foodstuffs Transport**, paper 426, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, IV:2062-2067, 1991 (6 pages with 11 figures and 5 tables, RDB5346)

screening of hydrocarbons and hydrofluorocarbons including R-218, R-227ca, R-227ea, R-236fa, R-245cb, R-263fb, R-272ca, R-281ea, R-281fa, and R-290 for transport refrigeration; tabulates their normal boiling points (NBP) and plots their acute toxicity (expressed as 10-min LC_{50} mouse concentrations) against NBP; examines the biological and environmental characteristics as well as costs for R-290 relative to those of older refrigerants; plots the capacities and efficiencies of R-12, R-22, and R-290 and shows comparative test results for these three refrigerants in a transport refrigeration unit (Truck Frigo F10-10); concludes that R-290 offers higher efficiency than R-12; notes that system optimization is needed and that costs could be reduced with substitution of liquified petroleum gas (LPG, approximately 95% propane) for R-290

K. R. Den Braven, T-A. S. Owre, and J. Slippy (University of Idaho), **Effect of Thermodynamic Property Formulations on the Prediction of Heat Pump Cycle Performance**, *IECEC '91* (proceedings of the 26th Intersociety Energy Conversion Engineering Conference, Boston, MA, 4-9 August 1991), Institute of Electrical and Electronic Engineers (IEEE), Piscataway, NJ, 2:522-527, 1991 (6 pages, rdb8968)

compares use of simplified equations and more precise formulations for performance predictions; focuses on the compromise between accuracy and the amount of computational time required in a system simulation or optimization; presents comparisons for R-12 and R-22 in the heating mode of a heat pump model; compares the predicted coefficient of performance (COP) and pressure ratio for the Carnahan-Starling-DeSantis (CSD) equation of state (EOS) and standard reference quality EOS explicit in Helmholtz energy (or fundamental equations, FEQs); presents results for various values of system temperature lift, heat exchanger temperature glide, and for three different sets of CSD coefficients for R-12; observes that the CSD equation predicts COP values that are 8-10% percent higher and require computational times nearly twice as long as the FEQ

M. Goto, N. Inoue, and J. Nakamura (Tokyo University of Mercantile Marine, Japan), **Performance of Vapor Compression Heat Pump System Using a Nonazeotropic Refrigerant Mixture**, paper 62, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, II:548-550, August 1991 (3 pages with 10 figures, RDB4676)

R-12, R-22, R-114, R-12/114, R-22/114, laboratory performance tests in a water-to-water heat pump

E. Granryd (Kungliga Tekniska Högskolan, KTH, Sweden), **Heat Transfer in Flow Evaporation of Nonazeotropic Refrigerant Mixtures - A Theoretical Approach**, paper 251, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, III:1330-1334, August 1991 (5 pages with 6 figures, rdb2409)

R-22, R-114, R-22/114, heat transfer calculations for zeotropic blends; hypothesizes an explanation for decrease in heat transfer in flow convective evaporation of mixtures

P. E. Hansen and L. Snitkjær (Danfoss-Flensburg GmbH, Germany), **Development of Small Hermetic Compressors for R-134a**, paper 223, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, III:1146-1150, August 1991 (5 pages with 8 figures and 2 tables, rdb4926)

R-134a, lubricants, materials compatibility

M. Högberg and T. Berntsson (Chalmers University, Sweden), **A Residential Heat Pump Working with the Nonazeotropic Mixture HCFC-22/HCFC-142b - Experimental Results and Evaluation**, paper 492, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, III:1595-1600, August 1991 (6 pages with 11 figures and 2 tables, rdb4675)

R-22/142b, capacity and efficiency

D. Jung and R. K. Radermacher (University of Maryland), **Performance Simulation of a Two-Evaporator Refrigerator-Freezer Charged with Pure and Mixed Refrigerants**, *International Journal of Refrigeration* (IJR), 14(7):254-263, September 1991 (10 pages with 10 figures and 4 tables, RDB4418)

M. Kauffeld, H. König, and H. H. Kruse (Universität Hannover, Germany), **Theoretical and Experimental Evaluation of Air Cycle Refrigeration and Air Conditioning**, paper 219, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, III:1124-1129, August 1991 (6 pages with 14 figures, RDB6931)

R-729 (air), air-cycle refrigeration; open Joule Cycle, also identified as the reversed Brayton Cycle, and variants; reviews cycle performance and examines the consequences of internal heat exchange for direct and indirect systems; discusses problems and potential solutions for use of air cycles; concludes that an air-cycle machine could be developed that would match the performance of current vapor-compression cycle equipment for mobile air conditioning systems and other applications with source and sink temperature glides, but that air cycle equipment cannot be used in all air-conditioning and refrigeration systems because of poor performance in applications with constant temperatures of the heat source and sink fluids

G. S. Kazachki (Acurex Environmental Corporation), **Derivation of Dimensionless Parameters for Thermodynamic Evaluation of Refrigerants in Vapor-Compression Cycles**, paper 106, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, II:597-601, 1991 (5 pages with 1 figure, rdb-6317)

outlines a method to estimate the basic characteristics of a vapor-compression cycle from refrigerant properties and to configure the cycle for optimal performance for specific refrigerants; cycle analysis; performance analysis

G. S. Kazachki (Acurex Environmental Corporation) and C. L. Gage (U.S. Environmental Protection Agency, EPA), **Thermodynamic Evaluation of Five Alternative Refrigerants in Vapor Compres-**

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sion Cycles, paper 535, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, II:611-615, 1991 (5 pages, rdb6324)

performance comparisons for R-12, R-22, R-32, R-125, R-134a, R-143a, R-152a, and R-502; cycle analysis; plots of efficiency as functions of evaporating temperature with throttling expansion, superheating, and both

Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Some Correlations for Saturated Liquid Density of Refrigerant Mixtures**, paper 533, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, II:644-647, August 1991 (4 pages with 3 figures and 6 tables, rdb4446)

thermodynamic properties of R-11, R-22, R-114, R-134, R-142b, R-152a, R-22/12, R-22/114, R-22/142b, R-22/152a, R-22/152a/142b, R-152a/-114, R-152a/134, and R-152a/142b: blends; thermophysical data

S. M. Miner (Engineering Consultant), **An Appraisal of Ammonia as an Alternative Refrigerant** paper 220, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, III:1130-1134, August 1991 (5 pages with 3 figures and 4 tables, RDB2844)

R-717; brief review of history and market status; contrasts accident concerns with those for other refrigerants; reviews performance and other technical aspects of use; describes research activities and tabulates recent R-717 installations; cites sources of training and support

A. Ophir (I.D.E. Technologies, Israel) and J. Paul (Integral Technologie GmbH, Germany), **The Ecochiller - A Mechanical Vapour Compression Cycle Using Water as Refrigerant**, paper 67, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, 573-577, August 1991 (5 pages with 5 figures and 1 table, RDB5437)

R-718; discusses use of water as a refrigerant; plots required compression ratio as a function of leaving source temperature and temperature lift; compares cycles for use of water and describes the components; proposes a system for use of water as a refrigerant and ice slurry as a heat transfer fluid

J. Paul (Integral Technologie GmbH, Germany), **Alternative, Environmentally Safe Refrigerants and Process for Cooling, Heat Pump, and Power Generating (ORC) Systems**, paper 165, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, 920-922, August 1991 (3 pages with 2 figures and 2 tables, rdb4A68)

R-718

S. F. Pearson and J. Brown (Star Refrigeration Limited, UK), **Development of a Substitute for R502**, paper 162, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, II:903-909, August 1991 (7 pages with 8 figures and 2 tables, RDB2425)

discusses development of a replacement for R-502 including R-403A and R-403B

J. Pettersen and H. Rekstad (Norgest Tekniska Högskole, NTH, Norway), **The Practical Performance of R-134a in Motorcar Air-Conditioning**, paper 225, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, III:1155-1160, 1991 (6 pages with 7 figures and 3 tables, rdb5B27)

R-134a with an unidentified polyoxalkylene glycol ether lubricant, capacity and efficiency in mobile air conditioning (MAC) system; laboratory measurements

R. G. Richard and I. R. Shankland (AlliedSignal Incorporated), **Flammability of Alternate Refrigerants**, paper 42, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, II:384-387, August 1991 (4 pages with 1 figure and 5 tables, RDB4441)

R-11, R-22, R-30, R-32, R-50, R-113, R-123, R-123a, R-124, R-125, R-134, R-134a, R-140a, R-141b, R-142b, R-143, R-143a, R-152, R-152a, R-161, R-E170, R-218, R-290, R-C318, R-600, R-600a, R-601, R-611, R-717, R-744, R-7146, flammability, LFL, UFL, tests by ASTM E681 method; critical flammability ratio (CFR) for R-22/152a, R-32/125, R-125/152a, R-125/290, R-134a/152a, R-143a/134a, and R-152a/124; influences of the ignition source, moisture content of the gas mixture, temperature, and mixture composition

J. M. Saiz Jabardo (University of Illinois at Urbana-Champaign, USA) and C. L. da Silva (Universidade Estadual Paulista, Brazil), **Modeling of the Nucleate Boiling of Refrigerant-Oil Mixtures**, paper 155, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, II:514-518, August 1991 (5 pages with 5 figures, rdb3B27)

R-11, R-113, R-114, heat transfer coefficients, heat exchangers, heat transfer

M. B. Shiflett and P. R. Reed (DuPont Chemicals), **Alternative Low-Temperature Refrigerants**, paper 163, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, II:910-915, August 1991 (6 pages with 10 figures and 4 tables, rdb2307)

R-22, R-125, R-502, and an undisclosed zeotrope identified as "Blend HP" [probably a developmental version of R-402B]; compressor calorimeter tests; saturation pressure comparison; theoretical refrigeration capacity and efficiency as functions of evaporator temperature; refrigeration capacity as a function of refrigerant charge; compressor discharge temperature

S. G. Sundaresan (Copeland Corporation), **Alternate Refrigerants and Lubricants for Refrigeration Compressors - Status on CFC12 and R502 Replacements**, paper 151, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, II:881-887, August 1991 (7 pages with 11 figures and 11 tables, RDB-2308)

evaluation of R-12, R-125, R-134a, R-143a, R-152a, R-32/125 (60/40), R-22/125/134a (52/15/33) (a developmental version of DuPont MP39, R-401A), R-22/125/134a (60/15/25) (a developmental version of DuPont MP66, R-401B), R-125/290/22 (a developmental version of DuPont blend HP81, R-402B, identified as "MP81" in the paper), and R-290/22/218 (6/85/9) (a developmental version of Rhône-Poulenc 69-S, R-403A); examination of associated lubricant and materials compatibility; concludes that R-134a is not attractive at low operating temperatures, but that blends of R-22/152a/124 (R-401 series) are viable candidates to replace R-12 when used with alkylbenzene (AB) or mixtures of AB and mineral oil (MO); also concludes that pentaerythritol ester (a polyolester, POE) and end-capped polyalkylene glycol (PAG) are viable lubricants for R-134a; finally concludes that "MP81" can be used with pentaerythritol esters to replace R-502, but that R-32/125 (60/40) would be unattractive for this use due to high pressures and discharge temperatures

H. Takamatsu, S. Koyama (Kyushu University, Japan), Y. Ikegami (Saga University, Japan), and T. Yara (Kyushu University, Japan), **An Experiment on a Vapor Compression Heat Pump System Using a Nonazeotropic Refrigerant Mixture**, paper 105, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, II:592-596, August 1991 (5 pages with 14 figures and 1 table, rdb4677)

R-22/114, zeotropic blends, effects of temperature for smooth and grooved tubes

T. Tiedemann, M. Kauffeld, K. Beermann, and H. H. Kruse (Universität Hannover, Germany), **Evaluation of Ozone-Safe, Low Greenhouse Warming Potential Zeotropic Refrigerant Mixtures in Household Refrigerators-Freezers**, paper 271, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, III:1166-1170, 1991 (RDB5B30)

performance evaluation of R-22/123, R-22/124, R-22/142b, R-22/152a, R-22/152a/123, R-23/-152a, R-32/142b, R-32/152a, R-143a/142b, R-143a/152a, R-152a/123, R-290/123, R-290/152a in refrigerators with dual evaporators (Lorenz-Meutzner cycle); energy savings of 12% were found in a German refrigerator for R-22/142b, but no improvement was found over R-12 for an American design, the differences in which are detailed; tabulates simulation results for each of the refrigerants and experimental results for R-22/142b; concludes that the energy improvements reported for R-22/11 in the 1970s by Lorenz and Meutzner could not be reached; difference is attributed to on-off cycling versus steady-state operation, in the earlier studies, and to the way the coefficient of performance (COP) is calculated

R. Tillner-Roth, H. D. Baehr, and F. Klobasa (Universität Hannover, Germany), **Measurements and Correlations of the Thermodynamic Properties of Refrigerant 134a**, paper 73, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute

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of Refrigeration (IIR), Paris, France, II:630-634, 1991 (5 pages with 6 figures and 1 table, RDB4407)

R-134a, thermodynamic properties, thermophysical data, equation of state based on Helmholtz function

J. Zheng and J. W. Pelava (AlliedSignal Incorporated), **Performance Test of R-12 Alternates in a Hermetic Compressor**, paper 149, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, II:871-875, August 1991 (5 pages with 3 figures and 4 tables, rdb2254)

This paper presents measured results of calorimeter tests of replacements for R-12 at -23 to 1 °C (-10 to 30 °F) evaporating and 38 and 49 °C (100 and 120 °F) condensing. The fluids tested included R-134a with a polyalkylene glycol (PAG) lubricant and four zeotropes with alkylbenzene (AB) lubricants. The blends included R-22/124 (55/45 and 43/57) and R-22/152a/124 (50/20/30 and 36/24/40). The compressor discharge temperature, compression ratio, cooling capacity, and efficiency are compared to those of R-12.

July 1991

D. Jung and R. K. Radermacher (University of Maryland**), Performance Simulation of Single-Evaporator Domestic Refrigerators Charged with Pure and Mixed Refrigerants**, *International Journal of Refrigeration* (IJR), 14(6):223-232, July 1991 (10 pages with 8 figures and 5 tables, RDB4417)

R-32/125 Azeotrope, technical data sheet 525658, AlliedSignal Incorporated, Morristown, NJ, July 1991 (1 page with 1 figure, RDB3221)

This data sheet provides a pressure-enthalpy diagram for a patented azeotropic blend, R-32/125 (60/40) in inch-pound (IP) units. R-32/125 (60/40) was a developmental formulation for AlliedSignal's Genetron(R) AZ-20 (subsequently reformulated) when this document was published.

June 1991

J. C. Bare, C. L. Gage (U.S. Environmental Protection Agency, EPA), D. Jung, and R. K. Radermacher (University of Maryland), **Simulation of Nonazeotropic Mixtures for Use in a Dual-Circuit Refrigerator/Freezer with Countercurrent Heat Exchangers**, paper IN-91-14-3(3540), *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(2):447-454, 1991 (9 pages with 3 figures and 3 tables, RDB4419)

zeotropic blends

S. J. Eckels and M. B. Pate (Iowa State University of Science and Technology), **In-Tube Evaporation and Condensation of Refrigerant-Lubricant Mixtures of HFC-134a and CFC-12**, technical paper 3494 (630-RP), *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(2):62-70, 1991; republished in *Alternative Refrigerants*, technical data bulletin 7(3), ASHRAE, 1-9, 1991 (9 pages with 17 figures and 2 tables, RDB2612)

M. Fukuta, M. Tanaka, T. Shimizu, and T. Yanagisawa, **Analysis of Oil Film on Vane Sides of Vane Compressors**, *Nippon Kikai Gakkai Ronbunshu* (Transactions of the Japan Society of Mechanical Engineers, JSME), JSME, Tokyo, Japan, 57(538):2007-2012, June 1991 (6 pages, rdb4C20)

lubrication

K. E. Hummel, T. P. Nelson, and P. A. Thompson (Radian Corporation), **Survey of the Use and Emissions of Chlorofluorocarbons from Large Chillers**, *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE), Atlanta, GA, 97(2):416-421, 1991 (6 pages with 4 figures and 4 tables, RDB6320)

CFC, refrigerant emissions, leak rates, loss rates

D. Jung and R. K. Radermacher (University of Maryland), **Prediction of Heat Transfer Coefficients of Various Refrigerants During Evaporation**, paper 3492, *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(2):48-53, 1991 (6 pages with 7 figures and 3 tables, RDB2347)

N. Kagawa (National Defense Academy, Japan), M. Uematsu, and K. Watanabe (Keio University, Japan), **Thermodynamic Surface of State for Refrigerant 22 Plus Refrigerant 114 System and an Application to Cycle Analysis**, *Preprints of the 11th Symposium on Thermophysical Properties* (Boulder, CO, 23-27 June 1991), American Society of Mechanical Engineers (ASME), New York, NY, 1991; republished in *Fluid Phase Equilibria*, 80(4):19-31, 30 November 1992 (12 pages, RDB4571) presents a fundamental equation (FEQ), with empirical mixing rules for R-22/114; this equation of state (EOS) was formulated using available pressure-volume-temperature-composition (PVTx) properties; it is effective for a range of temperatures from -23 to 227 °C (-10 to 440 °F) for pressures up to 10 MPa (1450 psia), which corresponds to the density range up to the critical value; compares values calculated with the EOS to experimental data and a theoretical heat pump cycle analysis with experimental data

M. O. McLinden, W. M. Haynes (National Institute of Standards and Technology, NIST, USA), J. T. R. Watson (National Engineering Laboratory, UK), and K. Watanabe (Keio University, Japan), **A Survey of Current Worldwide Research on the Thermodynamic Properties of Alternative Refrigerants**, report NISTIR 3969, National Institute of Standards and Technology, Boulder, CO, June 1991 (84 pages, available from NTIS as document PB92112366INZ, RDB2262)

presents a survey of worldwide research activities addressing either measurements or correlations of thermophysical properties of alternative refrigerants: the targeted fluids include R-22, R-23, R-32, R-123, R-123a, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, and blends containing them; also identifies research of R-124a, R-E134 (bis(difluoromethyl)ether), R-225ca, R-227ea, fluoroethers, and hydrofluoroethers; blends covered include R-14/23, R-23/13, R-23/22, R-23/142b, R-32/134a, R-32/152a, R-125/124, R-125/134a, R-143a/22, R-22/12, R-22/114, R-22/123, R-22/134a, R-22/142b, R-22/-152a, R-22/152a/114, R-22/152a/124, R-22/-152a/142b, R-134a/123, R-134a/134, R-134a/-141b, R-134a/152a, R-152a/114, R-152a/134, R-152a/142b, and R-227ea/123; properties addressed are phase equilibria, dielectric constant, refractive index, and other thermodynamic and transport properties; tables provide summary information about each research activity, including the ranges of data, estimated accuracy, and references; tabulates the organizations and investigators involved as well as apparatus and techniques employed by country; neither actual property data nor correlating equations are presented; the objectives were to assist in coordination of research programs, to expedite acquisition of required property data, and to serve as a guide for planning future research; The collaborative effort to compile this information was undertaken under Annex 18, *Thermophysical Properties of the Environmentally Acceptable Refrigerants*, of the Advanced Heat Pump Programme of the International Energy Agency.

P. I. Rothfleisch and D. A. Didion, **A Performance Evaluation of a Variable Speed, Mixed Refrigerant Heat Pump**, report NISTIR 4597, National Institute of Standards and Technology (NIST), Gaithersburg, MD, June 1991 (64 pages with 10 figures and 7 tables, available from NTIS at price code A04, RDB3337)

This report evaluates the performance of an innovative heat pump, equipped with a distillation column to shift the composition of a zeotropic refrigerant mixture. This product was commercialized in Japan on a limited basis, but has since been withdrawn. The report contrasts loads to equipment capacity and shows the composition shifting strategy schematically. It outlines equilibrium (or flash) and continuous rectification approaches for distillation. It reviews prior work in the area and describes the test model, which uses a blend of 20% R-13B1 and 80% R-22 by weight. Measured performance at standard rating conditions and seasonal energy calculations are summarized for both the heating and cooling modes. No composition shifting was observed in the tests. Simulations using an ideal-cycle model are described to demonstrate the potential value of composition control. While heating seasonal performance gains were found to be small, avoidance of auxiliary heat requirements were substantial. Cooling performance is indicated to be approximately 2% lower with R-13B1/22 (20/80) blend than with R-22 alone.

S. M. Sami (University of Moncton, Canada) and T. N. Duong (University of Sherbrooke, Canada), **Dynamic Performance of Heat Pumps Using Refrigerant R-134a**, *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(2):41-47, 1991; republished in *Alternative Refrigerants*, technical data bulletin 7(3), ASHRAE, 21-27, October 1991 (7 pages with 16 figures, RDB2614)

presents a new computer program to predict the dynamic performance of water-to-water and water-to-air heat pumps using R-134a; compares the behavior to that with R-12

E. A. Vineyard (Oak Ridge National Laboratory, ORNL), **The Alternative Refrigerant Dilemma for Refrigerator-Freezers: Truth or Consequences**, *Transactions*, American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE), Atlanta, GA, 97(2), 1991 (rdb6311)

alternative refrigerants, performance

K. Watanabe and H. Sato (Keio University, Japan), **Progress of the Thermophysical Properties Research on Environmentally Acceptable Refrigerants in Japan**, *Preprints of the 11th Symposium on Thermophysical Properties* (Boulder, CO, 23-27

please see page 6 for ordering information

June 1991), American Society of Mechanical Engineers (ASME), New York, NY, 1991; republished in *Fluid Phase Equilibria*, 80(4):1-17, 30 November 1992 (17 pages, rdb4570)

summarizes the research status of thermophysical properties for refrigerants in Japan: describes both experimental measurements and modeling efforts; discusses promising alternative refrigerants including R-123, R-134, R-134a, R-141b, R-142b R-152a, and blends including R-22/142b and R-22/152a/142b

Alternative Refrigerant Research for Residential Refrigerator-Freezers, research project 614-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1989 - June 1991 (ASH0614)

The contractor for this project was Oak Ridge National Laboratory, led by E. Vineyard; it was sponsored by ASHRAE Technical Committees 3.1, *Refrigerants and Brines*, and 7.1, *Residential Refrigerators and Food Freezers*. [see RDB2412 for findings]

Thermophysical Property Data for Water-Lithium Bromide at High Temperatures and Concentrations, research project 527-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, July 1987 - June 1991 (ASH0527)

The contractor was the Georgia Tech Research Institute, led by A. S. Teja; the project was sponsored by ASHRAE Technical Committee 8.3, *Absorption and Heat-Operated Machines*.

May 1991

D. P. Grob (Underwriters Laboratories, Incorporated), **Summary of Flammability Characteristics of R-152a, R-141b, R-142b, and Analysis of Effects of Potential Applications**, *Proceedings of the 42nd Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, May 1991), IATC, Batavia, IL, May 1991 (RDB4925)

G. Mouton, **Fluorocarbon Refrigerants and the Environment**, *International Journal of Refrigeration* (IJR), 14(4):209-216, May 1991 (8 pages, rdb5961)

ozone depletion, global warming

S. H. Rice, Y. Iikubo, M. L. Robin (Great Lakes Chemical Corporation), V. W. Goldschmidt, and D. R. Tree (Purdue University), **Refrigerant Alternative to R-12: Preliminary Testing in a Domestic Refrigerator**, *Proceedings of the 42nd Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, May 1991), IATC, Batavia, IL, 367-378, 1991; republished in *Proceedings of the International Appliance Technical Conference - China*, 141-149, November 1991 (12 pages, rdb4A36)

R-227ea blends

A. Tanka, **Effects of Alternative Refrigerants on Friction and Wear of Nylon and Polyacetar**, paper E-20, *Proceedings of the JAST Tribology Conference*, Tokyo, Japan, May 1991 (rdb4C39)

P. E. J. Vermeulen, **The Use of Ammonia as Refrigerant in the Dutch Food Industry**, report number 92-180, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, May 1991 (in Dutch, rdb5685)

R-717, safety

T. Yanagisawa, T. Shimizu, and M. Fukuta (Shizuoka University, Japan) **Foaming Characteristics of an Oil-Refrigerant Mixture**, *International Journal of Refrigeration* (IJR), 14(3):132-136, May 1991 (5 pages, rdb4C29)

refrigerant-lubricant properties

Handbook for the Montreal Protocol on Substances That Deplete the Ozone Layer, document UNEP/OzI.Pro.3/7, United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, May 1991 (130 pages, RDB2349)

This version has been superseded (see RDB2702 for update).

April 1991

R-32/125 Azeotrope, technical data sheet 525643, AlliedSignal Incorporated, Morristown, NJ, April 1991 (2 pages with 1 figure and 2 tables, RDB3220)

This data sheet provides information on a patented azeotropic blend, R-32/125 (60/40). It provides physical property data, in inch-pound (IP) units, including the chemical formula, molecular weight, atmospheric boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), flammability, and ozone depletion potential. It also indicates the liquid density and specific heats of the liquid and vapor at 26.7 °C (80 °F). It then presents a tabular comparison of performance with R-22, R-32, R-125, and R-502. The document provides a vapor pressure chart for the blend for -40 to 49 (-40 to 120 °F). R-32/125 (60/40) was a developmental formulation for AlliedSignal's Genetron(R) AZ-20 (subsequently reformulated) when this document was published.

March 1991

J. Gallagher, M. O. McLinden, and G. Morrison, **REFPROP, A Program for the Calculation of the Thermodynamic Properties of Refrigerants and Refrigerant Mixtures**, NIST Standard Reference Database 23 version 2.0, National Institute of Standards and Technology, Gaithersburg, MD, March 1991 (software and documentation available from NIST, RDB1105)

Version 2.00 of REFPROP calculates properties for 18 pure refrigerants and 24 binary mixtures of them in user-selected units of measurement. These refrigerants include R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-113, R-114, R-115, R-123, R-124, R-125, R-134, and R-134a, R-142b, R-152a, and R-C270.

D. P. Grob (Underwriters Laboratories, Incorporated), **Flammability Characteristics of R-32 and R-32 Mixtures**, proceedings (Symposium to Evaluate R-32 and R-32 Mixtures in Refrigeration Applications, Washington, DC, 19-20 March 1991), U.S. Environmental Protection Agency (EPA), Washington, DC, 1991 (RDB4A04)

flammability, LFL, UFL

H. Honda, B. Uchima, S. Nozu, E. Torigoe, and S. Imai (Okayama University, Japan), **Film Condensation of Downward Flowing R-113 Vapour on Staggered Bundles of Horizontal Finned Tubes**, *Proceedings of the Third ASME/JSME Thermal Engineering Joint Conference* (Reno, NV, 17-22 March 1991), American Society of Mechanical Engineers (ASME), New York, NY, and Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, 2:487-494, 1991 (8 pages, rdb5732)

R-113, heat transfer, enhanced tubes

Y. Maezawa, H. Sato, K. Watanabe, and S. Oshima (Keio University, Japan), **Saturated Liquid Densities and Bubble-Point Pressures of Binary HFC-152a + HFC-134 System**, *Proceedings of the Third ASME/JSME Thermal Engineering Joint Conference* (Reno, NV, 17-22 March 1991), American Society of Mechanical Engineers (ASME), New York, NY, Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, 3:443-450, 1991 (8 pages, rdb5469)

thermodynamic properties of R-152a/134: thermophysical data

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **An Equation of State for HFC-134a**, *Proceedings of the Third ASME/JSME Thermal Engineering Joint Conference* (Reno, NV, 17-22 March 1991), book 10309C, American Society of Mechanical Engineers (ASME), New York, NY, Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, 3:435-442, 1991 (8 pages with 13 figures and 5 tables, RDB4148)

presents a 25 coefficient, virial equation of state (EOS) for R-134a: EOS is described as effective in the entire fluid phase of pressures up to 15 MPa (2200 psia), temperatures from -33 to 207 °C (-28 to 404 °F), and densities from 0 to 1400 kg/m^3 (0 to 88 lb/ft^3); thermodynamic properties; thermophysical data

K. Yamashita and A. Yabe (Toshiba Corporation, Japan), **Heat Transfer Characteristics of an EHD Condenser**, *Proceedings of the Third ASME/JSME Thermal Engineering Joint Conference* (Reno, NV, 17-22 March 1991), American Society of Mechanical Engineers (ASME), New York, NY, Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, 3:61-67, 1991 (7 pages, rdb8B10)

use of the electrohydrodynamic (EHD) technique to enhance heat transfer: analysis of a condenser after 1000 hr of continuous operation with found no negative effects on the working fluid, the electrode, or heat transfer surface

Technical Bulletin / Sulfur Hexafluoride: Accu-Dri(R) SF_6, bulletin 524-999, AlliedSignal Incorporated, Morristown, NJ, March 1991 (24 pages with 6 figures and 5 tables, RDB5A35)

R-7146, physical and thermodynamic and properties, liquid density equation, vapor pressure equation, equation of state (EOS), applications

February 1991

T. Atwood (AlliedSignal Incorporated), **Refrigerants of the Future - Facts and Fallacies**, *ASHRAE Journal*, 33(2):30-35, February 1991 (6 pages with 3 figures and 1 table, RDB4442)

alternative refrigerants

J. M. Calm (Air-Conditioning and Refrigeration Institute, ARI), **Global Warming (the Next Challenge)**, presentation charts, Seminar on Refrigerant Practices, National Institute of Standards and Technology (NIST), Gaithersburg, MD, 12 February 1991 (9 pages with 14 charts, available from JMC as RDB1207)

presentation charts: survey of scientific views of the likelihood of global warming; definition and importance of greenhouse effect; ozone depletion potential (ODP), global warming potential (GWP), atmospheric lifetime, heat trapping strength, and estimated emissions for common refrigerants; direct and indirect warming effects; efficiency relative to cost; alternative refrigerants

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S. Corr, R. D. Gregson, A. Halse, A. Lindley (ICI Chemicals and Polymers, Limited), and T. W. Dekleva (ICI Americas, Incorporated), **Retrofitting Mobile Air-Conditioning Systems: The First Alternative, Part I**, seminar presentation at the Society of Automotive Engineers (SAE) International Congress and Exposition (Detroit, MI), ICI Americas Incorporated, New Castle, DE, USA, 26 February 1991 (14 pages with 17 charts, rdb2616)

S. Corr, R. D. Gregson, A. Halse, A. Lindley (ICI Chemicals and Polymers, Limited), and T. W. Dekleva (ICI Americas, Incorporated), **Retrofitting Mobile Air-Conditioning Systems: The First Alternative, Part 2**, seminar presentation at the Society of Automotive Engineers (SAE) International Congress and Exposition (Detroit, MI), ICI Americas Incorporated, New Castle, DE, USA, 26 February 1991 (14 pages with 16 charts, RDB2617)

N. Kagawa (National Defense Academy, Japan), H. Ikeda, H. Kawano, M. Uematsu, and K. Watanabe (Keio University, Japan), **Thermodynamic State Surface and Cycle Analysis for Refrigerant 22 Plus Refrigerant 114 System**, *Nippon Kikai Gakkai Ronbunshu* (Transactions of the Japan Society of Mechanical Engineers, JSME), JSME, Tokyo, Japan, B57(534):597-603, February 1991 (7 pages in Japanese, rdb3868)

> presents an equation of state (EOS) coupled with empirical mixing rules for R-22/114 developed to enable cycle analyses with this zeotropic blend: the EOS was formulated with available measurements of pressure, volume, temperature, and composition data; it is expressed as a Helmholtz equation as a function of temperature, density and composition, and is effective for a range of temperatures from -23 to 227 °C (-10 to 440 °F) for pressures up to 10 MPa (1450 psia), which corresponds to the density range up to the critical value; the cycle analysis of the heat pump and refrigeration systems indicate that R-22/114 is promising for industrial heat pumps or air-conditioning and heat pump water heaters (HPWH); predicted changes in composition were confirmed by testing [see RDB8967 for English translation of this paper]

H. O. Spauschus (Spauschus Associates, Incorporated), **Emerging HVACR Issues - Energy, Environment, and Economics**, *ASHRAE Journal*, 32(2):23-27, February 1991 (rdb4357)

Survey of the Use and Emission of Chlorofluorocarbons from Large Chillers, research project 603-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, March 1989 - February 1991 (ASH0603)

> The contractor for the project was the Radian Corporation, led by T. J. Nelson; it was sponsored by the ASHRAE Task Group on *Halocarbon Emissions*

January 1991

M. C. Adams, J. N. Moore (University of Utah Research Institute), and P. N. Hirtz (Thermochem, Incorporated), **Preliminary Assessment of Halogenated Alkanes as Vapor-Phase Tracers**, *Proceedings of the Sixteenth Workshop on Geothermal Reservoir Engineering* (Stanford University, 23-25 January 1991), report SGP-TR-34, Stanford University, Palo Alto, CA, 57-62, 1991 (6 pages with 2 figures, Rdb8B33)

> examination of R-12, R-13, R-14, R-22, R-23, R-31, R-116, R-218, R-C318, R-702, R-704, and R-7146 as potential tracer for hydrogeological studies; discussion of stability, toxicity, solubility in water, and environmental impacts

S. Corr, P. D. Guy, F. T. Murphy, G. Tompsett (ICI Chemicals and Polymers, Limited), and T. W. Dekleva (ICI Americas, Incorporated), **Performance Characteristics of R-134a and Alternative Lubricants**, seminar presentation at the ASHRAE Winter Meeting (New York, NY), ICI Americas Incorporated, New Castle, DE, USA, 22 January 1991 (26 pages with 19 charts, RDB2522)

D. L. Fenton, A. F. Noeth, and R. L. Gorton (Kansas State University, KSU), **Absorption of Ammonia into Water**, *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(1):204-211, 1991 (rdb3462)

> R-717, venting, emergency releases

J. E. Galloway and V. W. Goldschmidt (Purdue University), **Air-to-Air Heat Pump Performance with Three Different Nonazeotropic Refrigerant Mixtures**, paper 3473, *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(1):296-303, January 1991 (rdb4678)

> performance tests with three binary zeotropic blends in an air-to-air heat pump operating at outdoor temperatures of 1.8-35.2 °C (35-95 °F): the tested refrigerants were R-13/12, R-22/114, and R-22/152a; R-22/152a (85/15) increased the coefficient of performance (COP) by at least 8% with less than 4% loss in capacity compared to R-22; a reduction in efficiency for the other blends was attributed to the crossflow design of conventional air-to-refrigerant heat exchangers

E. Heinzelmann and M. S. Ussyk (Empresa Brasileira de Compressores S/A, Embraco), **Hermetic Refrigerating Compressors and CFC Substitution**, *International Journal of Refrigeration* (IJR), 14(1):10-15, January 1991 (6 pages with 11 figures, RDB1201)

This paper presents a basic methodology for screening substitutes for R-12 in refrigerating compressors. Simple analysis of refrigerant thermodynamic properties are presented within the ranges of evaporating and condensing temperatures in which small refrigerating systems operate. Comparisons of vapor pressure, coefficients of performance (COPs), compression ratio, final isentropic compression temperature, and volumetric refrigerant effect are presented for R-12, R-22, R-134a, and R-152a. Additionally, a procedure for developing compressors for use with alternative refrigerants is presented. Material compatibility, performance, reliability, and means of production are considered. The differences between developed and developing countries are noted, using Brazil as an example.

D. Jung and R. K. Radermacher (University of Maryland), **Transport Properties and Surface Tension of Pure and Mixed Refrigerants**, paper 3445, *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(1):90-99, 1991 (rdb3B48)

thermophysical data

J. Paul (Integral Technologie GmbH, Germany), **Wasser als Arbeitsmittel für Kühlanlagen, Wärmepumpen und Abwärmekraftwerke** [Water as a Working Fluid for Refrigeration, Heat Pumps, and Power Generation from Waste-Heat], *Luft- ünd Kältetechnik,* Germany, 27:15-25, January 1991 (16 pages in German, rdb4A69)

R-718

L. M. Schlager, M. B. Pate, and A. E. Bergles, **Oil Quantity Measurements in Smooth and Micro-Fin Tubes During Evaporation and Condensation of Refrigerant-Oil Mixtures (469-RP)**, *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(1), 1991 (rdb2241)

M. L. Timm, **An Improved Method for Calculating Refrigerant Line Pressure Drops**, *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(1):194-203, January 1991 (10 pages, rdb-4634)

R. L. Webb and C. Pais (Pennsylvania State University), **Nucleate Pool Boiling Data for Five Refrigerants on Three Tube Geometries**, technical paper 3443 (392-RP), *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97(1):72-78, 1991 (7 pages, rdb2404)

measurements of heat transfer in nucleate boiling on a 1024 fpm (26-fpi) integral finned tube and two enhanced tube geometries for R-11, R-12, R-22, R-113, R-123, and R-134a at 27 °C (80 °F): presents the data and shows comparative pool boiling performance of the various refrigerants and tube geometries: data were taken on 165 mm (6½") long tubes having an outside diameter of 19.05 mm (3/4"); the pool boiling coefficients for R-123 and R-134a for the finned tube were approximately equal to those for R-11 and R-12, respectively; the boiling coefficients of R-123 and R-134a were approximately 40% and 10% below those of R-11 and R-12, respectively, for one of the enhanced tubes, but approximately 20% and 10% below the corresponding coefficients for R-11 and R-12 with the second enhance tube; the paper indicates that additional tests are underway to measure the same data at 4 °C (40 °F)

Chemical Analysis and Recycling of Used Refrigerant from Field Systems, research project 601-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, March 1989 - January 1991 (ASH0601)

This study identified and quantified typical contaminant levels in refrigerants from both normally operating and failed air-conditioning and refrigerating systems. These samples included R-11 from centrifugal chillers, R-12 from commercial refrigeration systems, R-22 from unitary heat pumps and air conditioners, and R-502 from low-temperature frozen food cases. The principal investigator was R. E. Kaufman at the University of Dayton Research Institute. The project was sponsored by ASHRAE Technical Committee 3.3, *Contaminant Control in Refrigerating Systems.* [see RDB2429 for findings]

Hoechst Refrigerant R 123, product bulletin AFK2321E/035, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, January 1991 (12 pages with 1 figure and 4 tables, RDB4775)

This bulletin provides data for R-123, identified as a substitute for R-11 in refrigeration engineering, and specifically for turbo (centrifugal) compressor chillers, in metric (SI) units of measure. The introduction reviews the phaseout of chlorine-containing refrigerants and criteria for substitutes. A table summarizes physical and thermodynamic property data for R-123, including the chemical formula and name, molecular mass, normal boiling point, and critical parameters (temperature, pressure, and density). It also gives the liquid and vapor densities at 20 and 40 °C (68 and 104 °F). A second table compares the compression ratio, suction flow rate, compressor discharge temperature, volumetric cooling capacity, and coefficient of performance (COP) of R-11 and R-123. The bulletin then discusses compatibility with metals, recommending avoidance only of zinc, magnesium, lead, and aluminum alloys with more than 2% magnesium. It reports storage tests that showed good stability to hydrolysis and no corrosive attack on ferritic steel, V2A steel, copper, brass, and aluminum. The bulletin provides elastomer swell, extraction, and elongation data for R-123 with butyl (IIR), nitrile (NBR, Perbunan(R)), chloroprene (CR, Neoprene(R)), fluorinated (FPM, DuPont Viton(R) A), and natural (NR) rubbers. The bulletin reports that neither R-123 nor R-11 passed the Philipp test for thermal stability with mineral oil, but that the stability of R-123 appears to be comparable to that of R-11. Moreover, R-123 is indicated as miscible with both mineral oil and alkylbenzene lubricants. A table provides thermodynamic property data including pressure; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover R-123 at saturated (wet vapor) conditions from -50 to the critical point of 183.79 °C (-58 to 362.82 °F). The bulletin concludes with a pressure-enthalpy (Mollier) diagram based on a U.K. Rombusch equation of state. Hoechst Chemical's product name for R-123 is Hoechst Refrigerant R 123.

Hoechst Refrigerant R 227, product bulletin AFK2323e/035, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, January 1991 (12 pages with 6 figures and 3 tables, RDB3A66)

This bulletin provides thermodynamic property and application data for R-227ea (1,1,1,2,3,3,3-heptafluoropropane) in metric (SI) units of measure. This hydrofluorocarbon (HFC) may be suitable as an alternative for R-12 and R-114 for some applications. The bulletin provides physical properties including the chemical formula and name, molecular mass, normal boiling point, critical parameters (temperature, pressure, and density), and liquid and vapor densities at 20 and 40 °C (68 and 104 °F). Four figures summarize comparative performance for R-12, R-114, and R-227ea for the range of -20 to 10 °C (-4 to 50 °F). The charts show compression ratios, volumetric cooling capacities, compressor discharge temperatures, and coefficients of performance (COPs). The compression ratio and cooling capacity of R-227ea lies between those of the other two refrigerants. The discharge temperature is nearly the same as for R-114, both below that of R-12. The COP, however, is 9-14% lower than the other two fluids. The bulletin then discusses materials compatibility with metals and elastomers, noting concerns with lead, magnesium, zinc, aluminum alloys containing more than 2% magnesium, and elastomeric hoses, the latter due to permeation differences. Tabular data are provided for weight change, extraction, and swell for R-227ea with butyl, acrylonitrilebutadiene, chloroprene, fluorinated, and natural rubbers (IIR, NBR, CR, FPM, and NR, respectively). R-227ea is noted as virtually immiscible with mineral oil and alkylbenzene lubricants, but adequately miscible with some polyglycols. Results of thermal stability tests with mineral oil are briefly outlined, indicating that R-227ea appears to be more stable than R-12 and at least comparable to R-114. Preliminary thermodynamic tables - giving pressure, specific volume, density, enthalpy, heat of vaporization, and entropy as functions of temperature - are provided for -40 to 99 °C (-40 to 210 °F). The bulletin concludes with a pressure-enthalpy (Mollier) diagram based on the U.K. Rombusch equation of state. Hoechst Chemical's product name for R-227ea is R 227.

JICOP Guide, Japan Industrial Conference for Ozone Layer Protection, Tokyo, Japan, January 1991 (8 pages, available from JMC as RDB1204)

JICOP was formed in 1988 as the *Promotion Conference for Rational Use of Specified CFCs* and renamed in June 1990. It is an organization of industrial producers and consumers addressing ozone-layer protection in Japan. Its main activities include publicity, information sharing, surveys of actions by other countries, preparation of guides, and training. This leaflet introduces the organization and lists the 55 current members. Included are the Japan Association of Refrigeration, Japan Association of Refrigeration and Air-Conditioning Contractors, Japan Flon Gas Association, and Japan Refrigeration and Air-Conditioning Industry Association.

1991 (month not indicated)

D. M. Amron and R. L. Moy, **Stratospheric Ozone Depletion and its Relationship to Skin Cancer**, *Journal of Dermatologic Surgery and Oncology*, 17:370-372, 1991 (3 pages, rdb3138)

bioenvironmental effects of ozone depletion including that from release of chlorinated and brominated refrigerants; environmental impacts

K. Arita, T. Tomizawa, Y. Nakagawa, and Y. Yoshida, **Vapor-Liquid Equilibrium of the Nonazeotropic Refrigerant Mixture Formed by Chlorofluoromethane and 1,1,1,2-Tetrafluoroethane**, *Fluid Phase Equilibria*, 63:151-156, 1991 (6 pages, rdb4A40)

thermodynamic properties of R-31, R-134a, and R-134a/31 blends; zeotropic blend

H. D. Baehr and R. Tillner-Roth (Universität Hannover, Germany), **Measurement and Correlations of the Vapor Pressures of 1,1,1,2-Tetrafluoroethane (R134a) and 1,1-Difluoroethane (R152a)**, *Journal of Chemical Thermodynamics*, 23:1063-1068, 1991 (6 pages, rdb4410)

thermodynamic properties of R-134a and R-152a; thermophysical data

K. Bärnthaler, **Chlorethan (R160) - ein neues Medium für Hochtemperaturkompressionswärmepumpen** [Chloroethane (R-160) - A New Working Medium for High Temperature Vapor-Compression Heat Pumps], dissertation, Technische Universität Graz, Graz, Austria, 1991 (rdb4331)

K. Bier et al. (Universität Karlsruhe, Germany), **Stoffpaares R134a/R152a als ozonunschädliche Alternative zum Kältemittel R12** [Working Pair R-134a/152a as an Ozone-Safe Alternative to Refrigerant R-12], *Verbundvorhaben Minderung von FCKW-Emissionen in der Kälte- und Klimatechnik* [Program for Reduction of CFC Emissions in Refrigeration and Air Conditioning], DKV-Statusbericht [Status Report], Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 8:13-21, 1991 (in German, rdb6548)

R-134a, R-152a, R-134a/152a

K. Bier, L. R. Oellrich, M. Türk, J. Zhai, M. Dressner, M. Christill, G. Geidel, and W. Leuckel (Universität Karlsruhe, Germany), **Untersuchungen des Stoffpaares R134a/R152a als ozonunschädliche Alternative zum Kältemittel R12** [Investigation of the Working Pair R-134a/152a as an Ozone-Safe Alternative to Refrigerant R-12], *Verbundvorhaben Minderung von FCKW-Emissionen in der Kälte- und Klimatechnik* [Program for Reduction of CFC Emissions in Refrigeration and Air Conditioning], DKV-Statusbericht [Status Report], Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 7:39-51, 1991 (in German, rdb4529)

R-134a, R-152a, R-134a/152a, thermal stability, flammability, performance

J. Bond, **Sources of Ignition. Flammability Characteristics of Chemical Products**, Butterworth-Heinemann, Limited, UK, 1991 (RDB4B91)

LFL, UFL, combustibility

M. A. Comeau, **Numerical and Experimental Analysis of the Dynamic Behavior of a Heat Pump Working with Nonazeotropic Refrigerant Mixtures**, MScA thesis (Mechanical Engineering Department), University of Moncton, Moncton, Canada, 1991 (rdb6717)

lumped parameter model to predict the dynamic behavior of heat pumps using zeotropic blends as refrigerants; R-22/114 (80/20) and (60/40); R-22/152a (80/20)

D. J. Davis and G. T. Christianson, **Firefighter's Hazardous Materials Reference Book**, Van Nostrand Reinhold Publishers, New York, NY, 1991 (rdb5164)

flammability, toxicity, and other safety data

R. Dickinson (University of Arizona), R. Monastersky (Science News), J. A. Eddy (University Corporation for Atmospheric Research, UCAR, Office for Interdisciplinary Earth Studies, OIES), K. Bryan (National Oceanic and Atmospheric Administration, NOAA), and S. Mathews (National Geographic Society), **Reports to the Nation on our Changing Planet: The Climate System**, report 1, UCAR-OIES, Boulder, CO, winter 1991 (24 pages with 12 figures, RDB3746)

explains the nature of climate and factors believed to be changing it in simple terms: addresses observed phenomena, the role of incoming sunlight, cloud and surface reflection, the greenhouse effect, and the global radiation balance; explains the mechanisms of planetary heat distribution ("the global heat engine") and oceanic effects; describes efforts to model climate and the inherent complexities in doing so; discusses prior ice ages, warm periods, the perceived warming trend, and uncertainties

J. T. Dieckmann, J. Bentley, and A. Varone (Arthur D. Little, Incorporated, ADL), **Non-Inert Refrigerant Study for Automotive Applications - Final Report**, report DOE/CE/50274-TI DE92 041034, U.S. Department of Energy (DOE), Washington, DC, 1991 (RDB4A03)

R-12 alternatives

Dutch Institute for the Working Environment and Dutch Chemical Industry Association, **Chemical Safety Sheets**, Kluwer Academic Publishers, Dordrecht, The Netherlands, and Norwell, MA, USA, 1991 (rdb5163)

flammability, toxicity, and other safety data

A. Factor and P. M. Miranda (General Electric Company), **An Investigation of the Mechanism of**

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the R12-Oil-Steel Reaction, *Wear*, 150:41-58, 1991 (18 pages with 3 figures and 12 tables, RDB2309)

A study of chemical interactions between R-12, hydrocarbon lubricating oils, and steel is summarized. While R-12 is quite stable thermally, it decomposes rapidly when heated above 150 °C (300 °C) in the presence of oils and metals, such as iron or aluminum. Sealed-tube tests were performed for 3 days at 200 °C (392 °F), using a naphthenic mineral oil (Witco Suniso® 3GS), to simulate conditions in an operating hermetic refrigeration compressor. The mechanism of the degradation reaction was explored by testing the effect of the presence of various probe and model compounds. The paper reviews prior studies, presents the experimental approach, and summarizes the subsequent analyses. It identifies the additives, free radical initiators, and inhibitors used to explore reactions and to passivate steel surfaces. The results of gas chromatography and GPC analyses are tabulated. The results indicate that except for formation of some $FeCl_3$ and R-22, free radical reactions do not appear to play a major role. The preponderance of the data indicates that Friedel-Crafts reactions, especially alkylation, play a key role in the decomposition.

Z. P. Hong, **An Overview Concerning Replacement and Treatment of Chlorofluorocarbons (CFCs)**, *Chinese Journal of Environmental Science*, 12(3):62-66, 1991 (5 pages, rdb5954)

reviews industrial application of chlorofluorocarbons (CFCs) and development of alternatives; discusses emission control, reclaim, recycling, decomposition, and destruction; reviews recent advances in scientific research and proposals for solving the problems in China

K. Hossner (Bitzer GmbH, Germany), **R-134a as a Substitute for R-12 - Behavior in a Screw Compressor**, *Ki Klima-Kälte-Heizung*, 19(1/2):28-32, 1991 (5 pages in German, rdb3C26)

This paper addresses use of R-134a in screw compressors. It also discusses the compatibility of gaskets and insulating materials for R-134a with a suitable lubricant. The results of performance measurements are plotted and compared to those with R-12. Long-term testing is discussed.

International Programme on Chemical Safety (IPCS), **Partially Halogenated Chlorofluorocarbons (Methane Derivatives)**, Environmental Health Criteria (EHC) report 126, World Health Organization (WHO), Geneva, Switzerland, 1991 (rdb5373)

R-21 and R-22: identification; summary properties; analytical methods; sources of human and environmental exposure; environmental transport, distribution, and transformation; environmental levels and human exposure; kinetics and metabolism; effects on laboratory mammals; in vitro tests; effects on humans; effects on other organisms in the laboratory and field; evaluation of human health risks and effects on the environment; recommendations for protection of human health and the environment

N. Z. Jiang, Z. L. Wu, W. B. Weng, et al. (Shanghai Institute of Mechanical Engineering, China), **Experiment**[al] **Research on Rotary Refrigerator Compressor Using HFC-134a**, *Proceedings of the Symposium on CFC Alternative Technology in China* (Guangzhou, China), 84-91, 1991 (8 pages, rdb6333)

R-134a

I. L. Karol, **Evaluation of the Potential Greenhouse Effect of Halocarbon Gases**, *Meteorol. Gidrol*., 7:57-63, 1991 (7 pages in Russian, rdb5955)

global warming, GWP

M. Kauffeld, H. König, and H. H. Kruse (Universität Hannover, Germany), **Luft als Kältemittel** [Air as a Refrigerant], *Kältetechnik-Klimatisierung*, Germany, 44(11):846-857, 1991 (12 pages in German, rdb-4346)

R-729 (air)

M. S. Kim, T. S. Kim, and S. T. Ro (Seoul National University, Korea), **Estimation of Thermodynamic Properties of Refrigerant Mixtures Using a Modified Carnahan-Starling Equation of State**, *Transactions*, Korean Society of Mechanical Engineers (KSME), Seoul, Korea, 15:2189-2205, 1991 (17 pages in Korean, rdb6767)

CS EOS, thermodynamic properties, thermophysical data

K. Kumagai, N. Yada, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of PVT Properties for the Binary Refrigerant HCFC-142b + HCFC-22**, *Journal of Chemical and Engineering Data*, 36:236-240, 1991 (5 pages, rdb5475)

R-22/142b, thermodynamic properties, thermophysical data

K. Kutsuna, Y. Inoue, and T. Mizutani, **Real Time Oil Concentration Measurements in Automotive Air Conditioning by Ultraviolet Light Absorption**, paper 910222, Society of Automotive Engineers (SAE), Warrendale, PA, 1991 (rdb4C25)

X-Z. Leng (Beijing Research Institute of Household Electric Appliances, China), **Testing Study about HFC-152a and the Mixture of HFC-152a with HCFC-22**, publication unknown, circa 1991 (8 pages with 8 figures and 1 table, available from JMC as RDB2513)

This paper analyzes use of R-152a and blends of R-152a with R-22, as substitutes for R-12 for domestic refrigerator/freezers. The freezer and food-section temperatures, suction and discharge pressures, run time, power, and energy use are compared for R-12, R-152a and three compositions of R-22/152a, namely 14, 22, and 33% by mass. These data were measured using an instrumented refrigerator/freezer (Hang-Tian model BCD-177A), reported as having the highest efficiency in the Chinese market. A blend containing approximately 14% R-22 by mass offered the lowest energy use, 8.2% less than with R-12; R-152a alone resulted in a savings of 1.0%. The study found that the freezer evaporator needs to be enlarged to use R-152a. Additional tests were performed changing the lubricant from mineral oil to an alkylbenzene, resulting in slightly higher energy use; compatibility was not addressed. The impacts of leakage were assessed based on compliance with the Chinese requirement (standard GB 8059.1-3.86) that refrigerant losses not exceed 0.5 g/yr (0.02 oz/yr). Assuming that all refrigerant lost is R-22, an R-22/152a (30/70 by mass) blend would fractionate to 25.3% R-22, improving performance slightly. The paper concludes that R-22/152a results in lower energy use than for R-12 without change in construction or performance.

J. M. H. Levelt Sengers (National Institute of Standards and Technology, NIST), **Solubility Near the Solvent's Critical Point**, *Journal of Supercritical Fluids*, 4(4):215 ff, 1991 (rdb3126)

transport properties, thermophysical data

R. Y. Li, G. X. Luo, and Y. P. Wang (Shanghai Institute of Mechanical Engineering, China), **Research and Adoption of Compatible Lubricants with New Refrigerant HFC-134a**, *Proceedings of the Symposium on CFC Alternative Technology in China* (Guangzhou, China), 162-170, 1991 (9 pages, rdb6334)

lubricants for R-134a

Z. Liu and R. H. S. Winterton, **A General Correlation for Saturated and Subcooled Flow Boiling in Tubes and Annuli**, *International Journal of Heat and Mass Transfer*, 34(11):2759-2766, 1991 (8 pages, rdb9411)

heat transfer [the correlation presented in this paper is identified by other authors as the Liu-Winterton correlation]

Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Saturated Liquid Densities and Bubble-Point Pressures of the Binary HCFC-22 + HFC-152a System**, *Fluid Phase Equilibria*, 61:-263-273, 1991 (11 pages, rdb4C05)

thermodynamic properties of R-22, R-152a, and R-22/152a: thermophysical data

Y. Maezawa, J. V. Widiatmo, H. Sato, and K. Watanabe (Keio University, Japan), **Saturated Liquid Densities and Bubble-Point Pressures of the Ternary HCFC-22/HFC-152a/HCFC-142b System**, *Fluid Phase Equilibria*, 67:203-212, 15 November 1991 (10 pages, rdb5470)

presents 71 data points for the saturated liquid density and bubble point pressure of R-22/-152a/142b (20/20/60), (20/40/40), (20/60/20), (40/20/40), (40/40/20), and (60/20/20); the data were measured with a magnetic densimeter coupled with a variable-volume cell for 7-117 °C (44-242 °F); estimates the experimental uncertainties in temperature, pressure, density and composition as not greater than ±0.15 °C (±0.027 °F), ±20 kPa (±2.9 psia), and ±0.2%; notes that the bubble point pressures were reproduced satisfactorily by the Peng-Robinson (PR) equation of state (EOS) with the optimized binary interaction parameters; the saturated liquid densities were reproduced reasonably well by the Hankinson-Brobst-Thomson (HBT) EOS with optimized temperature-independent binary interaction parameters

Y. Maezawa, J. V. Widiatmo, H. Sato, and K. Watanabe (Keio University, Japan), **Saturated Liquid Densities and Bubble-Point Pressures of the Binary HFC-152a + HCFC-142b System**, *International Journal of Thermophysics*, 12:1029-1038, 1991 (10 pages, rdb5471)

thermodynamic properties of R-142b, R-152a, and R-152a/142b blends: thermophysical data

G. Morrison (National Institute of Standards and Technology, NIST), **Alternative Refrigerant Properties Measurement and Correlation Program at NIST (National Institute of Standards and Technology)**, *Proceedings of the XIth Conference on Chemical Thermodynamics* (Como, Italy), International Union of Pure and Applied Chemistry (IUPAC); republished in *Pure and Applied Chemistry*, 63:1465-1472, 1991 (8 pages with 12 figures and 1 table, RDB6437)

describes activities to obtain both thermophysical properties and correlations for alternatives to fully halogenated refrigerants; describes seven

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property measurement apparatuses including a variable-volume vapor-liquid equilibrium (VLE) cell, a Burnett gas-phase pressure-volume-temperature (PVT) device, a high-pressure oscillating tube densimeter, low- and high-pressure ebulliometers, a surface tension and refractive index cell, a dielectric constant measurement cell, and a spherical acoustical resonator; also describes three property correlation projects using the Carnahan-Starling-DeSantis (CSD), and 32- and 90-term modified Benedict-Webb-Rubin (MBWR) equations of state (EOS); tabulates the dipole moments and molecular polarizabilities of R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, R-143, and R-143a; thermodynamic properties data research

G. Morrison (National Institute of Standards and Technology, NIST), **Azeotropes in Refrigerant Mixtures**, Conference Report Number 18, Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 109 ff, 1991 (in English, rdb4438)

G. Morrison and D. K. Ward (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of Two Alternative Refrigerants, 1,1-Dichloro-2,2,2-trifluoroethane (R-123) and 1,1,1,2-Tetrafluoroethane (R-134a)**, *Fluid Phase Equilibria*, 62(1-2):65-86, February 1991 (22 pages with 11 figures and 7 tables, preprint available from JMC as RDB0907)

This paper describes property measurements for R-123 and R-134a. A simple variable-volume sapphire cell was used to obtain vapor-liquid-equilibrium measurements. Vapor pressures and saturation liquid densities are presented for R-134a from -5 °C (23 °F) to the critical temperature, and for R-123 at 30-100 °C (85-210 °F). Saturation vapor density was also determined for R-134a from 35 °C (95 °F) to the critical point, where the critical conditions were measured. A mechanical oscillator densimeter was used to provide density measurements of the compressed liquids. These measurements are presented from the saturation pressure to 5.5 MPa (800 psi) for R-134a and to 3.5 MPa (500 psi) for R-123 at 5-95 °C (40-200 °F). Results are summarized and compared with similar measurements made by other groups.

M. Mrzyglod and K. Stephan (Universität Stuttgart, Germany), **Caloric Properties of Mixtures of Refrigerants R22-R114**, *Fluid Phase Equilibria*, 70:175-184, 1991 (10 pages, rdb9921)

thermodynamic properties of R-22/114 blends

C. A. Nieto de Castro (Universidade de Lisboa, Portugal), R. A. Perkins, and H. M. Roder (National Institute of Standards and Technology, NIST, USA), **Radiative Heat Transfer in Transient Hot-Wire Measurements of Thermal Conductivity**, *International Journal of Thermophysics*, 12:985-997, 1991 (13 pages, rdb8472)

measurement, instrumentation, transport properties, thermophysical data

J. C. Nieuwoudt (Shell Development Company) and I. R. Shankland (AlliedSignal Incorporated), **Oscillating Body Viscometers**, *Experimental Thermodynamics*, edited by W. A. Wakeham, A. Nagashima, and J. V. Sengers, Blackwell Scientific Publishers, UK, III:9-48, 1991 (40 pages, RDB4655)

R. A. Perkins, H. M. Roder (National Institute of Standards and Technology, NIST, USA), and C. A. Nieto de Castro (Universidade de Lisboa, Portugal), **A High-Temperature Transient Hot-Wire Thermal Conductivity Apparatus for Fluids**, *Journal of Research of the NIST*, National Institute of Standards and Technology (NIST), Gaithersburg, MD, 96:247-269, 1991 (23 pages, rdb8465)

measurement, instrumentation, transport properties, thermophysical data

E. Preisegger (Hoechst Aktiengesellschaft, Germany), **Refrigeration/Refrigerants**, *Ki Klima-Kälte-Heizung,* Germany, 11:456-460, 1991; translated by Quest Technology, Incorporated (file QU01043), Arlington Heights, IL (16 pages with 8 figures and 2 tables, RDB3A21)

R-227ea, miscibility, materials compatibility, toxicity, thermodynamic properties, performance

M. V. Rane, **Experimental Investigation of Two Stage Vapor-Compression Heat Pump with Solution Circuits**, doctoral dissertation, University of Maryland, College Park, MD, 1991 (rdb4416)

M. R. Schoeberl and D. L. Hartmann, **The Dynamics of the Stratospheric Polar Vortex and Its Relations to Springtime Ozone Depletions**, *Science*, 251:46-52, 4 January 1991 (7 pages with 5 figures, RDB1203)

R. B. Stewart, R. T. Jacobsen, and W. Wagner, **Thermodynamic Properties of Oxygen from the Triple Point to 300 K with Pressures to 80 MPa**, *Journal of Physical and Chemical Reference Data*, 20(5):917-1021, 1991 (105 pages, rdb7974)

R-732 (oxygen): thermodynamic properties up to 27 °C (80 °F) and up to 80 MPa (11,600 psia), thermophysical data

T. Takaichi (Showa Denko K.K., Japan), **Development of Alternative Fluorocarbons**, *Petrotech*, 14(6):513-518, 1991 (6 pages, rdb3324)

S. Tang, J. V. Sengers, and Z. Y. Chen (University of Maryland), **Nonasymptotic Critical Thermodynamic Behavior of Fluids**, *Physica A*, 179:344-377, 1991 (34 pages, rdb9511)

equation of state (EOS) in the critical region

O. B. Tzvetkov and A. G. Asembaev, **The Heat Conductivity of R134a at the State of Dilute Gas**, *Heat and Mass Transfer in Cryo-Engineering and Thermophysical Properties of Refrigerants*, LTIHP, Russia, 72-79, 1991 (8 pages, rdb5446)

R-134a, thermodynamic data, thermal conductivity; thermophysical data

N. A. Van Gaalen and M. B. Pate, **Methods of Measuring the Solubility and Viscosity of Lubricating Oil/Refrigerant Mixtures**, report ISU-ERI-Ames-91191, Iowa State University of Science and Technology, Ames, IA, 1991; final report for 580-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1991 (rdb2345)

R-22, R-502, lubricants

L. J. Van Poolen, V. G. Niesen, and J. C. Rainwater (National Institute of Standards and Technology, NIST), **Experimental Method for Obtaining Critical Densities of Binary Mixtures: Application to Ethane + n-Butane**, *Fluid Phase Equilibria*, 66:161-185, 1991 (25 pages with 12 figures and 3 tables, available from JMC as RDB9118)

presents a method to determine the critical density of binary blends and provides an illustration for R-170/600 (ethane/n-butane): method entails an experimental and analytical procedure involving measurement of rectilinear diameters based on measured vapor-liquid coexistence densities along a path of constant overall density and composition; validates the proposed method with comparisons of the results to densities generated with a modified Leung-Griffiths correlation and with extensive vapor-liquid equilibrium (VLE) data from a published study; thermodynamic properties; thermophysical data

N. Yada and K. Watanabe (Keio University, Japan), **Correlations of Dew Point and Bubble Point Pressures for Binary Refrigerant Mixtures**, *Nippon Kikai Gakkai Ronbunshu* (Transactions of the Japan Society of Mechanical Engineers, JSME), JSME, Tokyo, Japan, B57:4167-4173, 1991 (7 pages, rdb5483)

thermodynamic properties of blends; thermophysical data

C. Yokoyama and S. Takahashi, **Saturated Liquid Densities of 2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123), 1,2-Dichloro-1,2,2-trifluoroethane (HCFC-123a), 1,1,1,2-Tetrafluoroethane (HFC-134a), and 1,1,1-Trifluoroethane (HFC-143a)**, *Fluid Phase Equilibria*, 67:227-240, 1991 (14 pages, rdb5440)

thermodynamic properties of R-123, R-123a, R-134a, and R-143a; thermophysical data

1991-1992 Threshold Limit Values for Chemical Substances in the Work Environment, *1991-1992 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, The American Conference of Government Industrial Hygienists (ACGIH), Cincinnati, OH, 1-56 and notes, 1991 (55 of 142 pages with 2 tables and 4 appendices, available from ACGIH for $6.00, rdb3744)

This book provides data for use as guidelines or recommendations in the control of potential hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document also lists intended changes and provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter.

Alternatives to Chlorofluorocarbons, bulletin AG-1 (document H-16411-1), DuPont Chemicals, Wilmington, DE, undated circa 1991 (8 pages with 3 figures and 3 tables, RDB3119)

This bulletin discusses nine alternative refrigerants including five hydrochlorofluorocarbons (HCFCs) - R-22, R-123, R-124, R-141b, and R-142b - and four hydrofluorocarbons (HFCs) – R-23, R-125, R-134a, and R-152a. It briefly outlines testing for safety and performance and provides a figure contrasting the ozone depletion (ODP) and global warming potentials (GWP) of these refrigerants. A second figure shows their relative photochemical reactivity, or relative contribution to ground-level smog. Tables summarize the range of applications, including as refrigerants, blowing agents, and for other uses, of these fluids and their physical properties. The tabulated data for each fluid include chemical name and formula, molecular weight, boiling and freezing points, critical pa-

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rameters (temperature, pressure, specific volume, and density), heat of vaporization, flammability limits in air, ODP, halocarbon GWP (HGWP), Toxic Substances Control Act (TSCA) inventory status, and recommended chronic exposure limit for toxicity. The density, specific heat, vapor pressure, thermal conductivity, viscosity, and solubility in water are given for 25 °C (77 °F). A plot shows the vapor pressure relations to temperature, in inch-pound units; R-11, R-12, R-113, and R-114 also are shown for reference.

Capillary Viscometers, *Experimental Thermodynamics*, edited by W. A. Wakeham, A. Nagashima, and J. V. Sengers, Blackwell Scientific Publishers, UK, III:51-75, 1991 (rdb4670)

Changing by Degrees: Steps to Reduce Greenhouse Gases, report OTA-O-482, Office of Technology Assessment, U.S. Congress, Washington, DC, September 1991 (354 pages, available from GPO, rdb4362)

climate change, environmental impacts, global warming

Design, Construction, and Safety Investigation on a Liquid-Cooled Heat Exchanger with the Refrigerant NH_3, *DKV-Statusbericht* [Status Report] 7, Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 1991 (rdb4535)

R-717, ammonia

Hazardous Chemicals Data, publication 49, National Fire Protection Association (NFPA), Quincy, MA, 1991 (RDB4C57)

flammability, toxicity, reactivity, safety classifications

Leak Detectors for Suva(R) Alternative Refrigerants, document ARTD-27 (H-31753), DuPont Chemicals, Wilmington, DE, undated circa 1991 (4 pages, available from JMC as RDB3507) [see RDB-4508 for update]

Performance of Refrigerant Recovery, Recycling, and/or Reclaim Equipment, ARI Standard 740-1991, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1991 (12 pages, RDB3104)

This standard establishes uniform methods of testing for rating and evaluating performance of equipment for refrigerant recovery, recycling, and/or reclaim. It addresses contaminant or purity levels, capacity, speed, and purge loss, the last to minimize emission into the atmosphere of refrigerants. The standard is intended for guidance of the industry, including manufacturers, refrigerant reclaimers, repackagers, distributors, installers, servicemen, contractors, and consumers. The refrigerants covered include R-11, R-12, R-13, R-22, R-113, R-114, R-500, R-502, and R-503. It does not apply to zeotropic mixtures of these or other refrigerants. The standard covers general equipment requirements, specifies a standard sample for testing, and outlines test apparatus. It prescribes a performance testing procedure, sampling and chemical analysis methods, performance calculations and rating, tolerances, and product labeling. The rating sample characteristics include contents of moisture, particulates, acids, mineral oil, and noncondensable gases. Conformance with the standard is voluntary, but conformance may not be claimed unless all requirements of the standard are met.

Prediction of Heat Transfer During Boiling of Refrigerants Inside Tubes, proposed research project 709-URP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1990-1991 (ASH0709)

This project was disapproved based on the recommendation of ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow*.

Proctor & Hughes' Chemical Hazards of the Workplace (third edition), edited by G. J. Hathaway, N. H. Proctor, J. P. Hughes, and M. L. Fischman, Van Nostrand Reinhold Publishers, New York, NY, 1991 (666 pages, rdb5159)

flammability, toxicity, and other safety data

Retrofitting CFC-11 Chillers with Suva(R) Centri-LP, document ARTD-25 (H-31751), DuPont Chemicals, Wilmington, DE, undated circa 1991 (4 pages with 1 table, available from JMC as RDB3506)

This bulletin briefly reviews considerations for retrofit decisions for chillers, noting that alternative refrigerants cannot be simply "dropped into" a system designed for chlorofluorocarbon (CFC) refrigerants. It notes that requirements may range from a minimum effort, such as lubricant replacement, to significant changes, such as replacing gears, impellers, or materials of construction. The document introduces a retrofit program, with four chiller manufacturers, to convert large chillers from CFCs to alternative refrigerants. A table compares the boiling point, flammability, toxicity, ozone depletion potential (ODP) and global warming potential (GWP) of R-11 and R-123. The discussion notes differences between these fluids including differences in efficiency and capacity as well four variables that will determine actual capacity loss in converted equipment. It notes that the loss generally increases with impeller speed and equipment size or, conversely, the loss can be minimized if the compressor and expansion system are slightly oversized. The bulletin discusses the influence of evaporator and condenser surfaces, originally optimized for R-11, on efficiency as well as differences in materials compatibility between R-11 and R-123. It suggests use of a high-efficiency purge unit and also addresses special handling requirements for R-123. The document then reviews field experience with a 1.7 MW (475 ton) York International open-drive centrifugal chiller converted to R-123 in September 1988. Subsequent inspections in December 1988 and 1989 showed minimal effect from R-123 operation. The bulletin also discusses measured machinery room concentrations, noting a brief spike of 8 ppm when breaking hose connections during charging and maintenance. Two other machines at the same site were converted in 1990 and are noted as subsequently operating without incident. The document also discusses a second conversion, of an open-drive, 3.5 MW (1000 ton) Carrier 17M chiller converted in February 1988. Testing in March 1989 indicated 18% capacity reduction. The compressor was rebuilt with larger impellers, resulting in restoration of capacity but a 13% decrease in efficiency. Normal machinery room concentrations were measured as 1-2 ppm, with brief spikes as high as 20 ppm during maintenance. A third case history is reported, for a 2.1 MW (600 ton) Trane hermetic centrifugal chiller. The unit was converted in October 1990. Performance was predicted to be the same and efficiency slightly lower after conversion, but measurements were not yet made. The normal emission levels are noted as 1-2 ppm. The report concludes by identifying several general considerations including proper system operation, component compatibility, and safety and handling procedures.

Retrofitting CFC-12 Chillers with Suva(R) Cold MP, document ARTD-26 (H-31752), DuPont Chemicals, Wilmington, DE, undated circa 1991 (4 pages with 1 table, available from JMC as RDB3450)

This bulletin briefly reviews considerations for retrofit decisions for chillers, noting that alternative refrigerants cannot be simply "dropped into" a system designed for chlorofluorocarbon (CFC) refrigerants. It notes that requirements may range from a minimum effort, such as lubricant replacement, to significant changes, such as replacing gears, impellers, or materials of construction. The document introduces a retrofit program, with four chiller manufacturers, to convert large chillers from CFCs to alternative refrigerants. A table compares the boiling point, flammability, toxicity, ozone depletion potential (ODP) and global warming potential (GWP) of R-12 and R-134a. The discussion notes differences between these fluids including separation of pressures as temperatures drop, a higher isentropic head for R-134a, and immiscibility with conventional mineral oils. The document then reviews field experience with a 2462 kW (700 ton) York International TurboPak(R) centrifugal chiller converted to R-134a in 1989 and an unidentified 300 SUS polyalkylene glycol (PAG) lubricant. Subsequent inspections and a second retrofitting of the drive gear are described, indicating satisfactory operation with a decrease in efficiency of up to 7% and an increase in capacity of up to 9%. The document also discusses a second conversion, of a SnyderGeneral McQuay PEH048 centrifugal chiller. With a change in gear set, the unit showed a 4.1% improvement in efficiency and a 0.8% increase in capacity using R-134a and mineral oil. A test to simulate an o-ring failure in the compressor shaft seal is described, in which oil placed in the evaporator did not return to the compressor due to poor miscibility. A second PEH048 chiller using R-500 and mineral oil was converted to R-134a with a Mobil ester-based lubricant. The unit showed a 0.1% decrease in efficiency and 1.3% decrease in capacity. The o-ring failure simulation was repeated with normal lubricant return to the sump. The report concludes by identifying several general considerations including proper system operation, component compatibility, and safety and handling procedures. DuPont's product names for R-134a in chillers are Suva(R) 134a and Suva(R) Cold-MP.

Scientific Assessment of Ozone Depletion: 1991, chaired by D. L. Albritton (National Oceanic and Atmospheric Administration, NOAH) and R. T. Watson (National Aeronautics and Space Administration, NASA), report 25, World Meteorological Organization (WMO), Global Ozone Research and Monitoring Project, Geneva, Switzerland, 1991 (340 pages, available from WMO; also available from JMC as RDB2701)

This definitive work updates the assessment used in governmental and international decision-making on protection of the stratospheric ozone layer and climate change. The volume addresses source gases including concentrations, emissions, and trends; ozone and temperature trends; heterogeneous processes including laboratory, field, and modeling studies; both stratospheric and tropospheric processes including observations and interpretations; ozone depletion and chlorine loading potentials (ODP and CLP values); radiative forcing of climate; future chlorine and bromine loading and ozone depletion; aircraft, rocket and space shuttle effects on stratospheric ozone; and ultraviolet radiation changes. The study was pre-

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pared by eleven international panels and subjected to peer reviews.

Speed of Sound Measurements in Liquid R-123, proposed research project 710-URP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1990-1991 (ASH0710)

This project was disapproved based on the recommendation of ASHRAE Technical Committee 3.1, *Refrigerants and Brines.*

Suva[(R)] Blend-MP Series, document ARTD-10 (H-08908-1), DuPont Chemicals, Wilmington, DE, undated circa 1991 (8 pages with 8 figures and 5 tables, available from JMC as RDB2A19)

This bulletin provides application data for two ternary blends, MP33 and MP39 [R-401A], of R-22/152a/124 developed as alternatives for R-12 in refrigeration and air-conditioning applications. A figure compares the ozone depletion and global warming potentials (ODP and GWP) of the two blends to those of R-12. A table compares boiling points, flammability, toxicity, performance, ODP, GWP, and costs for the blends with R-12 and R-134a. The bulletin discusses the ability to adjust the vapor pressure of the blends, by varying the composition, and a figure contrasts the pressure-temperature relations to those of R-12. Two figures show the pressure changes resulting from repeated leakage, resulting in 50% weight loss, and recharging as well as flammability shifts as the initial composition fractionates during complete evaporation. The bulletin then addresses materials compatibility, summarizing stability tests (rated by color changes and measured copper plating) for R-12 and MP33. Lubricant solubility is discussed, noting that the blends are fully soluble in alkylbenzene lubricants in the concentrations and temperatures of interest. Desiccant compatibility and performance data are tabulated for UOP 4A-XH-6 and XH-9 molecular sieves. Motor insulation compatibility for MP33 is described as comparable to that with R-12 alone and more favorable in mixtures with naphthenic mineral oil or alkylbenzene. Theoretical performance analyses and compressor calorimeter test results are summarized. The document then discusses system design considerations and discusses temperature glide, compressor durability, and ongoing tests. The bulletin concludes that MP39 is a good candidate for retrofit of R-12 systems and that MP33 is a good alternative for new equipment.

Trichlorofluoromethane (FC 11) Toxicology Data Summary, Elf Atochem North America, Incorporated, King of Prussia, PA, January 1991 (RDB5145)

R-11

1990

December 1990

S. C. Bhaduri (Indian Institute of Technology, India) and H. K. Varma, **Liquid Heat Capacity of R22 Based Binary Mixtures**, *Proceedings of the 6th International Symposium on Heat and Mass Transfer* (Miami, FL, 10-12 December 1990), 1990 (rdb6316)

R-22/absorbent, properties

R. A. Cole, **Ammonia as a Refrigerant in Light of the CFC Phase-Out**, *ASHRAE Journal*, 32(1):28-32, December 1990 (5 pages, rdb6353)

R-717

J. R. Lloyd and P. J. Marto, **A Predictive Model to Describe the Pool Boiling Behavior of Refrigerant-Oil Mixtures**, technical report NPS ME-90-07, Naval Postgraduate School, Monterey, CA, 31 December 1990 (42 pages with 4 figures, RDB3B28)

S. M. Miner (Engineering Consultant), **Ammonia as a Refrigerant of Choice**, *ASHRAE Journal*, 32(12):-43-44, December, 1990 (3 pages, RDB6355)

R-717

R. D. C. Shone (COMRO, South Africa), **Examination of the Split Ammonia System Refrigeration Cycle**, *Journal of the Mine Ventilation Society of South Africa*, 43(12):223-230, December 1990 (8 pages, rdb3346)

describes a non-conventional R-717 (ammonia) system to cool deep mines with a "split system" approach: the system uses underground evaporators connected to surface condensers - separated by several kilometers (several miles) - with compressors at both levels; discusses implications for the piping design and necessary measures to ensure the safety of underground workers; examines the refrigeration cycle for the split system with focus on the thermodynamic and costs aspects; describes ammonia as readily available, relatively inexpensive, environmentally 'clean', efficient, having excellent thermal transport properties that result in comparatively small heat exchangers, but a concern for safety based on its toxicity; discusses conventional use of ammonia chillers installed on the surface to make chilled water or ice, with precautions to ensure that no ammonia reaches the underground environment

1991-1992 Research Plan, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1 December 1990 (32 pages, RDB1152)

Newly Found Viruses Might be the Key to Controlling Seas, *R&D Magazine*, 32(12):86, December 1990 (1 page, RDB1114)

This news brief announces the discovery of a group of unspecified aquatic viruses that may aid in reducing global warming. These viruses encourage reproduction of a class of phytoplankton that absorb carbon dioxide. Other aquatic viruses could control reproduction of oxygen-absorbing phytoplankton that kill marine life by robbing water of oxygen. Additional research is required to better understand these viruses and their affect on marine life.

November 1990

K. Bier, M. Crone, M. Türk, W. Leuckel, M. Christill, and B. Leisenheimer (Universität Karlsruhe, Germany), **Untersuchungen zur thermischen Stabilität sowie zum Zünd- und Brennverhalten der Kältemittel R152a and R134a** [Investigation of the Thermal Stability, Ignition, and Combustion Behavior of Refrigerants R-152a and R-134a], *DKV Tagungsberichte* (Heidelberg, Germany, November 1990), Deutscher Kälte- und Klimatechnischer Verein [DKV, German Association of Refrigeration and Air-Conditioning Engineers], Germany, 17(2):-169-191, 1990 (22 pages in German, rdb3C14)

This paper presents experimental studies on the stability and safety of R-134a, R-152a, and their mixtures. The studies examined the possibility of suppressing the relatively high flammability of R-152a by mixing it with R-134a, without substantial loss of the benefits of its low global warming potential.

J. C. Conklin and E. A. Vineyard (Oak Ridge National Laboratory, ORNL), **Tubeside Evaporation of Nonazeotropic Refrigerant Mixtures from Two Enhanced Surfaces**, paper 90-WA-HT-8 (ASME Winter Annual Meeting, Dallas, TX), American Society of Mechanical Engineers (ASME), New York, NY, November 1990 (7 pages with 9 figures, RDB2342)

heat transfer

T. W. Dekleva (ICI Americas, Incorporated**), Lubricants for Use with R-134a in Domestic Appliances**, unpublished presentation at the International CFC and Halon Alternatives Conference (Baltimore, MD), Alliance for Responsible CFC Policy, Arlington, VA, November 1990 (40 pages with 30 charts, available from JMC as RDB2524)

B. Frehn, **Propan als alternatives Kältemittel für Wärmepumpen - Erste Betriebserfahrungen** [Propane as an Alternative Refrigerant for Heat Pumps - Experience with the First Installation], *DKV-Tagungsberichte* (Heidelberg, Germany, November 1990), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 20:51-63, 1993; republished in *Warmepumpe 3* [Heat Pumps 3], Rheinische-Westfälisches Elektrizitätswerk Energie AG (RHENAG), Essen, Germany, 1993 (rdb4345)

R-290

E. Granryd (Kungliga Tekniska Högskolan, KTH, Sweden) and J. C. Conklin (Oak Ridge National Laboratory, ORNL), **Thermal Performance Analysis for Heat Exchangers Using Nonazeotropic Refrigerant Mixtures**, *Heat Transfer in Advanced Energy Systems*, American Society of Mechanical Engineers (ASME), New York, NY, HTD-151 /AES-18:25-32, November 1990 (8 pages with 10 figures, available from JMC as RDB2330)

heat transfer

J. Paul (Integral Technologie GmbH, Germany), **Wasser als Kältemittel: II** [Water as a Refrigerant: Part II], *Bericht über die Kälte-Klima-Tagung* [Proceedings of the Refrigeration and Air-Conditioning Conference] (Heidelberg, Germany, November 1990), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 1990 (in German, rdb4A71)

R-718

R. K. Radermacher and D. Jung (University of Maryland), **Replacement Refrigerants for R-22**, published draft report, U.S. Environmental Protection Agency (EPA), Washington, DC, November 1990 (80 pages with 24 exhibits, RDB1134)

This peer-review draft examines alternative refrigerants for R-22. The report summarizes the simulation programs used, HAC and HACT, to examine candidate refrigerants. Coefficients of performance (COPs) and seasonal performance factors (SPFs) were calculated for a number of mixtures. The report also reviews the design modifications considered and discusses requirements for future research. No single-component refrigerant was found suitable as a substitute, but binary and ternary blends appear promising. The R-32/152a blend was identified as the most promising option, with an estimated COP increase of 11%. A further increase by 4%

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was estimated with use of a suction gas heat exchanger. Addition of a third, nonflammable component is suggested to reduce flammability. (This published draft was replaced by RDB2509.)

H. Wijaya and H. M. Hughes (AlliedSignal Incorporated), **A Proposed Procedure for Qualifying Halogen Leak Detectors**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD), Alliance for Responsible CFC Policy, Arlington, VA, November 1990 (9 pages with 10 figures and 3 tables, RDB2316)

M. Yamagishi and K. Oguchi (Kanagawa Institute of Technology, Japan), **Experimental Study of PVT Properties of HCFC-123 ($CHCl_2CF_3$)**, *Proceedings of the 31st High Pressure Conference* (Osaka, Japan, 19-21 November 1990), Japan, 12-13, 1990 (2 pages, rdb9138)

thermodynamic properties of R-123; thermophysical data

October 1990

K. Doya, Y. Aoki, and M. Onoyama (Showa Shell Sekiyu Company, Limited, Japan), **Refrigerant Oil for Alterable Refrigerant 134a**, *Reito* [Refrigeration], Japan, 65(756):47-52 also numbered 1047-1052, October 1990 (6 pages with 3 figures and 10 tables, in Japanese with summary in English, RDB3C12)

This paper addresses polyalkylene glycol (PAG) lubricants for use with R-134a, as an alternative for R-12, in mobile air-conditioning (MAC) systems. It discusses lubricity for aluminum-aluminum and/or aluminum-steel contacts, miscibility with R-134a, and compatibility with nonferrous metals. The paper presents data from a study of two PAGs and a *hindered* polyolester (POE) for automotive air conditioners. Among the topics presented are miscibility, thermal stability, effects of additives, hydrolysis resistance, and corrosion.

G. J. O'Neill and R. S. Holdsworth (W. R. Grace and Company), **Bis (Difluoromethyl) Ether Refrigerant**, U.S. patent 4,961,321, 9 October 1990 (4 pages, RDB1133)

This patent describes the use of R-E134 as a refrigerant, either as a single component or in a blend. The refrigerant is described as environmentally safe, nontoxic, and nonflammable and as having the desired physical, chemical, and thermodynamic properties necessary for a refrigerant.

As Easy as 123, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE; The Trane Company, La Crosse WI; and York International Corporation, York, PA; October 1990 (12-minute videotape, RDB1137)

This video explains how R-123 was developed to replace R-11 by balancing ozone-depletion, global-warming, and energy-efficiency considerations.

September 1990

K. Azami, H. Hosoi, and N. Ishikawa (Sanden Corporation), **Lubricant Screening for HFC-134a Car Air Conditioning Compressor Reliability**, paper 901735 (Passenger Car Meeting, Dearborn, MI, 17-20 September 1990), Society of Automotive Engineers, Warrendale, PA, September 1990 (12 pages with 5 figures and 11 tables, RDB2209)

R-134a

J. Gallagher, M. O. McLinden, and G. Morrison, **REFPROP, A Program for the Calculation of the Thermodynamic Properties of Refrigerants and Refrigerant Mixtures**, NIST Standard Reference Database (SRD) 23 version 1.02, National Institute of Standards and Technology, Gaithersburg, MD, 28 September 1990 (software and documentation, RDB0916)

Version 1.02 of REFPROP calculates properties for 16 pure refrigerants and 24 binary mixtures of them in user-selected units of measurement. These refrigerants include R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-113, R-114, R-123, R-124, R-125, R-134, and R-134a, R-142b and R-152a. [This version has been superseded; see RDB2430.]

August 1990

M. Buschmeier, W. J. Mulroy, and D. A. Didion, **An Initial Laboratory Evaluation of a Single Solution Circuit Cycle for Use with Nonazeotropic Refrigerants**, report NISTIR 4406, National Institute of Standards and Technology (NIST), Gaithersburg, MD, August 1990 (available from NTIS, RDB5498)

zeotropic blends, modifications

Intergovernmental Panel on Climate Change, **Climate Change - the IPCC Scientific Assessment**, edited by J. T. Houghton, G. J. Jenkins, and J. J. Ephraums (Meteorological Office, UK), IPCC Secretariat World Meteorological Organization (WMO), Geneva, Switzerland, August 1990; republished by the Cambridge University Press, Cambridge, UK, 1990 (365 pages, rdb1157) global warming, greenhouse gases, environmental impact

Intergovernmental Panel on Climate Change, **IPCC First Assessment Report**, IPCC Secretariat, World Meteorological Organization (WMO), Geneva, Switzerland, August 1990; republished by the Cambridge University Press, Cambridge, UK, 1990 (rdb1158)

This volume comprises an *Overview* and four policy makers' summaries. They address the *Scientific Assessment of Climate Change* (Working Group I), *Potential Impacts of Climate Change* (Working Group II), *Formulation of Response Strategies* (Working Group III), and *Special Committee on the Participation of Developing Countries*.

July 1990

D. Arnaud (Elf Atochem S.A., France) and J. P. Caillie, **Comparative Performance of HFA-134a and CFC-12 in a Reciprocating Water Chiller**, *Proceedings of the 1990 USNC/IIR Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 354-364, July 1990 (11 pages, RDB6325)

R-12, R-134a

E. C. Berlinck, C. A. T. Uriu, T. B. Herbas, and J. A. R. Parise (Pontifícia Universidade Católica do Rio de Janeiro, Brazil), **Performance Analysis of Domestic Heat Pump Units Running on CFC Substitutes**, presented at the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference (Purdue University, West Lafayette, IN, July 1990); published in the *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, 2:693-702, July 1992 (10 pages with 5 figures, RDB2843)

P. A. Domanski and M. O. McLinden (National Institute of Standards and Technology, NIST), **A Simplified Cycle Simulation Model for the Performance Rating of Refrigerants and Refrigerant Mixtures**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 466-475, July 1990 (10 pages with 6 figures and 1 table, available from JMC as RDB2C05)

[see RDB3448 for corrected and updated version]

S. J. Eckels and M. B. Pate (Iowa State University of Science and Technology), **An Experimental Comparison of Condensation Heat Transfer Coefficients for HFC-134a and CFC-12**, *Proceedings of* the *1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference,* edited by D. R. Tree, Purdue University, West Lafayette, IN, July 1990; republished in the *International Journal of Refrigeration* (IJR), 13(8):70-77, November 1990 (possibly 14(1):70-77, March 1991) (8 pages, rdb2238)

R-12, R-134a, heat transfer

J. F. Ely and M. L. Huber (National Institute of Standards and Technology, NIST), **A Predictive Extended Corresponding States Model for Pure and Mixed Refrigerants**, *Proceedings of* the *1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 383-392, July 1990 (10 pages, RDB7608)

extended corresponding states (ECS) equation of state (EOS); PROZPER (PRoperties of OZone Protecting Environmentally acceptable Refrigerants) microcomputer program; thermodynamic properties for R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-32, R-113, R-114, R-115, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, and R-218; 32-term modified Benedict-Webb-Rubin (MBWR) EOS for R-134a reference equation; shape factor correlations; thermophysical data

S. K. Fischer and J. R. Sand (Oak Ridge National Laboratory, ORNL), **Thermodynamic Calculations for Mixtures of Environmentally Safe Refrigerants Using the Lee-Kesler-Plöcker Equation of State**, *Proceedings of* the *1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 373-382, July 1990 (10 pages with 6 figures and 2 tables, available from JMC as RDB3910)

LKP EOS, thermophysical property data, LKP

S. T. Jolley, **New and Unique Lubricants for Use in Compressors Utilizing R-134a Refrigerant**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference,* edited by D. R. Tree, Purdue University, West Lafayette, IN, 145-152, July 1990 (8 pages with 1 figure and 5 tables, RDB2C06)

D. Jung (University of Maryland) and D. A. Didion (National Institute of Standards and Technology, NIST), **Mixing Rule for Liquid Viscosities of Refrigerant Mixtures**, *International Journal of Refrigeration* (IJR), 13(6):243-247, July 1990 (5 pages with 2 figures and 2 tables, RDB6409)

R-500, R-502, R-503, R-504, R-506, R-32/12 (87/13), R-115/152a (69/31), mixing rules, Hildebrand's correlation, Grunberg and Nissan's correlation

S. Kitaichi, S. Sato, R. Ishidoya, and T. Machida (Toshiba Corporation, Japan), **Tribological Analysis of Metal Interface Reactions in Lubricant Oils/CFC-12 and HFC-134a System**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 153-162, July 1990 (10 pages with 13 figures and 3 tables, RDB4C23)

R-12, R-134a

A. A. Kornhauser, **The Use of an Ejector as a Refrigerant Expander***, Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 10-13, July 1990 (4 pages, RDB6439)

cycle modifications, minimizing expansion losses

L. J. M. Kuijpers, J. A. de Wit, A. A. J. Benschop, and M. J. P. Janssen (Phillips Research Laboratories, The Netherlands), **Experimental Investigations into the Ternary Blend HCFC-22/124/152a as a Substitute in Domestic Refrigeration**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 314-324, July 1990 (11 pages with 6 figures and 4 tables, RDB4430)

R-22/152a/124, R-401 series

L. E. Manzer (E. I. duPont de Nemours and Company), **The CFC-Ozone Issue: Progress on the Development of Alternatives to CFCs**, *Science*, 249:31-35, 6 July 1990 (5 pages, Rdb3134)

outlines the history of chlorofluorocarbons (CFCs), selection of appropriate substitutes, potential manufacturing routes to producing alternatives, and process development; comments on cooperative programs to examine the toxicity and environmental aspects of alternatives and remaining key issues; indicates that it would be irresponsible to immediately cease CFC production pending the difficult identification of suitable substitutes; notes that DuPont had organized a *Seminar on the Ecology of Fluorocarbons* already in 1972, which led to a cooperative industry program to investigate effects on the fate and impact of CFCs in the atmosphere

N. Masuda (Mitsubishi Electric Corporation, Japan), **Some Evaluation Results of HFC-134a/-PAG Mixtures for Refrigeration**, *Proceedings of* the *1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 297-307, July 1990 (11 pages with 14 figures and 6 tables, RDB4C24)

R-134a

G. D. Short (CPI Engineering Services, Incorporated) and R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Selection and Performance of Synthetic and Semi-Synthetic Lubricants for Use with Alternative Refrigerants in Refrigeration Applications**, *Proceedings of* the *1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 163-172, July 1990 (10 pages with 10 figures, RDB2220)

W. K. Snelson, J. W. Linton, P. F. Hearty (National Research Council, Canada, NRCC), and T. N. Duong (University of Sherbrooke), Canada, **Some Thermodynamic Performance Test Results of Refrigerant 134a**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 344-353, July 1990 (10 pages with 10 figures and 1 table, RDB4433)

M. W. Spatz and J. Zheng (AlliedSignal Incorporated), **An Experimental Evaluation of the Heat Transfer Coefficients of R-134a Relative to R-12**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 225-233, July 1990 (9 pages with 8 figures, RDB0501)

comparative heat transfer of R-12 and R-134a

S. G. Sundaresan and W. R. Finkenstadt (Copeland Corporation), **Status Report on Polyalkylene Glycol Candidates with HFC-134a in Refrigeration Compressors**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, 138-144, July 1990 (7 pages with 3 figures and 6 tables, RDB4355)

R-134a, PAG lubricants

C. L. Yaws, H. C. Yang, J. R. Hopper, and K. C. Hansen, **Organic Chemicals: Water Solubility Data**, *Chemical Engineering*, 115-118, July 1990 (4 pages, rdb5C35)

R-32 and others

Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference, edited by D. R. Tree, Ray W. Herrick Laboratories, Purdue University, West Lafayette, IN, July 1990 (526 pages with 56 papers, RDB1140)

June 1990

E. Johnson and J. Noble, **A Survey of Alternatives to Ozone-Destroying Technologies**, Greenpeace International, Washington, DC, June 1990 (35 pages, RDB1154)

This report is a survey of innovations old and new that could provide the goods and services currently dependent on ozone-destroying chemicals. It is represented as an attempt to show the range of technologies that could be used as replacements without adverse impact on the ozone layer. The survey notes that the HCFC and HFC alternatives have not been proven to be harmless to the ozone layer, but are greenhouse gases and have serious toxicity problems.

S. P. Manwell and A. E. Bergles (Rensselaer Polytechnic Institute, RPI), **Gas-Liquid Flow Patterns in Refrigerant-Oil Mixtures**, paper SL-90-1-4, *Transactions* (Annual Meeting, St. Louis, MO, 9-13 June 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 96(2):456-464, 1990 (9 pages, rdb4971)

J. R. Sand, E. A. Vineyard (Oak Ridge National Laboratory, ORNL), and R. J. Nowak (Purdue University), **Experimental Performance of Ozone Safe Alternative Refrigerants**, paper 3399, *Transactions* (Annual Meeting, St. Louis, MO, 9-13 June 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 96(2):173-182, 1990 (10 pages with 1 figure and 8 tables, RDB4129)

performance comparisons for R-12, R-22, R-32, R-114, R-124, R-125, R-134, R-134a, R-142b, R-143, R-143a, R-152a, R-218, and R-C318 at four standard heat pump rating conditions

N. A. Van Gaalen, M. B. Pate, and S. C. Zoz (Iowa State University of Science and Technology), **The Measurement of Solubility and Viscosity of Oil/Refrigerant Mixtures at High Pressures and Temperatures: Test Facility and Initial Results for R-22/Naphthenic Oil Mixtures**, *Transactions* (Annual Meeting, St. Louis, MO, 9-13 June 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 96(2):183-190, 1990 (8 pages, rdb2231)

solubility and viscosity of R-22 with a 150 SUS, naphthenic mineral oil (MO): presents measurements for mixtures of 10-40% R-22 by mass for 38-149 °C (100-300 °F)

Absorption of Ammonia into Water, research project 591-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1988 - June 1990 (ASH0591)

The contractor for the project was Kansas State University (KSU) at Manhattan, led by D. L. Fenton and R. L. Gorton; it was sponsored by ASHRAE Technical Committee 10.1, *Custom Engineered Refrigeration Systems*.

Montreal Protocol on Substances That Deplete the Ozone Layer, working version, United Nations Environment Programme (UNEP), June 1990 (28 pages, RDB1119)

This text is an unofficial composite version of the Montreal Protocol as amended in London in June 1990. This version has been superseded; see RDB2702.

NIOSH Pocket Guide to Chemical Hazards, publication 90-117, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, June 1990 (available from GPO for $7.00 as document #1992-322-002, 256 pages with 6 tables, RDB3903)

This document lists safety information in tabular form for 398 chemicals found in the work environment. Many of them are regulated by the U.S. Occupational Safety and Health Administration (OSHA). Each entry identifies the chemical by name, synonym(s), trade name(s), structural or empirical chemical formula, Chemical Abstract Service (CAS) and Registry of Toxic Effects of Chemical Substances (RTECS) numbers, and assigned U.S. Department of Transportation identification and guide numbers. It then gives the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL), ceiling REL (REL-C), Short Term Exposure Limit (STEL), carcinogenic identification or cautions, and/or Immediately Dangerous to Life or Health (IDLH) value. It also indicates the OSHA Permissible Exposure Limit (PEL), PEL ceiling value (PEL-C), or STEL. The entries also provide physical descriptions and summary chemical and physical properties, as available. They include concentration conversion factors, molecular weight, normal boiling point, solubility in water, flash point, ionization potential, representative vapor pressure, melting or freezing point temperature, flammability limits, representative specific gravity, and relative density of gases referenced to air. Entries list incompatibilities, reactivities, and

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measurement methods for the chemicals along with recommendations for personal protection, sanitation, and respirators. The entries conclude with health hazard summaries that identify body entry routes, symptoms, first aid measures, and impacted target organs. An introduction briefly describes these data and the codes used in the listings. Appendices provide recommendations on potential occupation carcinogens, identify 13 OSHA-regulated carcinogens, discuss supplementary exposure limits, discuss exposure limits for certain substances without established RELs, and provide miscellaneous notes. They also provide indices by synonym and trade names as well as by CAS registry numbers. A number of historical, current, and candidate refrigerants are covered. They include R-10, R-11, R-12, R-12B2, R-13B1, R-21, R-30, R-40, R-112, R-113, R-114, R-290 (propane), R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), and others.

May 1990

V. D. Baxter, **Report of Foreign Travel: 9-11 May 1990** [Application of Zeotropic Mixture Refrigerants in Refrigerators and Use of the Lee-Kesler-Plöcker Equation of State], ORNL/FTR-3611, Oak Ridge National Laboratory, Oak Ridge, TN, 14 May 1990 (20 pages, RDB1153)

This informal report summarizes the final working meeting of the International Energy Agency (IEA) research project on *State and Transport Properties of High-Temperature Working Fluids and Nonazeotropic Mixtures* (Annex XIII). It also addresses research at the Universität Hannover, funded by the U.S. Environmental Protection Agency (EPA), on application of refrigerant blends in refrigerators and separate work to use the Lee-Kesler-Plöcker (LKP) equation of state to predict refrigerant properties.

S. Komatsuzaki and Y. Homma (Hitachi Limited, Japan), **Antiseizure and Antiwear Properties of Lubricating Oils Under Refrigerant Gas Environments**, paper 90-AM-6C-1 (45th Annual Meeting, Denver, CO, 7-10 May 1990), Society of Tribologists and Lubrication Engineers (STLE), May 1990; republished in *Lubrication Engineering*, 47(3):193-198, 1991 (6 pages, rdb2213)

B. Petersson and H. Thorsell (Kungliga Tekniska Högskolan, KTH, Sweden), **Comparison of the Refrigerants HFC 134a and CFC 12**, *International Journal of Refrigeration* (IJR), 13:176-180, May 1990 (5 pages, rdb4434)

R-12, R-134a, comparative performance

Alternative Fluorocarbons Environmental Acceptability Study, program description, AFEAS, Washington, DC, 31 May 1990 (4 pages with 1 figure and 1 table, available from JMC as RDB1149)

This leaflet introduces the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), initiated in December 1988. The program was formed to assess the potential impacts of chlorofluorocarbon (CFC) refrigerant alternatives on the environment. AFEAS is a cooperative research effort sponsored by 12 leading chemical producers. Results were presented at the United Nations Environment Programme (UNEP) meeting in Nairobi in August 1989, and were incorporated as an appendix to the Scientific Assessment under the Montreal Protocol on Substances that Deplete the Ozone Layer. The study is being expanded to conduct further related research. One cited goal is to identify and help resolve the uncertainties regarding potential environmental effects of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). A second is to stimulate prompt dissemination of scientific information to the research community, government decision makers, affected industries, and the public. A table lists potential alternatives to CFCs, including HCFCs R-22, R-123, R-124, R-141b, R-225ca, and R-225cb and HFCs R-125, R-134a, and R-152a. A figure contrasts the atmospheric lifetimes, global warming potentials (GWPs), and ozone-depletion potentials (ODPs) of CFCs and alternative HCFCs and HFCs.

Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) Summaries, AFEAS, Washington, DC, 31 May 1990 (12 pages with 4 figures, available from JMC as RDB1150)

This series of six leaflets summarizes key AFEAS objectives and findings. A summary of *Atmospheric Fluorocarbons and Stratospheric Ozone* reviews the mechanisms of stratospheric ozone depletion and provides values for ozone depletion potentials (ODPs). A sheet on *UV-B Radiation Measurements* discusses the importance of the ozone layer in shielding ultraviolet-B (UV-B) radiation in sunlight and monitoring of intensity. A summary of *Alternative Fluorocarbons and Global Warming* compares the global warming potentials (GWPs) of CFCs to those of HCFCs and HFCs. It also contrasts the calculated warming effects of these compounds to other greenhouse gases, including carbon dioxide, methane, and nitrous oxide. A review of the *Breakdown Products of Alternatives* outlines the mechanisms and consequences of hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) breakdown, including the potential impacts of degradation products. A *Glossary of Terms* explains key terminology for discussion of the atmospheric effects of alternative fluorocarbons. The last sheet briefly outlines the history and activities of both AFEAS and the companion Programme for Alternative Fluorocarbon Toxicity Testing (PAFT).

1-Chloro-1,2,2,2-tetrafluoromethane (HFA-124) - CAS Registry Number 2837-89-0, Joint Assessment of Commodity Chemicals (JACC) report 12, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, May 1990 (28 pages, RDB3720)

R-124; 2-chloro-1,1,1,2-tetrafluoroethane, environmental impacts, toxicity

Compatibility of Elastomers with CFC-12 and/or Paraffinic Oil, report ARTD-16 (H-26830), DuPont Chemicals, Incorporated, Wilmington, DE, 7 May 1990 (16 pages with 1 figure and 12 tables, available from JMC as RDB3124)

This report summarizes an investigation of the compatibility of 11 elastomers at 25 and 80 °C (77 and 176 °F) with R-12, an unidentified paraffinic mineral oil, and a 50/50 mixture of them. This refrigerant-lubricant pair is widely used in automotive air conditioners; the measurements were made for comparison with similar data for alternative refrigerants and lubricants. The data presented were taken after 27 days of immersion ("temporary") and also after subsequent drying in air at 25 °C (77 °F) for 14 days ("final"). The elastomers also are rated on a scale of 0 ("no change") to 5 ("severe, unacceptable change") based on the "temporary" data. The "final" data are suggested as a guide for seal replacement after equipment tear down. The report outlines the experimental approach and presents a table with the ratings. Eleven subsequent tables present measured changes in length, weight, and Shore A hardness as well as elasticity and visual (both the liquid and the polymer) ratings. The elastomers tested include urethane (Uniroyal Adiprene(R) C), Buna N and S, butyl rubber, chlorosulfonated polyethylene (DuPont Hypalon(R) 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel(R)), silicone, polysulfide (Morton Thiokol(R) FA), and fluoroelastomer (DuPont Viton(R) A). A figure shows the scale used for swell and hardness ratings. The report cautions that the effects of refrigerants on elastomers depend on the nature of the polymer, the compounding formulation used, the curing or vulcanizing condition, the presence of plasticizers or extenders, and other elastomer variables. While the data serve as a guide, generalizations from the results are difficult to make.

Constants and Estimated Transport Properties for HFC-32, preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, undated circa May 1990 (2 pages with 5 tables, available from JMC as RDB0547)

Physical property data, equation coefficients, and enthalpy and entropy reference points (Ho and So) are tabulated for R-32 in inch-pound (IP) units of measure. The data include critical point parameters (temperature, pressure, and density), normal boiling point, and molecular mass. The coefficients enable calculation of equation of state properties (pressure, enthalpy, and entropy) using a Martin-Hou equation, liquid density, vapor pressure, and ideal gas heat capacity. [The equations for these coefficients are presented in RDB0505, RDB0507, RDB0511, and RDB0506, respectively.] Equations are presented to estimate transport properties, including liquid and vapor viscosity and thermal conductivity. The information presented is preliminary and estimated.

Constants for AZ-20 (60% R-32, 40% R-125), preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, undated circa May 1990 (1 pages with 5 tables, available from JMC as RDB0548)

Physical property data, equation coefficients, and enthalpy and entropy reference points (Ho and So) are tabulated for R-32/125 (60/40) in inch-pound (IP) units of measure. The data include critical point parameters (temperature, pressure, and density), normal boiling point, and molecular mass. The coefficients enable calculation of equation of state properties (pressure, enthalpy, and entropy) using a Martin-Hou equation, liquid density, vapor pressure, and ideal gas heat capacity. [The equations for these coefficients are presented in RDB0505, RDB0507, RDB0511, and RDB0506, respectively.] AlliedSignal's product name for R-32/125 is Genetron(R) AZ-20 [the composition was subsequently reformulated from that described in this document.]

Constants for AZ-50 (45% R-125, 55% R-143a), preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, undated circa May 1990 (1 pages with 5 tables, available from JMC as RDB-0549)

Physical property data, equation coefficients, and enthalpy and entropy reference points (Ho and So) are tabulated for R-125/143a (45/55) in inch-pound (IP) units of measure. The data include critical point parameters (temperature, pressure, and density), normal boiling point, and molecular mass. The coefficients enable calculation of equation of state properties (pressure, enthalpy, and entropy) using a Martin-Hou equation, liquid density, vapor pressure, and ideal gas heat capacity. [The equations for these coefficients are presented in RDB0505, RDB0507, RDB0511, and RDB0506, respectively.] AlliedSignal's product name for R-125/-143a is Genetron(R) AZ-50 [the composition was subsequently reformulated from that described in this document.]

1,1-Dichloro-2,2,2-trifluoromethane (HFA-123) - CAS Registry Number 306-83-2, Joint Assessment of Commodity Chemicals (JACC) report 13, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, May 1990 (38 pages with 3 tables, RDB3719)

R-123, 2,2-dichloro-1,1,1-trifluoroethane, environmental impacts, toxicity

Gas Heat Capacity, preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, 23 May 1990 (1 page with 1 table, available from JMC as RDB0506)

An equation is provided to calculate the gas heat capacity of refrigerants in Btu/lb·°R as a function of temperature in °R. Coefficients are provided for R-123, R-123a, R-124, R-125, R-134, R-134a, and R-143a. The information presented is preliminary and estimated.

Liquid Density, preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, 1 May 1990 (1 page with 1 table, available from JMC as RDB0507)

An equation is provided to calculate the liquid density of refrigerants in lb/cf as a function of critical properties. Coefficients are provided for R-123, R-123a, R-124, R-125, R-134, R-134a, and R-143a. The information presented is preliminary and estimated.

Liquid Viscosity Correlation, preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, 23 May 1990 (1 page with 1 table, available from JMC as RDB0508)

A correlation is provided to calculate the viscosity of refrigerants, in lb/hr·ft, in their liquid state as a function of temperature, in °R. Coefficients, based on measurements in the range of -20 to 80 °C (-4 to 176 °F), are provided for R-123, R-123a, R-124, R-125, and R-134a. An equation is included to estimate the viscosity of R-134a in its vapor state. The information presented is preliminary and estimated.

Liquid Thermal Conductivity Correlation, preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, 23 May 1990 (1 page with 1 table, available from JMC as RDB0509)

A correlation is provided to calculate the thermal conductivity of refrigerants, in Btu/hr·ft·°F, in their liquid state as a function of temperature, in °F. Coefficients, based on measurements in the range of 25-70 °C (77-158 °F), are provided for R-123, R-123a, R-124, R-125, and R-134a. The information presented is identified as preliminary and estimated.

Martin-Hou Equations of State, preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, May 1990 (4 pages with 3 tables, available from JMC as RDB0505)

A Martin-Hou (MH) equation of state (EOS) and related equations to calculate the enthalpy and entropy of refrigerants are presented. Reference points and coefficients are tabulated in consistent inch-pound units for R-123, R-123a, R-124, R-125, R-134, R-134a, and R-143a. Reference points (constants of Ho and So) also are presented for of R-32/125 (60/40) and R-125/143a (45/55). [These blends were developmental versions (subsequently reformulated) of AZ-20 and AZ-50, respectively.] The information presented is identified as preliminary and estimated.

Programme for Alternative Fluorocarbon Toxicity Testing, program description, PAFT, Bristol, United Kingdom, 31 May 1990 (4 pages with 1 figure and 1 table, available from JMC as RDB1151)

This leaflet introduces the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), initiated in December 1987. The program is designed to expedite the development of toxicology data for possible substitute fluorocarbons to replace chlorofluorocarbons (CFCs), or more broadly halogenated fluoroalkanes, that may be catalyzing a decrease in stratospheric ozone levels. PAFT is a cooperative research effort sponsored by 15 of the leading CFC producers. Four PAFT program sectors are identified including PAFT I to address R-123 and R-134a, PAFT II for R-141b, PAFT III for R-124 and R-125, and PAFT IV for R-225ca and R-225cb. The leaflet summarizes program objectives and schedules. It notes that there are nearly 100 individual toxicology tests in the program, at a cost of $3-5 million per compound. It also indicates that 12 testing laboratories in Europe, Japan, and the United States are performing tests, the results of which will be published in peer-reviewed journals and presented at scientific conferences. The program comprehensively addresses acute, subchronic, developmental and chronic toxicity/-carcinogenicity studies, and environmental studies.

Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries, PAFT, Bristol, United Kingdom, 31 May 1990 (10 pages, available from JMC as RDB1159)

Five data sheets summarize the status and findings of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). They address *HCFC-123 in Comparison with CFC-11*, *HFC-134a in Comparison with CFC-12*, *HCFC-141b in Comparison with CFC-11*, *Other PAFT Programs* (HCFC-124 and HFC-125 compared to CFC-114 and CFC-115, respectively), and a Glossary of Terms. The summaries outline studies of acute toxicity (short-term exposures to high concentrations, such as accidental leakages), genotoxicity (effects on genetic material, an early screen for possible carcinogenic activity), subchronic toxicity (repeated exposure to determine any overall toxicological effect), developmental toxicity (teratology, assessment of the potential for causing birth defects), and chronic toxicity/carcinogenicity (lifetime testing to assess late-in-life toxicity or increased evidence of cancer). Interim results and program plans are summarized for R-123, R-134a, R-141b, R-124, and R-125.

Selected Physical Properties of HCFC-123, HCFC-123a, HCFC-124, HFC-125, HFC-134, HFC-134a, and HFC-143a, preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, May 1990 (1 page with 1 table, available from JMC as RDB0504)

The critical temperature in °F, critical pressure in psia, critical density in lb/cf, boiling point temperature in °F, and molecular weight (relative molecular mass) are tabulated for R-123, R-123a, R-124, R-125, R-134, R-134a, and R-143a. The information presented is preliminary and estimated.

Vapor Thermal Conductivity Correlation, preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, 23 May 1990 (1 page with 1 table, available from JMC as RDB0510)

A correlation is provided to calculate the thermal conductivity of refrigerants, in Btu/hr·ft·°F, in their vapor state as a function of temperature, in °F. Coefficients, based on measurements in the range of 25-70 °C (77-158 °F), are provided for R-123, R-123a, R-124, and R-134a. The information presented is preliminary and estimated.

Vapor Pressure, preliminary information bulletin, AlliedSignal Incorporated, Buffalo, NY, 1 May 1990 (1 page with 1 table, available from JMC as RDB-0511)

An equation is provided to calculate the vapor pressure of refrigerants in psia as a function of temperature in °R. Coefficients are provided for R-123, R-123a, R-124, R-125, R-134, R-134a, and R-143a. The information presented is preliminary and estimated.

April 1990

J. M. Calm, **Research of Alternative Refrigerants**, presentation charts, ARI Spring Meeting, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 2-4 April 1990 (6 pages, RDB0310)

D. A. Fisher, C. H. Hales, D. L. Filkin (E. I. duPont de Nemours and Company, USA), M. K. Ko, N-D. Sze (Atmospheric and Environmental Research, Incorporated, AER, USA), P. S. Connell, D. J. Wuebbles (Lawrence Livermore National Laboratory, LLNL, USA), I. S. A. Isaksen, and F. Stordal (Institute of Geophysics, Norway), **Model Calculations of the Relative Effects of CFCs and Their Replacements on Stratospheric Ozone**, *Nature*, 344(6266):-508-512, 5 April 1990 (5 pages with 3 figures and 4 tables, RDB5851)

alternative refrigerants, reactions and effects of hydrohalocarbons and specifically hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) chemicals, ozone depletion potential (ODP): calculated responses, depicted as ground-level mixing ratios and ozone column change, for single releases of R-11, R-22, and R-123; chemical rate data and ODP values (calculated by four atmospheric modeling groups) for R-10, R-11, R-12, R-22, R-113, R-114, R-115, R-123, R-124, R-125, R-134a, R-140a, R-141b, R-142b, R-143a, and R-152a; uncertainties

D. A. Fisher (E. I. duPont de Nemours and Company), C. H. Hales, W-C. Wang, M. K. W. Ko, and N-D. Sze (Atmospheric and Environmental Research, Incorporated, AER), **Model Calculations of the Relative Effects of CFCs and Their Replacements on Global Warming**, *Nature*, 344(6266):513-516, 5 April 1990 (4 pages, rdb3328)

alternative refrigerants, global warming potential (GWP)

M. Kauffeld, W. J. Mulroy, M. O. McLinden, and D. A. Didion, **An Experimental Evaluation of Two Nonazeotropic Refrigerant Mixtures in a Water-to-Water Breadboard Heat Pump**, report NISTIR 90-4290, National Institute of Standards and Technology (NIST), Gaithersburg, MD, April 1990 (68 pages with 24 figures and 4 tables, available from NTIS, RDB4731)

R-22/114, R-13/12

Sealed-Tube Stability Tests: Ternary Blends (KCD-9430 and 9433), document ARTD-13, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, April 1990 (11 pages with 6 tables, available from JMC as RDB0542)

please see page 6 for ordering information

March 1990

H. D. Baehr (Universität Hannover, Germany), **New Refrigerants, Research into Their Thermodynamic Property Data**, *Proceedings of the 3rd International Energy Agency Heat Pump Conference* (Tokyo, Japan, 12-15 March 1990), edited by T. Saito and Y. Igarashi, Pergamon Press, Elmsford, NY, 243-251, 1990 (12 pages with 1 figure and 3 tables, RDB0406)

review of the research of research on thermodynamic properties of refrigerants in Germany under the Deutsche Forschungsgemeinschaft (DFG) *Schwerpunkt-Programm*; status of thermodynamic property data for R-22, R-123, R-134a, R-142b, R-152a, R-717, R-22/152a/142b, and R-134a/152a; thermophysical properties

I. Borde, M. Jelinek, and N. C. Daltrophe (Ben-Gurion University of the Negev, Israel), **Research on Thermophysical Properties of Absorption Working Fluids at the Energy Laboratory of Ben-Gurion University**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, 37-46, 1990 (10 pages with 9 figures, RDB5527)

R-630 (methylamine, monomethylamine, MMA), dimethylamine (DMA), ethylene glycol (EG), MMA/EG, DMA/EG, R-22/N-methylpyrolidone (R-22/NMP), thermodynamic data, cycle analysis, absorption cycles

R. C. DeVault, **Advanced Absorption Cycles: System Development and Supporting Research**, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, March 1990 (48 pages, rdb1145)

D. A. Didion (National Institute of Standards and Technology, NIST), R. Cohen, and D. R. Tree (Purdue University), **The Role of R-22 in Refrigerating and Air-Conditioning Equipment**, International Colloquium on Refrigeration and CFCs (Brussels, Belgium, March 1990), International Institute of Refrigeration, Paris, France; republished in *Proceedings: Meeting Customer Needs with Heat Pumps - 1991* (Dallas, TX, October 1991), report TR-101944, Electric Power Research Institute (EPRI), Palo Alto, CA, 5-1 - 5-19, December 1992 (19 pages with 6 figures and 3 tables, RDB0921)

T. P. Gross, **Sealed-Tube Tests - Grace Ether (E-134)**, York International Corporation, York, PA, 28 March 1990 (2 pages with 3 tables, available from JMC as RDB0904)

This memo summarizes sealed-tube tests to compare the stability of R-114 and R-E134 when aged for up to 72 hours with several lubricants at temperatures as high as 182 °C (360 °F). The lubricants tested included York C, Zerol(R) 300 alkylbenzene, and UCON LB-165 polyglycol. Aluminum, copper, and iron wires were included as catalysts. R-E134 was found to be somewhat less stable than R-114.

G. Herres and D. Gorenflo (Universität Paderborn, Germany), **Calculations of the Vapour-Liquid Equilibrium of Some Binary Systems of Refrigerants by Various Cubic Equations of State**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, 169-176, 1990 (8 pages with 3 figures and 4 tables, RDB5490)

thermodynamic properties of R-22/114, R-22/115 [R-502], R-7146/12 (blend of SF_6 and R-12), and R-7146/22: Redlich-Kwong-Soave (RKS), Peng-Robinson (PR), Trebble-Bishnoi (TB), Schreiner equations of state (EOS); thermophysical data

M. Jelinek, N. C. Daltrophe, and I. Borde (Ben-Gurion University of the Negev, Israel), **Prediction and Evaluation of the Thermophysical Properties of Monomethylamine and Dimethylamine**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, 123-127, 1990 (5 pages, RDB5453)

R-630 (methylamine), dimethylamine, thermodynamic data, specific volume, enthalpy, entropy

D. Naito (Daikin Industries, Limited), **Alternatives to CFC Refrigerants**, *Proceedings of the 3rd International Energy Agency Heat Pump Conference* (Tokyo, Japan, 12-15 March 1990), edited by T. Saito and Y. Igarashi, Pergamon Press, Elmsford, NY, 713-720, 1990 (8 pages, RDB0407)

M. Okada, T. Umayahara, M. Hattori (Nagaoka University of Technology, Japan), and K. Watanabe (Keio University, Japan), **Measurements of the Surface Tension of HCFC 123 and HFC 134a**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, 69-75, 1990 (7 pages with 4 figures and 2 tables, RDB5629)

R-123, R-134a, transport properties, thermophysical data

I. R. Shankland, **Transport Properties of CFC Alternatives**, unpublished presentation *(Symposium* *on Global Climate Change and Refrigerant Properties*, AIChE Spring National Meeting, Orlando, FL, 18-22 March 1990), Buffalo Research Laboratory, Allied Signal Incorporated, Buffalo, NY, March 1990 (31 pages with 13 figures and 12 tables, available from JMC as RDB0517)

This paper provides transport property data for alternative refrigerants. The data and correlations cover liquid viscosity for R-123, R-123a, R-124, R-125, R-134a, and R-141b; liquid thermal conductivity for R-123, R-123a, R-124, R-125, and R-134a; and vapor thermal conductivity for R-123, R-123a, R-124, and R-141b. Comparative data are provided for R-11, R-12, R-22, R-114, and R-502. The data and correlations are plotted to facilitate comparisons and to illustrate the regression deviations. The paper describes the experimental procedures and estimated accuracies. Thermal conductivity measurements were performed using a transient hot-wire apparatus. Liquid viscosity measurements were performed using an Ubbelohde suspended level capillary type viscometer. The paper notes that the transport properties of the alternatives yield lower performance in some instances, such as foam blowing, when compared to chlorofluorocarbons. In other cases, the properties offer advantages, such as improved heat transfer characteristics for R-134a. One consequence is the need to redesign and optimize systems that utilize the new fluids.

J. G. Smale (DuPont Canada, Incorporated), **New Refrigerants and Mixtures for Heat Pump Opportunities in Canada**, *Proceedings of the 3rd International Energy Agency Heat Pump Conference* (Tokyo, Japan, 12-15 March 1990), edited by T. Saito and Y. Igarashi, Pergamon Press, Elmsford, NY, 1990 (10 pages with 5 figures and 11 tables, RDB2A13)

K. Stephan and R. Krauss (Universität Stuttgart, Germany), **A Database System for Thermophysical Properties of Pure Fluids and Fluid Mixtures**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, 49-55, 1990 (6 pages with 2 figures and 4 tables, RDB5529)

thermodynamic properties, thermophysical data

K. Watanabe (Keio University, Japan), **Current Status of Thermophysical Properties Research on CFC Alternatives**, *Proceedings of the 3rd International Energy Agency Heat Pump Conference* (Tokyo, Japan, 12-15 March 1990) edited by T. Saito and Y. Igarashi, Pergamon Press, Elmsford, NY, 263-282, 1990 (22 pages, RDB0408)

thermodynamic and transport data

K. Watanabe and H. Sato (Keio University, Japan), **Thermophysical Properties Research on Environmentally Acceptable Refrigerants**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, 29-36, 1990 (8 pages with 3 figures, RDB3344)

R-123, R-134a, R-141b, R-142b, blends, thermodynamic properties, thermophysical data

Thermophysical Properties of Pure Substances and Mixtures for Refrigeration, proceedings (Meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, 1990 (278 pages with 33 papers, RDB1103)

thermodynamic data, transport properties

February 1990

D. J. Alofs, M. M. Hasan, and H. J. Sauer, Jr. (University of Missouri at Rolla), **Influence of Oil on Pressure Drop in Refrigerant Compressor Suction Lines**, *Transactions* (Winter Meeting, Atlanta, GA, 10-14 February 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, 96(1), 1990 (rdb4603)

C. J. Andrews, **Designing Strategically for the Possibility of a Future Without R-22 and R-134a**, *Transactions* (Winter Meeting, Atlanta, GA, 10-14 February 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 96(1):1437-1445, 1990 (9 pages with 3 figures, rdb5613)

D. J. Bateman (DuPont Chemicals), **Current Development Status of HFC-134a for Automotive Air Conditioning**, paper 900213 (SAE International Congress and Exposition, Detroit, MI, 26 February - 2 March 1990), Society of Automotive Engineers (SAE), Warrendale, PA, February 1990 (15 pages with 6 figures and 11 tables, RDB2201)

R-134a

D. J. Bateman, D. B. Bivens, R. A. Gorski, W. D. Wells (DuPont Chemicals), R. A. Lindstrom, R. L. Morse, and R. L. Shimon (Tecumseh Products Company), **Refrigerant Blends for the Automotive Air Conditioning Aftermarket**, paper 900216 (SAE International Congress and Exposition, Detroit, MI, 26 February - 2 March 1990), Society of Automotive Engineers (SAE), Warrendale, PA, February 1990 (14 pages with 12 figures and 8 tables, RDB2206)

please see page 6 for ordering information

KCD-9430 [R-22/152a/114 (36/24/40)], KCD-9433 [R-22/152a/124 (36/24/40)], KCD-9451 [R-22/152a/124 (31/24/45)], KCD-9452 [R-22/-152a/114 (30/23/47)], R-12, R-134a

S. J. Eckels and M. B. Pate (Iowa State University of Science and Technology), **A Comparison of R-134a and R-12 In-Tube Heat Transfer Coefficients Based on Existing Correlations**, *Transactions* (Winter Meeting, Atlanta, GA, 10-14 February 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 96(1), 1990; republished in *CFC Alternatives,* technical data bulletin 6(1), ASHRAE, 25-34, June 1990 (10 pages with 16 figures and 2 tables, RDB-2239)

R-12, R-134a, heat transfer

R. El-Bourini, K. Hayashi, and T. Adachi (Calsonic Corporation), **Automotive Air Conditioning System Performance with HFC-134a Refrigerant**, paper 900214 (SAE International Congress and Exposition, Detroit, MI, 26 February - 2 March 1990), Society of Automotive Engineers (SAE), Warrendale, PA, February 1990 (12 pages with 14 figures and 3 tables, RDB2252)

R-134a

S. G. Kandlikar, **A General Correlation for Saturated Two Phase Boiling Heat Transfer Inside Horizontal and Vertical Tubes**, *Journal of Heat Transfer*, 112:219-228, February 1990 (10 pages, rdb3B44)

heat transfer

M. C. MacCracken (Lawrence Livermore National Laboratory, LLNL) et al., **Energy and Climate Change (Report of the DOE Multi-Laboratory Climate Change Committee)**, Lewis Publishers, Chelsea, MI, USA, February 1990 (182 pages, rdb-2313)

global warming, greenhouse gases, environmental impact: emissions, changing atmospheric composition, atmospheric chemistry, radiative forcing of the atmosphere, climatic consequence of composition changes, impacts for the human environment, technological options for response, National Energy Strategy (NES)

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **An Experimental Study for PVT Properties of CFC Alternative Refrigerant 1,1,1,2-Tetrafluoroethane (R-134a)**, *Transactions* (Winter Meeting, Atlanta, GA, 10-14 February 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 96(1):132-140, 1990; republished in *CFC Alternatives*, technical data bulletin 6(1), ASHRAE, 1-9, June 1990 (9 pages with 8 figures and 4 tables, RDB2334)

thermodynamic properties, thermophysical data

T. G. Statt (U.S. Department of Energy), **An Overview of Ozone-Safe Refrigerants for Centrifugal Chillers**, *Transactions* (Winter Meeting, Atlanta, GA, 10-14 February 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, 96(1):1424-1428, 1990; republished in *CFC Alternatives*, technical data bulletin 6(1), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 35-39, June 1990 (5 pages with 2 figures and 5 tables, RDB2335)

R. A. Struss, J. P. Henkes, and L. W. Gabbey (Modine Manufacturing Company), **Performance Comparison of HFC-134a and CFC-12 with Various Heat Exchangers in Automotive Air-Conditioning Systems**, paper 900598 (SAE International Congress and Exposition, Detroit, MI, 26 February - 2 March 1990), Society of Automotive Engineers (SAE), Warrendale, PA, February 1990 (12 pages with 13 figures and 7 tables, RDB2A17)

This paper reviews vehicular wind tunnel tests that were carried out on two automotive air-conditioning systems. The test data compare performance of R-12 and R-134a with various heat exchangers. The vehicles, heat exchangers, test facilities, approach, and findings are reviewed. R-12 was tested with a 525 SUS viscosity mineral oil. R-134a was tested with a proprietary polyalkylene glycol, supplied by DuPont Chemicals. The heat exchangers included both a serpentine and a parallel flow designs. Refrigerant charge requirements were determined by comparative tests. R-134a resulted in higher head pressures, but the same compartment temperatures as with R-12. Heat exchanger selection was found to influence charge levels, indicated as important with use of the more expensive R-134a. An appendix describes the wind tunnel used.

Prospects for Future Climate. A Special US-USSR Report on Climate and Climate Change, edited by M. C. MacCracken (Lawrence Livermore National Laboratory, LLNL), A. D. Hecht, M. I. Budyko, and Y. A. Izrael, Lewis Publishers, Chelsea, MI, USA, February 1990 (270 pages, RDB3971)

global warming, greenhouse gases, environmental impact: past changes, recent trends, changes in atmospheric composition including discussion of halocarbons, projections of future concentrations, theoretical estimates of climate change induced by greenhouse gas, empirical estimating methods, impacts, prospects

January 1990

K. Hearle, F. Riza, A. Whitfield, J. Hemby, J. S. Hoffman, and S. Seidel, **Analysis of the Environmental Implications of the Future Growth in Demand for Partially-Halogenated Chlorinated Compounds**, report EPA 400/1-90-001, U.S. Environmental Protection Agency (EPA), Washington, DC, January 1990 (304 pages, RDB1113)

T. Sabusawa, **Recent Developments in Refrigeration Compressors and Lubrication**, *Japanese Journal of Tribology*, 35(9):1061-1067, January 1990 (7 pages, RDB4B02)

REFPROP, A Program for the Calculation of the Thermodynamic Properties of Refrigerants and Refrigerant Mixtures, description, National Institute of Standards and Technology, Gaithersburg, MD, January 1990 (4 pages, RDB1104)

REFPROP calculates thermodynamic properties of refrigerants, both single component and mixtures. Tables produced by REFPROP can be used in estimating the efficiency and capability for a wide range of equipment with conventional and alternative refrigerants. This user friendly package generates saturation property tables at desired temperatures or pressures, as well as tables of properties with the independent variables chosen from pressure, volume, temperature, entropy, and enthalpy. Dependent variables include those mentioned plus constant-pressure and constant-volume heat capacities, and velocities of sound. Version 1.0 of REFPROP calculates properties for 15 pure refrigerants and 20 binary mixtures. The calculations are based on wide-ranging measurements, including new data for refrigerants R-123, R-124, R-134, and R-134a, as well as revised correlations for R-11, R-13, R-13B1, R-14, R-22, R-23, R-113, R-114, R-142b and R-152a. The Carnahan-Starling-DeSantis (CSD) equation of state (EOS) and ideal gas heat capacities are used. REFPROP runs on IBM-compatible personal computers. Future upgrades will include additional refrigerants and ternary blends.

1990 (month not indicated)

T. Aida, R. Higuchi, and H. Niyama, *Chem. Letters*, 2247-2250, 1990 (4 pages, rdb5252)

decomposition of R-12 over gold catalyst

H. U. Amberg (Gesellschaft Kältetechnik-Klimatechnik mbH, Germany), **Atmospheric Consequences of Chlorofluorocarbons**, *Ki Klima-Kälte-Heizung,* Germany, 18(10):422-426, 1990 (5 pages in German, RDB3C13)

This paper examines the effects of chlorofluorocarbons (CFCs) on the ozone layer. It discusses potential substitutes, including both absorption-cycle chillers using water/lithium bromide (W/LB) and reciprocating liquid chillers using R-22 and R-717 (ammonia). The paper also addresses R-22 chillers supplemented by ice tank, thermal storage. Experience with this option is noted as favorable. For 1000 kW cooling capacity (284 tons), it reduces ozone depletion to less than 1% of that with common R-11 and R-12 centrifugal chillers.

K. Bier, L. R. Oellrich, M. Türk, and J. Zhai (Universität Karlsruhe, Germany), **Untersuchungen zum Phasengleichgewicht von neuem Kältemitteln und Kältemittelgemischen in einem großen Temperaturbereich** [Investigations of the Equilibrium Between Phases of New Refrigerants and Refrigerant Blends in a Wide Range of Temperatures], *Bericht über die Kälte-Klima-Tagung* [Proceedings of the Refrigeration and Air-Conditioning Conference], Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 17(2):233-260, 1990 (33 pages in German, RDB4B48)

saturated conditions, vapor-liquid equilibrium, thermodynamic properties, thermophysical data

T. S. Brown, V. G. Niesen (National Institute of Standards and Technology, NIST), E. D. Sloan, and A. J. Kidnay, **Vapor-Liquid Equilibria for the Binary Systems of Nitrogen, Carbon Dioxide, and n-Butane at Temperatures from 200-344 K**, *Fluid Phase Equilibria*, 53:7-14, 1990 (8 pages, rdb9116)

presents measured vapor-liquid equilibrium (VLE) and density data for R-728/600, R-728/744, and R-744/600 for -73 to 71 °C (-100 to 160 °F)

Z. Y. Chen, P. C. Albright, and J. V. Sengers (University of Maryland), **Crossover from Singular Critical to Regular Classical Thermodynamic Behavior of Fluids**, *Phys. Rev. A*, 41:3161-3177, 1990 (17 pages, rdb9510)

equation of state (EOS) in the critical region

Z. Y. Chen, A. Abbaci, S. Tang, and J. V. Sengers (University of Maryland), **Global Thermodynamic Behavior of Fluids in the Critical Region**, *Phys. Rev. A*, 42:4470-4484, 1990 (15 pages, rdb9508)

equation of state (EOS) in the critical region

D. L. Cooper et al., **Reactions of Hydrofluorocarbons and Hydrochlorofluorocarbons with the Hydroxyl Radical**, *Atmospheric Environment*, 24A(9):2417-2419, 1990 (3 pages, rdb5836)

alternative refrigerants, HFCs, HCFCs, lifetime, reactions

please see page 6 for ordering information

K. Cornwell and J. G. Einarsson (Heriot-Watt University, Scotland), **Influence of Fluid Flow on Nucleate Boiling from a Tube**, *Experimental Heat Transfer*, 3(2):101-116, 1990 (16 pages with 14 figures and 1 table, RDB5547)

R-113; mechanisms of nucleate boiling on the outside of a horizontal tube differ fundamentally from those on a flat plate; variations at the base, top, and sides; influences of bubble formation

F. de Rossi, R. Mastrullo, S. Sibilio (Università di Napoli "Frederico II", Italy), P. Mazzei, and M. Sasso (Università degli Studi di Salerno, Italy), **EASY: Exergetic Analysis of SYstems - Interactive Computer Code for Refrigerants Thermodynamic Properties Evaluation and Exergetic Analysis of Vapor Compression Systems**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, 95-101, 1990 (7 pages with 8 figures, RDB5630)

R-11, R-12, R-13, R-13B1, R-21, R-22, R-23, R-113, R-114, R-114B2, R-115, R-124a [probably R-124], R-134a, R-142b, R-152a, R-C318, R-500, R-502, R-503, R-717, thermodynamic properties, thermophysical data

R. T. Ellington and M. Meo, **Development of a Greenhouse Gas Emissions Index**, *Chemical Engineering Progress*, 86(7):58-63, 1990 (6 pages, rdb5830)

global warming

J. F. Ely and M. L. Huber, **NIST Thermophysical Properties of Hydrocarbon Mixtures (Supertrapp)**, Standard Reference Database (SRD) 4 version 1.0, National Institute of Standards and Technology (NIST), Gaithersburg, MD, 1990 (software and documentation available from NIST, rdb8225)

thermophysical properties of R-50, R-170, R-290, R-600, R-600a, and others as well as mixtures of them

H. R. Engelhorn and A. M. Reinhart, **Investigations on Heat Transfer in a Plate Evaporator**, *Chemical Engineering Proc*., 28:143-146, 1990 (4 pages, rdb-6434)

effects of flow distribution on performance of a compact brazed-plate heat exchanger using R-22 and R-22/114

D. Gorenflo (Universität Paderborn, Germany), K. Stephan, and R. Krauss (Universität Stuttgart, Germany), **Prospects Concerning the Development of Substitute Refrigerants - An Example: R134a (CH_2FCF_3)**, *Proceedings of the International Colloquium (Brussels)*, International Institute of Refrigeration (IIR), Paris, France, 197-226, 1990 (30 pages, rdb5618)

properties, performance, and prospects for use of R-134a

J. E. Hansen and A. A. Lacis, **Sun and Dust versus Greenhouse Gases: An Assessment of their Relative Roles in Global Climate Change**, *Nature*, 346:713-719, 1990 (7 pages, rdb7A76)

environmental impacts

R. Heide and H. Lippold, **Thermophysical Properties of the Refrigerants R 134a and R 152a**, *Progress in the Science and Technology of Refrigeration in Food Engineering* (proceedings of the IIR Conference, Dresden, Germany, 1990), International Institute of Refrigeration (IIR), Paris, France, 237-240, 1990 (4 pages, rdb5487)

R-134a, R-152a, thermophysical data

J. S. Hoffman (U.S. Environmental Protection Agency, EPA), **Replacing CFCs: The Search for Alternatives**, *Ambio*, 19(6-7):329-333, 1990 (5 pages, rdb5839)

alternative refrigerants

International Programme on Chemical Safety (IPCS), **Fully Halogenated Chlorofluorocarbons**, Environmental Health Criteria (EHC) report 113, World Health Organization (WHO), Geneva, Switzerland, 1990 (172 pages with 16 tables, rdb5367)

R-11, R-12, R-13, R-112, R-112a, R-113, R-113a, R-114, R-114a, and R-115: identification; summary properties; analytical methods; sources of human and environmental exposure; environmental transport, distribution, and transformation; environmental levels and human exposure; ecological effects; kinetics and metabolism; effects on laboratory animals; in vitro tests; effects on humans; evaluation of human health risks and effects on the environment; recommendations for protection of human health and the environment; significant reduction in ventilatory lung capacity, bradycardia, and increased variability in heart rate have been noted following exposures to 2,300-21,400 ppm v/v R-114 for 15, 45, or 60 seconds as reported in RDB5340

V. V. Klimenko and M. Fyodorov, **Prediction of Heat Transfer for Two-Phase Forced Flow in Channels of Different Orientation**, *Heat Transfer 1990* (proceedings of the Ninth International Heat Transfer Conference, Jerusalem, Israel), Hemisphere Publishing Corporation, New York, NY, 5:65-70, 1990 (6 pages, rdb4973)

mechanistic method to predict the transition from stratified to unstratified flow during boiling

H. H. Kruse and M. Kauffeld (Universität Hannover, Germany), **Kaltluftkältemaschinen nach dem Joule-Prozess** [Air-Cycle Refrigeration Equipment Based on the Joule Process], *Ki Klima-Kälte-Heizung*, 18(5):206-211, 1990 (6 pages in German, rdb6930)

R-729 (air), air-cycle refrigeration

A. A. Lacis, D. J. Wuebbles (Lawrence Livermore National Laboratory, LLNL), and J. A. Logan, **Radiative Forcing of Climate by Changes in the Vertical Distribution of Ozone**, *Journal of Geophysical Research* (JGR), 95:9971-9981, 1990 (12 pages, rdb7A35)

stratospheric ozone depletion and global climate change, interactions

P. A. LaRue, **Vapour-Liquid Equilibrium Measurements**, technical report 664-DE00521, Centre de Recherche Industrielle du Québec, Québec, Canada, 1990 (rdb4206)

thermodynamic properties, thermophysical data, VLE

D. A. Lashof and D. R. Ahuja, **Relative Contributions of Greenhouse Gas Emissions to Global Warming**, *Nature*, 344:529-531, 1990 (3 pages, rdb7C33)

climate change, environmental impacts, global warming, role of fluorochemical refrigerants

R. J. Lewis, Sr., **Hazardous Chemicals Desk Reference** (second edition), Van Nostrand Reinhold Publishers, New York, NY, 1990 (rdb5165)

flammability, toxicity, and other safety data

C-C. Piao (Keio University, Japan), Y. Ikeya (Sumitomo Heavy Industries, Limited, Japan), H. Sato (Keio), and K. Watanabe (Keio), **An Experimental Study of Isobaric Specific Heats for CFC Alternatives**, paper B106, *Proceedings of the 11th Japan Symposium on Thermophysical Properties*, 99-102, 1990 (4 pages with 8 figures, RDB4A57)

isobaric specific heats of R-22 and R-134a in their gaseous phases; thermodynamic properties; thermophysical data

B. Platzer, A. Polt, and G. Maurer, **Thermophysical Properties of Refrigerants**, Springer Verlag, Berlin, Germany, 1990 (488 pages, rdb4C09)

thermodynamic data, transport data

G. K. Lavrenchenko, M. G. Khmelnuk, G. Ya. Ruvinskij, V. F. Vozniy (Kiev NPO "Vesta", Russia), **Energy Characteristics of Cycles for Small Refrigerating Machines Using R-134a**, *Kolloidnyi Tekhnika* [Refrigeration Technology], 7:14-18, 1990 (in Russian, rdb3C10)

This paper examines the refrigerating effect and efficiency of R-134a as a replacement for R-12. R-134a is indicated to be suitable for use in home refrigerators, but the efficiency is reduced in refrigerator/freezers.

G. Morrison and J. S. Gallagher (National Institute of Standards and Technology, NIST), **REFPROP: A Thermodynamic Properties Software Program for Refrigerants and Their Mixtures**, publication unknown, 1990 (12 pages with 2 figures, available from JMC as RDB0914)

This paper introduces REFPROP, a computer software package that produces tables of thermodynamic properties for 15 refrigerants and 20 of their binary mixtures. It addresses the Carnahan-Starling-DeSantis (CSD) equation of state chosen for property calculations, the software subroutines included, and sources used to obtain the incorporated property data. The paper compares output to source data for R-123.

S. Nakagawa, H. Sato, and K. Watanabe (Keio University, Japan), **Specific Heat at Constant Pressure for Liquid New Refrigerants**, *Proceedings of the 27th National Heat Transfer Symposium of Japan*, Nagoya, Japan, 421-423, 1990 (rdb5439)

thermodynamic properties, thermophysical data

V. G. Niesen (National Institute of Standards and Technology, NIST), **Critical Locus, (Vapor + Liquid) Equilibria, and Coexisting Densities of (Carbon Dioxide + Propane) at Temperatures from 311 to 361 K**, *Journal of Chemical Thermodynamics*, 22:777-795, 1990 (19 pages, rdb9115)

presents measured vapor-liquid equilibrium (VLE) and density data for R-744/290 for 38-88 °C (100-190 °F)

S. F. Pearson (Star Refrigeration Limited), **Refrigeration after CFCs**, *Proceedings of the Low Temperature Engineering and Cryogenics Conference*, Southampton, 1990 (rdb2237)

R-403A and R-403B

M. J. Prather (National Aeronautics arid Space Administration, NASA), and C. M. Spivakosky, **Tropospheric OH and the Lifetimes of Hydrochlorofluorocarbons (HCFCs)**, *Journal of Geophysical Research* (JGR), 95:18723-18729, 1990 (7 pages, rdb8108)

environmental impacts, scaling method to determine the partial lifetime due to removal in the troposphere via reaction with the hydroxyl radical

W. Rott, **Zum Wärmeübergang and Phasengleichgewicht siedener R22/114-Kältemittel-Gemische** [On the Boiling Heat Transfer and

please see page 6 for ordering information

Phase Equilibrium of R-22/114 Refrigerant Mixtures], dissertation, Universität Paderborn, Germany, 1990 (RDB5491)

R-22/114

H. Seiki, **Recent Trend of Compressor Oils**, *Journal of the Japanese Society of Tribologists*, 35(9):615-620, 1990 (6 pages, rdb4C36)

P. Sokol, H. Schömann, W. Rott, and D. Gorenflo (Universität Paderborn, Germany), **Heat Transfer During Nucleate Boiling of New Refrigerants**, *DKV-Tagungsberichte* (Heidelberg, Germany, November 1990), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 17(2):323-339, 1990; translated by Quest Technology, Incorporated (file QU0467), Arlington Heights, IL (24 pages with 8 figures and 4 tables, RDB3A18)

R-12, R-22, R-113, R-114, R-123, R-134a, R-227ea

G. Stängl and F. Mayinger (Technische Universität München, TUM, Germany), **Void Fraction Measurement in Subcooled Forced Convective Boiling with Refrigerant-12**, *Experimental Heat Transfer*, 3(3):323-340, 1990 (18 pages with 17 figures, rdb6808)

void fraction and pressure drop of R-12 in forced, convective boiling; prediction model based on drift flux

K. H. U. Ström (Chalmers University of Technology, Sweden), **A Study of Molar Volumes for Some Pure Halogenated Hydrocarbons and their Binary Mixtures**, *Canadian Journal of Chemical Engineering*, 68:645-651, 1990 (7 pages, rdb7C58)

R-12/R-114, R-22/114, and others: thermodynamic properties, thermophysical data, Thomson-Brobst-Hankinson (TBH), Lee-Kesler-Plöcker (LKP), Carnahan-Starling-DeSantis (CSD) equations of state (EOS)

Y. Takaishi and K. Oguchi (Kanagawa Institute of Technology, Japan), **Vapor Pressures of R12/Oil and R22/Oil Mixtures**, *Nippon Reito Kyokai Ronbunshu* [Transactions of the JAR], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 7:75-84, 1990 (10 pages in Japanese, rdb5435)

R-12, R-22, mineral oil

J. P. Wattelet, **Design, Building, and Baseline Testing of an Apparatus Used to Measure Evaporation Characteristics of Ozone-Safe Refrigerants**, MS thesis (Department of Mechanical Engineering), University of Illinois at Urbana-Champaign, Urbana, IL, 1990; republished with J. C. Chato as report TR-2, Air-Conditioning and Refrigeration Center (ACRC), University of Illinois at Urbana-Champaign, Urbana, IL, August 1990 (141 pages, rdb3B53)

heat transfer

J. Yata, **Thermal Conductivity of Alternatives to CFCs**, *Proceedings of the Eleventh Japan Symposium on Thermophysical Properties*, 143-146, 1990 (4 pages, rdb3920)

R-123 and others: thermophysical data

S. M. You, T. W. Simon, A. Bar-Cohen, and W. Tong, **Experimental Investigation of Nucleate Boiling Incipience with a Highly-Wetted Dielectric Fluid (R-113)**, *International Journal of Heat and Mass Transfer*, 33(1):105-117, 1990 (13 pages, rdb3B62)

1990-1991 Threshold Limit Values for Chemical Substances in the Work Environment, *1990-1991 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, The American Conference of Government Industrial Hygienists (ACGIH), Cincinnati, OH, 1-49 and notes, 1990 (55 of 132 pages with 2 tables and 4 appendices, RDB2B05)

This book provides data for use as guidelines or recommendations in the control of potential hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include common refrigerants based on both chronic and acute effects. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document also lists intended changes and provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter.

Boundary Lubrication of Ternary Blends (KCD-9430 and 9433), document ARTD-12, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1990 (3 pages with 1 table, available from JMC as RDB0541)

This document summarizes a study to determine the lubricity of a 150 SUS viscosity alkylbenzene (Shrieve Zerol(R) 150) lubricant with two developmental refrigerants, KCD-9430 and KCD-9433. Both are ternary zeotropic blends,

R-22/152a/114 (36/24/40) and R-22/152a/124 (36/24/40), respectively. Measurements were made using a modified Falex pin and v-block test machine, with refrigerant bubbled through the lubricant; the test procedure is outlined. Failure loads are tabulated for the lubricant alone, with R-12 for comparison, and with the two blends. Data are provided for the neat lubricant, with two unidentified additives, and with both additives together. The document concludes that the alkylbenzene lubricant with additives provides acceptable lubrication with either blend. The refrigerant-lubricant mixtures were deemed suitable for further compressor durability testing.

Guide to Occupational Exposure Values - 1990, The American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1990 (122 pages, RDB3902)

This reference document compares the most recent toxicity exposure limits. It includes Threshold Limit Values (TLV) from the American Conference of Governmental Industrial Hygienists (ACGIH), the 1989 amended Permissible Exposure Limits (PEL) from the Occupational Safety and Health Administration (OSHA) [subsequently vacated pursuant to a court order], the Recommended Exposure Limits (REL) from the National Institute for Occupational Safety and Health (NIOSH), and the 1989 maximale Arbeitsplatz Konzentrationen [maximum workplace concentration] (MAK) and biologischer Arbeitsstoff-Toleranz-Wert [biological tolerance value] (BAT) from the Deutsche Forschungsgemeinschaft [German Research Association] (DFG) Commission for the Investigation of Health Hazards of Chemical Compounds in the Workplace. It also identifies carcinogens found in the workplace that are identified by the above organizations, the International Agency for Research on Cancer (IARC), and the U.S. National Toxicology Program (NTP). The refrigerants addressed include R-11, R-12, R-12B2, R-21, R-22, R-30, R-40, R-114, R-115, R-170 (ethane), R-290 (propane), R-600 (butane), R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-7146 (sulfur hexafluoride), and others.

Oils for Alternative Refrigerants, document ARTD-11, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1990 (4 pages with 1 figure and 2 tables, available from JMC as RDB0540)

This bulletin reviews the properties desired in developmental lubricants, including acceptable solubility, lubricity, stability, compatibility, toxicity, and cost. Test results are reported for non-proprietary oils with ternary zeotropic blends and for proprietary lubricants with R-134a. The solubility of four unidentified polyalkylene glycols (PAGs) with different viscosities, covering appliance through automotive applications, are plotted for mixtures with R-134a. Their phase separation indicates incomplete solubility, as contrasted to full solubility for mineral oils used with R-12. Implications on flow, heat transfer, and oil return are briefly mentioned. The results of stability tests with aluminum, copper, and steel coupons are tabulated for R-12 with both naphthenic and paraffinic mineral oils and for R-134a with a PAG. One test is included with nylon also present. The results indicate that the R-134a and PAG system has acceptable stability. Plans for ongoing and future tests are noted. Solubility and lubricity tests for mineral oils and alkylbenzenes with ternary zeotropic blends, comprising R-22/152a/114 (36/24/40) and R-22/152a/124 (36/24/40), are briefly reviewed. They indicate that the mineral oils did not meet solubility goals. The blend and alkylbenzene systems did not perform favorably without additives, but responded well with addition of extreme pressure (EP) additives already used in air-conditioning and refrigeration systems. Chemical stability test results are tabulated for two paraffinic and one naphthenic mineral oils and an alkylbenzene lubricant (all unidentified) with R-12 and the two zeotropes. Qualitative findings are presented for liquid color, effect on metals, and copper plating; quantitative data are included for chloride and fluoride ion content. The bulletin concludes that the blend-alkylbenzene combination is more stable than R-12/mineral oil systems and that the blend containing R-124 (KCD-9433) is more stable than that containing R-114 (KCD-9430). Further test needs are briefly summarized.

PAFT Update, document H-24080-1, DuPont Chemicals, Wilmington, DE, undated, circa 1990 (4 pages with 2 tables, available from JMC as RDB-1156)

This bulletin outlines the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) and summarizes both the testing schedule and interim findings. It indicates that PAFT is designed to expedite the development of toxicology data for possible substitute fluorocarbons. The programs integrate past and present toxicological information to perform a careful risk assessment. The bulletin identifies the main types of studies conducted by PAFT. They include acute toxicity by several different routes of exposure, genotoxicity, subchronic toxicity by inhalation, developmental toxicity by teratology and inhalation, chronic toxicity and carcinogenicity by inhalation, and environmental toxicity. A table gives the schedule for testing, bro-

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ken into phases the longest of which requires four years. Four programs are identified: PAFT I, which began in 1987, covers R-123 and R-134a. PAFT II, initiated in 1988, addresses R-141b. PAFT III, begun in late 1989, is studying R-124 and R-125. PAFT IV, established in May 1990, will examine R-225 isomers for solvent cleaning. A table summarizes key results as of June 1990 for the fluids names as well as for R-11 and R-12 for comparison. The data include ALC/LC_{50}, oral LD_{50}, cardiac sensitization thresholds, Ames assay, in vivo mutagenicity, subchronic no observed effect level (NOEL), teratogenic, chronic inhalation, and flammability data. The completion schedule and recommended exposure limits are included.

Policy Options for Stabilizing Global Climate, Report to Congress, edited by D. A. Lashof and D. A. Tirpak, Office of Policy, Planning and Evaluation, U.S. Environmental Protection Agency (EPA), Washington, DC, 1990 (rdb4363)

climate change, environmental impacts, global warming

Production, Sales and Calculated Release of CFCs 11 and 12 through 1989, Chemical Manufacturers Association (CMA), Washington, DC, 1990 (rdb3127)

production and emission data for R-11 and R-12

Production, Sales and Calculated Release of CFCs 113, 114 and 115 through 1989, Chemical Manufacturers Association (CMA), Washington, DC, 1990 (rdb3128)

production and emission data for R-113, R-114, and R-115

Scientific Assessment of Stratospheric Ozone: 1989 (**Appendix: AFEAS Report)**, report 20, World Meteorological Organization (WMO), Geneva, Switzerland, II, 1990 (536 pages, available from AFEAS, also available from JMC as RDB1117)

Summary of Physical Property, Solubility, and Compatibility Data for [HC]**FC-123**, report NIST-9, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1990 (11 pages with 3 figures and 4 tables, available from JMC as RDB0305)

Liquid density, vapor pressure, viscosity, surface tension, and Kauri-butanol number are provided for R-123. The solubility of water and various substances in R-123 also are given. Additionally, the report qualitatively summarizes compatibility tests with various magnet wire varnishes, including Alkanex terephthalate polyester, enamel oleoresin, Ensolex acrylic, epoxy, Anavar isocyanate-modified polyvinyl, Lecton acrylic, Nylclad nylon-coated polyvinyl, polyimide, polyurethane, and Formvar polyvinyl.

Ternary Refrigerant Blends, document ARTD-10, E. I. DuPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1990 (6 pages, available from JMC as RDB0539)

Ternary Refrigerant Blends for the Automotive Aftermarket, document ARTD-1, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1990 (12 pages with 9 figures and 7 tables, available from JMC as RDB0535)

Test results for R-22/152a/114 (36/24/40) (blend KCD-9430) and R-22/152a/124 (36/24/40) (blend KCD-9433) for automotive use; concludes that the blends are not *drop-in* replacements for R-12, but that technologies exist or can be developed to accomplish retrofit while maintaining acceptable performance; topics covered include environmental impacts; toxicity; properties; flammability; compatibility data for hoses constructed of nylon, DuPont Hypalon® 48, nitrile; compatibility data for elastomers including epichlorohydrin, neoprene, nitrile; compatibility data for molecular-sieve desiccants; and solubility and lubricity data for BVM-100N, Idemitsu, and Mopar mineral oils and Zerol® 500 alkylbenzene oils, the last with three additives for the lubricity tests.

Thermodynamic Properties of [H]**FC-134a**, report NIST-6, E. I. DuPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1990 (27 pages with 2 tables, available from JMC as RDB0302)

This report provides thermodynamic property data for R-134a in inch-pound (IP) units of measure calculated with the Redlich-Kwong equation of state. A table presents pressure, volume, density, enthalpy, and entropy at saturated conditions for the temperature range of -73 to 100 °C (-100 to 212 °F) in 0.6 °C (1 °F) increments and for the critical temperature of 100.6 °C (213.0 °F). A second table presents volume, enthalpy, and entropy data for superheated vapor at constant pressure.

1989

December 1989

H. Honda, B. Uchima, S. Nozu, H. Nakata, and E. Torigoe (Okayama University, Japan), **Film Condensation of Downward Flowing R113 Vapour on In-Line Bundles of Horizontal Finned Tubes**, *Heat Transfer with Phase Change* (Winter Annual Meeting, San Francisco, CA, 10-15 December 1989), edited by I. S. Habib and R. J. Dallman, American Society of Mechanical Engineers (ASME), New York, NY, HTD-108:117-125, 1989 (9 pages, rdb5733)

R-113, heat transfer, enhanced tubes

T. Suzuki, Y. Kai, S. Enomoto, and T. Sakai, **Refrigerator Lubricating Oil**, *Kokai Tokkyo Kono*, Japan, December 1989 (rdb4B20)

November 1989

T. Atwood (AlliedSignal Incorporated), **The Need for Standardized Nomenclature for Refrigerants**, *ASHRAE Journal*, 31(11):44-47, November 1989 (3 pages with 1 table, RDB0545)

J. M. Calm (Air-Conditioning and Refrigeration Institute, ARI), **Composition Designations for Refrigerants**, *ASHRAE Journal*, 31(11):48-51, November 1989 (3 pages, available from JMC as RDB0546)

This paper provides recommendations for consistent use of prefixes for refrigerant designations. The need for uniform nomenclature and a survey, performed for the Technology Council and the Research and Technical Committee (R&T) of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), are summarized. The requirement surfaced with increasing regulatory and legislative actions to limit production, use, and emission of refrigerants of environmental concern. A variety of composition-designating identifiers were introduced to distinguish between refrigerants, but nonuniform usage resulted in confusion rather than clarification. [The recommendations of this paper were incorporated into ASHRAE Standard 34-1992, see RDB2909]

J. E. Hansen, A. A. Lacis, and M. J. Prather (National Aeronautics and Space Administration, NASA), **Greenhouse Effects of Chlorofluorocarbons and Other Trace Gases**, *Journal of Geophysical Research* (JGR), 94(D13):16417-16421, November 1989 (5 pages, rdb5557)

environmental impacts

J. Paul (Integral Technologie GmbH, Germany), **Wasser als Kältemittel** [Water as a Refrigerant], *Bericht über die Kälte-Klima-Tagung* [Proceedings of the Refrigeration and Air-Conditioning Conference] (Hannover, Germany, 22 November 1989), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 1989 (in German, rdb4A72)

R-718

L. M. Schlager, M. B. Pate, and A. E. Bergles, **Performance of Micro-Fin Tubes with Refrigerant 22 and Oil Mixtures**, *ASHRAE Journal*, 31(11):17-28, November 1989 (12 pages with 8 figures and 2 tables, rdb2243)

R-22, naphthenic mineral oil, copper tubes, micro fin and low fin surface enhancement, heat transfer

H. O. Spauschus (Georgia Institute of Technology), **Refrigerant Mixtures - Challenges and Opportunities**, *ASHRAE Journal*, 31(11):38-41, November 1989 (rdb4234)

Compatibility of Elastomers with the Ternary Blends of HCFC-22/HFC-152a/CFC-114 and HCFC-22/HFC-152a/HCFC-124, document ARTD-3, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 7 November 1989 (26 pages, available from JMC as RDB0537)

R-22/152a/114, R-22/152a/124

October 1989

K. Bärnthaler, J. Fresner, and H. Schnitzer (Technische Universität Graz, Austria), **Ethyl Chloride - A New Working Medium for Compression Heat Pumps with Low Ozone Depletion Potential**, Proceedings of the Fifth International Symposium on Solar Energy, Heat Pumps, and Floor Heating, Istanbul, Turkey, 23-24 October 1989 (rdb4332)

R-160

H. Kawahira, Y. Kubo, T. Yokoyama (Tokyo Electric Power Company, Japan), and J. Ogata (Mitsubishi Heavy Industries, Limited, Japan), **The Effect of an Electric Field on Boiling Heat Transfer of Refrigerant-11 - Boiling on a Single Tube**, paper IUSD 87-61, *IEEE Transactions on Industry Applications* (Industry Applications Society Annual Meeting, Atlanta, GA, 19-23 October 1989), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 26(2):359-365, March/April 1990 (7 pages with 9 figures, rdb3C20)

This paper summarizes an experimental investigation of the effect of an electric field on pool boiling of R-11 on a single, smooth tube with several rows of electrodes. It reviews prior studies and describes, and illustrates the experimental apparatus. The paper discusses the influences of 0-2% (by weight) mineral oil (Witco Suniso(R) 4GS), the surface roughness of the test tube, and the strength and polarity of an

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applied voltage. The paper concludes that: 1) the number of boiling bubbles decreases but the heat transfer coefficient increases as the applied voltage increases; 2) the polarity of the applied voltage affects the boiling heat transfer (a negative direct current electric field yields better heat transfer with neat refrigerant), and 3) a negative field does not adversely affect heat transfer for a refrigerant-oil mixture, but enhanced transfer results in a positive field.

S. C. McDonald, **International Aspects of Restrictions on Ozone-Depleting Substances**, report PNL-7163, Pacific Northwest Laboratory, Richland, WA, October 1989 (72 pages with 7 tables, available from NTIS, RDB2B06)

This report summarizes international efforts related to protection of stratospheric ozone as well as implications for the United States. It includes a discussion of activities in other countries to meet restrictions in production and use of ozone-depleting substances (ODSs). Data are presented on use of controlled ODSs in these countries. The document concludes with presentation of trade and international competitiveness issues relating to transition to alternatives to the regulated chlorofluorocarbons and halons. Information is provided on foreign chemical manufacture and the search for alternatives to regulated substances. Appendices identify participants in the Vienna Convention and Montreal Protocol, a draft declaration from the Helsinki meeting in May 1989 of parties to the Montreal Protocol, and the 1987 text of the Protocol itself.

L. A. Weber (National Institute of Standards and Technology, NIST), **Vapor-Liquid Equilibrium in Binary Systems of Chlorotrifluoromethane with n-Butane and Isobutane**, *Journal of Chemical and Engineering Data*, 34:452-455, October 1989 (4 pages with 4 figures and 4 tables, RDB6706)

thermodynamic properties of R-13/600 and R-13/600a fit to Peng-Robinson (PR) equations of state (EOS): measurements of the vapor-liquid equilibrium (VLE) phase compositions at 38, 77, and 127 °C (100, 170, and 260 °F); presents derivations of Henry's constants, an indicator of gas solubility in the liquid; compares their temperature behavior with predicted values

Investigation of Horizontal Tube Falling-Film Absorbers, research project 405-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1985 - October 1989 (ASH0405)

The contractor for the project was the University of Texas at Austin, led by G. C. Vliet; it was sponsored by ASHRAE Technical Committee 8.3, *Absorption and Heat-Operated Machines.*

Isotron 12 (CFC-12) Toxicology Data Summary, Elf Atochem North America, Incorporated, King of Prussia, PA, October 1989 (RDB5146)

R-12, toxicity

Report to the Secretary of Energy on Ozone-Depleting Substances, U.S. Department of Energy, Washington, DC, October 1989 (63 pages, RDB-1112)

analysis of the energy and economic effects of phasing out certain organic chlorine and bromine products

September 1989

J. L. Boot (Whirlpool Corporation), **An Overview of CFC Alternatives for Domestic Refrigerators and Freezers**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 75-80, 1990; republished in *International Journal of Refrigeration* (IJR), 13(2):100-105, February 1990 (6 pages with 8 figures and 4 tables, RDB3121)

alternative refrigerants

D. A. Didion (National Institute of Standards and Technology, NIST) and D. B. Bivens (DuPont Chemicals), **The Role of Refrigerant Mixtures as Alternatives to CFCs**, *CFCs: Today's Options -Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 57-69, 1990; *International Journal of Refrigeration* (IJR), 13(5):163-175, May 1990 (13 pages with 33 figures, RDB2C04)

azeotropic and zeotropic blends

F. C. Hayes (The Trane Company), **Centrifugal Water Chillers**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 71-73, 1990 (3 pages with 4 tables, RDB3120)

R-11, R-12, R-22, R-114, R-123, R-134a, R-290, R-500, R-717, usage, emissions, new designs, conversions, environmental impacts

D. Jung (University of Maryland), M. O. McLinden (National Institute of Standards and Technology, NIST), R. K. Radermacher (University of Maryland), and D. A. Didion (NIST), **A Study of Flow-Boiling Heat Transfer with Refrigerant Mixtures**, *Interna-*

tional Journal of Heat and Mass Transfer, 32(9):1751-1764, September 1989 (14 pages, rdb-2348)

flow boiling of zeotropic blends inside smooth tubes; prediction correlations

W. L. Kopko (York International Corporation), **Beyond CFCs: Extending the Search for New Refrigerants**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE's CFC Technology Conference, National Institute of Standards and Technology, Gaithersburg, MD, September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 39-46, 1990; republished in *International Journal of Refrigeration* (IJR), 13(3):79-85, March 1990 (8 pages 6 figures and 3 tables, RDB2304)

H. H. Kruse (Universität Hannover, Germany), **CFC Research Activities in Europe**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 97-106, 1990; republished in *International Journal of Refrigeration* (IJR), 13(3):122 ff, March 1990 (10 pages with 11 figures and 3 tables, RDB3123)

L. J. M. Kuijpers (Phillips Research Laboratories, The Netherlands), **UNEP Assessment of the Montreal Protocol: Refrigeration within the Framework of the Montreal Protocol**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1-4, 1990 (4 pages, RDB2109)

This paper outlines the process for assessment of the Montreal Protocol under the auspices of the United Nations Environment Programme (UNEP). The introduction identifies both the panels involved and their chairmen, including that on "*Refrigeration, Air Conditioning, and Heat Pumps*." It is chaired by the paper's author and is a part of the larger Technology Review Panel. The paper reviews the drafting process and schedule for a Technical Options Committee (TOC) report, a peer reviewed document prepared by approximately 50 experts in the area. It then summarizes its key conclusions. The paper concludes that chlorofluorocarbon (CFC) consumption can be substantially reduced by following good practices and substituting other products or processes. It suggests that a reduction of 85-90% referenced to 1986 consumption levels is feasible by 2000, assuming availability of substitutes by 1994.

M. J. Kurylo (National Aeronautics and Space Administration, NASA, and National Institute of Standards and Technology, NIST), **The Chemistry of Stratospheric Ozone: Its Response to Natural and Anthropogenic Influences**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 5-15, 1990 (11 pages with 1 figure and 3 tables, RDB2110)

M. O. McLinden (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of CFC Alternatives - A Survey of Available Data**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 17-31, 1990; republished in *International Journal of Refrigeration* (IJR), 13(3):149-162, May 1990 (15 pages with 29 figures and 5 tables, available from JMC as RDB0912)

Thermodynamic properties, from a variety of sources including unpublished data, are summarized for ten potential substitutes for CFC refrigerants. The fluids include R-22, R-23, R-32, R-123, R-124, R-125, R-134a, R-142b, R-143a, and R-152a. The data include triple-point, normal boiling point, and critical point parameters, and the temperature dependence of the vapor pressure saturated liquid density, and ideal-gas data heat capacity. Also considered are single-phase PVT data. The saturation and ideal-gas data are fit to simple correlations.

E. B. Muir (Copeland Corporation), **Commercial Refrigeration and CFCs**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 81-86, 1990 (6 pages with 19 figures and 1 table, RDB3122)

K. Ushimaru (Energy International, Incorporated), **Impact of CFC Curtailment on Refrigeration and Mitigation Research in Japan**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE's 1989 CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 107-117, 1990; republished in *International Journal of Refrigeration* (IJR), 13(3):131-141, March 1990 (10 pages with 10 figures and 2 tables, RDB1205)

This paper focuses on efforts in Japan to develop technical options for reducing CFC emissions. Alternative refrigerants for R-12 (used in

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automobile air-conditioners and residential refrigerators) and R-113 (used extensively as a solvent and cleaning agent) are presented. CFC mitigation options are discussed for control technologies, work practices and economics, chemical substitutes, and product substitutes. Japan's usage profile and historical background on its environmental responsiveness are addressed. The article notes that R-113 recovery and recycling equipment are already marketed in Japan and that the demand for this equipment is projected to grow to $15 billion by 1998. Additionally, leading Japanese chemical producers are moving forward with plans for the production of R-134a as a substitute for R-12.

I. R. Shankland (AlliedSignal Incorporated), **CFC Alternatives for Thermal Insulation Foams**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE's CFC Technology Conference, National Institute of Standards and Technology, Gaithersburg, MD, September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 87-95, 1990; republished in *International Journal of Refrigeration* (IJR), 13(2):113-121, February 1990 (9 pages, RDB0518)

H. O. Spauschus (Spauschus Associates, Incorporated), **Compatibility Requirements for CFC Alternatives**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 33-38, 1990; *International Journal of Refrigeration* (IJR), 13(3):73-78, March 1990 (6 pages, RDB1101)

This paper reviews the materials compatibility and fluid property information required for design and successful commercial application of air-conditioning and refrigeration equipment. Information on alternative refrigerants, including the leading candidates, future prospects, and long-term possibilities, are summarized. Methods of predicting compatibility based on structural information and modeling are proposed.

W. F. Stoecker (University of Illinois at Urbana-Champaign), **Expanded Applications of Ammonia - Coping with Releases to the Atmosphere**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 47-55, 1990 (9 pages with 18 figures, RDB2111)

R-717, venting, dispersion

CFCs: Today's Options - Tomorrow's Solutions (proceedings of 1989 ASHRAE CFC Technology Conference, Gaithersburg, MD, September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1990 (128 pages with 13 papers, RDB1139)

August 1989

P. A. Domanski, **EVSIM - An Evaporator Simulation Model Accounting for Refrigerant and One Dimensional Air Distribution**, report NISTIR 89-4133, National Institute of Standards and Technology (NIST), Gaithersburg, MD, August 1989 (148 pages with 15 figures and 6 tables, available from NTIS, RDB4729)

heat and mass transfer

Y. You (Yangzhou Industrial Institute, China), Y. T. Ma, and C. R. Lu (Tianjin University, China), **A New Heat Pump System of Continuous Capacity Control with Nonazeotropic Mixtures**, paper 899420, proceedings of the 24th Intersociety Energy Conversion Engineering Conference (IECEC, Washington, DC, 6-11 August 1989), publication CH2781-3, Institute of Electrical and Electronic Engineers (IEEE), New York, NY 6:2117-2119, 1989 (3 pages with 2 figures, RDB3C18)

This paper presents a conceptual approach to continuously modulate the capacity of a heat pump, without performance loss, by controlling the composition of the zeotropic mixture used as its refrigerant. The concept is compared to systems proposed by others. The authors conclude that the new scheme is comparatively simple in structure, convenient to operate, and has a wide range of modulation. The new system can automatically control the composition based on changes in the indoor-air or return water temperature. No specific zeotropes are cited, but a schematic of the heat pump and a generic temperature-composition diagram, showing dew-point and bubble-point curves, are given.

Impact of a CFC Ban on the Cost and Performance of Household Refrigerators, Centrifugal Chillers, and Commercial/Industrial Systems, technical memorandum to U.S. Department of Energy, Arthur D. Little, Incorporated, Cambridge, MA, August 1989 (82 pages, RDB1110)

This report assesses the potential response of and impacts on the refrigeration industry to a regulatory ban on the production of CFC working fluids by the year 2000. The primary focus is on the most likely alternatives, in each application category, and their impact on the design and performance of new equipment.

Potential Costs of Restricting Chlorofluorocarbon Use, report SR/ESD/89-01, Energy Information Administration, U.S. Department of Energy, Washington, DC, August 1989 (88 pages with 33 figures, 10 tables, and 2 appendices, RDB1111)

This report analyzes economic costs for the United States to phase out production of chlorofluorocarbons (CFCs) by the year 2000. CFCs are divided into two groups for the study, one comprising foams, solvents, and fire extinguishants and one for application in refrigeration and air conditioning. The latter is addressed by analyzing the phase out costs for new equipment, impacts on energy efficiency and the economy, and premature obsolescence of existing equipment. The report reviews CFC uses, substitutes, problems associated with phase out, the assessment of impacts, and comparison with a separate but related study. The report concludes that substitutes will increase costs by 2% in new equipment, equating to an increase of $6.4-12.5 billion in 1989 dollars. It also found a 1.2% decrease in energy efficiency, leading to 30-90 TWh (0.1-0.3 quadrillion Btu) higher primary energy use. The largest impact would result from premature obsolescence costs, as high as $13-2 billion with 75% attributable to automobile air conditioners.

Research Needs for Energy Efficient Alternatives to Chlorofluorocarbons, request for proposals DE-RP01-89ER30155, U.S. Department of Energy (DOE), Washington, DC, August 1989 (170 pages, RDB1141)

July 1989

H. B. Ginder, **R-123 versus R-11 Performance Test**, York International Corporation, York, PA, 19 July 1989 (2 pages with 1 table, available from JMC as RDB0008)

The performance of a 200-ton chiller, designed for R-11 operation, is compared at nominal rating conditions for R-123 and R-11 with a naphthenic oil. The chiller employs a single-stage centrifugal compressor with an open drive and air-cooled motor. The results at full load indicate a 16.3% reduction in capacity and an increase of 9.2% in kW/ton (8% lower efficiency. Although testing at loads of 20-100% capacity and varied evaporator and condenser conditions are indicated, part-load performance is not reported.

K. G. Joback and G. Stephanopoulos (Massachusetts Institute of Technology, MIT), **Designing Molecules Possessing Desired Physical Property Values**, *Foundations of Computer-Aided Process Design* (proceedings of the Third International Conference on Foundations of Computer-Aided Process Design, FOCAPD, Snowmass, CO, 10-14 July 1989), Elsevier, New York, 363-387, 1989 (22 pages with 7 figures and 13 tables, RDB7702)

strategy for computer-aided molecular design (CAMD) to identify or develop refrigerants with desired properties, by optimizing the influences of selected structural groups: illustrates a search for R-12 replacements for automotive air conditioners

J. R. Sand, E. A. Vineyard (Oak Ridge National Laboratory, ORNL), and R. J. Nowak (Purdue University), **Comparable Refrigerant Performance Data**, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, July 1989 (8 pages with 1 figure and 5 tables as RDB0543)

performance comparisons for R-12, R-22, R-32, R-114, R-124, R-125, R-134, R-134a, R-142b, R-143, R-143a, R-152a, R-218, and R-C318 at four standard heat pump rating conditions [also see RDB4129]

Assessment of the Impacts Associated with a Total CFC Phase Out, final report, Putnam, Hayes and Bartlett, Incorporated, Washington, DC, July 1989 (60 pages, RDB1118)

Compatibility of Elastomers with HFC-134a at About 25 °C, report NIST-2, Freon(R) Products Laboratory, E. I. duPont de Nemours and Company, Incorporated, Wilmington DE, 17 July 1989 (15 pages with 13 tables, available from JMC as RDB0532)

A broad range of elastomers were tested to compare compatibility with R-134a to that with R-12. The tests were performed at approximately 25 °C (77 °F), for consistency with historic data. The influences of the refrigerant were measured after immersion for 27 days and again after 14 days of drying in air. Length, weight, Shore A hardness, appearance and physical properties are tabulated, the last based on qualitative observations for stretching, bending, squeezing, and flexing. The elastomers tested include urethane (Uniroyal Adiprene(R) C), Buna N and S, butyl rubber, chlorosulfonated polyethylene (DuPont Hypalon(R) 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel(R)), silicone, polysulfide (Morton Thiokol(R) FA), and fluoroelastomer (DuPont Viton(R) A). For R-134a, Adiprene L, Buna N, butyl rubber, Hypalon 48, natural rubber, neoprene W, and Nordel were judged to be preferred and Thiokol FA recommended, but not preferred. For R-12, Adiprene L, Buna N, and Hypalon 48 were preferred, and neoprene W, Nordel, Thiokol FA recommended, but not at the preferred level.

please see page 6 for ordering information

Buna S, silicone, and Viton A were not recommended for either R-12 or R-134a.

June 1989

L. J. M. Kuijpers et al., **Refrigeration, Air Conditioning, and Heat Pumps (Technical Options Report)**, *Technical Progress on Protecting the Ozone Layer*, United Nations Environment Programme (UNEP), Paris, France, 30 June 1989 (172 pages with 13 figures and 24 tables, available from JMC as RDB2317)

This report is one of five Technical Options committee (TOC) reports prepared to assess the status of technologies impacted by the Montreal Protocol and to identify options for achieving compliance. The report was prepared by an international panel of 48 individuals, pursuant to Article 6 of the Protocol. It addresses the Protocol and reassessment procedure, refrigerants, domestic refrigeration (including refrigerators and other appliances), retail refrigeration (including commercial uses), transport refrigeration, cold storage, industrial refrigeration, comfort air conditioning, mobile air conditioning, heat pumps, and refrigerant recycling.

D. Parent and P. A. LaRue (Centre de Recherche Industrielle du Québec, Canada), **Testing and Modeling of a Water-to-Air Heat Pump Operating with a Nonazeotropic Refrigerant Mixture**, *Transactions* (Annual Meeting, Vancouver, BC, 24-28 June 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 95(2):405-410, 1989 (6 pages with 19 figures and 5 references, RDB5611)

R-13B1/152a, R-22/114, R-23/22, zeotropic blends, Simpac program, simulation

K. S. Sanvordenker, **Materials Compatibility of R-142b for Hermetic Units**, Tecumseh Products Company, Ann Arbor, MI, June 1989 (7 pages with 2 figures and 5 tables, available from JMC as RDB-0002)

Two figures compare the miscibility of R-142b and R-22 with Capella B and Calumet R015 mineral oils. The miscibility of R-142b with Zerol(R) 150 alkylbenzene lubricant also is discussed. Quantitative data on two magnet wire insulations (polyester-imide and polyester enamel overcoated with amide-imide) with R-142b and R-22 are given for refrigerant absorption, softening, blistering, and retained dielectric strength. R-142b and R-22 effects on the core-bond tensile strength of two unidentified solvent-based epoxy-type varnishes also are presented. Additionally, swell tests of R-142b with four elastomeric (neoprene, EPR, nitrile, and fluoroelastomeric (DuPont Viton(R) B) o-rings are given. In each investigation, R-142b exhibited characteristics comparable to, or better than, R-22.

L. M. Schlager, M. B. Pate, and A. E. Bergles, **Design Equations for Predicting Heat Transfer and Pressure Drop Performance with Refrigerant-Oil Mixtures in Smooth and Internally Finned Tubes**, technical paper 3293 (469-RP), *Transactions* (Annual Meeting, Vancouver, BC, 24-28 June 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 95(2), 1989 (rdb2245)

R-22

H. O. Spauschus and D. R. Hurst, **New Stability Test Methods for Alternative Refrigerants and Mixtures,** presentation slides and abstract (seminar on *Ozone/CFC - Alternative Studies Update*), ASHRAE 1989 Annual Meeting (Vancouver, BC, Canada, 24-28 June 1989) Spauschus Associates, Atlanta, GA, June 1989 (15 pages, available from JMC as RDB0544)

compatibility test methods

T. G. Statt (U.S. Department of Energy, DOE), **Energy Implications of Global Climate Change**, presentation charts, 1989 ASHRAE Annual Meeting (Vancouver, BC, 24-28 June 1989), U.S. Department of Energy Washington, DC, June 1989 (16 pages, RDB1109)

E. A. Vineyard, J. R. Sand, and W. A. Miller (Oak Ridge National Laboratory, ORNL), **Refrigerator-Freezer Energy Testing with Alternative Refrigerants**, *Transactions* (ASHRAE Annual Meeting, Vancouver, BC, Canada, 24-28 June 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 95(2), 1989; republished in ASHRAE Special Publication, *CFCs: Time of Transition*, ASHRAE, 205-210, 1989 (6 pages with 2 figures and 3 tables, RDB2121)

R-134a, R-22/142b, R-12/DME, R-500

L. Weitzman (Acurex Corporation), **Evaluation of Refrigerant from Mobile Air Conditioners**, project summary EPA/600/S2-89/009, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, June 1989 (4 pages with 1 table, available from JMC as RDB5444)

refrigerant purity

IEA Heat Pump Center Newsletter, issue on *Heat Pumps and the Environment*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, 7(2), June 1989 (64 pages, RDB0925)

This issue focuses primarily on refrigerant environmental impacts of refrigerants.

May 1989

D. Jung (National Institute of Standards and Technology, NIST), **Horizontal-Flow Boiling Heat Transfer Using Refrigerant Mixtures**, report ER-6364, Electric Power Research Institute (EPRI), Palo Alto, CA, May 1989 (236 pages with 62 figures, 14 tables, and two appendices, RDB2B08)

This report documents a study of horizontal, convective, boiling heat transfer, including experiments to measure two-phase heat transfer coefficients of refrigerant mixtures. The report reviews the properties of mixtures, including those unique to azeotropes, and associated heat transfer. It then describes experimental apparatus designed to simulate evaporator conditions in heat pump and refrigeration systems. Measurement approaches are presented both for heat transfer and composition determination. Measured data are summarized for zeotropic mixtures of R-12 and R-114, both an azeotropic and zeotropic mixtures R-12 and R-152a, and their pure components for ranges of heat flux and mass flow rates. Differences in bubble growth are discussed between pure and mixed fluids. The results indicate two distinct regions of heat transfer, namely partial boiling and convective evaporation, the former governed by suppression of nucleate boiling. The report reviews analytical studies to predict the transition quality. Measured, local heat transfer coefficients were as much as 36% lower than the weighted average of the components for mixtures in the convective region. The study attributes this reduction to observed differences in composition in the annular liquid film for mixtures with large difference in component volatilities, such as R-22/114. An approach is proposed to account for mixture effects based on phase-equilibrium information.

L. J. M. Kuijpers (Phillips Research Laboratories, The Netherlands) and S. M. Miner (Consultant), **The CFC Issue and the CFC Forum at the 1988 Purdue IIR Conference**, *International Journal of Refrigeration* (IJR), 12(3):118-124, May 1989 (8 pages with 4 figures and 2 tables, RDB1108)

review of refrigerant substitutes including R-22, R-32, R-125, R-134, R-134a, R-141b, R-142b, R-143, R-143a, R-152, R-152a, R-161, and R-717; performance comparisons for R-12, R-134, R-134a, and R-152a and for R-114, R-142b, and R-143; international standards and research activities; summary of forum on chlorofluorocarbon (CFC) replacement held during the IIR meeting at Purdue University in July 1988, with general remarks on selected papers

J. R. Sand and E. A. Vineyard, **Report of Foreign Travel: 2-5 May 1989** [Zeotropic Blends in Refrigerators], ORNL/FTR-3251, Oak Ridge National Laboratory, Oak Ridge, TN, 18 May 1989 (14 pages, available from JMC as RDB1135)

This informal report summarizes meetings on refrigerator/freezer testing with zeotropic blends of refrigerants *(nonazeotropic mixtures of refrigerants or NARMs)* at the Universität Hannover (Hannover, FRG). The research investigated a freezer, modified with a polystyrene block to form separate freezer and fresh-food compartments, operating with an R-22/142b refrigerant blend. The simulation program, testing protocol, instrumentation, and plans for testing other blends were reviewed. Also addressed is a visit to AEG GmbH (Kassel, FRG), a major manufacturer of domestic appliances, to discuss research on alternative refrigerants. Compressor components were reviewed after 1000 hours accelerated life testing in R-134a and in R-22/142b. Parts from the R-134a compressor looked very good, whereas parts from the R-22/142b test unit showed much more thermal breakdown. Some AEG engineers favor R-152a, or blends of R-152a with R-22 or R-134a, as an alternative to R-12.

G. D. Short (CPI Engineering Services, Incorporated), **Synthetic Lubricants and their Refrigeration Applications**, paper 89-AM-7A-1 (44th Annual Meeting, Atlanta, GA, 1-4 May 1989), *Lubrication Engineering*, 46(4):239-247, April 1990 (12 pages with 9 figures and 1 table, RDB2221)

This paper reviews the requirements and use of synthetic fluids as lubricants for refrigeration systems. R-12, R-13, R-22, R-114, R-134a, R-502, R-503, propane (R-290), and ammonia (R-717) are addressed. Requirements are discussed for thermal and chemical stability, miscibility, solubility, and viscosity. Failure mechanisms including improper viscosity, dilution, loss or breakdown of lubricant, failure of hydrodynamic lubrication, foaming, and starvation related to solubility and miscibility characteristics are reviewed for rotary screw, reciprocating piston, and rotary vane (both fixed and rotating) compressors. Petroleum-based, including both naphthenic and high-viscosity index (HVI) paraffinic mineral oils, and synthetic lubricants are discussed. The synthetics are grouped as polyalphaolefin (PAO), alkylbenzene, and polyalkylene glycol (PAGs) synthetic hydrocarbon (SHC) oils. They also include esters such as diesters (or dibasic acid esters), neopentyl (or polyol) esters, and modified complex esters. The chemical structures and characteristics of

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these lubricants are reviewed, and viscosity and miscibility plots are provided for representative refrigerant-lubricant systems. Typical properties are tabulated for complex esters of ISO 150 and 320 viscosity. The unique requirements for R-134a, propane (R-290), and ammonia (R-717) are outlined, concluding that the synthetic lubricants described offer a major contribution for system advancement.

Comments on the Manufacture, Use, and Disposal of Ozone-Depleting Chemicals (CFCs) to the Subcommittee on Environmental Protection of the Committee on Environment and Public Works of the United States Senate, Motor Vehicle Manufacturers Association (MVMA), Detroit, MI, 19 May 1989 (RDB1155)

Compatibility of Nonmetallic Materials with Refrigerants and Lubricants, ICI Chemicals and Polymers Limited, Runcorn, Cheshire, UK, 16 May 1989 (3 pages with 1 table, available from JMC as RDB0004)

A table summarizes the swell (dimensional change) and weight gain of various elastomeric and plastic materials immersed in R-134a. The materials included Buna(TM), Butyl(TM), DuPont Hypalon(R), NBR, Garlock neoprene, nitrile, nitrile Dunlop, nylon, Oilite and M229 rubber asbestos, polyetheretherketone (PEEK), Polypenco Nylatron, polytetrafluoroethylene (PTFE), Reinz Thermolit K, terylene braid, and fluoroelastomer (DuPont Viton(R)). Quantitative results are presented for refrigerant-lubricant mixtures with 10% polyalkylene glycol (PAG); the lubricants, ranging in viscosity from ISO 33 to 120, are not specifically identified. Some results also are given with 100% refrigerant.

Flammability Characteristics of Isotron 142b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page, available from JMC as RDB0525)

Lower and upper flammability limits (LFL and UFL), as a volume percentage of refrigerant in humid air, are given for R-142b based on ASTM E681 tests. The LFL cited is 7.8% at 21 °C (70 °F) using a fuse wire as the ignition source. The cited LFL and UFL, using a match as the ignition source, are 6.9-17.0% at 21 °C (70 °F) and 6.1-17.8% at 120 °C (250 °F). The maximum explosion pressure and maximum rate of pressure rise are tabulated for the same temperatures. Flammability characteristics of ethyl alcohol and R-290 (propane) are presented for comparison. A higher concentration of R-142b is required for flammability. Additionally, R-142b exhibits significantly lower rates of pressure rise and lower heats of combustion.

Isotron 22/142b Blends for Refrigeration: Material Compatibility, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page with 1 table, available from JMC as RDB0520)

This bulletin summarizes the procedure and findings for two-week exposures of selected refrigeration system materials both to R-12 and to a blend of R-22/142b (55/45). The materials tested included copper wire, polyimide insulation, and several plastics and elastomers. The plastics included nylon (DuPont Zytel(R) 101), polytetrafluoroethylene (PTFE), FEP, PVDF (Kynar), PVC, low-density polyethylene, polypropylene, polystyrene, high-impact polystyrene, and high-gloss ABS. The elastomers included neoprene, Butyl(TM), Buna(TM) N, and fluoroelastomer (DuPont Viton(R)). Swell (length increase percentage), weight gain (percentage), and appearance (including qualitative observations on hardness and embrittlement) are tabulated.

Isotron R-141b Foam Blowing Agent: Material Compatibility, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page with 1 table, available from JMC as RDB0519)

A table provides quantitative and qualitative data on weight change and swelling for common elastomers, plastics, refrigerator liner materials, and roofing membrane materials after a two week exposure to R-11 and R-141b. The elastomeric materials include neoprene, Butyl(TM), Buna(TM) N, and fluoroelastomer (DuPont Viton(R)). The plastics and refrigerator liner materials include ABS polymer, FEP, Kynar PVDF, polyethylene, polypropylene, polystyrene, polytetrafluoroethylene (PTFE), and polyvinyl chloride (PVC). The ABS polymer, Buna N, Viton, and PVC materials exhibited much greater swelling and weight gain after exposure to R-141b than to R-11. The other materials exhibited results lower than, or comparable to, R-11 after R-141b exposures.

Results of Testing: Flashpoint of Isotron 141b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page, available from JMC as RDB0523, picture missing)

The procedure and results of measuring the flash point of R-141b are summarized based on ASTM D1310 tests using a Fisher/Tag open cup apparatus. No flash point was observed for this fluid even though it has lower and upper flammability limits. The nature of the liquid is such that it does not produce a vapor layer that will flash according to the standard test method. The document notes that similar behavior has been observed for chlorinated solvents such as R-30 (methylene chloride) and R-140a (methyl chloroform).

Results of Testing: Limits of Flammability for Isotron 141b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (4 pages with 5 figures and 1 table, available from JMC as RDB0522, picture missing)

Lower and upper flammability limits (LFL and UFL), as a volume percentage of refrigerant in humid air, are given for R-141b based on ASTM E681-85 tests. The limits cited are 7.4-15.5% at 21 °C (70 °F) and 5.8-16.5% at 120 °C (250 °F). Comparative data are presented for R-600a (isobutane) and ethanol, 1.86-8.5% and 3.46-18.4% respectively. A modified test procedure and the method of determining flammability limits are presented. Additionally, the effects of humidity, temperature, and ignition source on flammability testing are discussed.

Results of Testing: Maximum Rate of Pressure Rise - Maximum Explosion Pressure of Isotron 141b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (2 pages with 1 table, available from JMC as RDB0524, picture missing)

The procedure and results of measuring the maximum rate of pressure rise and maximum explosion pressure of R-141b are summarized. The rate of pressure rise is reported as 262 and 220 kPa/s (38 and 32 psi/s) at 21 °C (70 °F) and 120 °C (250 °F), respectively, in a 0.37 m^3 (13.1 cf) vessel. The maximum pressure is reported as 78 and 57 psig at corresponding conditions. A comparison of normalized rates of pressure rise (the Kg) shows R-141b to be approximately 230 times less severe than R-290 (propane) and 50 times less severe than ethanol.

Results of Testing: Flashpoint of Isotron 142b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page with 1 figure, available from JMC as RDB0527, picture missing)

The procedure and results of measuring the flash point of R-142b are summarized based on ASTM D1310 tests using a Fisher/Tag open cup apparatus. No flash point was observed for this fluid. An upward extension of a test flame was observed when passed over a sample of the refrigerant. The extension grew with increasing temperature of the refrigerant, but the vapor space above the liquid neither flashed nor burned away from the test flame.

Results of Testing: Limits of Flammability for Isotron 142b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (4 pages, available from JMC as RDB0526, picture missing)

Lower and upper flammability limits (LFL and UFL), as a volume percentage of refrigerant in humid air, are given for R-142b based on ASTM E681 tests. The LFL cited is 7.8% at 21 °C (70 °F) using a fuse wire as the ignition source. The cited LFL and UFL, using a match as the ignition source, are 6.9-17.0% at 21 °C (70 °F) and 6.1-17.8% at 120 °C (250 °F). Comparative data are presented for R-600a (isobutane) and ethanol, 1.86-8.5% and 3.46-18.4% respectively. A modified test procedure and the method of determining flammability limits are presented. Additionally, the effects of humidity, temperature, and ignition source on flammability testing are discussed.

Results of Testing: Maximum Rate of Pressure Rise - Maximum Explosion Pressure of Isotron 142b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (2 pages with 1 table, available from JMC as RDB0528, picture missing)

The procedure and results of measuring the maximum rate of pressure rise and maximum explosion pressure of R-142b are summarized. The rate of pressure rise is reported as 606 and 634 kPa/s (88 and 92 psi/s) at 21 °C (70 °F) and 120 °C (250 °F), respectively, in a 0.37 m^3 (13.1 cf) vessel. The maximum pressure is reported as 88 and 68 psig at corresponding conditions. A comparison of normalized rates of pressure rise (Kg) shows R-142b to be approximately 100 times less severe than R-290 (propane) and 23 times less severe than ethanol.

State of Knowledge Summary of Chlorofluorocarbon Handling Technologies: Destruction, Recycling, and Encapsulation, draft report for U.S. Department of Energy, E. A. Mueller Consulting Engineers, Baltimore, MD, May 1989 (65 pages, RDB1107)

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April 1989

March 1989

W. F. Stoecker (University of Illinois at Urbana-Champaign), **Growing Opportunities for Ammonia Refrigeration**, *Technical Papers of the 11th Annual Meeting* (12-15 March 1989, Austin, TX), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, March 1989; republished in *CFCs: Time of Transition*, ASHRAE, 128-139, 1989 (12 pages with 3 figures and 7 tables, RDB4236)

R-717

February 1989

D. J. Bateman (E. I. duPont de Nemours and Company, Incorporated), **Performance Comparison of HFC-134a and CFC-12 in an Automotive Air-Conditioning System**, paper 890305 (SAE International Congress and Exposition, Detroit, MI, 27 February - 3 March 1989), Society of Automotive Engineers (SAE), Warrendale, PA, February 1989 (10 pages with 9 figures and 2 tables, RDB4231)

summarizes comparative tests of R-12 and R-134a in a pickup truck based on testing in a wind tunnel: discusses the effects of ambient conditions, speed, operating conditions, and passenger compartment temperatures; concludes that R-134a is the best alternative for R-12 for mobile air-conditioning system (MAC) applications, but that significant development and redesign will be required to optimize its use

D. B. Bivens, R. A. Gorski, W. D. Wells, A. Yokozeki (DuPont Chemicals), R. A. Lindstrom, and R. L. Shimon (Tecumseh Products Company), **Evaluation of Fluorocarbon Blends as Automotive Air Conditioning Refrigerants**, paper 890306 (SAE International Congress and Exposition, Detroit, MI, 27 February - 3 March 1989), Society of Automotive Engineers (SAE), Warrendale, PA, February 1989 (rdb4232)

S. K. Fischer and F. A. Creswick, **Energy-Use Impact of Chlorofluorocarbon Alternatives**, report ORNL/CON-273, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, February 1989 (138 pages, available from NTIS, RDB0924)

This study estimates energy-use impacts of phase out of chlorofluorocarbon (CFC) refrigerants under the Montreal Protocol. Major energy-related applications of the fully halogenated CFCs (R-11, R-12, R-113, R-114, and R-115) were identified. Four groups of alternative refrigerants then were considered: 1) chemicals with very similar properties *(near drop-in substitutes)*; 2) a *fallback* scenario relying on available compounds with more product development; 3) a *worst case* in which no new chemicals become available, chlorine-containing compounds (e.g., R-22) cannot be used, and fiberglass insulation is used in place of CFC-blown foams; and 4) an *advanced technology* using highly efficient insulation and refrigeration systems. Energy use will not increase significantly if *near drop-in* compounds (principally R-134a, R-123, and R-141b) are used. If they do not become available, national energy use will increase by 1-2 quad (10^{15} Btu) per year. Development of advanced technologies could reduce annual energy use by about 0.83 quad. The major impacts are in applications using foam insulations blown with CFCs (e.g., refrigerators, freezers, water heaters, roofs of commercial buildings, and insulated building foundations). The penalty associated with refrigeration equipment is smaller, but is contingent upon attaining the high compressor efficiencies for alternative refrigerants that are available for CFCs.

Possible Environmental Effects of Chlorofluorocarbons, position statement and paper, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 2 February 1989 (12 pages, RDB1115)

January 1989

R. Krauss and K. Stephan (Universität Stuttgart, Germany), **Thermal Conductivity of Refrigerants in a Wide Range of Temperature and Pressure**, *Journal of Physical and Chemical Reference Data*, 18(1):43-76, January 1989 (34 pages, rdb5533)

thermophysical properties, transport data

L. M. Schlager, M. B. Pate, and A. E. Bergles, **Heat Transfer and Pressure Drop During Evaporation and Condensation of R-22 in Horizontal Micro-Fin Tubes**, *International Journal of Refrigeration* (IJR), 12(1):6-14, January 1989 (9 pages, rdb2244)

R-22, heat and mass transfer

E. A. Vineyard, J. R. Sand (Oak Ridge National Laboratory, ORNL), and T. G. Statt (U.S. Department of Energy, DOE), **Selection of Ozone-Safe, Nonazeotropic Refrigerant Mixtures for Capacity Modulation in Residential Heat Pumps**, paper 3199, *Transactions* (Winter Meeting, Chicago, IL, 28 January -1 February 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 95(1):34-46, 1989; republished in ASHRAE Special Publication, *CFCs:*

Time of Transition, ASHRAE, 149-161, 1989 (13 pages with 6 figures and 2 tables, RDB1136)

1989 (month not indicated)

T. Atwood (AlliedSignal Incorporated), E. M. Clark (E. I. duPont de Nemours and Company), R. C. Downing (Consultant), and M. O. McLinden (National Institute of Standards and Technology, NIST), **Refrigerants**, *ASHRAE Handbook - Fundamentals* (published in separate editions with inch-pound and SI metric units), American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, chapter 16, 16.1-16.10, 1989 (10 pages with 2 figures and 15 tables, RDB0036)

> This chapter summarizes information on common refrigerants, including designations, physical and electrical properties, performance, safety data, leak detection methods, and effects on construction materials. The refrigerants addressed include R-10, R-11, R-12, R-13, R-13B1, R-14, R-20, R-21, R-22, R-23, R-30, R-31, R-32, R-40, R-41, R-50, R-110, R-111, R-112, R-112a, R-113, R-113a, R-114, R-114a, R-114B2, R-115, R-116, R-120, R-123, R-124, R-124a, R-125, R-133a, R-134a, R-140a, R-142b, R-143a, R-150a, R-152a, R-160, R-170, R-218, R-290, R-C316, R-C317, R-C318, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-600, R-600a, R-610, R-611, R-630, R-631, R-702, R-704, R-717, R-718, R-720, R-728, R-729, R-732, R-740, R-744, R-744A, R-764, R-1112a, R-1113, R-1114, R-1120, R-1130, R-1132a, R-1140, R-1141, R-1150, and R-1270. Molecular mass, normal (atmospheric) boiling point, freezing point, critical properties, surface tension, and refractive index are tabulated for most of these fluids. Dielectric constants, volume resistivity, velocity of sound, latent heat of vaporization, safety classifications, and explosive limits are presented for the more common fluids. Swell data are tabulated for R-11, R-12, R-13, R-13B1, R-21, R-22, R-30, R-40, R-113, R-114, R-502, and R-600 for eight elastomers. They include nitrile butyl rubber (Buna(TM) N), butadiene styrene (Buna(TM) S, GR-S), Butyl(TM) (GR-1), natural rubber, neoprene GN, polysulfide rubber (Thiokol(R) FA), fluoroelastomer (DuPont Viton(R) B), and silicone. Diffusion data are tabulated for water, R-12, and R-22 through neoprene, Buna N, synthetic rubber (DuPont Hypalon(R) 40), Butyl, Viton, polyethylene, and natural rubber. Mass density, specific heat, and viscosity are plotted for water/lithium bromide solutions (for absorption cycles) as functions of the mass fraction of lithium bromide.

T. Atwood (AlliedSignal Incorporated), **Refrigerant Tables and Charts**, *ASHRAE Handbook - Fundamentals* (published in separate editions with inch-pound and SI metric units), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, chapter 17, 17.1-17.71, 1989 (71 pages with 33 figures and 34 tables, RDB0037)

> This chapter provides pressure-enthalpy (Mollier) diagrams and tabulates thermodynamic and thermophysical properties for R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-50, R-113, R-114, R-142b, R-152a, R-170, R-290, R-500, R-502, R-503, R-600, R-600a, R-717, R-744, R-1150, and R-1270. The tabular data include temperature, pressure, vapor volume, liquid density, enthalpy, entropy, viscosity, thermal conductivity, specific heat, and the velocity of sound. Temperature-entropy (ts) diagrams and properties are provided for cryogenic fluids including R-702, R-702p, R-704, R-720, R-728, R-729, R-732, and R-740. An enthalpy-concentration diagram and tabular data for the specific volume at saturation are presented for ammonia/water for absorption cycles. Enthalpy equilibrium and concentration diagrams are similarly provided for water/lithium bromide solutions.

H. D. Baehr and S. Kabelac (Universität Hannover, Germany), **Vorläufige Zustandsgleichungen für das ozonunschädliche Kältemittel R 134a** [Preliminary Equations of State for the Ozone-Safe Refrigerant R-134a], *Ki Klima-Kälte-Heizung*, Germany, 17(2):69-71, 1989 (3 pages, in German, rdb5214)

> R-134a, thermodynamic properties, thermophysical data

C. Baroncini, G. Giuliani, and F. Polonara (Università degli Studi di Ancona, Italy), **Experimental Evaluation of the Vaporization Enthalpy of Several Refrigerant Fluids**, *Proceedings of the Fourth International Conference on Thermodynamics of Solutions of Nonelectrolytes*, Santiago de Compostela, Spain, 1989 (rdb4B47)

> latent heat of vaporization, thermodynamic properties, thermophysical data

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> thermodynamic properties, thermophysical data

please see page 6 for ordering information

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A. C. Brown, C. E. Canosa-Mas, J. M. T. Pierce, A. D. Parr, and R. P. Wayne, **Tropospheric Lifetimes of Halogenated Anesthetics**, *Nature*, 341:635-637, 1989 (4 pages, rdb8314)

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F. A. Creswick, S. K. Fischer, and J. R. Sand (Oak Ridge National Laboratory, ORNL), **Potential Impacts of CFC Restrictions on Refrigeration and Air-Conditioning Equipment**, *International Journal of Refrigeration* (IJR), 11:217-221, 1989 (5 pages with 3 tables, RDB4204)

F. de Rossi, R. Mastrullo (Università di Napoli "Frederico II", Italy), and P. Mazzei (Università degli Studi di Salerno, Italy), **Caratterizzazione termodinamica di fluidi di lavoro per cicli inversi a compressione** [Thermodynamic Characteristics of Working Fluids for Reversed Compression Cycles], *Gli Impianti nelle Grandi Infrastrutture* (proceedings of the AICARR Meeting, Rome, Italy, 1989), AICARR [Italian Association of Air-Conditioning, Heating, and Refrigeration], Milan, Italy, 1989 (rdb5632)

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E. Hahne and Y. W. Song (Universität Stuttgart, Germany), **Messung der Wärmeleitfähigkeit von R115 bei hohen Drücken mit der Heißdraht-Methode** [Measurements of the Thermal Conductivity of R-115 at High Pressures by the Transient Hot-Wire Method, *Wärme- und Stoffübertragung* [Heat and Mass Transfer], Germany, 24:79-85, 1989 (7 pages in German, rdb5642)

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Y. Homma and S. Komatsuzaki (Hitachi Limited, Japan), **Friction and Wear Characteristics in a Freon Atmosphere**, *Proceedings of the 34th National Conference of the Japanese Society of Tribologists*, 185 ff, 1989 (in Japanese, rdb4B02)

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R-740 (argon): thermodynamic properties from the triple point to 927 °C (1700 °F) and pressures to 1000 MPa (145,000 psia), thermophysical data

J. A. Jones and A. Lund, **Low-Ozone Damaging Fluid Mix Substitutes for Refrigerant 12**, Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, CA, 1989 (rdb2338)

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D. Jung and R. K. Radermacher (University of Maryland), **Prediction of Pressure Drop During Horizontal Annular Flow Boiling of Pure and Mixed Refrigerants***, International Journal of Heat and Mass Transfer*, 32(12):2435-2446, 1989 (12 pages, rdb3B50)

D. Jung (University of Maryland), M. O. McLinden (National Institute of Standards and Technology, NIST), R. K. Radermacher (University of Maryland), and D. A. Didion (NIST), **Horizontal Flow Boiling Heat Transfer Experiments with a Mixture of R-22/114**, *International Journal of Heat and Mass Transfer*, 32(1):131-145, 1989 (15 pages, rdb2903)

D. Jung (University of Maryland), M. O. McLinden (National Institute of Standards and Technology, NIST), R. K. Radermacher (University of Maryland),

Measurement Techniques for Horizontal Flow Boiling Heat Transfer with Pure and Mixed Refrigerants, *Experimental Heat Transfer*, 2(3):237-255, 1989 (19 pages with 10 figures and 1 table, RDB6424)

R-12, R-22, R-114, R-152a, R-12/152a [R-500], R-22/114; pressure, composition, and temperature measurement; flow boiling of pure and mixed refrigerants in a horizontal, tube

H. Kubota, T. Yamashita, Y. Tanaka, and T. Makita, **Vapor Pressures of New Fluorocarbons**, *International Journal of Thermophysics*, 10(3):629-637, 1989 (9 pages, rdb4120)

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A-D. Leu and D. B. Robinson (University of Alberta, Canada), **Vapor-Liquid Equilibrium in Selected Binary Systems**, paper 271, AIChE Symposium Series, American Institute of Chemical Engineers (AIChE), New York, NY, 85:44-50, 1989 (7 pages with 6 figures and 6 tables, RDB4C51)

This paper presents experimental vapor-liquid equilibrium (VLE) data on six binary mixtures at pressures from 24 to 2736 kPa (3-400 psia). They include R-22/218 for 0 and 25 °C (32 and 77 °F), R-116/22 for -10 and 25 °C (14 and 77 °F), R-E170 (dimethyl ether) with methyl tertiary butyl ether (MTBE) for 25 and 75 °C (77 and 167 °F), tertiary butanol with propionaldehyde, tertiary butanol with acrolein, and acetone with isobutyraldehyde. The data were developed to improve the performance and efficiency of industrial plants, primarily those involved in petroleum or petrochemical processing. The paper notes that the data also may be used to refine equations of state and property prediction methods for the blends examined. The paper reviews the experimental apparatus (based on a pistoned sapphire cell), instrumentation, and procedures used. Measured equilibrium properties are tabulated and plotted as pressure versus composition. The VLE plot for R-22/218 reveals azeotropic behavior at both temperatures.

H. Lippold, **Die thermodynamischen Stoffwerte von R 134a** [The Thermodynamic Properties of R-134a], *Luft- und Kältetechnik*, Germany, (4):182-185, 1989 (4 pages in German, rdb5536)

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A. J. Masson, **An Investigation into the Effects of Lubricating Oil on Evaporator Performance and Possible Improvements Utilizing a Regenerative Expansion Process**, D.Phil. thesis, University of Ulster, Coleraine, Northern Ireland, UK, 1989 (rdb-8439)

heat transfer coefficient (HTC) analyses of refrigerant-lubricant (RL) influences

M. O. McLinden (National Institute of Standards and Technology, NIST), **Physical Properties of Alternatives to the Fully Halogenated Chlorofluorocarbons**, *International Journal of Thermophysics*, 10:563-576, 1989 (14 pages with 9 figures and 14 tables, preprint available from JMC as RDB-0906)

The properties of nine halogenated hydrocarbons are collected from a variety of sources, including unpublished data. These data are evaluated and correlated. Considered are the triple point, normal boiling point, and critical point parameters and the temperature dependence of the vapor pressure, saturated liquid density, solubility in water, and hydrolysis rates. The fluids, which are potential alternatives to the fully halogenated chlorofluorocarbons, are R-22, R-123, R-124, R-125, R-124, R-134a, R-141b, R-142b, and R-152a; also included is the solvent R-140a (methyl chloroform).

B. A. Nagengast (Consulting Engineer), **A History of Refrigerants**, *CFCs: Time of Transition*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 3-15, 1989 (13 pages with 13 figures, RDB2113)

R-10 (carbon tetrachloride), R-11, R-12, R-13, R-21, R-22, R-30 (methylene chloride), R-40 (methyl chloride), R-114, R-115, R-152a, R-160 (ethyl chloride), R-160B1 (ethyl bromide), R-E170 (methyl ether), R-290 (propane), R-500, R-502, R-600 (butane), R-600a (isobutane), R-601 (pentane), R-611 (methyl formate), R-630 (methyl amine), R-631 (ethyl amine) R-717 (ammonia), R-728 (air), R-744 (carbon dioxide), R-744A (nitrous oxide), R-764 (sulfur dioxide), R-1120 (trichloroethylene, trieline), R-1130 (dielene), R-1270 (propylene), R-12/764 (92/8) (DL-8), alcohol, caoutchoucine, chymogene, gasoline, isobutylene, methyl acetate, methylic ether, naphtha, petroleum distillates, sulfuric (ethyl) ether, and others; historical contributions of John Beath, David Boyle, Frederic Bramwell, R. A. Brookman, Willis H. Carrier, Edmund Copeland, T. R. Crampton, Francis De Coppet, Harry Edwards, John Enright, Oliver Evans, J. Gamgee, John Gorrie, John Hague, James Harrison, Albert L. Henne, Daniel L. Holden, B. S. Lacy, Maurice LeBlanc, Thaddeus S. C. Lowe, Robert R. McNary, George Mertz, Thomas Midgley, Jr., Andrew Muhl, Eugene Nicolle, Cassius C. Palmer, Jacob Perkins, Raoul Pictet, Fredrich Schipper, D. Siebe, Julius Sedlacek, Charles Tellier, Alexander Twinning, P. H. Van der Weyde, Karl von Linde, C. Vincent, H. J. West, Franz Windhausen, Fred Wolf, and others

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V. G. Niesen (National Institute of Standards and Technology, NIST), **(Vapor + Liquid) Equilibria and Coexisting Densities of (Carbon Dioxide + n-Butane) from 311 to 395 K**, *Journal of Chemical Thermodynamics*, 21:915-923, 1989 (9 pages, rdb-6869)

presents measured vapor-liquid equilibrium (VLE) and density data for R-744/600 for 38-122 °C (100-251 °F)

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Properties of HFC-134a**, *Proceedings of the Second Asian Thermophysical Properties Conference* (Sapporo, Japan), 531-536, 1989 (6 pages with 9 figures and 2 tables, RDB5461)

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B. Platzer and G. Maurer, **Ein Programmpacket zur Berechnung thermodynamischer Zustandsgrößen reiner Fluide mit Hilfe der Zustandsgleichung von Bender** [Software for Thermodynamic Property Calculations of Pure Fluids by the Bender Equation of State], *DKV Jahrestagung* [Proceedings of the DKV Annual Meeting] (Hannover, Germany, 1989), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), 1989 (in German, rdb5619)

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R. G. Richard and I. R. Shankland (AlliedSignal Incorporated), **A Transient Hot-Wire Method for Measuring the Thermal Conductivity of Gases and Liquids**, *International Journal of Thermophysics*, 10(3):673-686, 1989 (11 pages with 1 figure and 1 table, RDB5620)

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S. L. Roan, **Ozone Crisis: The 15-Year Evolution of a Sudden Global Emergency**, John Wiley and Sons, Incorporated, NY, New York, 1989 (292 pages, RDB1208)

This book reviews the 15-year history of action and reaction to the ozone-depletion problem. The text specifically addresses the intervention of politics, and the control both it and economic pressures had over the scientific community.

A. Saitoh, H. Sato, and K. Watanabe (Keio University, Japan), **A New Apparatus for the Measurements of the Isobaric Heat Capacity of Liquid Refrigerants**, *International Journal of Thermophysics*, 10:649-660, 1989 (12 pages with 1 figure and 1 table, RDB5336)

property measurement, thermophysical data

K. H. U. Ström, U. B. Grén, and K. Lundqvist (Chalmers University of Technology, Sweden), **Representation of Vapor-Liquid Equilibrium Data for Binary Refrigerant Mixtures**, *Journal of Chemical and Engineering Data*, 34:252-257, 1989 (6 pages, rdb8444)

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K. Srinivasan, **Saturated Liquid Densities of Cryogenic Liquids and Refrigerants**, *International Journal of Refrigeration* (IJR), 12:194-197, 1989 (4 pages, rdb8511)

R-22 and others, thermodynamic properties, thermophysical data

B. Sukornic [possibly Sukornick], **Potentially Acceptable Substitutes for Chlorofluorocarbons: Properties and Performance Features of HFC-134a, HCFC-123, and HCFC-141b**, *International Journal of Thermophysics*, 10(3):553-561, 1989 (9 pages, rdb4319)

R-123, R-134a, R-141b, thermodynamic properties, thermophysical data

Y. Tanaka, H. Kawachi, C. Takata, H. Kubota, and T. Makita (Kobe University, Japan), **Solubility of 1,1,1,2-Tetrafluoroethane (R-134a) in Refrigeration Oils**, *Proceedings of the Second Asian Thermophysical Properties Conference* (Sapporo, Japan), 375-379, 1989 (6 pages with 6 figures, available from JMC as RDB2B11)

This paper discusses the solubility of R-134a in lubricants at temperatures of 303-363 K (86-194 °F) and pressures up to 2.5 MPa (360 psia). It describes experimental apparatus, procedures, and calculations to determine solubility. The lubricants tested included a naphthenic mineral oil (Witco Suniso(R) 4GS), perfluoropolyether (Daikin Demnum(R) S-65), polyethylene glycol (Wako), and polypropylene glycol (Wako). R-134a was found to be completely miscible with the perfluoropolyether, partially miscible with the two polyglycols, and almost immiscible with the naphthenic oil. Solubility plots are presented.

S. Tanikawa, Y. Kabata, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of the Vapor-Liquid Coexistence Curve in the Critical Region of HCFC-123**, *Proceedings of the Second Asian Thermophysical Properties Conference* (Sapporo, Japan), 513-518, 1989 (8 pages, rdb4320)

thermodynamic properties of R-123; thermophysical data

K. Watanabe (Keio University, Japan), **A Challenge to the CFC Problems - Thermophysical Properties of Promising Alternatives**, *Proceedings of the Second Asian Thermophysical Properties Confer-*

ence (Sapporo, Japan), 45-56, 1989 (12 pages, RDB3123)

thermodynamic and transport data

L. A. Weber (National Institute of Standards and Technology, NIST), **Simple Apparatus for Vapor-Liquid Equilibrium Measurements with Data for the Binary Systems of Carbon Dioxide with n-Butane and Isobutane**, *Journal of Chemical and Engineering Data*, 34:171-175, April 1989 (5 pages with 5 figures and 5 tables, RDB6868)

describes the design, construction, and testing of a test apparatus to control and measure the temperature, pressure, and composition of fluids in the range of 27-227 °C (80-440 °F) at pressures up to 15 MPa (2200 psia); presents data along with excess Gibbs functions and excess enthalpies for the binary blends of R-744/600 and R-744/600a

T. Yamashita, H. Kubota, Y. Tanaka, T. Makita, and H. Kashiwaga, **Physical Properties of New Halogenated Hydrocarbons**, *Proceedings of the Tenth Japan Symposium on Thermophysical Properties* (20-22 September 1989), Shizuoka University, Japan, 75-78, 1989 (4 pages, rdb4323)

R-123 and others: thermodynamic properties, thermophysical data

S. Yoshida, T. Matsunaga, H-P. Hong, and M. Miyazaki (Kyushu University, Japan), **An Experimental Investigation of Oil Influence on Heat Transfer to a Refrigerant Inside Horizontal Evaporator Tubes**, *Nippon Kikai Gakkai Ronbunshu* (Transactions of the Japan Society of Mechanical Engineers, JSME), JSME, Tokyo, Japan, B55(513):1410-1416, 1989 (in Japanese); republished in *Heat Transfer - Japanese Research*, Scripta Technica, Incorporated (Wiley Company), 20(2):113-129, May 1991 (17 pages with 14 figures, in English, rdb2905)

evaporative heat transfer of R-22 inside smooth copper tubes; measurement of average and local heat transfer coefficients (HTCs)

H. Zhimai, Z. Yeeng, and H. Jianfen, **Measurements of the Critical Parameters and the Vapor-Liquid Coexistence Curve for Chlorofluoromethane**, *Proceedings of the Second Asian Thermophysical Properties Conference* (Sapporo, Japan), 519-523, 1989 (5 pages, rdb9119)

thermodynamic properties of R-31: thermophysical data

Alternative Refrigerant Blends, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1989 (18 pages, available from JMC as RDB-0530)

CFCs: Time of Transition, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1989 (274 pages with 32 papers, RDB1138)

Compatibility of Alternative Refrigerants with Elastomers, report NIST-11, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1989 (3 pages available from JMC as RDB0307)

This report summarizes an investigation to determine the compatibility of two elastomers, Neoprene W and Buna(TM) N, with R-123 and R-124. Swell data are tabulated after immersions for 1 hour and 1, 2, and 3 days at room temperature. Qualitative observations on discoloration of the refrigerant also are reported. Based on a criterion of swell substantially exceeding 10%, both elastomers were deemed incompatible with R-123 and Buna N was judged incompatible with R-124. The experimental procedure is outlined.

Current Development Status of HFC-134a for Automotive Air Conditioning, document ARTD-2, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1989 (16 pages, available from JMC as RDB0536)

mobile air conditioner (MAC) alternative refrigerants

Genetron(R) 1113 CTFE Monomer, product bulletin 525-301, AlliedSignal Incorporated, Morristown, NJ, 1989 (12 pages with 9 figures and 5 tables, RDB4B10)

R-1113, properties, application, handling and storage

Oil Quantity Measurements in Smooth and Micro-Fin Tubes During Evaporation and Condensation in Refrigerant-Oil Mixtures, research project 469-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, circa 1989 (ASH0469)

The contractor was Iowa State University of Science and Technology led by A. E. Bergles and M. B. Pate.

Progress in Japan with Substitutes for CFC Refrigerants: Report on Trip to Japan (17 November - 2 December 1989), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1989 (17 pages including 2 tables, RDB0C04)

This report summarizes observations made during a trip to Japan to investigate progress with substitutes for chlorofluorocarbon refrigerants, with emphasis on materials compatibility and lubricant research issues. The report summarizes status of refrigerants, research, and testing techniques; an itinerary and list of contacts are included. The substitutes being addressed match those being pursued in the United States, but the effort and depth of analysis are greater.

Report on Alternatives to Currently-Used Chlorofluorocarbon (CFC) Refrigerants, report USNC181 Project 89NK14414, Underwriters Laboratories, Incorporated, Northbrook, IL, 1989 (RDB-4A06)

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Scientific Assessment of Stratospheric Ozone: 1989, chaired by D. L. Albritton (National Oceanic and Atmospheric Administration, NOAH) and R. T. Watson (National Aeronautics and Space Administration, NASA), report 20, World Meteorological Organization (WMO), Geneva, Switzerland, 1989 (534 pages, RDB1116)

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R. S. Basu, I. R. Shankland, and R. G. Richard (AlliedSignal Incorporated), **Thermodynamic and Transport Properties of 1,1,1,2-tetrafluoroethane (R-134a) - An Alternative CFC Substitute in Refrigeration and Air Conditioning**, presented paper (AIChE Winter Annual Meeting, Washington, DC, 1988), Buffalo Research Laboratory, AlliedSignal Incorporated, Buffalo, NY, November 1988 (26 pages, RDB0515)

thermophysical data

S. K. Fischer and F. A. Creswick (Oak Ridge National Laboratory, ORNL), **How Will CFC Bans Affect Energy Use?**, *ASHRAE Journal*, 30(11), November 1988; republished in *CFCs: Time of Transition*, ASHRAE, 29-34, 1989 (6 pages with 4 figures and 1 table, RDB2258)

impacts on U.S. energy use for near-drop-in substitutes, fallback options, worst-case substitutes, and advanced technology alternatives for building equipment, building envelopes, and transportation; impacts on refrigeration systems (specific alternatives are not identified)

B. A. Nagengast (Consulting Engineer), **A Historical Look at the CFC Refrigerants**, *ASHRAE Journal*, 30(11):37-39, November 1988 (3 pages, rdb-2114)

R. Pool, **The Elusive Replacements for CFCs**, *Science*, 242:666-668, 4 November 1988 (3 pages with no figures or tables, Rdb3133)

briefly summarizes the status of chlorofluorocarbons (CFCs) and potential replacements; identifies R-134a as the leading candidate for refrigeration, R-123 and R-141b as possible blowing agents; indicates that R-132b, investigated as a solvent to replace R-113, was disqualified based on finding of reproductive toxicity; comments on the added complexity and costs to manufacture the alternatives; notes that R-134a cannot be made by a single-step process as for the common CFCs

HCFC-123 Refrigerant Analyses, report NIST-9, Chemistry Laboratory, The Trane Company, La Crosse, WI, 24 November 1988 (1 page with 1 table, available from JMC as RDB0030)

A table compares the purity of new, used, and distilled-used specimens of R-123. No change from new R-123 was found by gas chromatography after use in model CVHE hermetic centrifugal chillers. Quantitative results are compared for moisture content and high-boiling residue. The high-boiling residues increased from 6 to 1591 ppm in use, but dropped to 1 ppm after redistillation. Moisture content decreased from 36 to 21 ppm, but increased to 31 ppm after redistillation.

October 1988

Measures of Rationalization of Use and Control of Emission for Specified CFCs, interim report, Ozone Layer Committee, Chemical Product Council, Ministry of International Trade and Industry, Tokyo, Japan, 26 October 1988 (34 pages, RDB1131)

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K. E. Hickman (York International Corporation), **Property Data Needs for Centrifugal Chillers**, NIST Workshop on Property Data for Ozone-Safe Refrigerants, National Institute of Standards and Technology (NIST), 22 September 1988 (RDB3345)

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Z. H. Ayub (E. L. Nickell Company, Incorporated), **Design Techniques for R-717, R-22, and R-12 Shell-and-Coil Subcoolers and Intercoolers**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), International Institute of Refrigeration, Paris, France, 63-71, July 1988 (9 pages with 5 figures and 2 tables, RDB4406)

heat exchangers, heat transfer

J. C. Blaise, T. Dutto (Électricité de France, ÈDF, France), and J. L. Amrosino (Institut Français du Pétrole, IFP, France), **The First Industrial Application of Nonazeotropic Mixture**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University West Lafayette, IN), International Institute of Refrigeration (IIR), Paris, France, 35-43, July 1988; republished in *International Journal of Refrigeration* (IJR), 11:255-258, February 1990 (9 pages with 8 figures and 4 tables, RDB4402)

zeotropic blends, performance

K. D. Gerdsmeyer and H. H. Kruse (Universität Hannover, Germany), **Comparison of Equations of State for Application to Nonazeotropic Refrigerant Mixtures**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), International Institute of Refrigeration, Paris, France, 53-62, July 1988 (10 pages with 10 figures, RDB4405)

thermodynamic properties

D. Gorenflo, P. Blein, G. Herres, W. Rott, H. Schömann, and P. Sokol (Universität Paderborn, Germany), **Heat Transfer at Pool Boiling of Mixtures with R22 and R114**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), International Institute of Refrigeration (IIR), Paris, France, 387-395, July 1988; republished without discussion pages in the *International Journal of Refrigeration* (IJR), 11(6):257-263, July 1988 (9 pages with 9 figures and 2 tables, RDB3449)

R-22/114

M. O. McLinden and D. A. Didion (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), **The Search for Alternative Refrigerants - A Molecular Approach**, proceedings of the meetings of IIR Commissions B1, B2, E1, and E2 (Purdue University, West Lafayette, IN), International Institute of Refrigeration (IIR), Paris, France, 2:91-99, July 1988 (9 pages with 5 figures, RDB2442)

W. Mulroy, M. Kauffeld, M. O. McLinden, and D. A. Didion (National Institute of Standards and Technology, NIST), **An Evaluation of Two Refrigerant Mixtures in a Breadboard Air Conditioner**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), International Institute of Refrigeration, Paris, France, 27-34, July 1988 (8 pages with 21 figures and 1 table, RDB4401)

R-22/114, R-13/12

H. O. Spauschus (Georgia Technical Research Institute, GTRI), **HFC-134a as a Substitute Refrigerant for CFC-12**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN, 18-21 July 1988), International Institute of Refrigeration (IIR), Paris, France, 397-400, 1988; republished in *International Journal of Refrigeration* (IJR), 11(6):389-392, November 1988; republished in *CFCs: Time of Transition*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 123-127, 1989 (4/5 pages, RDB1102)

This paper discusses compressor and refrigeration system requirements and information gaps for R-134a applications. It summarizes the reasons R-134a is viewed as a leading candidate for replacement of R-12. The paper reviews some of the basic properties of R-134a, including stability, system chemistry, solubility, and lubricity. Additional information that is system specific will need to be developed for each major application: automotive, home appliance, or centrifugal chillers.

S. G. Sundaresan (Copeland Corporation), **Standards for Acceptable Levels of Contaminants in Refrigerants**, *International Journal of Refrigeration* (IJR), 11(4), July 1988; republished in ASHRAE Special Publication, *CFCs: Time of Transition*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 220-223, January 1989 (4 pages with 1 table, RDB-5554)

ARI Standard 700P, refrigerant purity, moisture, mineral acids, total organics, organic acids, solids, boiling point and range, high boiling residue, other refrigerants, noncondensables

please see page 6 for ordering information

Y. Yoshida, S. Suzuki, Y. Mukai, K. Nakatani, and K. Fujiwara (Matsushita Electric Industrial Company, Limited, Japan), **Development of Rectifying Circuit with Mixed Refrigerants**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), International Institute of Refrigeration, Paris, France, 45-52, July 1988 (8 pages with 10 figures, RDB4404)

Status of CFCs - Refrigeration Systems and Refrigerant Properties, proceedings of the meetings of IIR Commissions B1, B2, E1, and E2 (Purdue University, West Lafayette, IN), International Institute of Refrigeration, Paris, France, July 1988 (438 pages with 51 papers, RDB1142)

June 1988

M. R. Ally, **Computer Simulation of Absorption Heat Pump Using Aqueous Lithium Bromide and Ternary Nitrate Mixtures**, report ORNL/TM-10392, Oak Ridge National Laboratory, Oak Ridge, TN, June 1988 (52 pages, available from NTIS, RDB-1143)

This report presents the results of a computer simulation study aimed at comparing the potential performance of lithium bromide (LiBr) and ternary nitrate aqueous mixtures in a heat pump. The falling-film heat transfer coefficient for the ternary nitrate mixture is estimated to be lower than that for LiBr by about one-third. Due to a lack of measured thermophysical properties, the estimates relied on extrapolations. The results show that the ternary nitrate mixture may be operated up to 260 °C (500 °F) boost temperature, which is approximately 80 °C (176 °F) higher than what has been demonstrated with LiBr. In higher temperature regimes, the nitrates show the potential for 10% higher COPs and a marginally greater absorber capacity than LiBr. Experimental measurements of the falling film heat transfer coefficient, subcooling, and thermophysical properties are required to make a more definitive investigation.

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Measuring the Concentration of a Flowing Oil-Refrigerant Mixture with a Bypass Viscometer**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 94(2), 1988 (RDB-2406)

R-12 and R-22 with naphthenic mineral oil, R-502 with an alkylbenzene lubricant

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Measuring the Concentration of a Flowing Oil-Refrigerant Mixture with a Vibrating U-Tube Densimeter**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 94(2):571-587, 1988 (17 pages with 12 figures and 1 table, RDB2407)

R-12 and R-22 with naphthenic mineral oil, R-502 with an alkylbenzene lubricant

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Measuring the Concentration of a Flowing Oil-Refrigerant Mixture with an Acoustic Velocity Sensor**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 94(2):602-615, 1988 (14 pages with 10 figures, RDB2408)

R-12 and R-22 with naphthenic mineral oil, R-502 with an alkylbenzene lubricant

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Measuring the Concentration of a Flowing Oil-Refrigerant Mixture: Instrument Test Facility and Initial Results**, paper 3122 (356-RP), *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 94(1):167-177, 1988 (11 pages with 6 figures, RDB-2247)

L. J. M. Kuijpers (Phillips Research Laboratories, The Netherlands), **The Influence of Refrigerant Charge on the Functioning of Small Refrigerating Appliances**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 94(2):-813-828, 1988 (16 pages with 11 figures and 1 table, RDB5553)

optimum charge, capacity, efficiency, void fraction correlation

L. M. Schlager, M. B. Pate, and A. E. Bergles, **Evaporation and Condensation of Refrigerant-Oil Mixtures in a Low-Fin Tube**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 94(2):1176-1194, 1988 (19 pages with 14 figures and 3 tables, RDB2343)

R-22 with naphthenic mineral oil

Methods of Measuring the Solubility and Viscosity of Lubricating Oil-Refrigerant Mixtures at High Discharge Pressures and Temperatures, research project 580-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, June 1988 (ASH-0580)

The contractor for the project was Iowa State University of Science and Technology, led by M. B. Pate. The project was sponsored by Technical Committees 3.4, *Lubrication*, and 8.1, *Positive Displacement Compressors*. [see RDB2344 and RDB2345 for findings]

May 1988

D. Jung, **Mixture Effects on Horizontal Convective Boiling Heat Transfer**, doctoral dissertation, Department of Mechanical Engineering, University of Maryland, College Park, MD, May 1988 (rdb2346)

L. J. M. Kuijpers, J. A. de Wit, and M. J. P. Janssen (Phillips Research Laboratories, The Netherlands), **Possibilities for the Replacement of CFC 12 in Domestic Equipment**, *International Journal of Refrigeration* (IJR), 11(4):284-291, May 1988 (8 pages, rdb2258)

R-12 alternatives

H. H. Kruse and U. Hesse (Universität Hannover, Germany), **Possible Substitutes for Fully Halogenated Chlorofluorocarbons Using Fluids Already Marketed**, *International Journal of Refrigeration* (IJR), 11(4):276-283, May 1988; republished in *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), IIR, Paris, France, July 1988 (8 pages, rdb2305)

M. O. McLinden, **Working Fluid Selection for Space-Based Two-Phase Heat Transport Systems**, report NBSIR 88-3812, National Institute of Standards and Technology (NIST, formerly the National Bureau of Standards, NBS), Gaithersburg, MD, May 1988 (80 pages with 3 figures and 13 tables, available from NTIS, RDB4728)

April 1988

A. P. Cohen, S. R. Dunne, and J. J. Seman, **Desiccants for Drying R-134a in Refrigeration Systems**, UOP Research and Molecular Sieve Technology, Tarrytown, NY, April 1988 (16 pages with 8 figures and 4 tables, available from JMC as RDB-0003)

This document summarizes tests of the effectiveness, compatibility, and physical strength of three Union Carbide Molecular Sieves for use as desiccants for R-134a. The molecular sieves tested were 4A-XH-5 and 4A-XH-6, both commercial products, as well as XH-7, a developmental item; all three were tested as 8x12 mesh beads. These desiccants were exposed to R-134a and a polyalkylene glycol lubricant (Union Carbide UCON LB-525) at 82 °C (180 °F) and then tested for fluoride content, water capacity, crush strength, and attrition. Plots of fluoride uptake and water-retention capacity, as functions of equivalent exposure time, are provided along with plots of water capacity, crush strength, and attrition versus fluoride content. Isotherms were generated for the three desiccants in R-134a. The document recommends against use of 4A-XH-5, currently used for R-12 drying, with R-134a. It suggests that the choice between the remaining types be based on the cost versus required performance, especially with respect to their relative strength characteristics. Significant build-up of fluoride was detected on the 4A-XH-5 molecular sieve, due to chemical reaction between R-134a and the desiccant. Further information on a long-term test of a 4A-XH-6 sample addressed is provided in document RDB0309.

March 1988

[R-]**123 Refrigerant Analyses**, report NIST-1, Chemistry Laboratory, The Trane Company, La Crosse, WI, 14 March 1988 (1 page with 1 table, available from JMC as RDB0022)

A table compares the chemical purity of R-123 samples, from AlliedSignal and DuPont Chemicals, with distilled R-11. Results are tabulated for chloride-ion content, high boiling temperature impurities, neutralization value, moisture content, and organic purity determined by gas chromatography. The moisture content in the R-123 samples was higher than expected, but not judged to be significant.

February 1988

S. C. Bhaduri (Indian Institute of Technology, India) and H. K. Varma, **Thermodynamic Properties of R22 - Cyclohexanone Combination for Vapour Absorption Refrigeration System**, *Proceedings of the VIIIth National Symposium on Refrigeration and Air-Conditioning* (Indian Institute of Technology, Kanpur, India, 26-27 February 1988), 129 ff 1988 (rdb6315)

R-22/absorbent, properties

R. E. Kauffman and W. E. Rhine (University of Dayton Research Institute), **Development of a Useful Lubricant Life Evaluation Technique, Part**

I: Differential Scanning Calorimetric Techniques, *Lubrication Engineering*, 44(2):154-161, February 1988 (8 pages, RDB3961)

C-C. Piao, **A Study of Thermodynamic Properties of CFC Alternative Refrigerants**, masters thesis (Department of Mechanical Engineering), Keio University, Yokohama, Japan, 1988 (rdb3748)

thermodynamic properties of R-123, R-134a, and others; thermophysical data

Real-Time Determination of Concentration of Oil Dissolved in a Refrigerant Flow Stream without Sample Removal, research project 356-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1984 - February 1988 (ASH0356)

The contractor was the Iowa State University of Science and Technology, led by A. E. Bergles; it was sponsored by ASHRAE Technical Committee 1.2, *Instruments and Measurements*.

January 1988

G. Angelino (Politecnico di Milano, Italy) and C. Invernizzi (Università di Brescia, Italy), **General Method for the Thermodynamic Evaluation of Heat Pump Working Fluids**, *International Journal of Refrigeration* (IJR), 11(1):16-25, January 1988 (10 pages with 10 figures, RDB3338)

general method to evaluate the performance of different classes of molecules as refrigerants for high-temperature heat pumps in the absence measured thermodynamic properties: identifies cycle quality, defined as the ratio of actual to ideal coefficient of performance (COP), as a function of the complexity of the molecular structure, reduced temperature for evaporation, and ratio of the temperature lift to the critical temperature; technical feasibility and efficiency are unsatisfactory for complex molecules, due to condensation during compression, unless regenerative precooling (e.g., by a suction-line/liquid-line heat exchanger) is applied prior to expansion of the refrigerant; evaporating reduced temperature (ration of the evaporating temperature to the critical temperature) should be moderate and preferably less than 0.7

Aluminum Corrosion in CFC Refrigeration, research project 425-RP, American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1984 - January 1988 (ASH0425)

The contractor for the project was Duke University, led by F. Cocks; it was sponsored by Technical Committee 3.2, *Refrigerant System Chemistry*. The results were not published, but partial documentation is available from the ASHRAE Manager of Research (+1-404/636-8400)

1988 (month not indicated)

S. C. Bhaduri (Indian Institute of Technology, India) and H. K. Varma**, Heat of Mixing of R22 - Absorbent Mixtures**, *International Journal of Refrigeration* (IJR), 11:92 ff, 1988 (rdb6314)

R-22/absorbent, properties

K. R. Bjorn, **Linear Least-Squares Regression Algorithm for the Optimization of Thermodynamic Equations of State**, thesis, University of Idaho, Moscow, ID, 1988 (rdb8C51)

thermodynamic properties, thermophysical data, equation of state (EOS)

Y. S. Chilipenok et al., **Heat Transfer in the Condensation of R12/R11 Freon Mixture in a Finned Plate Condenser**, *Heat Transfer - Soviet Research*, 20(5):676-683, 1988 (8 pages, rdb6447)

experimental data on condensation of R-12/11 in a vertical plate condenser: The diffusion layer decreases condensation for mixtures with a large difference in component boiling temperatures.

F. de Rossi, O. Manca, R. Mastrullo (Università di Napoli "Frederico II", Italy), and P. Mazzei (Università degli Studi di Salerno, Italy), **Exergy-Enthalpy Diagrams of R502 and R503 and their Application**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 94(2), 1988 (rdb-5634)

R-502, R-503, thermodynamic properties, thermophysical data

P. E. DiNenno, **SFPE Handbook of Fire Protection Engineering**, National Fire Protection Association (NFPA), Quincy, MA, 1988 (RDB4C54)

flammability, flame limits, LFL, UFL, combustibility, ignition

J. S. Gallagher, M. O. McLinden, and G. Morrison (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), **Thermodynamic Diagrams for Refrigerant Mixtures**, paper OT-88-20-5, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 94(2):2119-2136, 1988 (18 pages with 10 figures and 3 tables, RDB5114) provides pressure-enthalpy (PH) diagrams for R-13/12 (40/60) and (60/40), R-22/11 (40/60) and (60/40), and R-22/114 (40/60) and (60/40) based on Carnahan-Starling-DeSantis (CSD) equations of state (EOS): also provides temperature-entropy (TS) diagrams for the R-22/114 blends and for R-22 and R-114 individually; describes the CSD EOS and preparation of the diagrams; zeotropic blends; thermodynamic properties; includes discussion by T. Z. Mazur (National Research Council, Canada, NRCC) and S. A. Sherif (University of Miami)

M. Goto, **Condensation on Single Horizontal Tube of Freon Refrigerants and Their Mixtures**, *Scientific Achievement Reports on Phase Change in Multicomponent Systems*, Japan, 66-67, 1988 (RDB6204)

R-114/11, R-12/114, zeotropic blends, method to correlate experimental data for condensation on a tube in a uniform filmwise manner based on two-phase boundary-layer theory

B. Kruppa, P. Jany, and J. Straub (Technische Universität München, TUM, Germany), **Experimental Apparatus for Measuring the Thermal Diffusivity of Pure Fluids at High Temperatures**, *International Journal of Thermophysics*, 9:911-921, 1988 (11 pages, rdb5628)

transport properties, thermophysical data

R. E. Lenga, **The Sigma-Aldrich Library of Chemical Safety Data** (second edition), Sigma-Aldrich Corporation, 1988 (rdb5162)

flammability, toxicity, and other safety data

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Ammonia: An Excellent Alternative**, *International Journal of Refrigeration* (IJR), 11:248-252, 1988 (5 pages, rdb4235)

R-717

E. E. A. Lund, R. G. Richard, and I. R. Shankland (AlliedSignal Incorporated), **A Performance Evaluation of Environmentally Acceptable Foam Blowing Agents**, *Polyurethanes 1988* (proceedings of the 31st Annual Technical and Marketing Conference), Society of the Plastics Industry (SPI), New York, NY, 290-296, 1988 (7 pages, RDB0502)

Y. T. Ma, C. R. Lu, J. X. Cui, X. L. Hu, and G. L. Zhang (Tianjin University, China), **Experimental Research of a Water-to-Water Heat Pump Cycle Using Nonazeotropic Mixture R-22/142**, *Experimental Heat Transfer, Fluid Mechanics, and Thermodynamics*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 1988 (rdb3C17)

T. Makita, **Protection of Stratospheric Ozone and Alternative Refrigerants**, *Kagaku Kogaku*, 52(8):-601-606, 1988 (6 pages, rdb5972)

environmental effects

R. Mastrullo (Università di Napoli "Frederico II", Italy) and P. Mazzei (Università degli Studi di Salerno, Italy), **Programma Interattivo per il calcolo della proprietà di refrigeranti e l'analisi di cicli inversi** [Interactive Computer Program for Calculation of Refrigerant Properties and Analysis of Reversed Cycles], *Il Freddo* [Refrigeration], Italy, 42(1):61 ff and 42(2):203 ff, 1988 (rdb5631)

R-11, R-12, R-13, R-13B1, R-21, R-22, R-23, R-113, R-114, R-114B2, R-115, R-124a [probably R-124], R-134a, R-142b, R-152a, R-C318, R-500, R-502, R-503, R-717, thermodynamic properties, thermophysical data

M. C. MacCracken, **Greenhouse Warming: What Do We Know?**, report UCRL-99998, Lawrence Livermore National Laboratory (LLNL), Livermore, CA, 1988 (rdb7A36)

global warming, greenhouse gases, environmental impact, atmospheric chemistry, radiative forcing of the atmosphere, climatic consequence of composition changes, impacts

M. O. McLinden (National Institute of Standards and Technology, NIST), **Thermodynamic Evaluation of Refrigerants in the Vapour Compression Cycle Using Reduced Properties**, *International Journal of Refrigeration* (IJR), 11:134-143, May 1988 (10 pages with 8 figures and 3 tables, RDB3212)

analyzes the effects of refrigerant properties on performance; shows that most involve a tradeoff between a high coefficient of performance (COP) and high capacity; shows that there is an optimum heat capacity, and that high critical pressure increases system capacity with no penalty on COP; concludes that the critical temperature is the most important factor in determining performance; also concludes that the approaches presented may lead to improved refrigerants for high-temperature (condensing temperatures above 100 °C, 212 °F) applications, but that superior refrigerants to those presently used are not likely for lower temperatures

J. T. McMullan, N. Murphy, and D. W. Hughes (University of Ulster, Northern Ireland, UK), **The Effect of Oil on the Performance of Heat Pumps and Refrigerators - Part 1. Experimental Test Facility**, *Heat Recovery Systems and CHP*, 8(1):53-68, 1988 (16 pages, rdb7816)

refrigerant-lubricant: performance reduction in soluble refrigerant-oil systems

please see page 6 for ordering information

J. T. McMullan, N. Murphy, and D. W. Hughes (University of Ulster, Northern Ireland, UK), **The Effect of Oil on the Performance of Heat Pumps and Refrigerators - Part 2. Experimental Results**, *Heat Recovery Systems and CHP*, 8(2):95-124, 1988 (30 pages, rdb7817)

refrigerant-lubricant: performance reduction in soluble refrigerant-oil systems

S. K. Naidu, E. E. Klaus, and J. L. Duda, **Thermal Stability of Esters Under Simulated Boundary Lubrication Conditions**, *Wear*, 121:211-222, 1988 (12 pages, rdb4930)

polyolester, POE

N. H. Proctor, J. P. Hughes, and M. L. Fischman, **Chemical Hazards of the Workplace** (second edition), J. B. Lippincott Company, Philadelphia, PA, 1988 (rdb5C50)

reference for toxicity and other safety data [referenced in RDB5C46]

R. K. Radermacher (University of Maryland) and J. Lavelle (Elf Atochem North America, Incorporated), **Comparison of R-12 with the Blend of R-22/142b**, *Proceedings of the ASME Winter Annual Meeting* (Chicago, IL), American Society of Mechanical Engineers (ASME), New York, NY, 22-30, 1988 (9 pages, rdb2339)

R-22/142b

V. Ramanathan, **The Greenhouse Theory of Climate Change: A Test by an Inadvertent Global Experiment**, *Science,* 240:293-299, 1988 (7 pages, rdb7A32)

global warming, greenhouse gas effect

S. Solomon, **The Mystery of the Antarctic Ozone Hole**, *Reviews of Geophysics*, 26:131-148, 1988 (18 pages, rdb4151)

ozone depletion, environmental impacts

K. Stephan and T. Heckenberger (Universität Stuttgart, Germany), **Thermal Conductivity and Viscosity Data of Fluid Mixtures**, *Chemistry Data Series X*, Deutsche Gesellschaft für chemisches Apparatewesen e.V. (DECHEMA), Frankfurt am Main, Germany, 1988 (rdb5530)

blends, transport properties, thermophysical data

Y. Takizawa and H. Muto, **Determination of Fluorocarbons Obtained by the Photochlorination**, *Fluoride*, 21(4):201-209, 1988 (9 pages, rdb5C03)

environmental effects

Y. Tanaka, A. Miyake, H. Kashiwagi, and T. Makita (Kobe University, Japan), **Thermal Conductivity of Liquid Halogenated Ethanes under High Pressure**, *International Journal of Thermophysics*, 9:465-479, 1988 (15 pages, rdb8436)

transport properties or R-123 and others; thermophysical data

R. Thiele and T. Hackensellner, **Industriewärmepumpen mit Kältemittel und Wasser als Arbeitsmedium** [Industrial Heat Pumps Using Refrigerants and Water as the Working Fluid], *Rationelle Energietechnik in der Lebensmittelindustrie* [Efficient Energy Technologies in the Food Processing Industry], report 675, Verein Deutscher Ingenieure (VDI) [Association of German Engineers] (München, Germany), VDI-Verlag, Düsseldorf, Germany, 261-275, 1988 (15 pages, rdb5A17)

R-718

E. A. Vineyard (Oak Ridge National Laboratory, ORNL), **Laboratory Testing of a Heat Pump System Using an R-13B1/152a Refrigerant Mixture**, paper 3130 *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 94(1), 1988 (11 pages with 8 figures and 4 tables, RDB2329)

R. T. Watson for the Ozone Trends Panel, M. J. Prather for the Ad Hoc Theory Panel, and M. J. Kurylo for the Panel for Data Evaluation **Present State of Knowledge of the Upper Atmosphere 1988: An Assessment Report**, reference publication 1208, National Aeronautics and Space Administration (NASA), Washington, DC, 1988 (rdb3135)

recognized assessment that challenged the adequacy of the original Montreal Protocol and suggested the need for more aggressive measures

N. Yada, M. Uematsu, and K. Watanabe (Keio University, Japan), **Study of the PVTx Properties for Binary R-152a + R-114 System**, *Nippon Reito Kyokai Ronbunshu* [Transactions of the JAR], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, 5(1):107-115, 1988 (9 pages in Japanese, rdb4230)

R-152a/114 blends, thermodynamic properties, thermophysical data

T. Yamashita, H. Kubota, Y. Tanaka, T. Makita, and H. Kashiwaga**, Measurement of Physical Properties of New Fluorocarbons**, *Proceedings of the Ninth Japan Symposium on Thermophysical Properties*, 227-230, 1988 (4 pages, rdb4324)

thermodynamic properties or R-134a and others; thermophysical data

A Comprehensive Evaluation of Alternative CFC Refrigerants from the Molecular Structure, research project 561-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, circa 1988 (ASH0561)

The contractor for the project was the National Bureau of Standards (NBS, now the National Institute of Standards and Technology, NIST), led by D. A. Didion and M. O. McLinden; it was sponsored by ASHRAE Technical Committee 3.1, *Refrigerants and Brines.*

Disassembly and Inspection of Compressor in Laboratory Refrigerator Charged with R-134a, report NIST-13, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1988 (40 pages with 50 figures and 3 tables, available from JMC as RDB0309)

This report documents a detailed inspection of a hermetic compressor, operated for 8.7 years with R-134a and a polyalkylene glycol (PAG) lubricant, Union Carbide UCON LB-525. An unmodified Frigidaire refrigerator was charged with R-134a in November 1977, but the compressor failed a month later. The failure analysis was not located, but the cause is believed to have been a manufacturing defect. The compressor was replaced and the refrigerator returned to service in July 1978; it operated without incident until March 1987. The refrigerator was functioning normally when shut down for compressor disassembly, to determine the long term effects of this refrigerant-oil system. This report provides a photographic record of the disassembly, summarizes detailed chemical and metallurgical analyses, and includes profilometer readings to evaluate the effect of slight copper plating on steel bearing surfaces. A hardened steel vane spring, which broke when dropped, had been severely fatigued during service. The polyethylene slot liner insulation showed embrittlement, but was not analyzed. Very limited refrigerant decomposition was found, and the report concludes that R-134a use had very little effect on the metal parts of the compressor. Particles trapped in the oil produced slight scars on metallic contact surfaces. The molecular sieve drier contained 5% residual water, compared to a saturation value of 19-20%. Unanswered questions remain concerning the refrigerant-lubricant stability; addition of an oil stabilizer or use of a different oil may be indicated. General Electric Company and Tecumseh Products Company assisted in disassembling the compressor and interpreting the visual evidence. Further examination of the desiccant used, Union Carbide molecular sieve type 4A-XH-6, is reported in document RDB0003.

Refrigeration Equipment and Heat Pumps Using CFCs/HCFCs: The Refrigerants Order and Comments, Swedish National Environmental Protection Agency, Stockholm, Sweden, 1988 (71 pages, RDB1130)

Specifications for Fluorocarbon Refrigerants, ARI Standard 700-88, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1988 (12 pages with two tables and 1 appendix, RDB3103)

The intent of this standard is to define a level of quality for new, reclaimed, and/or repackaged refrigerants for use in new and existing refrigeration and air-conditioning products. Specified contaminant levels were chosen to be within the sensitivity of recommended test methods, to be economically achievable, and to provide satisfactory performance. The standard does not apply where refrigerant captured from a particular system is returned on site to the same system. It defines and classifies contaminants based on standard test methods. It also specifies acceptable purity requirements for various fluorocarbon refrigerants, regardless of source. These refrigerants include R-11, R-12, R-13, R-22, R-113, R-114, R-500, R-502, and R-503. It addresses the boiling point and range as well as allowable content of vapor-phase contaminants, and water, chloride ion, acidity, high-boiling residues, particulates and solids, and other refrigerants. It identifies accepted industry test procedures for these determinations.

1987

December 1987

Assessing the Risks of Trace Gases that Can Modify the Stratosphere, report EPA-400/1-87/001, U.S. Environmental Protection Agency (EPA), Washington, DC, December 1987 (rdb3745)

fluorocarbon refrigerants, environmental impacts

November 1987

R. J. Denny (Air-Conditioning and Refrigeration Institute, ARI), **The CFC Footprint**, *ASHRAE Journal*, 29(11), November 1987; republished in *CFCs: Time of Transition*, ASHRAE, 23-28, 1989 (6 pages with 13 figures and 1 table, RDB2257)

alternative refrigerants, ozone depletion potential (ODP), comparative efficiencies, "drop-in" refrigerants, refrigerant use

please see page 6 for ordering information

M. O. McLinden (National Institute of Standards and Technology, NIST) and R. K. Radermacher (University of Maryland), **Methods for Comparing the Performance of Pure and Mixed Refrigerants in the Vapor Compression Cycle**, *International Journal of Refrigeration* (IJR), 10(8):318-325, November 1987 (8 pages with 8 figures and 2 tables, RDB2508)

October 1987

H. O. Spauschus (Spauschus Associates, Incorporated), **Developments in Refrigeration: Technical Advances and Opportunities for the 1990s**, *International Journal of Refrigeration* (IJR), 9:263-270, October 1987 (8 pages, rdb2731)

September 1987

Y. A. Repin, **Method for Raising the Wear Resistance of the Cylinder Surface of a Reciprocating Compressor**, Soviet Engineering Research, 7(9):33-34, September 1987 (2 pages, RDB4C28)

August 1987

D. Arnaud and J. C. Tanguy (Atochem Groupe Elf Aquitaine), **Propriétés Thermophysiques des Réfrigérants R 124 et R 134a** [Thermophysical Properties of Refrigerants R-124 and R-134a], *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVllth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, 159-166, 1987 (8 pages, rdb-5534)

R-124, R-134a, thermophysical data

Y. Higashi, Y. Kabata, and K. Watanabe (Keio University, Japan), **Thermodynamic Behavior of the Vapor-Liquid Coexistence Curve for Binary Refrigerant Mixtures**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVIIth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, 13:128-133, 1987 (6 pages, rdb4108)

thermodynamic properties of blends; thermophysical data

Y. Kabata, Y. Higashi, and M. Uematsu (Keio University, Japan), **Correlation of the Vapor-Liquid Coexistence Curve for Binary Refrigerant Mixtures**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVllth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, 8:140-145, August 1987 (6 pages, rdb4109)

thermodynamic properties of blends; thermophysical data

M. Küver and H. H. Kruse (Universität Hannover, Germany), **Thermodynamic Data of the Binary Mixture R22/R114**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVllth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, 13:152-158, August 1987 (7 pages, rdb4110)

R-22/114 blends, thermophysical properties

M. O. McLinden, D. A. Didion (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), and C. D. MacCracken (Calmac Manufacturing Company), **Refrigerant Mixture of Trichlorofluoromethane and Dichlorohexafluoropropane**, U.S. patent 4,687,588, 18 August 1987 (3 pages, RDB6814)

use of R-11/216aa, R-11/216ba, R-11/216ca, or R-11/216cb to improve the pressure lift capabilities and operating range of centrifugal compressors; R-11 and the four R-216 isomers form an azeotrope in a 74/11 blend

R. K. Radermacher (University of Maryland), **Vapor-Compression Heat Pump Cycle with Desorber-Absorber Heat Exchange**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVllth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, August 1987 (rdb6414)

Y. Takaishi and K. Oguchi (Kanagawa Institute of Technology, Japan), **Measurements of Vapor Pressures of R22/Oil Solutions**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVllth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, B:217 ff, August 1987 (rdb5438)

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L. C. Tan and J. M. Yin, **Thermodynamic Analysis of R22/R114 Refrigeration Cycle**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVllth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, 13:670-675, 1987 (6 pages, rdb4111)

R-22/114

July 1987

Influence of Oil on Pressure Drop in Refrigerant Lines, research project 336-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1983 - July 1987 (ASH0336)

The contractor was the University of Missouri at Rolla, led by R. Howell; it was sponsored by ASHRAE Technical Committee 10.3, *Refrigerant Piping.*

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H. O. Spauschus and L. M. Speaker (Georgia Institute of Technology), **A Review of Viscosity Data for Oil-Refrigerant Solutions**, technical paper 3094 (444-RP), *Transactions* (Annual Meeting, Nashville, TN, 27 June - 1 July 1987), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 93(2):667-681, 1987 (15 pages, RDB2224)

lubricants, properties of refrigerant-lubricant mixtures

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K. E. Güngör and R. H. S. Winterton, **Simplified General Correlation for Saturated Flow Boiling and Comparisons of Correlations with Data**, *Chemical Engineering Research and Design* (Journal of the Institution of Chemical Engineers, Rugby, UK), 65:148-156, March 1987 (9 pages, rdb5247)

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R. P. Vallort, J. Sanchez, and W. V. Richards, **Ammonia and Air Conditioning**, *Technical Papers of the Ninth Annual Meeting*, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 89-98, March 1987 (10 pages, RDB4238)

R-717

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G. Alefeld, **What Needs to be Known About Working Fluids to Calculate COPs**, *Proceedings of the International Energy Agency (IEA) Heat Pump Conference* (Orlando, FL, January 1987), 1987 (rdb8363)

sensitivity of performance to refrigerant selection and properties; calculation of the coefficient of performance (COP)

S. Komatsuzaki, T. Tomobe, and Y. Homma (Hitachi Limited, Japan), **Additive Effects on Lubricity and Thermal Stability of Refrigerator Oils**, *Lubrication Engineering*, 43(1):31-36, January 1987 (6 pages, rdb2423)

refrigerant-lubricant chemistry; compatibility; lubricity; additives

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D. E. Briggs and E. H. Young, **Modified Wilson Plot Techniques for Obtaining Heat Transfer Correlations for Shell-and-Tube Heat Exchangers**, *Chemical Engineering Progress Symposium Series*, American Institute of Chemical Engineers (AIChE), New York, NY, 65:35-45, 1987 (11 pages, rdb4657)

D. Gorenflo and V. Bieling (Universität Paderborn, Germany), **Heat Transfer at Pool Boiling of Mixtures with R22 and R115**, *Proceedings of the XVIIIth International Symposium on Heat and Mass Transfer in Cryoengineering and Refrigeration*, 243-257, 1986 or 1987 (15 pages, rdb6411)

R-22/115, R-502

R. Heide, **Properties of Refrigerating Machine Oil Lüfrigöl XK 30 and its Mixtures with Refrigerants**, *Luft- und Kältetechnik*, Germany, 23(3):160-162, 1987 (3 pages in German, rdb4C33)

refrigerant-lubricant properties; vapor pressure, viscosity, and density plotted as functions of temperature and pressure with R-13, R-13B1, and R-22

P. Jany and J. Straub (Technische Universität München, TUM, Germany), **Thermal Diffusivity of Fluids in a Broad Region Around the Critical Point**, *International Journal* of *Thermophysics*, 8:165-180, 1987 (16 pages, rdb5627)

transport properties, thermophysical data

please see page 6 for ordering information

P. Jany and J. Straub (Technische Universität München, TUM, Germany), **Thermal Diffusivity of Five Pure Fluids**, *Chemical Engineering Communications*, 57:67-76, 1987 (rdb5626)

transport properties, thermophysical data

A. Kanungo, T. Oi, S. Popowicz, and T. Ishida (State University of New York), **Vapor Pressure Isotope Effects in Liquid Methylene Difluoride**, *Journal of Physical Chemistry*, 91(15):4198-4203, 1987 (6 pages, rdb4144)

vapor pressures of isotopic R-32, thermodynamic properties, thermophysical data

I. L. Karol and V. V. Babanova, **Global Dispersion of Chlorofluorocarbons in the Atmosphere**, *Meteorol. Gidrol*., (3):39-46, 1987 (8 pages in Russian, rdb5269)

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H. Lippold and S. Reinhold, **Laboratory Tests of the Tribological Characteristics of Refrigerating Machine Oils Under the Influence of Refrigerants**, *Luft- und Kältetechnik*, Germany, 23(4):218-220, 1987 (3 pages in German, rdb4C34)

load-bearing tests of steel-steel bearings with various lubricants with R-12 and R-22

M. J. Prather (National Aeronautics and Space Administration, NASA), M. McElroy, S. Wofsy, G. Russel, and D. Rind, **Chemistry of the Global Troposphere: Fluorocarbons as Tracers of Air Motion**, *Journal of Geophysical Research* (JGR), 92:6579-6613, 1987 (35 pages, rdb5904)

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V. Ramanathan, L. Callis, R. Cess, J. E. Hansen, I. Isaksen, L. Kuhn, A. A. Lacis, F. Luther, J. D. Mahlman, R. Reck, and M. Schlesinger, **Climate-Chemical Interactions and Effects of Changing Atmospheric Trace Gases**, *Reviews of Geophysics*, 25:1441-1482, 1987 (42 pages, rdb7A34)

R-11, R-12, and others, environmental impacts

H. D. Ross (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), R. K. Radermacher, M. di Marzo (University of Maryland), and D. A. Didion (NBS), **Horizontal Flow Boiling of Pure and Mixed Refrigerants**, *International Journal of Heat and Mass Transfer*, 30(5):979-992, 1987 (14 pages in German, rdb5115)

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P. A. Sanders (formerly E. I. duPont de Nemours and Company) **Handbook of Aerosol Technology**, Robert E. Krieger Publishing Company, Malabar, FL, 1987 (rdb7294)

flammability and toxicity data for aerosol propellants, many of which also are used as refrigerants; flammability data for blends of R-11, R-12, R-21, R-22, R-114, R-123, R-124, R-133a with R-142b or R-152a and with R-290, R-600, R-600a, R-601, or R-601a

K. Stephan, R. Krauss, and A. Laesecke (Universität Stuttgart, Germany), **Viscosity and Thermal Conductivity of Nitrogen for a Wide Range of Fluid States**, *Journal of Physical and Chemical Reference Data*, 16(4):993-1023, 1987 (11 pages, rdb5532)

transport properties for R-728 (nitrogen); thermophysical data

M. Takahashi, C. Yokoyama, and S. Takahashi, **Viscosities of Gaseous R13B1, R142b, and R152a**, *Journal of Chemical and Engineering Data*, 32:98-103, 1987 (6 pages, rdb3931)

transport properties for R-13B1, R-142b, and R-152a; thermophysical data

A. Valtz, S. Laugier, and H. Richon, **Bubble Pressures and Saturated Liquid Molar Volumes of Trifluorotrichloroethane-Fluorochlorohydrocarbon Mixtures. Experimental Data and Modelization**, *Journal of Chemical Engineering*, 32:397-400, 1987 (4 pages, rdb7C48)

R-113 blends with fluorochemicals, thermodynamic properties, thermophysical data; R-12/152a/113 as reported in RDB7945

T. M. Vogel, C. S. Criddle, and P. L. McCarty, **Transformations of Halogenated Aliphatic Compounds** *Environmental Science and Technology*, 21:722-736, 1987 (15 pages, rdb8448)

hydrolysis rates, environmental fate

Oil-Flooded Propylene Refrigeration Screw Compressor, *Kobelco Technology*, Japan, 2(2):63 ff, 1987 (rdb4C18)

R-1270, propene

The Ozone Layer, document 2, Environment Monitoring System (GEMS), United Nations Environment Programme (UNEP), Nairobi, Kenya, 1987 (limited copies available from JMC as RDB2703)

Thermophysical Properties of Freons, Part 2, edited by T. B. Selover, Jr., for the Izdatel'stvo Standartov [National Standard Reference Data Service of the USSR (NSRDS)], Hemisphere Publishing Company, New York, 1987 (rdb9130)

thermodynamic and transport properties, thermophysical data

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R. C. Castro-Gomez, G. A. Inglesias-Silva, W. R. Lau, J. C. Holste, K. N. Marsh, K. R. Hall, and P. T. Eubank (Texas A&M University), **Experimental Enthalpies and Densities of Compressed Liquid Refrigerants**, paper 86-WA/HT-57 (Winter Annual Meeting, Anaheim, CA, 7-12 December 1986), American Society of Mechanical Engineers (ASME), New York, NY, 1986 (rdb8206)

thermodynamic properties, thermophysical data

J. A. Tichy, N. A. Macken, W. M. B. Duval and C. K. Kong, **Heat Transfer in Forced-Convective Condensation and Evaporation of Oil-Refrigerant Mixtures**, *Heat Transfer in Air-Conditioning and Refrigeration Equipment* (Winter Annual Meeting, Anaheim, CA, 7-12 December 1986), edited by J. A. Kohler and J. W. B. Lu, American Society of Mechanical Engineers (ASME), New York, NY, HTD65, 1986 (rdb6740)

heat transfer, effect of lubricants

An Experimental Investigation of the Effects of Refrigerant-Oil Mixture on Condensation Heat Transfer Coefficient and Pressure Drop in Water-Cooled Shell-and-Tube Condensers, research project 378-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, December 1982 - December 1986 (ASH0378)

The contractor for the project was Concordia University, Canada, led by J. Wang; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

November 1986

October 1986

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August 1986

G. Morrison and M. O. McLinden, **Application of a Hard Sphere Equation of State to Refrigerants and Refrigerant Mixtures**, NBS Technical Note 1226, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, August 1986 (156 pages, available from JMC as RDB0911)

The Carnahan-Starling-DeSantis (CSD) equation of state is applied to halogenated hydrocarbon refrigerants and their mixtures. A set of thermodynamic functions is derived from the PVT equation of state and the ideal gas heat capacities. Reference states are discussed for both pure materials and mixtures. Although the model exhibits a critical point, it does not quantitatively represent properties in the critical region. Despite this limitation, this model can represent both liquid and gaseous mixtures away from their own critical points, even at conditions near to and above the critical points of their components. Algorithms and Fortran routines for the use of this model are presented along with the numerical coefficients for 11 pure refrigerants and 7 mixtures. Routines for evaluating the coefficients from saturation data are included. Several examples of the application of this equation of state are presented to demonstrate its versatility. The average deviation from the tabulated saturation properties of the 11 pure refrigerants is 0.54% for pressures, 0.09% for liquid volumes, and 0.50% for vapor volumes.

H. D. Ross, **An Investigation of Horizontal Flow Boiling of Pure and Mixed Refrigerants**, report NBSIR 86-3450, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, August 1986 (376 pages with 68 figures and 13 tables, available from NTIS, rdb4727)

heat transfer, blends

July 1986

J. C. Blaise and T. Dutto (Électricité de France, EDF, France), **Some Practical Results Obtained**

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with Nonazeotropic Mixture of Refrigerants in High Temperature Heat Pump, *Proceedings of the Meeting of IIR Commissions B1, B2, E1, and E2* (Purdue University West Lafayette, IN, July 1986), International Institute of Refrigeration, Paris, France, 1986 (rdb4403)

zeotropic blends, performance

R. L. Cox, **Improvements and Enhancements of the ABSORB Computer Program for Modeling Chemical Absorption Heat Pump Systems**, report ORNL/TM-9957, Oak Ridge National Laboratory, Oak Ridge, TN, July 1986 (56 pages, available from NTIS, RDB1144)

This report provides documentation for updates to ABSORB, a simulation program for modeling chemical absorption heat pump systems of varying configuration. A number of improvements and enhancements have been incorporated to improve the robustness, flexibility, and applicability of this code; these modifications include: 1) a revised strategy of solving the system equations, 2) increased modularization of the program, and 3) the first efforts to employ the code to determine an optimum economic design of a heat pump system. A listing of the Fortran source code for ABSORB is included as an appendix. The listing excludes the optimizing package NPSOL, which is proprietary and must be separately obtained. User documentation to run ABSORB is published separately in report ORNL/Sub/43337/2.

T. H. Kuehn and R. E. Gronseth, **The Effect of a Nonazeotropic Binary Refrigerant Mixture on the Performance of a Single Stage Refrigeration Cycle**, *Proceedings of the Meeting of IIR Commissions B1, B2, E1, and E2* (Purdue University West Lafayette, IN, July 1986), International Institute of Refrigeration, Paris, France, 119, 1986 (rdb7A24)

zeotropic blends, performance

T. Yanagisawa and T. Nomura (Daikin Industries, Limited, Japan), **Application of Nonazeotropic Refrigerant Mixtures in Multi-Zone Heat Pump Room Air Conditioner with Hot Water System**, *Proceedings of the Meeting of IIR Commissions B1, B2, E1, and E2* (Purdue University West Lafayette, IN, July 1986), International Institute of Refrigeration, Paris, France, 61-69, 1986 (9 pages with 8 figures and 2 tables, RDB5513)

performance of R-13B1/12, R-22/114; zeotropic blends

T. Shimizu, **Study of the Flow Characteristics of Refrigerating Oil Dissolved with Refrigerant**, *Nippon Kikai Gakkai Ronbunshu* (Transactions of the Japan Society of Mechanical Engineers, JSME), JSME, Tokyo, Japan, 52(479):2581-2587, July 1986 (7 pages in Japanese, rdb4C30)

flow characteristics of mineral oil lubricant in R-22, comparison of predicted and measured data

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R. K. Radermacher (University of Maryland), **Advanced Versions of Heat Pumps with Zeotropic Refrigerant Mixtures**, *Transactions* (Annual Meeting, Portland, OR, 22-25 June 1986), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 92(2A):52-59, 1986 (8 pages, rdb4880)

Study to Increase the State of the Art of Solubility and Viscosity Relationships for Lubricating Oil-Refrigerant Mixtures, research project 444-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1985 - June 1986 (ASH0444)

The contractor for the project was the Georgia Tech Research Institute, led by H. O. Spauschus; it was sponsored by Technical Committee 3.4, *Lubrication*.

May 1986

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L. M. Speaker and H. O. Spauschus (Georgia Institute of Technology), **A Study to Increase the State-of-the-Art Solubility and Viscosity Relationships for Oil-Refrigerant Mixtures**, final report for 444-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 20 February 1986 (RD82504)

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J. J. Baustian, M. B. Pate, and A. E. Bergles, **Properties of Oil-Refrigerant Liquid Mixtures with Applications to Oil Concentration Measurement: Part I - Thermophysical and Transport Properties**, *Transactions* (Winter Meeting, San Francisco, CA, 19-22 January 1986), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 92(1A):55-73, 1986 (19 pages, rdb3B59)

refrigerant-lubricant (RL) properties

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Properties of Oil-Refrigerant Liquid Mixtures with Applications to Oil Concentration Measurement: Part II - Electrical and Optical Properties**, *Transactions* (Winter Meeting, San Francisco, CA, 19-22 January 1986), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 92(1A):74-92, 1986 (19 pages with 16 figures and 3 tables, RDB4924)

This paper presents an investigation of electrical and optical properties of liquid oil-refrigerant mixtures as possible bases for real-time measurement of lubricant concentrations. It recommends measurement of capacitance and refractive index as two options, but also addresses light absorption and dielectric constant.

M. P. Bertinat, **Fluids for High Temperature Heat Pumps**, *International Journal of Refrigeration* (IJR), 9(1):43-50, January 1986 (8 pages, rdb7723)

refrigerants for high temperature conditions

J. B. Chaddock and G. Buzzard (Duke University), **Film Coefficients for In-Tube Evaporation of Ammonia and R-502 with and without Small Percentages of Mineral Oil**, *Transactions* (Winter Meeting, San Francisco, CA, 19-22 January 1986), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 92(1A):22-40, 1986 (19 pages, rdb8517)

measurements and correlations of local heat transfer coefficients inside horizontal tubes for R-502 with a mineral oil (MO, Witco Suniso(R) 3GS) and R-717 with Capella WF68 oil; effect of lubricants; concentrations of 0-10% lubricant decreased heat transfer

T. Yanagisawa and T. Shimizu, **Foaming of Refrigerating Oil in a Rolling Piston Type Compressor**, *International Journal of Refrigeration* (IJR), 9(1):17-20, January 1986 (4 pages, rdb4C31)

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S. C. Bhaduri (Indian Institute of Technology, India) and H. K. Varma, **P-T-X Behavior of R22 with Five Different Absorbents**, *International Journal of Refrigeration* (IJR), 9:362 ff, November 1986 (rdb6313)

R-22/absorbent, thermodynamic properties

I. Borde and M. Jelinek (Ben-Gurion University of the Negev, Israel), **Thermodynamic Properties of Binary Fluid Mixtures for Absorption Refrigeration Systems**, paper 86-WA/HT-60 (ASME Winter Annual Meeting, Anaheim, CA, 7-12 December 1986), American Society of Mechanical Engineers (ASME), New York, NY, 1986 (rdb5528)

R-22/N-methylpyrolidone (R-22/NMP), thermophysical data, absorption cycles

D. P. Degrush, **Measurements of Heat Transfer Coefficients of Nonazeotropic Refrigerant Mixtures Inside Horizontal Tubes**, MS thesis (Department of Mechanical Engineering), University of Illinois at Urbana-Champaign, 1986 (172 pages, rdb5559)

zeotropes, blends

R. E. Dickinson and R. J. Cicerone (University of California, Irvine, UCI), *Nature*, 319:109 ff, 1986 (rdb3C43)

role of chlorofluorocarbons (CFCs) in stratospheric ozone depletion

P. A. Domanski, **Modelling of a Heat Pump Charged with a Nonazeotropic Refrigerant Mixture**, NBS Technical Note 1218, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, 1986 (408 pages with 28 figures and 12 tables, available from GPO, also available from JMC as RDB6856)

analysis of the vapor compression cycle and the main components of an air-to-air heat pump charged with R-13B1/152a for steady-state operation: includes the User's Manual and a listing of the source code for the simulation model, named HPBI, and validation with experimental data; cycle analysis for a zeotropic blend

J. F. Ely, **An Equation of State Model for Pure CO_2 and CO_2-Rich Mixtures**, *Proceedings of the 65th Annual Gas Processors Association Convention*, Gas Processors Association, Tulsa, OK, 185-192, 1986 (6 pages, rdb7A31)

R-744 (carbon dioxide) thermodynamic data: equation of state (EOS), thermophysical properties

P. H. Gamlen, B. C. Lane, P. M. Midgley, and J. M. Steed, **The Production and Release to the Atmosphere of CCl_3F and CCl_2F_2 (Chlorofluorocarbons CFC 11 and CFC 12)**, *Atmospheric Environment*, 20(6):1077-1085, 1986 (9 pages, RDB5504)

R-11, R-12, production and emission data

V. Z. Geller, **Thermophysical Properties of Working Fluids for Refrigerants**, *Publ. High Education*, Ukraine, Russia, 1986 (rdb6329)

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thermodynamic and transport data, refrigerants

J. L. Glajch and W. G. Schindel, **Column Packing for On-Line GC Analysis of Fluorocarbons in the Presence of Reactive Gases**, *LC-GC*, 4(6), 1986 (rdb3512)

R-12, R-22, R-134a, separation of refrigerant mixtures

A. Golombek and R. G. Prinn, **A Global Three-Dimensional Model of the Circulation and Chemistry of $CFCl_3$, CF_2Cl_2, CH_3CCl_3, CCl_4, and N_2O**, *Journal of Geophysical Research* (JGR), 91:3985-4001, 1986 (17 pages, rdb5905)

R-11, R-12, R-140a, R-10, R-744A, environmental impacts

U. Gropp and E. Schlunder, **The Influence of Liquid-Side Mass Transfer and Sensitivity During Surface and Nucleate Boiling of Liquid Mixtures in a Falling Film**, *Chemical Engineering Process.*, 20(2):103-114, 1986 (12 pages, rdb6412)

nucleate boiling of liquid, azeotropic and zeotropic blends

K. E. Güngör and R. H. S. Winterton, **A General Correlation for Flow Boiling in Tubes and Annuli**, *International Journal of Heat and Mass Transfer*, 29(3):351-358, 1986 (8 pages, rdb5248)

heat transfer

J. K. Hammitt (Rand Corporation), **Product Uses and Market Trends for Potential Ozone-Depleting Substances**, report EPA/R-3386, U.S. Environmental Protection Agency (EPA), Washington, DC, 1986 (rdb8146)

fluorochemical refrigerants and others, statistics, applications

Y. Higashi, M. Uematsu, and K. Watanabe (Keio University, Japan), **Measurements of the Vapor-Liquid Coexistence Curve and Critical Locus for Several Refrigerant Mixtures**, *International Journal of Thermophysics*, *7*:128-133, 1986 (11 pages, rdb4125)

thermodynamic properties of blends; thermophysical data

H. Honda, B. Uchima, S. Nozu and T. Fujii (Okayama University, Japan), **Effect of Vapour Velocity on Film Condensation of R113 on Horizontal Tubes in a Crossflow**, *International Journal of Heat and Mass Transfer*, 29:429-438, 1986 (10 pages, rdb5734)

R-113, heat transfer

J. T. Kiehl and S. Solomon (National Oceanic and Atmospheric Administration, NOAA), **On the Radiative Balance of the Stratosphere**, *Journal of Atmospheric Science*, 43:1525-1534, 1986 (10 pages, rdb7649)

environmental impact, fluorochemical refrigerants, GWP

V. A. Isidorov and B. V. Ioffe, **Nonanthropogenic Sources of Halocarbons in the Earth's Atmosphere**, *Dokl. Akad. Nauk. S.S.S.R.*, Russia, then USSR), 287(1):86-90, 1986 (5 pages, rdb5267)

natural sources of fluorocarbons, environmental effects

R. T. Jacobsen, R. B. Stewart, and M. Jahangiri (University of Idaho), **Thermodynamic Properties of Nitrogen from the Freezing Line to 2000 K with Pressures to 1000 MPa**, *Journal of Physical and Chemical Reference Data*, 15(2):735-909, 1986 (175 pages, rdb7A20)

R-728 (nitrogen): thermodynamic properties from the freezing line to 1727 °C (3140 °F) and 1000 MPa (145,000 psia), thermophysical data, equation of state (EOS)

M. Jahangiri, R. T. Jacobsen, R. B. Stewart, and R. D. McCarty, **Thermodynamic Properties of Ethylene from the Freezing Line to 450 K with Pressures to 260 MPa**, *Journal of Physical and Chemical Reference Data*, 15(2):593-734, 1986 (142 pages, rdb7A16)

R-1150 (ethylene): thermodynamic properties up to 177 °C (350 °F) and up to 260 MPa (38,000 psia), thermophysical data

P. Jany, **Die Temperaturleitfähigkeit reiner Fluide im weiten Zustandsbereich um den kritischen Punkt** [Thermal Diffusivity of Pure Fluids in a Broad Region Around the Critical Point], thesis, Technische Universität München (TUM), Germany, 1986 (rdb5625)

transport properties, thermophysical data

M. K. Jensen and H. P. Bensler, **Saturated Forced Convective Boiling Heat Transfer with Twisted-Tape Inserts**, *Journal of Heat Transfer*, 108:93-99, 1986 (7 pages, rdb6415)

blend heat transfer

Y. Kanome and I. Fujita, BS thesis (Department of Mechanical Engineering), Keio University, Yokohama, Japan, 1986 (rdb8449)

density of R-152a: thermodynamic properties, thermophysical data

R. S. Katti, R. T. Jacobsen, R. B. Stewart, and M. Jahangiri, **Thermodynamic Properties for Neon for Temperatures from the Triple Point to 700 K**

at Pressures to 700 MPa, *Advances in Cryogenic Engineering*, 31:1189-1197, 1986 (9 pages, rdb-7A19)

R-720 (neon): thermodynamic properties from the triple point to 426 °C (800 °F) and up to 700 MPa (102,000 psia), thermophysical data, equation of state (EOS)

G. Morrison and M. O. McLinden (National Bureau of Standards, NBS), **Application of the Carnahan-Starling-DeSantis Equation of State to Refrigerants and Refrigerant to Mixtures of Refrigerants**, paper 86-WA/HT-59 (ASME Winter Annual Meeting, Anaheim, CA, 7-12 December 1986), American Society of Mechanical Engineers (ASME), New York, NY, 1986 (rdb3508)

describes a modification to the Carnahan-Starling (CS) equation of state (EOS) to describe the properties of refrigerant materials and their binary and ternary mixtures: discusses application to R-22 and R-22/114; thermodynamic properties, thermophysical data

W. J. Mulroy and D. A. Didion, **The Performance of a Residential Sized Heat Pump Operating with a Nonazeotropic Binary Refrigerant Mixture**, report NBSIR 86-3422, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, 1986 (available from NTIS, RDB6413)

zeotropic blends

S. Pourezza-Djourshari and R. K. Radermacher (University of Maryland), **Calculation of the Performance of Vapor-Compression Heat Pumps with Solution Circuits Using the Mixture R22/DGEDME**, *International Journal of Refrigeration* (IJR), 9:, 1986 (rdb4444)

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Rand Corporation, **Product Uses and Market Trends for Potential Ozone-Depleting Substances. 1985-2000**, report EPA/R-3386, U.S. Environmental Protection Agency (EPA), Washington, DC, 1986 (rdb4568)

J. V. Sengers (University of Maryland) and J. M. H. Levelt Sengers (National Bureau of Standards, NBS), **Thermodynamic Behavior of Fluids Near the Critical Point**, *Ann. Rev. Phys. Chem.*, 37:189-222, 1986 (34 pages, rdb9512)

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P. G. Seybold et al., **On the Physical Properties of Halogenated Hydrocarbons**, *Acta Pharmaceutica Jugoslavica*, Yugoslavia, 36(2):253-266, 1986 (14 pages, rdb5837)

alternative refrigerants

V. A. M. Soares, B. J. V. S. Almeida, I. A. McLure, and R. A. Higgins, **Surface Tension of Pure and Mixed Simple Substances at Low Temperature**, *Fluid Phase Equilibria*, 32:9-16, 1986 (8 pages, rdb-7A10)

R-14 and others: surface tension for single-compound refrigerants and blends, transport properties, thermophysical data

T. N. Tandon, H. K. Varma, and C. P. Gupta, **Generalized Correlation for Condensing of Binary Mixtures Inside a Horizontal Tube**, *International Journal of Refrigeration* (IJR), 9:, 1986 (rdb5117)

heat transfer, condensation, blends, azeotropic, zeotropic

H. C. Ünal, **Prediction of Nucleate Boiling Heat Transfer Coefficients for Binary Mixtures**, *International Journal of Heat and Mass Transfer*, 29(4):-637-640, 1986 (4 pages, rdb4422)

blends, heat transfer

A. Valtz, S. Laugier, and H. Richon, **Bubble Pressures and Saturated Liquid Molar Volumes of Difluoromonochloroethane-Fluorochloroethane Binary Mixtures**, *International Journal of Refrigeration* (IJR), 9:282-295, 1986 (4 pages, rdb4207)

R-142b/21, R-21, R-142b, blends, thermodynamic properties, thermophysical data; vapor pressure and density of R-142b as reported in RDB7945

T. Yokoyama (Tokyo Electric Power Company, Japan), **The Effect of an Electric Field on Boiling Heat Transfer of Fluorocarbon R-11**, XVII International Conference for Heat and Mass Transfer, Dubrovnik, Yugoslavia, 1986 (rdb3C19)

heat transfer, electrohydrodynamic (EHD) enhancement

V. P. Zhelezny (Odessa State Academy of Refrigeration, Ukraine then USSR), J. A. Kachurka, and L. D. Lasota, **Scaling Principles in Predicting Thermodynamic Properties of Nonassociated** [possibly Immiscible] **Liquids and their Binary Mixtures in Saturation**, *Novosybirsk* (proceedings of the Seventh All-Union Conference on Thermophysical Properties of Substances), ABOK, Moscow, USSR, 31-32, 1986 (2 pages in Russian, rdb6C26)

thermodynamic properties, thermophysical data

M. J. Zion, **Lubricating Oils for Refrigeration Systems**, *Technical Papers of the Eighth Annual Meeting,* International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 137-154, 1986 (18 pages, rdb3340)

R-717, lubricants

please see page 6 for ordering information

Documentation of the Threshold Limit Values (fifth edition), American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1986 (rdb4150)

This book documents the bases for threshold limit values (TLVs) for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). The refrigerants addressed include R-11, R-12, R-12B2, R-21, R-22, R-30, R-40, R-113, R-114, R-115, R-170 (ethane), R-290 (propane), R-600 (butane), R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-7146 (sulfur hexafluoride), and others.

Present State of Knowledge of the Upper Atmosphere: An Assessment Report, National Aeronautics and Space Administration (NASA), Washington, DC, 1986 (rdb5565)

atmospheric concentrations of fluorochemicals, environmental impacts

Refrigerant Property Tables (I-P Units), research project 407-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, completed in 1986 (ASH0407)

The contractor for the project was the University of Idaho, led by R. B. Stewart; it was sponsored by ASHRAE Technical Committee 3.1, *Refrigerants and Brines.*

1985

December 1985

November 1985

October 1985

September 1985

August 1985

Heat Transfer and Pressure Drop in Condensing and Evaporating Multicomponent Flow, research project 221-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, December 1980 - August 1985 (ASH0221)

The contractor for the project was Rensselaer Polytechnic Institute (RPI), led by J. A. Tichy; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

July 1985

June 1985

T. Berntsson, K. M. Berntsson, and H. Panholzer (Chalmers University, Sweden), **Heat Transfer of Nonazeotropic Mixtures in a Falling Film Evaporator**, *Transactions* (Annual Meeting, Honolulu, HI, 23-26 June 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 91(2B):1337-1350, 1985 (14 pages, RDB6416)

zeotropic blends

J. M. Calm (Electric Power Research Institute, EPRI) and D. A. Didion (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), **Research and Development of Heat Pumps Using Nonazeotropic Mixture Refrigerants**, *Advances in Nonazeotropic Mixture Refrigerants for Heat Pumps*, technical data bulletin 1(9), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 132-139, June 1985 (8 pages with no figures or tables, RDB2353)

zeotropes, blends, research needs, status

G. Morrison and M. O. McLinden (National Bureau of Standards, NBS), **Two Refrigerant Mixtures and the Hard Sphere Fluid**, paper HI-85-18-3, *Transactions* (ASHRAE Annual Meeting, Honolulu, HI, June 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 91(2):929-935, 1985 (14 pages with 9 figures and 1 table, available from JMC as RDB3509)

binary blends, azeotropes, zeotropes, equation of state (EOS)

U. W. Schulz (Carrier Corporation), **The Characterization of Fluid Mixtures and Their Utilization in Vapor Compression Refrigeration Systems**, *Transactions* (Annual Meeting, Honolulu, HI, 23-26 June 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 91(2B), 1985; republished in *Advances in Nonazeotropic Mixture Refrigerants for Heat Pumps*, technical data bulletin 1(9), ASHRAE, 12-22, 1985 (11 pages, RDB6418)

azeotropic and zeotropic blends, predicted versus measured performance

W. F. Stoecker and E. Kornota (University of Illinois at Urbana-Champaign), **Condensing Coefficients When Using Refrigerant Mixtures**, *Transactions* (ASHRAE Annual Meeting, Honolulu, HI, June 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 91(2B):1351-1367, 1985 (17 pages with 20 figures and 4 tables, RDB5116)

heat transfer, condensation

E. G. Wright (E. I. duPont de Nemours and Company, Incorporated), **Prediction of Refrigerant Ternary Mixture Properties Using the Redlich-Kwong-Soave Equation of State**, *Advances in Nonazeotropic Mixture Refrigerants for Heat Pumps*, technical data bulletin 1(9), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 37-52, June 1985 (16 pages, RDB2331)

Redlich-Kwong-Soave (RKS) equation of state (EOS), thermodynamic properties of blends, thermophysical data

May 1985

C. Nolden, **Synthetic Lubricants**, *Plant Engineering*, 39(9):30-41, May 1985 (12 pages, rdb4C27)

April 1985

March 1985

Freon(R) Fluorocarbons Properties and Applications, bulletin G-1 (document E-03528-1), E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, March 1985 (12 pages with 1 figure and 8 tables, RDB3511)

This brochure summarizes physical, thermodynamic, safety, and application data for R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-113, R-114, R-115, R-116, R-500, R-502, and R-503. Key physical parameters are tabulated for application of these refrigerants. The brochure reviews safety considerations for refrigerant use, noting that none of the compounds addressed are flammable or explosive though mixtures with other gases may be flammable. Health effects are reviewed with attention to relative toxicity and exposure limits, dermal effects (skin and eye contact), oral toxicity, central nervous system (CNS) effects, and cardiac sensitization. The brochure briefly discusses thermal decomposition products and handling of major spills and releases. Stability and decomposition data are provided for R-11, R-12, R-13, R-22, R-113, R-114, and R-115. Hydrolysis data with water, alone and in solution with sodium hydroxide, are presented for R-22 and R-23. The brochure discusses compatibility with commonly-used construction metals including aluminum, cast iron, brass, copper, lead, steel, and tin. It notes that some of the metals may act as catalysts for refrigerant breakdown at high temperatures. Alkali, and alkaline earth metals (sodium, potassium, barium, etc.), magnesium, and finely ground or powdered aluminum may be reactive with some or all refrigerants. Swell data with elastomers are tabulated for R-11, R-12, R-13, R-13B1, R-22, R-30 (methylene chloride), R-40 (methyl chloride), R-113, R-114, R-115, R-140a (methyl chloroform), and R-502 with neoprene GN, butadiene acrylonitrile (Buna(TM) N), butadiene styrene (Buna(TM) S), isoprene isobutylene (Butyl(TM)), and polysulfide and natural rubbers. Compatibility data are discussed with lubricants and plastics. A vapor pressure-temperature chart is included.

February 1985

Mitsubishi Heavy Industries, Limited, **Prevention of Oxidative Degradation of Lubricating Oils for Refrigeration Compressors**, *Kokai Tokkyo Kono,* Japan, February 1985 (rdb4B19)

lubricant stability

please see page 6 for ordering information

January 1985

G. Morrison (National Bureau of Standards, NBS), **The Importance of Including the Liquid Phase in Equations of State for Nonazeotropic Refrigerant Mixtures**, *Transactions* (Winter Meeting, Chicago, IL, 27-30 January 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 91(1B):260-273, January 1985 (14 pages, rdb6431)

equation of state (EOS), thermodynamic properties, thermophysical data, zeotropic blends

K. S. Sanvordenker (Tecumseh Products Company), **Mechanism of Oil-R12 Reactions - the Role of Iron Catalyst in Glass Sealed Tubes**, paper 2881, *Transactions* (Winter Meeting, Chicago, IL, 27-30 January 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 91(1A):356-369, January 1985 (14 pages with 7 figures and 1 table, RDB2217)

This frequently cited paper presents the chemistry of oil and R-12 reactions in sealed-tube tests in detail. The paper reviews the mechanisms postulated in earlier publications [see RDB2326 and RDB2526] and observations based on infrared absorbance. The paper concludes that iron acts as a participant in the reaction, rather than as a catalyst. Large amounts can be solubilized, and the process of solubilization begins early. The iron-oil molecule and R-12 react with the glass; this reaction also starts much earlier than previously indicated. The reaction forms boron-hydrogen and silicone fluorine compounds, while precipitating out the solubilized iron. Based on gas analysis by infrared, a criterion is defined to identify the entry of glass in sealed-tube reactions. The paper traces through the postulated reactions and experiments conducted, to identify actual reactions by elimination of participating materials. Based on the finding that reactions involving glass start at an early stage in systems containing R-12, oil, and steel, data in prior publications that show large amounts of reaction products need to be reexamined.

J. A. Tichy, N. A. Macken, and W. M. B. Duval, **An Experimental Investigation of Heat Transfer in Forced-Convection Condensation of Oil-Refrigerant Mixtures**, *Transactions* (Winter Meeting, Chicago, IL, 27-30 January 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 91(1A):297-309, 1985 (13 pages with 5 figures and 2 tables, rdb3B52)

R-12, mineral oil, heat transfer

1985 (month not indicated)

T. Adamek, **Rechenmodelle der Filmkondensation an engberippten Kondensatorrohren** [Calculation Model for Film Condensation for Tightly Spaced Condenser Tubes] in *Wärme- und Stoffübertragung* [Heat and Mass Transfer], Germany, 19:145-157, 1985 (13 pages in German, rdb4733)

heat exchangers, heat transfer

V. V. Altunin, V. Z. Geller, E. A. Kremenevskaya, I. L. Perelshtein, and E. K. Petrov, **Thermophysical Properties of Freons, Methane Serie, Part 2**, National Standard Reference Data Service of the USSR (NSRDS), Moscow, USSR, 2:31-76, 1985; republished by Hemisphere Publishing Company, New York, 1987 (rdb5449)

transport properties, thermophysical data

R. Camporese, G. Bigolaro (Consiglio Nazionale delle Ricerche, CNR, Italy), and L. Rebellato (Istituto per la Tecnica del Freddo del CNR, Italy), **Calculation of the Thermodynamic Properties of Refrigerants by the Redlich-Kwong-Soave Equation of State**, *International Journal of Refrigeration* (IJR), 8(3):147-151, 1985 (5 pages, rdb8443)

RKS equation of state (EOS), thermophysical data

M. W. Chase, C. A. Davies, J. R. Downey, D. J. Frurip, R. A. McDonald, and A. N. Syverd (National Institute of Standards and Technology, NIST**) JANAF Thermochemical Tables** (Third Edition), *Journal of Physical and Chemical Reference Data*, 14(supplement 1):1-1856, 1985 (1856 pages, rdb-7A12)

chemical properties, thermophysical data

D. H. Enhalt and U. Schmidt, **The Effect of Man-Made Halocarbons on Stratospheric Ozone**, *Pollutants - Their Ecotoxicological Significance*, 97-118, 1985 (22 pages, rdb6289)

ozone depletion

N. Enjo and M. Noguchi, **Refrigerant and Lubricating Oil**, *Reito* [Refrigeration], Japan, 60(694):38-44, 1985 (7 pages, rdb4329)

E. Fernandez-Fassnacht and F. del Rio, **Vapor Pressures of CCl_3F, CCl_2F_2, and $CClF_3$**, *Cryogenics*, 25:204-207, 1985 (4 pages, rdb7A73)

R-11, R-12, and R-13: thermodynamic properties, thermophysical data

G. Grossman and E. Michelson, **Absorption Heat Pump Simulation and Studies, Part I: A Modular Computer Simulation of Absorption Systems,** report ORNL/Sub/43337/2, Oak Ridge National Laboratory, Oak Ridge, TN, circa 1985 (available from NTIS, rdb0926)

N. Hasegawa, M. Uematsu, and K. Watanabe (Keio University, Japan), **Measurements of p, v, T, x Properties of the R22 + R114 System**, *Journal of Chemical and Engineering Data*, 30:32-36, 1985 (5 pages, rdb4124)

thermodynamic properties of R-22/114: measurements of pressure, volume, temperature, and quality; thermophysical data

I. Jonsson, **Plate Heat Exchangers as Evaporators and Condensers for Refrigerants**, *Australian Refrigeration, Air Conditioning, and Heating*, 39(9):19-31, 1985 (13 pages, rdb6435)

use of compact brazed-plate heat exchangers

H. H. Kruse and M. Schroeder (Universität Hannover, Germany), **Fundamentals of Lubrication in Refrigeration Systems and Heat Pumps**, *International Journal of Refrigeration* (IJR), 8:347-355, 1985 (9 pages with 9 figures and 5 tables, rdb3461)

revision to RDB3411

J. T. McMullan, D. W. Hughes, and R. Morgan (University of Ulster, Northern Ireland, UK), **A Suite of Computer Programs for Calculating Refrigerant Properties**, *Heat Recovery Systems and CHP*, 5(2):143-180, 1985 (38 pages, rdb5273)

thermodynamic properties of R-12 and others; thermophysical data

N. E. Murphy, **Effects of Lubricating Oil on Evaporator Performance**, D.Phil. thesis, University of Ulster, Coleraine, Northern Ireland, UK, 1985 (rdb-8441)

lubricant influences on heat transfer

V. Ramanathan, R. J. Cicerone, H. B. Singh, and J. T. Kiehl, **Trace Gas Trends and their Potential Role in Climate Change**, *Journal of Geophysical Research* (JGR), 90:5547-5566, 1985 (20 pages, rdb3136)

R-11, R-12, and others, environmental impacts

A. Rojey, **Practical Use of Non-Azeotropic Refrigerant Mixtures in Heat Pumps and Air Conditioners**, Institut Français du Pétrole, Rueil Malmaison, France, 1985 (30 pages with 8 figures and 4 tables, RDB5521)

R-22/11, R-290/600, R-290/600a, zeotropic blends, early field test of refrigerant mixtures

H. D. Ross, **An Investigation of Horizontal Flow Boiling of Pure and Mixed Refrigerants**, doctoral dissertation, Department of Mechanical Engineering, University of Maryland, College Park, MD, 1985 (rdb6419)

single-compound refrigerants, azeotropic and zeotropic blends, heat transfer in tubes

R. H. Schlosberg, A. Kurs, G. D. Dupre, and R. J. Pancirov, **Thermal Chemistry of Esters and Ketones**, *Liquid Fuel Technology*, 3(4):465 ff, 1985 (rdb4356)

thermal degradation of ester lubricants

R. Schmidt and W. Wagner, **A New Form of the Equation of State for Pure Substances and its Application to Oxygen**, *Fluid Phase Equilibria*, 19:175-200, 1985 (26 pages, RDB7965)

R-732 (oxygen), equation of state (EOS), thermodynamic properties, thermophysical data [the fundamental equation (FEQ) presented is identified by some other authors as the Schmidt-Wagner EOS]

M. Schroeder, **Development and Test of a Low Cost Screw Compressor for Refrigerants R-12 and R-114**, dissertation, Universität Hannover, Hannover, Germany, 1985 (rdb4285)

K. Shinsaka, N. Gee, and G. R. Freeman, **Densities Against Temperature of 17 Organic Liquids and of Solid 2,2-Dimethylpropane**, *Journal of Chemical Thermodynamics*, 17:1111-1119, 1985 (9 pages, rdb7B18)

thermodynamic properties of R-14, R-23, R-32, R-601b (neopentane), and others; thermophysical data

Y. W. Song, J. L. Yu, and S. Y. Fu, **KDR-1 Thermal Conductivity Instrument for Liquid and Solid by Transient Hot-Wire Method**, *Chinese Journal of Scientific Instrumentation*, 6:369-381, 1985 (13 pages, rdb5640)

measurement, instrumentation, thermophysical properties

G. van der Waal (Unichema Chemie BV, The Netherlands), **The Relationship Between the Chemical Structure of Ester Base Fluids and their Influence on Elastomer Seals, and Wear Characteristics**, *Journal of Synthetic Lubricants*, 1:280-301, 1985 (22 pages with 20 figures and 4 tables, RDB2233)

Standard Test Method for Concentration Limits of Flammability of Chemicals, standard E681-85, American Society of Testing and Materials (ASTM), West Conshohocken, PA, 1985, reapproved in 1991 (RDB2919)

flammability limits, LFL, UFL

please see page 6 for ordering information

1984

L. Brodsky, J. Zielinski, G. Perrault, and R. Schmaus, **Commercial Experience with Diester Based Synthetic Industrial Lubricants**, *Iron and Steel Engineer,* 61(12):41-46, December 1984 (6 pages, rdb4C19)

polyolester, POE

D. A. Didion, unpublished letter report on the energy performance potential of "R-176", National Bureau of Standards (NBS), Gaithersburg, MD, 29 November 1984 (20 pages with 6 figures and 4 tables, available from JMC as RDB2320)

This letter report summarizes an investigation of the performance potential of a ternary zeotropic blend, namely R-22/12/142b, commercially identified as "R-176". The document addresses the blend's characteristics, to determine if an azeotrope exists within the temperature and composition ranges of interest. It also presents an evaluation of potential capacity and efficiency benefits, relative to those for R-22, in an unaltered (except for the expansion device) heat pump. The document provides a generic discussion of azeotropic behavior and determination. A figures illustrates the phenomena of both positive and negative azeotropes. Composition measurements, as liquid and vapor mole fractions, are tabulated for the specific blend at -15 and 0 °C (5 and 32 °F) and illustrated relative to the R-22/12 binary azeotrope on a composition diagram. The document provides a liquid saturation (bubble point) plot for -35 to 60 °C (-31 to 140 °F) and reviews thermodynamic cycle predictions for the blend. The document presents the experimental evaluation approach, including determination of expansion device sensitivity. Performance measurements are tabulated at standard rating conditions (-8.3 and 8.3 °C for heating and 27.8 and 35 °C for cooling, 17, 47, 82 and 95 °F respectively). Composition shifts, their determination, and their impacts are discussed. The document concludes that no azeotrope exists for this ternary mixture for any combination of components where the mole fraction of R-142b is 0.05-0.93 for the temperature range of interest for heat pumps, air conditioning, and refrigeration. The blend resulted in a 40-50% decrease in capacity in both the heating and cooling modes, 5-13% decrease in cooling coefficient of performance (COP), and 10-25% decrease in heating COP. The document notes that some COP increase may be observed in certain systems, particularly where heat exchangers are undersized. [The designation "R-176" is a trade name, derived by summing the component designation numbers, rather than a refrigerant number conforming to ASHRAE Standard 34].

J. N. Friedman, **Experimental Evaluation of Alaskan Air Conditioning Company's Mixed Refrigerant R-176**, Carrier Corporation, Syracuse, NY, 17 August 1984 (13 pages with 2 figures and 4 tables, available from JMC as RDB1B01)

The measured performance of a zeotropic ternary blend, R-22/12/142b (25/15/60) is compared to that of R-22 for two residential heat pumps. The units tested included an air-to-water heating-only model and an air-to-air heating and-cooling model. The charge and expansion device orifice (Accurator(R) piston size) were optimized for capacity and efficiency. The heating capacity and coefficient of performance (COP) were approximately 52 and 15% lower, respectively, with the refrigerant blend than with R-22 in the air-to-water heat pump. The heating and cooling capacities were approximately 35 and 46% lower, respectively, in the air-to-air heat pump, but the efficiency increased by approximately 10% in the cooling mode and was nearly the same for heating. The test procedures and conditions are described in the report. The study concluded that the mixture is not a viable replacement in Carrier heat pump systems operating in the heating mode. Additional testing is recommended to determine if increases in efficiency can be achieved with the mixture in the cooling mode, based on further capillary tube and refrigerant charge optimization, despite the decreased cooling capacity.

K. Fushimi, **Heat Pump with Nonazeotropic Refrigerant Mixture**, Daikin Industries, Limited, Osaka, Japan, 25 July 1984 (13 pages with 6 figures and 5 tables, rdb2356)

R-22/114, zeotropic blends

R. C. Downing (E. I. duPont de Nemours and Company), **Development of Chlorofluorocarbon Refrigerants**, *Transactions* (Annual Meeting, Kansas City, MO, 17-20 June 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 90(2B):481-491, 1984; republished in *CFCs: Time of Transition*, ASHRAE, 16-22, 1989 (11/7 pages with 2 figures and 1 table, RDB2436)

D. J. Glova (Chevron Research Company), **High-Temperature Solubility of Refrigerants in Lubricating Oil**, *Transactions* (Annual Meeting, Kansas City, MO, 17-20 June 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, 90(2B):806-824, 1984; republished in *ASHRAE Journal*, 26(5), 1984 (19 pages with 8 figures and 3 tables, RDB2211)

R-12, R-22, R-502, alkylbenzene lubricant

R. K. Radermacher (University of Maryland), **Heat Pump Cycles with Nonazeotropic Refrigerant**

Mixtures in Thermodynamic Diagrams, *Transactions* (Annual Meeting, Kansas City, MO, 17-20 June 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 90(2A):166-174, 1984 (9 pages with 4 figures, RDB3519)

zeotropic blends

K. S. Sanvordenker (Tecumseh Products Company), **Lubrication by Oil-Refrigerant Mixtures: Behavior in the Falex Tester**, paper KC-84-14-3, *Transactions* (Annual Meeting, Kansas City, MO, 17-20 June 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 90(2):799-805, 1984; republished in *ASHRAE Journal*, 26:59 ff, 1984 (7 pages with 2 figures and 3 tables, RDB2422)

The effects of test parameters, with reference to the fundamentals of boundary lubrication, are discussed for Falex pin and v-block tests. Such tests are widely used by equipment manufacturers and lubricant suppliers to simulate lubrication in refrigerant compressors and to screen refrigeration lubricants. When modified to provide a closed, pressure-tight chamber, the Falex machine permits laboratory simulation of lubricants in hermetic compressors. The paper review fundamental theories of boundary lubrication and wear to explain laboratory data that may appear to be anomalous. In doing so, the paper explains that trouble-free operation of hermetic compressors under high-oil dilution conditions of liquid feedback has been simulated. The unanticipated result is explained on the basis of dissipation of frictional heat from the rubbing surfaces. The behavior of additive-free lubricants is described and compared to that with antiwear additives, such as tricresyl phosphate (TCP).

H. O. Spauschus (Georgia Institute of Technology), **Evaluation of Lubricants for Refrigeration and Air-Conditioning Compressors**, *Transactions* (Annual Meeting, Kansas City, MO, 17-20 June 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 90(2B):784-798, 1984; republished in *ASHRAE Journal*, 26(5):59 ff, 1984 (15 pages with 4 figures, rdb2225)

R-12, R-22, petroleum-based and synthetic lubricants, bench and compressor tests

D. W. Hughes, J. T. McMullan, K. A. Mawhinney, and R. Morgan, **Influence of Oil on Evaporator Heat Transfer (Results for R-12 and Shell Clavus 68)**, *International Journal of Refrigeration* (IJR), 7(3):150-158, May 1984 (10 pages, rdb0923)

Experiments to investigate the influence of lubricating oil on heat transfer and refrigerant flow in evaporators are described. R-12 and Shell Clavus 68 oil were used. Efforts were made to model actual operation as closely as possible. The oil was found to have a significant effect on refrigerant flow and pressure drop. Measurements made on the heat transfer coefficient indicated that the oil had different effects depending on the fluid flow regime. No effect was apparent for annular-wavy regimes, but the presence of oil significantly reduced the heat transfer coefficient for annular-film flows.

H. H. Kruse and M. Schroeder (Universität Hannover, Germany), **Fundamentals of Lubrication in Refrigeration Systems and Heat Pumps**, paper KC-84-14-1, *Transactions* (Annual Meeting, Kansas City, MO, 17-20 June 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 90(2B):763-783, 1984 (21 pages); republished in *ASHRAE Journal*, 26(5), May 1984 (17 pages with 8 figures and 7 tables, rdb3411)

R-11, R-12, R-13, R-14, lubricants: overview, common lubrication problems

W. F. Stoecker (University of Illinois at Urbana-Champaign), **Selecting the Size of Pipes Carrying Hot Gas to Defrost Evaporators**, *International Journal of Refrigeration* (IJR), 7(4):225-228, May 1984 (4 pages, rdb4633)

pipe sizing

T. J. Clancey and S. R. Dunne, **Methods of Testing Desiccants for Refrigerant Drying**, *Transactions* (Winter Meeting, Atlanta, GA, 29 January - 1 February 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 90(1):164-178, 1984 (15 pages, rdb-2431)

R. R. R. Scharf, V. W. Goldschmidt, and L. White (Purdue University), **Measurement of Refrigerant Leakage in Reversing Valves**, *Transactions* (Winter Meeting, Atlanta, GA, 29 January - 1 February 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 90(1A):185-195, 1984 (11 pages with 7 figures and 1 table, RDB5614)

describes a test method and measurements of flow leakage in heat pump reversing valves

Y. C. Y. Wang, M. Truaga, S. Lin, and P. Fazio, **The Effects of Refrigerant-Oil Mixtures on Condensation Heat Transfer on External Surfaces of Horizontal Tubes in Shell-and-Tube Condensers**, *Transactions* (Winter Meeting, Atlanta, GA, 29 January - 1 February 1984), American Society of Heating, Refrigerating, and Air-Conditioning

please see page 6 for ordering information

Engineers (ASHRAE), Atlanta, GA, 90(1B):26-38, 1984 (20 pages, rdb5617)

heat transfer, effects of lubricants

R. L. Webb (Pennsylvania State University), **Shell-Side Condensation in Refrigerant Condensers**, *Transactions* (Winter Meeting, Atlanta, GA, 29 January - 1 February 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 90(1B):5-25, 1984 (20 pages, rdb5616)

R-11, R-12, R-21, R-22, R-113, R-717 (ammonia), R-718 (water, steam), heat transfer, effects of noncondensable gases and lubricants, tube bundle design, tube surface enhancement

L. Batt, **The Role of Freons in the Chemistry of the Upper Atmosphere**, report Eur 9436, *Communications of the European Communities*, 293-295, 1984 (3 pages, rdb5843)

fluorocarbon refrigerants, environmental reactions, physical and chemical behavior of atmospheric pollutants

T. Berntsson, K. Lundkvist (Chalmers University, Sweden), F. Moser, and H. Schnitzer (Graz University, Austria), **High-Temperature Working Fluids and Nonazeotropic Mixtures in Compressor Driven Heat Pumps**, report on IEA HPC Annex VI, International Energy Agency (IEA) Heat Pump Centre (HPC), Sittard, The Netherlands (then in Karlsruhe, Germany), 1984 (rdb5517)

zeotropic blends

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please see page 6 for ordering information

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tabular findings of swell when immersed in liquid refrigerant at room temperature and weight change after drying in air for two weeks following immersions for eight refrigerants and 16 plastics; the refrigerants included R-11, R-12, R-13B1, R-21, R-22, R-112, R-113, and R-114; the plastics included acetal resin (DuPont Delrin(R)), cellulose acetate, cellulose nitrate, chlorotrifluoroethylene polymer, acrylic resin (Lucite(R)); polyester film (DuPont Mylar(R)), polyamide 6/6 nylon (DuPont Zytel(R) 101), phenol formaldehyde resin, polyethylene, linear polyethylene, polypropylene, polystyrene, polyvinyl alcohol, polyvinyl chloride, polyvinylidene chloride, and tetrafluoroethylene resin (TFE, DuPont Teflon(R)); data also are tabulated for immersion tests of 14 plastics in R-11, R-112, and R-113 for five minutes at their boiling points; the plastics tested included linear polyethylene resin (Alathon(R) 7050), polypropylene resin (Alathon(R) 9140), acetal resin (DuPont Delrin(R)), epoxy resin, ethyl cellulose, ABS polymer (USS Chemicals Kralastic(R)), polycarbonate (General Electric Lexan(R)), cast methylmethacrylate resin (Lucite(R)), polyvinyl alcohol, unplasticized polyvinyl chloride, polystyrene (Dow Chemical Styron(R) 475), Ionomeric resin (Surlyn(R) A), TFE (DuPont Teflon(R), and polyamide 6/6 nylon (DuPont Zytel(R) 101); permeability data are tabulated for R-11, R-12, R-13, R-21, R-22, R-114, R-732 (oxygen), and R-728 (nitrogen) with 19 plastic films; limited data also are reported for R-116 and R-C318; the films tested included chlorinated polyether, polyester (DuPont Mylar(R) and Hostaphen(R)), aluminized polyester, nylon, polyethylene (unspecified, Suprathen(R) N, V56, and V57), polypropylene (unspecified and PP11), polyvinyl alcohol, polyvinyl chloride (Genotherm(R) UG), polyvinyl fluoride, polyvinylidene chloride (Saran(R)), TFE (DuPont Teflon(R) 100-X FEP), and polyester urethane; bulletin concludes that most plastics are not appreciably affected by the tested refrigerants, that the effect on plastics becomes less as the amount of fluorine in the molecule is increased (except for fluorinated polymers which tend to swell slightly in highly fluorinated refrigerants), and that plastic materials should be tested for compatibility for each application

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presence of lubricants in circulating refrigerants raises the boiling point; refrigerant-lubricant (RL) properties

B. Toekes (Sperry Research Center), **Dichlorotetrafluoroethane Sensitivity of Various Elastomers in Geothermal Energy Conversion Applications**, *I&EC Product Research & Development*, American Chemical Society, Washington, DC, 20(1):190-193, 1981 (4 pages, RDB7204)

R-114, compatibility with a copolymer of ethylene and methyl acrylate with a third monomer for curing (DuPont Vamac 91680-187 and ON-0803-47), fluoroelastomer (3M Fluorel Cpd C), polysulfide rubber (Thiokol FA), NBR (Polysar Krynac 50.75), filled polytetrafluoroethylene (PTFE, Dixon Rulon A, described as DuPont Teflon(R) with undisclosed fillers), ethylene-propylene-diene terpolymer (EPDM, Goodrich Epcar), methyl trifluoropropyl silasene (Dow Corning Silastic LS 2249 and LS2332), and phosphonitrilic fluoroelastomer (Firestone PNF); dimensional stability (swell), hardness, and thermal stability tests

Frigen(R) Primer for Refrigeration, Air Conditioning and Energy Technology, product bulletin AFK1479E/46, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, December 1981 (104 pages with 4 figures and 22 tables, RDB4779)

This bulletin provides information on the properties, application, and handling of R-11, R-12, R-12B1, R-13, R-13B1, R-22, R-23, R-113, R-114, R-115, R-500, R-502, and R-503 in metric (SI) units of measure. Chemical names, formulae, container data, and valve information are discussed. The bulletin then reviews stability, moisture effects, compatibility with metals, seal materials, lubricants, safety precautions, and toxicity indicators for the subject refrigerants. It also discusses evacuation, leak detection, charging, leakage replenishment, moisture removal, and uses. A table summarizes physical and thermodynamic property data including the chemical formula and name, molecular mass, normal boiling point, freezing point, and critical parameters (temperature, pressure, and density). It also gives the heat of vaporization, surface tension, liquid specific heat, liquid density, specific heat ratio, solubility of water, liquid refractive index, relative dielectric strength, and dielectric constant at selected conditions. A plot compares the pressure-temperature curves. 13 tables provide thermodynamic property data at saturated (wet vapor) conditions. They indicate the saturation vapor pressure; liquid and vapor specific volumes and enthalpies; and the heat of vaporization. Hoechst Chemicals identifies its refrigerants with the trade name Frigen(R) and those that are chlorine free, and meet ecological and technical requirements, as Reclin(R).

H. A. Connon and D. W. Drew (E. I. duPont de Nemours and Company), **Estimation and Application of Thermodynamic Properties for a Nonazeotropic Refrigerant Mixture**, paper presented at the meeting of IIR Commissions B1, B2, E1, and E2 (Essen, Germany, September 1981), International Institute of Refrigeration (IIR), Paris, France, 1981; republished in the *International Journal of Refrigeration* (IJR), 6:203-208, 1983 (6 pages, rdb4205)

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C. Y. Chan and G. G. Haselden (University of Leeds, UK), **Computer-Based Refrigerant Thermodynamic Properties, Part I: Basic Equations**, *International Journal of Refrigeration* (IJR), 4(1):7-12, January 1981 (6 pages, rdb5459)

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R-740 (argon): thermodynamic properties from the triple point to 927 °C (1700 °F) and pressures to 1000 MPa (145,000 psia), thermophysical data

S. Okada, K. Asano (Hitachi Cable Limited, Japan), Y. Mukoyama, and Y. Osada (Hitachi Chemical Limited, Japan), **A New Class 200°C Enameled Wire**, paper CH1717-8/81, Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 121-125, 1981 (5 pages with 8 figures and 6 tables, RDB6665)

R-12, R-22, compatibility, motor materials: properties of polyester (terephthalic), ester-imide, ester-imide THEIC, amide-imide, polyimide, amide-imide/ester-imide, and ester-imide/amide-imide

M. M. Shah, **Heat Transfer During Film Condensation in Tubes and Annuli - A Review of the Literature**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-29 January 1981), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 87(1):1086-1105, 1981 (20 pages with 2 figures and 5 tables, RDB-3638)

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R-720, neon, thermophysical data, equation of state (EOS)

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This report examines the relative efficiencies of R-11, R-12, R-13, R-21, R-22, R-112, R-113, R-114, R-115, R-140a, R-142b, R-500, R-502, and R-503 to reduce stratospheric ozone concentrations. The efficiencies are expressed per unit of mass, per molecule, and per chlorine atom emitted. They are normalized to those of R-11,

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identified as the most efficient for ozone destruction. The report describes the calculations, which used a one-dimensional (1-D), transport kinetics model. The decomposition reactions and kinetic reaction rates are tabulated for the 14 compounds and azeotropic blends. The results indicate that there is no direct correspondence between atmospheric lifetime and the calculated change in total column ozone. This finding refutes earlier suggestions that the change in ozone would be proportional to the product of lifetime, the number of chlorine atoms, and the emission rate. The departure is greatest for halocarbons with long atmospheric lives, including R-13 and R-115. The underlying mechanisms are discussed. They include chlorine that is not dissociated in molecules with long lives and tropospheric attack, by hydroxyl radicals, for those containing hydrogen. [The ozone depletion potential (ODP) index originated from this report.]

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summary toxicity data and outline of toxicological considerations for fluorocarbons using R-11 as a prototype; also addresses comparative toxicity of R-12, R-21, R-22, R-113, R-114, R-115, R-142b, R-152a, R-C318; animal models for evaluation of fluorocarbon toxicity

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lubricants, test methods, effects of dissolved oligomers on compressors

W. F. Stoecker (University of Illinois at Urbana-Champaign), **Improving the Energy Effectiveness of Domestic Refrigerators by the Application of Refrigerant Mixtures**, report ORNL/Sub/7855463/1, Oak Ridge National Laboratory, Oak Ridge, TN (available from NTIS, rdb2445)

zeotropic blends

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R-12, lubricants, refrigerant-lubricant properties

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S. Olund (Shrieve Chemicals), **Solubility of Refrigerants in Compressor Crankcases**, *ASHRAE Journal*, 19(12):34 ff, December 1977 (rdb4641)

F. C. Scheideman (Carrier Corporation), M. L. Jacobs (Union Carbide Corporation), S. M. Kazem (Kabul University, Afghanistan), and N. A. Macken (Rensselaer Polytechnic Institute, RPI), **Pressure Loss of Oil-Refrigerant Mixtures in Suction and Discharge Lines**, paper 2463 (109-RP), *Transactions* (Annual Meeting, Halifax, NS, Canada, 26-30 June 1977), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 83(2), 1977 (18 pages with 15 figures and 5 tables, RDB5209)

This paper documents research of pressure drops for suction and discharge lines for R-12 and R-22 with mineral oil. It also presents correlations and tabular data to allow use of the results in system design. The paper describes and schematically illustrates the test apparatus. It entailed a closed refrigerant loop with oil injection and separation means as well as both horizontal and vertical test sections. The loop was an oil-vapor system with pressure and flow maintained by a 37.3 kW (50 hp) compressor. The horizontal test sections comprised three parallel tubes, 3 m (10') in length, of 12.7, 25.4, and 76.2 mm (½, 1, and 3") diameter, with valves to enable selection. The vertical test section was a 25.4 mm (1") tube. The paper explains the test procedure, instrumentation, and theoretical derivation for the form of the correlations used. R-12 was tested with both 150 and 300 SUS mineral oil (unidentified) and R-22 with the former. Tests were performed at six temperatures from -40 to 38 °C (-40 to 100 °F) with 11-56 °C (20-100 °F) of superheat; the oil fraction ranged from 0.1 to 5% by weight. Figures show the solubility of the refrigerants in the lubricants, the viscosity of the mixtures, and defined Lockhart-Martinelli and Chisholm correlations for the horizontal and vertical pressure drops. Four tables provide refrigerant capacities in tons that result in a 1.1 °C (2 °F) pressure drop per 30 m (100') equivalent length of piping for horizontal suction and discharge lines and for suction and hot gas risers. They cover 12.7-105 mm (½-4¼") pipes for 1% oil. The paper concludes that oil causes a significant and predictable increase in the pressure drop, which can be estimated with the data and correlations provided.

Line Sizing with Refrigerants 12, 22, 502, and 717, research project 185-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, July 1975 - June 1977 (ASH0185)

The contractor for the project was D. D. Wile, Consulting Engineer. This research project was sponsored by ASHRAE Technical Committee 8.9.

V. V. Altunin and V. Z. Geller, **Thermophysical Properties of Freons**, Hemisphere Publishing Company, New York, NY, 1977 (rdb6328)

thermodynamic and transport data, refrigerants

R. Döring, **Thermodynamische Eigenschaften des Kältemittels R114B2** [Thermodynamic Properties of Refrigerant R-114B2], *Die Kälte- und Klimatechnik*, Germany, 1977 (in German, rdb4975)

R-114B2, thermophysical data

T. Fukushima, A. Arai, et al., **Simulation of Refrigeration Cycle for Air Conditioners**, *Reito* [Refrigeration], Japan, 52(593):19 ff, 1977 (rdb6855)

cycle analysis for refrigerants

R. Heide, **Concerning the Viscosities of Refrigerant-Oil Mixtures for Refrigeration Machines**, *Luft und Kältetechnik*, Germany, 13(1):34-37, 1977 (4 pages in German, rdb4251)

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H. P. Jaeger, **Calculation of the Viscosity of Oil and Refrigerant Mixtures**, *Il Freddo* [Refrigeration], Italy, 31(5):376-386, 1977 (11 pages in Italian, rdb4614)

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R. L. McCarthy, F. A. Bower, and J. P. Jesson, **The Fluorocarbon-Ozone Theory - 1. Production and Release: World Production and Release of CCl_3F and CCl_2F_2 (Fluorocarbons 11 and 12)**, *Atmospheric Environment*, 11:491-497, 1977 (7 pages, rdb5505)

R-11, R-12, production and emission data

L. Z. Meltser, T. S. Dremluh, S. K. Chernyshev, L. B. Silina, B. V. Gunchuk, A. A. Chek, and A. P. Voloshin (Odessa Technological Institute, USSR), **Thermophysical Properties of Refrigerator Oils and Their Solutions with Freon 12**, *Teplofizicheskie Svoistva Veshchestv i Materialov* [Thermophysical Properties of Substances and Materials], Izdatel'stvo Standartov, Moscow, Russia, 11:99-118, 1977 (20 pages in Russian, rdb4629)

R-12, lubricants, refrigerant-lubricant properties

S. R. Orfeo, D. F. Harnish, and H. Magid (AlliedSignal Incorporated, then Allied Chemical Corporation), **Chlorofluorocarbons in the Atmosphere - A Manufacturer's View**, paper 770021, Society of Automotive Engineers (SAE), Warrendale, PA, 1977 (13 pages with 8 figures and 3 tables, RDB5834)

reviews the status of (then) fluorocarbon-ozone depletion theory based on theoretical calculations and experimental observations; summarizes the activities of the Fluorocarbon Technical Panel (FCTP) of the Manufacturing Chemists Association (MCA) to determine the scientific validity of ozone depletion; outlines industry efforts to identify alternative refrigerants, aerosol propellants, and foam blowing agents

U. Plöcker, **Berechnung von Hochdruck-Phasengleichgewichten mit einer Korrespondenzmethode unter besonderer Berücksichtigung asymmetrischer Gemische** [Calculation of High-Pressure Phase Equilibria by Means of a Correspondence Method Under Special Consideration of Asymmetric Mixtures], doctoral dissertation, Technische Universität Berlin, Berlin, Germany, 1977 (181 pages in German, rdb3342)

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R-13, R-13B1, R-744 (carbon dioxide), R-7146: thermodynamic and transport properties, thermophysical data

L. J. Van Poolen (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), **Analysis of Property Data in the Critical Region Using the Function Liquid Volume Fraction**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 83:222 ff, 1977 (rdb9121)

method of determining critical point thermodynamic properties; thermophysical data

R. B. Stewart and R. T. Jacobsen, **A Thermodynamic Property Formulation for Oxygen for Temperatures from 55 K to 3000 K and Pressures to 34 MPa**, *Proceedings of the Seventh Thermophysical Properties Symposium*, American Society of Mechanical Engineers (ASME), New York, NY, 549-563, 1977 (15 pages, rdb3955)

R-732 (oxygen): thermodynamic data for -218 to 2727 °C (-360 to 4940 °F) and pressures to 34 MPa (4930 psia), thermophysical data, equation of state (EOS)

W. Wagner, **A New Correlation Method for Thermodynamic Data Applied to the Vapour-Pressure Curve of Argon, Nitrogen, and Water**, report PC/T 15, International Union of Pure and Applied Chemistry (IUPAC) Thermodynamic Tables Project Centre, 1977 (rdb8226)

R-718. R-728, R-740, thermodynamic properties, thermophysical data

D. D. Wile, **Refrigerant Line Sizing**, publication 90250, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1977 (48 pages, RDB4635)

This document provides charts to simplify sizing of refrigerant lines. It covers suction, discharge, and liquid lines for both copper tubes and steel pipes with R-12, R-22, and R-502 as well as for steel pipes with R-717 (ammonia).

1976

J. B. Chaddock (Duke University), **Two-Phase pressure Drop in Refrigerant Liquid Overfeed Systems-Design Tables**, paper 2409 (134-RP), *Transactions* (Annual Meeting, Seattle, WA, 27 June - 1 July 1976), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 82(2):107-133, 1976 (27 pages with 6 figures and 7 tables, RDB7722)

line sizing for liquid overfeed systems, Hughmark and Dukler constant-slip calculation method, design tables for refrigerant recirculation systems for R-12, R-22, R-502, and R-717

M. L. Jacobs (Carnegie-Mellon University, CMU), F. C. Scheideman (Carrier Corporation), F. C. Kazem (Kabul University, Afghanistan), and N. A. Macken (Rensselaer Polytechnic Institute, RPI), **Oil Transport by Refrigerant Vapor**, paper 2423, *Transactions* (Annual Meeting, Seattle, WA, 27 June -1 July 1976), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 82(2):318-327, 1976 (10 pages with 8 figures and 2 tables, RDB4631)

This paper presents correlations to determine the flow velocity needed for oil entrainment by refrigerant vapor in suction and hot gas risers. Oil transport was determined in vertical tubes, for R-12 with 150 and 300 SUS naphthenic mineral oils and for R-22 with 150 SUS oil. The tests were conducted in an all-vapor loop driven by a reciprocating-piston compressor. The paper summarizes the experimental apparatus and procedures, flow theory involved, and analysis of the data. Figures depict the apparatus and test section. The findings are reduced to correlations for the minimum mass flux and tonnage for entrainment. Calculated values based on the refrigerant saturation temperature and common pipe sizes, from 13-105 mm (½ to 4 1/8"), are tabulated.

M. M. Shah (Gilbert/Commonwealth Company), **A New Correlation for Heat Transfer During Boiling Flow Through Pipes**, paper 2407, *Transactions* (Annual Meeting, Seattle, WA, 27 June - 1 July 1976), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 82(2):66-86, 1976 (21 pages with 15 figures and 3 tables, RDB3B47)

graphical method of solution, identified as CHART, to determine the heat transfer coefficient (HTC) for refrigerant evaporation: tabular summary of published heat transfer data from other studies; heat and mass transfer data for R-11, R-12, R-22, R-113, R-718 (water), and cyclohexane

B. K. Sthapak, H. K. Varma, and C. P. Gupta , **Heat Transfer Coefficients in the Dry-Out Region of a Horizontal-Tube, Water-Heated, R-12 Evaporator**, *Transactions* (Annual Meeting, Seattle, WA, 27 June - 1 July 1976), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 82(2), 1976 (rdb3320)

heat transfer

S. H. Stradley, H. E. Phillips, and H. J. Borchardt, **Thermodynamic Properties of** [HC]**FC-123**, report NIST-5, E. I. DuPont de Nemours and Company, Incorporated, Wilmington, DE, 1 April 1976 (44 pages with 1 figure and 3 tables, available from JMC as RDB0301)

This report provides thermodynamic property data for R-123 in inch-pound (IP) units of measure. Measured physical and estimated critical properties are tabulated. Four basic equations for vapor pressure, the Redlich-Kwong equation of state (EOS), density of the saturated liquid, and heat capacity of the vapor are presented. A table presents pressure, volume, density, enthalpy, and entropy at saturated conditions for the temperature range of -73 to 184 °C (-100 to 363 °F) in 0.6 °C (1 °F) increments and for the critical temperature of 184 °C (363.2 °F). A second table presents volume, enthalpy, and entropy of superheated vapor at constant pressure. The report concludes with a pressure enthalpy diagram.

Technical Panel of Fluorocarbon Research **The effect of Fluorocarbons on the Concentration of atmospheric Ozone**, Manufacturing Chemists Association, 1 March 1976 (rdb3525)

investigation of the role of fluorochemicals in and the potential for stratospheric ozone depletion; environmental impacts

N. A. Macken, F. C. Scheideman, M. L. Jacobs, and S. M. Kazem (Carnegie-Mellon University, CMU), **An Experimental Study of Pressure Drop and Liquid Transport of Oil-Refrigerant Mixtures**, final report for 109-RP Phases II and III, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, dated both December 1975 and January 1976 (96 pages with 39 figures and 7 tables, RDB4A09)

This report describes a study of two-phase pressure drop and liquid transport in refrigerant-lubricant mixtures.

Transport of Oil in Pipes by Refrigerant Vapor, research project 109-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1970 - January 1976 (ASH0109)

The contractor for the project was Carnegie-Mellon University (CMU), led by S. W. Gouse; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow*.

P. J. Cox, R. G. Derwent, A. E. J. Eggleton, and J. E. Lovelock, **Photochemical Oxidation of Halocarbons in the Troposphere**, *Atmospheric Environment*, 10:305-308, 1976 (4 pages, rdb8132)

refrigerant decomposition, destruction, disposal, environmental fate

R. DeSantis, F. Gironi, and L. Marrelli, **Vapor-Liquid Equilibrium from a Hard-Sphere Equation of State**, *Industrial Engineering Chemistry Fundamentals*, 15:183-189, 1976 (7 pages, rdb2354)

EOS, thermodynamic properties, thermophysical data, VLE

A. G. Dickson and J. P. Riley, **The Distribution of Short-Chain Halogenated Aliphatic Hydrocarbons in Some Marine Organisms**, *Marine Pollution Bulletin*, *7*:167-169, 1976 (3 pages, rdb7229)

refrigerant decomposition, destruction, fate, environmental impacts

V. Z. Geller, **Viscosity of Freon 21, Freon 22, and Freon 23**, *Kolloidnyi Tekhnika* [Refrigeration Technology], 22:41-45, 1976 (5 pages in Russian, rdb-4A49)

R-21, R-22, R-23, thermodynamic properties, thermophysical data

L. P. Gorlina, N. E. Zaev, and N. S. Zakharkina, **Infrared Spectroscopic Study of the Stability of KF-22-24 Cooling Oil During Thermal Aging**, *Kolloidnyi Tekhnika* [Refrigeration Technology], 8:19-21, 1976 (3 pages, in Russian, RDB4607)

R-22

J. H. Grim, **Lubrication Requirements for the Refrigeration and Air-Conditioning Industry**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 82(II):567-571, 1976 (5 pages, rdb2528)

G. Hackstein, **A Contribution on the Experimental Determination of the Values of Thermodynamic Properties for Halogenated Hydrocarbons, Especially for Their Mixtures with Refrigerating Oils**, dissertation, Technische Universität Dresden, Dresden, Germany, 1976 (in German, RDB4248)

H. J. M. Hanley, **Prediction of the Viscosity and Thermal Conductivity Coefficients for Mixtures**, *Cryogenics*, 16:643-651, 1976 (9 pages, rdb8506)

transport properties of blends, thermophysical data

J. J. Healey, J. D. De Groot, and J. Kestin, **The Theory of the Transient Hot-Wire Method for Measuring Thermal Conductivity**, *Physica A*, 82C:392-408, 1976 (17 pages, rdb5638)

measurement, instrumentation, thermophysical properties

J. Kestin and W. A. Wakeham, **A Contribution to the Theory of the Transient Hot-Wire Technique for Thermal Conductivity Measurements**, *Physica A*, 92A:102-116, 1976 (15 pages, rdb5B64)

measurement, instrumentation, thermophysical properties

L. Z. Meltser, Z. I. Geller, and B. V. Gunchuk (Odessa Technological Institute, USSR), **Experimental Study of the Kinematic Viscosity Coefficient of Oil-Freon Solutions**, *Kolloidnyi Tekhnika* [Refrigeration Technology], 22:73-76, 1976 (4 pages in Russian, rdb4271)

This paper describes a capillary viscometer, immersed in a temperature controlled liquid, to determine the viscosity of refrigerant-lubricant solutions. It presents plots of the viscosities of R-12 with KhF-12-18 oil and R-22 with KhF-22S-16 at -30 to 80 °C (-22 to 176 °F).

National Research Council (NRC), **Halocarbons: Effects on Stratospheric Ozone**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1976 (rdb3131)

environmental impacts

C. A. Nieto de Castro (Universidade de Lisboa, Portugal), J. C. G. Calado, W. A. Wakeham, and M. Dix, **An Apparatus to Measure the Thermal Conductivity of Liquids**, *Journal Phys. E. Sci. Instr.*, 9:1073-1079, 1976 (7 pages, rdb5637)

thermodynamic properties, thermophysical data

D. Y. Peng and D. B. Robinson, **A New Two-Constant Equation of State**, *Industrial Engineering Chemistry Fundamentals*, 15(1):59-64, 1976 (6 pages, rdb4876)

thermodynamic properties, thermophysical data, Peng-Robinson (PR) equation of state (EOS)

K. Raznjevic, **Handbook of Thermodynamic Tables and Charts**, Hemisphere Publishing Corporation, Washington, DC, and McGraw-Hill Book Company, New York, NY, 1976 (RDB3211)

R-11, R-12, R-13, R-22, R-40, R-170 (ethane), R-290 (propane), R-717 (ammonia), R-718 (water/steam), R-744 (carbon dioxide), R-764 (sulfur dioxide), thermodynamic properties, thermophysical data

S. Shiono, T. Imamura, J. Enomoto, and K. Kuyama (Mitsubishi Electric Corporation, Japan), **A Study of the Reaction Rate of Refrigerant 12 and Refrigerant Oils and the Effect of Aluminum on the Reaction as a Catalyst**, *Reito* [Refrigeration], Japan, 51(583):361-368, 1976 (8 pages, rdb6C37)

R-12, mineral oil

Thermophysical Properties of Refrigerants, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1976 (252 pages with 42 tables, RDB3210)

This reference provides viscosity, thermal conductivity, and specific heat data for refrigerants, along with empirical or semi-empirical property

please see page 6 for ordering information

equations, in inch-pound (IP) units. Conversion tables are provided for other units of measure. The fluids addressed include R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-23, R-40 (methyl chloride), R-50 (methane), R-113, R-114, R-115, R-142b, R-152a, R-170 (ethane), R-290 (propane), R-C318, R-500, R-502, R-503, R-504, R-600 (butane), R-600a (isobutane), R-702 (hydrogen), R-702a (p-hydrogen), R-704 (helium), R-717 (ammonia), R-718 (water), R-720 (neon), R-728 (nitrogen), R-729 (air), R-732 (oxygen), R-740 (argon), R-744 (carbon dioxide), R-1150 (ethene), and R-1270 (propene). More than 1000 references are cited.

1975

N. A. Macken (Rensselaer Polytechnic Institute, RPI), F. C. Scheideman (Carrier Corporation), and M. L. Jacobs (Carnegie-Mellon University, CMU), **An Experimental Study of Pressure Drop and Liquid Transport of Oil-Refrigerant Mixtures**, paper 75-WA/HT-26 (Winter Annual Meeting, Houston, TX, 30 November - 4 December 1975), American Society of Mechanical Engineers (ASME), New York, NY, 1975 (12 pages with 16 figures, RDB5206)

R. Foon and K. P. Schug, symposium paper E3, *Molecular Rate Processes*, Royal Australian Chemical Institute, Warburton, Australia, August 1975 (possibly 1995) (rdb5213)

> decomposition kinetics of various chlorofluorocarbons (CFCs), formation of free radicals as a halocarbon breakdown mechanism

H. M. Roder and R. D. McCarty, **Modified Benedict-Webb-Rubin Equation of State for Parahydrogen-II**, report NBSIR 75-814, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, June 1975 (available from GPO, rdb3949)

> R-702p, p-hydrogen, parahydrogen, thermodynamic properties, thermophysical data

Council on Environmental Quality (CEQ) of the Federal Council for Science and Technology (FCST), **Fluorocarbons and the Environment**, report 75-403, National Science Foundation (NSF), Arlington, VA (then Washington, DC), June 1975 (122 pages, Rdb7C65)

> report of the U.S. Federal Interagency Task Force on Inadvertent Modification of the Stratosphere (IMOS): assessment of the potential for and actions to avoid atmospheric modifications from human activities, referred to as the "fluorocarbon-ozone question"; concludes that releases of fluorochemicals are a legitimate cause for concern and that unless scientific evidence is found to dispel this concern, it is necessary to restrict uses of R-11 and R-12 to replacement fluids in existing air-conditioning and refrigeration (ACR) equipment and to closed recycled systems and other uses not involving atmospheric release; report comprises an executive summary, conclusions on federal actions, and sections on stratospheric effects, biological effects of ozone reduction, human health effects of ozone reduction, the fluorocarbon industry, and federal authorities

B. I. Lee and M. G. Kesler (Mobil Research and Development Corporation), **A Generalized Thermodynamic Correlation Based on Three-Parameter Corresponding States**, *AIChE Journal*, 21(3):510-527, May 1975 (18 pages with 6 figures and 14 tables, RDB3341)

> modified Benedict-Webb-Rubin (MBWR) equation of state (EOS)

K. Benke and J. Reichelt, **Synthetische Flüssigschmiermittel für Tieftemperatur-Kälteanlagen** [Synthetic Lubricants for Low-Temperature Refrigeration Installations], *Die Kälte- und Klimatechnik*, Germany, (5):172-176 and (6):208-214, 1975 (12 pages in German, rdb4918)

> refrigeration oils

H. J. Borchardt, **New Findings Shed Light on Reactions of Fluorocarbon Refrigerants**, *DuPont Innovation*, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 6(2), Winter 1975; republished as bulletin RT-58, DuPont, May 1979 (6 pages with 4 figures and 2 tables, RDB3731)

> R-11 (decomposes into chlorine and R-112); R-12 (forms chlorine and R-114 when initially pyrolyzed, then R-11 and R-13 a "disproportionation" reaction; the final products of long-term pyrolysis are R-13, chlorine, and carbonaceous solids); R-13 (decomposes into chlorine and R-116); R-22 (described as "one of the least stable" fluorocarbon refrigerants based on experimental tests; pyrolysis of R-22 to manufacture tetrafluoroethylene, the DuPont Teflon(R)) monomer); R-114 (decomposes, in part, into R-12); and R-115 (decomposes, in part, into R-13); reactions with oil; reactions of aluminum with R-12 and oil; stabilization with 1% R-744A (nitrous oxide)

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> thermophysical data for R-134a and others

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H. Finger, C. Staege, B. Lilly, R. Stoeffgen, G. Koeppert, **Demands on Oils for Hermetic Refrigerating Machines and Testing of a New, Fully Synthetic Oil**, *Schmierungstechnik* [Tribology], Germany, 6(12):372-377, 1975 (6 pages in German, rdb4338)

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D. Lillian, H. B. Singh, A. Appleby, L. Lobban, R. Arnts, R. Gumpert, R. Hague, J. Toomey, J. Kazazis, M. Antell, D. Hansen, and B. Scott, **Atmospheric Fates of Halogenated Compounds**, *Environmental Science and Technology*, 9(12):1042-1048, 1975 (7 pages, rdb8161)

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R-702 thermodynamic and transport data: equation of state (EOS), thermal conductivity, viscosity, and others

L. Z. Meltser, T. S. Dremluh, B. V. Gunchuk, Y. G. Zatvornskii, and A. A. Chek (Odessa Technological Institute, USSR), **Properties of a Solution of KhA-30-Oil and Freon 22**, *Kolloidnyi Tekhnika* [Refrigeration Technology], 21:27-29, 1975 (3 pages with 6 figures, in Russian, rdb4272)

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M. M. Shah (Gilbert/Commonwealth Company), **Visual Observation in an Ammonia Evaporator**, *Transactions* (Semiannual Meeting, Atlantic City, NJ, 26-30 January 1975), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 81(1):295-306, 1975 (12 pages, rdb8516)

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G. W. Gatecliff (Tecumseh Products Company) and E. R. Lady (University of Michigan), **Explicit Representation of the Thermodynamic Properties of Refrigerants 12 and 22 in the Superheat Region**, *Proceedings of the 1974 Purdue Compressor Technology Conference* (10-12 July 1974), Purdue University, West Lafayette, IN, 287-290, July 1974 (4 pages with 3 tables, rdb6908)

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K. S. Sanvordenker and W. J. Gram (Tecumseh Products Company), **Laboratory Testing Under Controlled Environment Using a Falex Machine**, *Proceedings of the 1974 Purdue Compressor Technology Conference* (10-12 July 1974), Purdue University, West Lafayette, IN, 67-75, July 1974 (9 pages, rdb2527)

modification of the Falex tester for evaluation of bearing materials, surface treatments, and lubricants; tests with R-12, R-22, and combinations with mineral oil

R. C. Downing (E. I. duPont de Nemours and Company), **Refrigerant Equations**, paper 2313, *Transactions* (Annual Meeting, Montreal, Canada, 23-27 June 1974), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 80(2):158-169, 1974 (12 pages with 6 tables, RDB3913)

assembles the equations and constants for calculation of liquid density, vapor pressure, pressure-volume-temperature (PVT) relationships of the vapor (Martin-Hou, MH, equation of state, EOS), and heat capacity of the vapor for R-11, R-12, R-13, R-14, R-21, R-22, R-23, R-113, R-114, R-C318, R-500, and R-502: demonstrates simplifications that do not affect the region of interest for air conditioning and refrigeration; provides derived equations for the latent heat of vaporization, enthalpy of vapor, entropy of vapor; thermodynamic properties; thermophysical data

Two-Phase Pressure Drop in Refrigerant Liquid Recirculating Systems, research project 134-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, July 1972 - June 1974 (ASH0134)

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equation of state (EOS), thermodynamic properties, thermophysical data

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D. F. Huttenlocher (General Electric Company**), Accelerated Sealed-Tube Test Procedure for Refrigerant 22 Reactions**, *Proceedings of the 1972 Purdue Compressor Conference*, Purdue University, West Lafayette, IN, pages 469-474, July 1972 (6 pages with 3 figures and 2 tables, RDB4927)

results of sealed-tube compatibility tests with R-22 and discussion of their inferences on the validity of thermal acceleration tests: introduction notes that because R-22 is much less reactive that R-12, reaction rates even at elevated tem-

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peratures can be much lower; accordingly, the temperature must be increased, sometimes interfering with the validity of tests, or the period of testing prolonged; attempts to interpret findings for shorter tests can be unreliable because some reactions do not proceed at uniform rates; paper gives examples of aging at 150 and 200 °C (302 and 392 °F) for R-22 with and without mineral oil lubricants in the absence of metal catalysts and in the presence of zinc die cast, valve steel, carbon steel, zinc-chromate plated steel, brass, and lead specimens; figures and tables show the relative reaction rates with these metals present and the dependences on temperature

H. J. Borchardt (E. I. duPont de Nemours and Company, Incorporated), **The Reaction of Aluminum with Refrigerant 12 and Oil**, *Transactions* (Annual Meeting, Nassau, Bahamas, 25-29 June 1972), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 78(2), 1972; republished in *Lubricants, Refrigerants, and Systems - Some Interactions,* symposium bulletin NA-72-5, ASHRAE, June 1972; republished as Product Information Bulletin RT-61, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1972 (8 pages with 1 figure and 6 tables, RDB3B64)

R-12, materials and experimental procedures, aluminum reactions at various temperatures, chemical reaction preceding aluminum attack, nature of the reaction, oil cracking, R-12 disproportionation: reaction between aluminum and R-12 was reproducibly initiated at 149 °C (300 °F) and higher, but the R-12/oil had to be degraded - resulting in high acid levels - before the reaction would start; partial removal of the protective aluminum oxide layer by severely degraded refrigerant-lubricant mixture, permitting direct contact between the refrigerant and the metal, may be necessary; reaction products included aluminum halides, carbonaceous matter, and R-13; overall stability was limited by the stability of the refrigerant oil mixture and not by the aluminum

K. P. Murphy (AlliedSignal Incorporated, then Allied Chemical Corporation), **Oil and Refrigerants - Characteristics of Several New Refrigerants**, *Transactions* (Annual Meeting, Nassau, Bahamas, 25-29 June 1972), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 78(2), 1972; republished in *Lubricants, Refrigerants, and Systems - Some Interactions*, symposium bulletin NA-72-5, ASHRAE, June 1972 (rdb4276)

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K. S. Sanvordenker and M. W. Larime (Tecumseh Products Company), **A Review of Synthetic Oils for Refrigeration Use**, *Transactions* (Annual Meeting, Nassau, Bahamas, 25-29 June 1972), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 78(2), 1972; republished in *Lubricants, Refrigerants, and Systems - Some Interactions,* symposium bulletin NA-72-5, ASHRAE, 14-19, June 1972 (6 pages with 1 table, RDB2218)

history of and opportunities for use of synthetic lubricants, with focus on synthetic hydrocarbons, alkylbenzenes, dibasic acid esters, neopentyl esters, phosphate esters, polyglycols, silicate esters, and silicones: concludes that all but the phosphate esters seem suited for refrigeration use and that the alkylbenzenes, polyglycols, dibasic acid esters, and silicate esters are the most attractive for low temperature applications; suggests that these candidates have much to offer, but that their cost effectiveness has to be left to the individual system designer

Refrigerant Forced Convection Condensation Inside Horizontal Tubes, research project 63-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1966 - March 1972 (ASH0063)

The contractor for the project was the Massachusetts Institute of Technology (MIT), led by J. S. Maulbetsch; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

K. W. Cooper and A. G. Mount, **The Effect of Oil Circulation on Compressor Capacity**, *ASHRAE Journal*, 39-42, October 1972 (4 pages, rdb3322)

N. F. Carnahan and K. E. Starling, **Intermolecular Repulsions and the Equation of State for Fluids**, *AIChE Journal*, 18:1184-1189, 1972 (6 pages, rdb-2333)

thermodynamic properties, thermophysical data

H. P. Jaeger, **Empirische Methoden zur Vorausberechnung thermodynamischer Eigenschaften von Öl-Kältemittel-Gemischen** [Empirical Methods for Predicting the Thermodynamic Properties of Oil-Refrigerant Mixtures], dissertation, Technische Universität Braunschweig, Germany, 1972; published by Verein Deutscher Ingenieure (VDI, Association of German Engineers) Verlag, Düsseldorf, Germany, 115(15):1239 ff, 1973 (in German, rdb-4255)

refrigerant-lubricant properties

G. E. Millward and E. Tschuikow-Roux, *Journal of Physical Chemistry*, 76(3):292-298, 1972 (7 pages, rdb6861)

decomposition kinetics of various chlorofluorocarbons (CFCs), formation of free radicals as a halocarbon breakdown mechanism

Z. Nipkpi, **Mutual Solubility of Freon 12 and Freon 22 in Refrigerating Oils and Its Effect on Compressor Operation**, *Khranit Prom*., 21(10):14 ff, 1972 (in Bulgarian, rdb4640)

R-12, R-22

J. Osugi and Y. Kanbayashi, **Measurement of the Solubility of Refrigeration Gas**, *Reito* [Refrigeration], Japan, 47(534):359-361, 1972 (3 pages in Japanese, rdb4642)

R-115

J. Osugi and M. Takahashi, **Measurement of the Solubility of Refrigeration Gas**, *Reito* [Refrigeration], Japan, 47(534):363-365, 1972 (4 pages in Japanese, rdb4643)

R-13B1, mineral oil (Witco Suniso(R) and 4GS)

1971

M. M. Feiger (General Electric Company), **The Determination of Varnish Bond Strength in Refrigerant Atmospheres**, *Insulation/Circuits*, 30-33, December 1971 (4 pages with 5 figures and 3 tables, RDB6667)

compatibility, motor materials, test method: describes method and equipment to determine bond strength of varnish to magnet wire in refrigerants at elevated temperatures and pressures; illustrative data for epoxy- and acrylic-type varnishes on urethane-modified, polyvinyl formal enameled magnet wire splints and helical coils in R-22 environments

G. J. Bich, J. R. Kweicinski, and F. A. Sattler (Westinghouse Electric Corporation), **Effect of Composition of Polyester-Amide-Imide Wire Enamels on Refrigerant 22 Resistance**, paper 71C38EI-40, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 126-128, 1971 (3 pages with 6 figures and 2 tables, RDB6661)

R-22, compatibility, motor materials, test methods

J. P. Hurtgen (General Electric Company), **Hermetic Motor Life Tests**, paper 71C38EI-36, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 113-116, 1971 (4 pages with 7 figures and 3 tables, RDB6663)

R-22, compatibility, motor materials, test methods

J. P. Hurtgen (General Electric Company), **R22 Blister Testing of Magnet Wire**, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 183-185, 1971 (3 pages with 5 figures and 5 tables, RDB2917)

R-22, compatibility with motor materials, varnish

R. P. Kokernak and C. L. Feldman, **The Velocity of Sound in Liquid R12**, *ASHRAE Journal*, 13:59 ff, 1971 (rdb4B74)

R-12, thermophysical properties

R. S. Olsen (General Electric Company), **Sealed Tube Techniques for Hermetic Enamel Evaluation**, paper 71C38EI-38, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 119 ff, 1971 (rdb6626)

compatibility with motor materials, magnet wire, varnish

R. D. Petry (A. O. Smith Corporation), **Hermetic Insulation Tests Using Motorettes in Autoclave**, paper 71C38EI-37, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 116-119, 1971 (4 pages with 4 figures and 4 tables, RDB6631)

R-22, compatibility with motor materials, hydrolytic stability, vibration, heat shock, rapid heat rise,

K. S. Sanvordenker and M. W. Larime (Tecumseh Products Company), **Screening Tests for Hermetic Magnet Wire Insulation**, paper 71C38EI-39, *Proceedings of the Tenth Electrical Insulation Conference* (EIC), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 122-126, September 1971 (5 pages with 3 figures and 5 tables, RDB2424)

This paper examines both the test methods and results of testing, for magnet wire insulation for

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hermetic compressors using R-22. Abrasion results (average cycles to failure) are tabulated and plotted as received and following exposures for 7-10 days, one month, and three months. The insulations examined included two batches of urethane modified polyvinyl formal (FU), two batches of polyester-imide (PEI), dual coat amide-imide topcoat on a polyester base (AI/PE), dual coat polyester (PE/PE), and polyimide (PI). The temperature and elapsed time for burnout are tabulated, for these five types of insulations, and compared between environments of R-22 and air. Data on retained dielectric strength are presented for FU, PEI, AI/PE, PE/PE, and for Formvar urethane and polyesteramide imide (PEAI); blister, resistance is tabulated for all but PE/PE. Because the interactions of enamels and R-22, the paper suggests that the rate of R-22 absorption be determined and exposures adjusted for complete saturation. Tests after saturation provide a common basis for comparisons and suitable screening approach for structurally-different enamels.

J. E. Hoffman (Sporlan Valve Company), **Caution: Alcohol at Work**, *Refrigeration Service and Contracting* (RSC), 18-20, August 1971 (3 pages with 1 figure, RDB6668)

clean up of systems that have been saturated with water by flushing with methyl alcohol, cautions for flammability, toxicity, and compressor damage

Pressure Drop in Liquid Overfeed Suction Lines, research project 107-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, March 1970 - July 1971 (ASH0107)

The contractor for the project was Duke University, led by J. B. Chaddock and D. P. Werner; it was sponsored by ASHRAE Technical Committee 9.1, *Large-Building Air-Conditioning Systems*.

Transport Properties of Refrigerants, research project 72-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, July 1968 - July 1971 (ASH0072)

The contractor for the project was Purdue University, led by P. E. Liley; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

K. J. Riedle, N. A. Macken, and S. W. Gouse, Jr. (Carnegie-Mellon University, CMU), **Oil Transport by Refrigerant Vapor**, report number CMU-40203-1, final report for 109-RP Phase I, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, June 1971 (94 pages with 36 figures, RDB5205)

W. D. Cooper (E. I. duPont de Nemours and Company, Incorporated), **Influence of Oil-Refrigerant Relationships on Oil Return**, *Transactions* (Semiannual Meeting, Philadelphia, PA, 24-28 January 1971), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 77(1):6-10, 1971; republished in *Effect of Oil on the Refrigeration System*, symposium bulletin PH-71-2, ASHRAE, 6-10, 1971 (5 pages, RDB4326)

R. F. Goldman and D. D. Rudy, **Permeation of Refrigerants through Elastomeric and Plastic Hoses**, paper 710039, Society of Automotive Engineers (SAE), Warrendale, PA, January 1971 (rdb4364)

R-12, leakage from mobile air-conditioning (MAC) and transport refrigeration systems

G. H. Green, **The Effect of Oil on Evaporator Performance**, *Transactions* (Semiannual Meeting, Philadelphia, PA, 24-28 January 1971), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 77(1), 1971; republished in *Effect of Oil on the Refrigeration System*, symposium bulletin PH-71-2, ASHRAE, 23-27, 1971 (5 pages, rdb8437)

refrigerant heat transfer coefficient (HTC) may be improved or impaired by the presence of oil, depending on the lubricant concentration and on the flow pattern; refrigerant-lubricant (RL) properties

M. Soliman and N. Z. Azer, **Flow Patterns During Condensation Inside a Horizontal Tube**, *Transactions* (Semiannual Meeting, Philadelphia, PA, 24-28 January 1971), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 77(1):210-224, 1971 (15 pages, rdb7458)

heat and mass transfer, annular flow model for condensation inside tubes

S. P. Soling, **Oil Recovery from Low Temperature Pump Recirculating Halocarbon Systems**, *Transactions* (Semiannual Meeting, Philadelphia, PA, 24-28 January 1971), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 77(1), 1971; republished in *Effect of Oil on the Refrigeration System*, symposium bulletin PH-71-2, ASHRAE, 19-22, 1971 (4 pages with 6 figures, rdb4648)

R. C. Downing, **Freon Refrigerants and Lubricating Oils**, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1971 (rdb4452) solubility of refrigerants and the effect of temperature should be similar for a naphthenic mineral oil (MO) should be similar to those with a paraffinic oil; presents data for R-12 with a naphthenic MO (Witco Suniso(R) 3GS) - as reported in RDB4C21

H. Henrici and G. Hesse, **Untersuchungen über den Wärmeübergang beim Verdampfen von R114 und R114-Öl-Gemischen an einem horizontalen Glattrohr** [Investigation of the Evaporating Heat Transfer of R-114 and R-114/Oil Mixtures on a Horizontal Plain Tube], *Kältetechnik-Klimatisierung*, Germany, 23:54-58, 1971 (5 pages in German, rdb4547)

heat transfer, lubricant effects

H. P. Jaeger and H. J. Löffler (Technische Universität Braunschweig, Germany), **Concerning the Behavior of R-22/Oil Mixtures**, *Kältetechnik-Klimatisierung*, 23(10):305-309, 1971 (5 pages in German, RDB4256)

R-22, refrigerant-lubricant properties

G. T. Kartsounes and R. A. Erth, **Computer Calculation of the Thermodynamic Properties of Refrigerants 12, 22, and 502**, *Transactions* (Annual Meeting, Washington, DC, 22-25 August 1971), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 77(II):88-103, 1971 (17 pages, rdb6B13)

R-12, R-22, R-502, thermodynamic properties, thermophysical data

K. Mall, **Studies on Aged Refrigerating Machine Oils and Gaseous Reaction Products from Motor Compressors**, *Kältetechnik-Klimatisierung*, 23(2):-58-63, 1971 (5 pages in German, rdb3513)

R-22, lubricants

L. Z. Meltser, T. S. Dremluh, and Y. P. Ram'yalg, **Fluidity of Refrigerating Oils and Their Mixtures with Agents at Low Temperatures**, *Kolloidnyi Tekhnika* [Refrigeration Technology], 12:49-52, 1971 (4 pages in Russian, rdb4274)

R. W. Murphy and A. E. Bergles, **Subcooled Flow Boiling of Fluorocarbons**, report DSR/71903-72, Massachusetts Institute of Technology (MIT), Cambridge, MA, 1971 (rdb3B61)

heat transfer

S. C. G. Schulz (possibly Schultz), **Equations of State for the System Ammonia-Water for Use with Computers**, *Proceedings of the XIIth International Congress of Refrigeration*, International Institute of Refrigeration (IIR), Paris, France, 2:431 ff, 1971 (rdb3234)

absorption, R-717, R-717/718, thermodynamic properties, thermophysical data

D. R. Stull and H. Prophet**, JANAF Thermochemical Tables**, report NSRDS-NBS37, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, 1971 (available from GPO, rdb4C07)

chemical properties, thermophysical data

M. V. Thierry (Anaconda Wire and Cable Company), **Choice of a Magnet Wire for Hermetic Motors**, paper 71C38EI-54, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 171-174, 1971 (4 pages with 2 figures and 6 tables, RDB6664)

R-22, compatibility, motor materials, apparatus for adhesion twist test, test methods

J. A. Zapp, Jr., **Fluorocarbons**, *Encyclopedia of Occupational Health and Safety*, McGraw-Hill Book Company, New York, NY, for the International Labour Office, United Nations, I:560-562, 1971 (3 pages with 1 table, RDB5271)

brief review of the toxicity, hazards, safety, and health measures of fluorocarbons: provides a table of formulae, normal boiling points, uses, and the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) for R-11, R-12, R-12B2, R-13, R-13B1, R-21, R-22, R-112, R-113, R-114, R-115, R-123B1, R-C318, R-1113, R-1114, R-1141, R-1131, and R-1216; discussion notes that R-12 induces dizziness in humans if inhaled at 50,000 ppm v/v and loss of consciousness at 150,000 ppm v/v, but has no narcotic effect at 1,000 ppm v/v; discusses the toxicity of R-1318 and notes a 4-hr LC_{50} rat of 0.76 ppm

1970

T. W. Phillips and K. P. Murphy (AlliedSignal Incorporated, then Allied Chemical Corporation), **Liquid Viscosity of Halogenated Refrigerants**, paper 2152, *Transactions* (Annual Meeting, Kansas City, MO, 28 June - 1 July 1970), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 76(2):146-156, June 1970 (12 pages with 5 figures and 3 tables, RDB-2315)

Liquid viscosity data are tabulated for R-11, R-12, R-13, R-22, R-114, R-115, R-133a, R-152a, R-500, R-502, R-31/114, R-115/152a, R-503, R-504, and R-32/12; transport properties, thermophysical data

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T. W. Phillips and K. P. Murphy (AlliedSignal Incorporated, then Allied Chemical Corporation), **Liquid Viscosity of Halocarbons**, *Journal of Chemical and Engineering Data*, 15(2):304-307, February 1970 (4 pages with 5 figures and 5 tables, RDB2314)

measurements of the saturated liquid viscosities or R-20, R-21, R-22, R-23, R-30, R-31, and R-32 die 10-2000 kPa (1.5-290 psia): modified, suspended level viscometer; transport properties; thermophysical data

J. A. Schofield, **Computer Calculation of the Theoretical Performance Properties of Fluorocarbon Refrigerants**, *Transactions* (Semiannual Meeting, San Francisco, CA, 19-22 January 1970), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 76(I):52 ff, 1970 (rdb7A53)

thermodynamic properties, thermophysical data

T. Atwood and K. P. Murphy (AlliedSignal Incorporated), **An Investigation of Refrigerants for Single-Stage Centrifugal Water Chillers**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 76:81-95, 1970 (15 pages, RDB2441)

M. Chaigneau and D. Barthes (Laboratoire Chimique Anal. Fac. Pharm., France), **Action of Dichlorodifluoromethane on Nickel, Aluminum, and Raney Nickel**, *Compte Rendu de l'Académie de Science*, Paris, France, series C, 170(7):624-626, 1970 (3 pages in French, rdb6683)

R-12 reactions, compatibility

R. Heide (Forschungszentrum für Luft- und Kältetechnik, Dresden, Germany), **Ein Beitrag zur Viskosität von Öl-Kältemittel-Gemischen** [A Contribution on the Viscosity of Oil-Refrigerant Mixtures], *Luft- und Kältetechnik*, Germany, 6(6):308-310, 1970 (3 pages with 3 figures, in German, rdb4249)

This paper provides plots of and regressions to estimate the kinematic viscosities of three mixtures of synthetic lubricants with refrigerants. They included 51KM33 oil with R-11, 51KM33 with R-12, and KM30 with R-22 for 50-100% concentrations for -40 to 60 °C (-40 to 140 °F). The refrigerants were obtained from VEB Fluorwerke Dohna and the three synthetic lubricants from VEB Leuna-Werke, both in the German Democratic Republic. The paper reviews prior measurements by others and outlines the experimental approach using falling-ball and rotating rheostat viscometers.

H. Henrici and K. Mall, **Thermodynamische Eigenschaften von Gemischen aus Trifluormonobrommethan (R13B1) und Ölen** [Thermodynamic Properties of Bromotrifluoromethane (R-13B1) with Oils], *Kältetechnik-Klimatisierung*, Germany, 22(8):-259-263, 1970 (5 pages in German, RDB3734)

lubricants

H. P. Jaeger and H. J. Löffler (Technische Universität Braunschweig, Germany) **Thermodynamischer Eigenschaften von Öl-Kaltemittel-Gemischen** [Thermodynamic Properties of Oil-Refrigerant Mixtures], *Kältetechnik-Klimatisierung,* 22(8):246-256, 1970 (11 pages with 10 figures and 38 tables, in German, RDB4257)

This paper provides solubility, density, vapor pressure, viscosity, and specific volume data for mixtures of R-10, R-12, R-13, R-13B1, and R-22 with five lubricants. They include naphthenic and paraffinic mineral oils, a synthetic lubricant, and a mixture of a mineral oil and a synthetic. The paper summarizes the experimental methods used and compares the findings to those from prior studies.

K. Mall, **Messeinrichtung zur Ermittlung des Dampfdruckes von Öl-Kältemittel Gemischen** [Measuring Apparatus for Determination of the Vapor Pressure of Oil-Refrigerant Mixtures], *Kältetechnik-Klimatisierung*, 22(8):257-259, 1970 (3 pages in German, rdb2502)

T. E. Morsy, **Extended Benedict-Webb-Rubin Equation of State - Application to Eight Fluorine Compounds**, *Journal of Chemical and Engineering Data*, 15(2):256-265, 1970 (10 pages, rdb5215)

R-13B1, R-717, and others; Benedict-Webb-Rubin (BWR) equation of state (EOS)

1969

R. Hall, **Magnet Wire in Hermetic Motors, Part II**, *ASHRAE Journal*, 11(12):53 ff, December 1969 (rdb-6649)

compatibility, motor materials

J. P. Hurtgen (General Electric Company), **Aluminum Magnet Wire in R12 Systems**, *ASHRAE Journal*, 11(11):45-47, November 1969 (3 pages with 4 figures, RDB4112)

This article presents materials compatibility findings for use of aluminum magnet wire for hermetic compressor motors in R-12 refrigeration systems. It focuses on wire coated with polyvinyl formal phenolic resin in windings of motor stators. The article notes that the change from copper magnet wire is complex, involving both motor design and manufacturing techniques, but that aluminum has been used in rotor windings, compressor parts, and evaporators. It cites aluminum incompatibility with R-14, R-40, and uninhibited R-140a as well as rapid and destructive exothermic reactions of R-12 with aluminum impellers where melting or abrasion could expose a fresh, film-free surface. The document also reviews published studies of aluminum chloride formation, and is function as catalyst to convert R-12 into R-11 and R-13, following R-12 reactions with oil. The article describes sealed-tube tests of enameled wire helixes with R-12 and oil. Tests at 150 and 170 °C (302 and 338 °F) indicated that aluminum wire ages more rapidly than copper in R-12, as evidenced by greater R-22 formation. The R-22 formation and reaction rates are plotted. Tests by other researchers are cited, for as long as 360 days at 130 °C (266 °F) and at 170 °C (338 °C) for more than two years; no significant differences between aluminum and copper wire systems were found. New tests of dielectric strength retention at 170 °C (338 °C) for 14-450 days are described. The plotted results showed gradual decline, but the author concludes that reactions will be very low and approximately equal for the two magnet wire types. Hermetic units tests performed for verification are summarized. Complete analyses did not disclose significant differences between the copper and aluminum units. Field trials, the longest of which exceeded four years, support the findings.

J. A. Callighan (Union Carbide Corporation), **The Thermal Stability of Fluorocarbons 114 and 216**, *ASHRAE Journal,* 11(9):65-69, September 1969 (5 pages with 5 figures and 4 tables, RDB3A02)

This article presents stability tests of R-114 and R-216. These fluids are noted as candidate turbine motive fluids [e.g., for organic Rankine cycles] based on cited characteristics: low toxicities, no appreciable odor, non-flammable, low freezing point, high liquid and vapor densities, and low corrosion rates in metal systems. Stability tests for 200-500 °C (392-932 °F) are described. The test approaches included thermal aging in a steel bomb, decomposition analyses after flow through a heated quartz tube (with and without metal coupons), and cycled vaporizing and condensing in steel dynamic test apparatus. Summary physical properties are tabulated and decomposition products indicated, based on mass spectroscopic analysis of fragmentation patterns. The paper concludes that R-114 and R-216 have about the same thermal stability, which increases exponentially with decreasing temperature in the range of 316-426 °C (600-800 °F). It further notes that the presence of oxygen, moisture, and hydrocarbon oils all decrease the thermal stability, but that corrosion rates on commonly used metals are generally low when the decomposition rates are low. Tables summarize the decomposition data by the tests performed and the corrosion rates with cast iron, mild steel, AOS stainless steel, and iconel metal. A plot relates the decomposition fraction to refrigeration oil concentration, but shows greatly reduced reactivity with polychlorotrifluoroethylene (PCTFE) lubricants. The presence of steel is shown to influence the decomposition rates, but insufficient data were obtained to prove a relation between exposed surface area and decomposition rates.

S. Nishizaki and A. Muramoto, **Evaluation of Hermetic Motor Insulation Systems**, *Proceedings of the Ninth Electrical Insulation Conference* (EIC, Boston, MA, 8-11 September 1969), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 250-253, 1969 (4 pages, rdb2918)

compatibility, motor materials

W. Tauscher, **Measurement of the Thermal Conductivity of Liquid Refrigerants by an Unsteady State Hot Wire Method**, *ASHRAE Journal*, 11(1):-97-104, 1969 (8 pages, rdb3917)

R-32 and others, thermophysical properties, conductivity data

W. W. Wareham, **New Standards and Tests for Hermetic Motor Wire**, *Proceedings of the Ninth Electrical Insulation Conference* (EIC, Boston, MA, 8-11 September 1969), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 250-253, 1969 (rdb6648)

compatibility, motor materials

Freon(R) 112 - Tetrachlorodifluoroethane, product information bulletin B-1, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, September 1969 (26 pages with 1 figure and 24 tables, RDB5161)

R-112, R-112a, R-112a/112, R-112/113, R-112a/112/113, properties, compatibility, stability, solubility, safety, toxicity, flammability

D. T. Gordon, J. F. Hamilton, and W. E. Fontaine, **An Empirical Equation for Predicting the Viscosity of Liquid Refrigerants**, *Transactions* (Semiannual Meeting, Chicago, IL, 27-30 January 1969), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 40-51, 1969 (12 pages, rdb4336)

E. L. Keating and R. A. Matula, **Correlation and Prediction of Viscosity and Thermal Conductivity of Vapor Refrigerants**, *Transactions* (Semiannual Meeting, Chicago, IL, 27-30 January 1969),

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American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 75(1), 1969 (rdb4632)

transport properties, thermophysical data

N. F. Carnahan and K. E. Starling, **Equation of State for Non-Attracting Rigid Spheres**, *Journal of Chemical Physics*, 51:635-636, 1969 (2 pages, rdb3246)

equation of state (EOS), thermodynamic properties, thermophysical data

R. L. Covington and H. L. Ravner, **Interactions in Neopentyl Polyol Ester-Tricresyl Phosphate-Iron Systems at 500 °F**, *Transactions*, American Society of Lubricating Engineers (ASLE), 12:280-286, 1969 (7 pages, rdb4563)

polyolester, POE, TCP

R. C. Downing (E. I. duPont de Nemours and Company), **General Equations and Constants for Thermodynamic Equations**, bulletins X-88B1 and X-88F, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1969 (rdb5635)

thermophysical properties, thermophysical data

H. P. Jaeger (Technische Universität Braunschweig, Germany), **Thermodynamischer Eigenschaften binärer Gemische aus Kältemischinenölen und Monofluortrichlormethan (R11)** [Thermodynamic Properties of Binary Mixtures of Mineral Oils and Trichlorofluoromethane (R-11)], *Kältetechnik-Klimatisierung*, 21(10):302-306 and 21(12):367-369, 1969 (8 pages in German, rdb4258)

refrigerant-lubricant properties

R. L. Jones, H. L. Ravner, and R. L. Cottington, **Inhibition of Iron-Catalyzed Neopentyl Polyolester Thermal Degradation Through Passivation of the Active Metal Surface by Tricresyl Phosphate**, American Society of Lubricating Engineers (ASLE) / American Society of Mechanical Engineers (ASME) Lubrication Conference (Houston, TX), 1969 (rdb4928)

POE, TCP

W. H. Mears, E. Rosenthal, and J. V. Sinka (Allied-Signal Incorporated, then Allied Chemical Corporation), **Physical Properties and Virial Coefficients of Sulfur Hexafluoride**, *Journal of Physical Chemistry*, 73:2254 ff, 1969 (rdb5A38)

R-7146, physical and thermodynamic properties, thermophysical data

B. Pierre, **Värmeövergang vid kokande köldmedier i horisontella rör** [Heat Transfer for Refrigerants in Horizontal Tubes], *Kylteknisk Tidskrift*, 28(5):3-12, 1969 (10 pages in Swedish, rdb9824)

flow boiling correlations for complete and incomplete evaporation; heat transfer; heat exchanger; evaporator

Freon(R) Compounds and Safety, bulletin S-16 (A-85178), E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1969 and republished February 1978 (16 pages with 7 tables, RDB5906)

flammability, reactivity, pressure, frostbite, effects on the eyes and skin, acute and chronic toxicity, anesthesia, decomposition, refrigerant safety

Stability of Several 'Freon' Compounds at High Temperatures, technical bulletin XIA, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1969 (rdb3867)

fluorocarbon refrigerants

1968

H. O. Spauschus and R. A. Sellers (General Electric Company), **Aging of Hermetic Motor Insulation**, paper 68C6EI-89, *Proceedings of the Eighth Electrical Insulation Conference* (EIC, Los Angeles, CA, 9-12 December 1968), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 156-161, 1968; republished in *Transactions of Electrical Insulation*, IEEE, EI-4(4), December 1969 (6 pages with 7 figures and 4 tables, RDB6627)

compatibility, motor materials

I. M. Wade, **Accelerated Test Performance of Imide-Modified Magnet Wire Insulations for Hermetic Motors**, *Proceedings of the Eighth Electrical Insulation Conference* (EIC, Los Angeles, CA, 9-12 December 1968), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 127-131, 1968 (5 pages, rdb6647)

compatibility, motor materials

D. F. Huttenlocher (General Electric Company), **A Bench Scale Test Procedure for Hermetic Compressor Lubricants**, *Transactions* (Annual Meeting, Lake Placid, NY, 24-26 June 1968), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 74(2):, 1968; republished in *ASHRAE Journal*, 11(6):85-89, June 1969 (5 pages with 3 figures and 3 tables, RDB2421)

presents a method for and results of wear tests for compressor lubricants, using a pin-and-vee block apparatus, by saturating the lubricant reservoir with R-22; classifies lubricants according to boundary conditions; correlates the bench test results with actual performance in equipment; results show that the presence of R-22 improved the lubricant performance especially as compared of operation in air and that use of an R-22 blanketing atmosphere excludes the gross effects of air and moisture

F. F. Trunzo, G. J. Bich, and G. W. Hewitt (Westinghouse Electric Corporation), **Repeated Scrape Abrasion Testing of Enameled Wires in Gaseous and Liquid Refrigerants**, *Transactions* (Annual Meeting, Lake Placid, NY, 24-26 June 1968), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 74(2):675 ff, 1968 (rdb6653)

compatibility, motor materials, test methods

K. S. Sanvordenker (Tecumseh Products Company), **A Rapid Plant Scale Quality Control Test for Refrigeration Oils**, *Transactions* (Annual Meeting, Lake Placid, NY, 24-26 June 1968), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 74(2), 1968; republished in *Today's Compressor Lubrication and its Environmental Chemistry in Hermetic Lubrication*, ASHRAE, 7-20, 1968 (14 pages with 3 and 5 tables, RDB6713)

presents a simplified, factory test method for preliminary evaluation and acceptance of refrigeration lubricants; the procedure involves aging an oil sample with copper and steel catalysts and R-10 (carbon tetrachloride) in a screw-cap test tube for 16 hours at 107 °C (225 °F); results are gauged by the acid number following titration; summarizes tests and nominal properties and refining methods of 11 commercial oils; provides plots and tables of measured results and dependence of acid number on the aging time and temperature; discusses repeatability and influences of each test parameter; shows the fraction of R-22 formed, measured by gas chromatography, in sealed-tube tests of the same lubricants and metals with R-12 at 175 °C (347 °F); discusses the roles of contaminants; includes discussion of the paper by C. M. Bosworth (Carrier Corporation), L. C. Flowers, and H. M. Elsey that notes the stabilizing influence of copper, versus steel alone, in decomposition reactions

K. S. Sanvordenker (Tecumseh Products Company), **Separation of Refrigeration Oil into Structural Components and their Miscibility with R-22**, *Transactions* (Semiannual Meeting, Columbus, OH, 5-8 February 1968), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 74(1):III.2.1 ff, 1968 (rdb4638)

R. C. Schwing, **Polyisobutyl Benzenes and Refrigeration Lubricants**, paper 2063, *Transactions* (Semiannual Meeting, Columbus, OH, 5-8 February 1968), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 74(1):III.I.1 ff, 1968 (rdb4639)

synthetic lubricants, polyisobutylbenzene

J. F. Wilson, **Effect of Methanol on the Performance of Polyester Film in Reciprocating Refrigeration Compressors**, *ASHRAE Journal*, 10(1):-43 ff, January 1968 (rdb2205)

compatibility

J. T. Ashton et al., **The Solubility of Certain Gaseous Fluorine Compounds in Water**, *Journal of the Chemical Society, Inorganic Physical Theory*, 1793 ff, 1968 (rdb5A36)

solubility, compatibility

E. Chochorowski, **Experimentelle and theoretische Untersuchungen über die Ölrückführung in Kompressions-Kälteanlagen** [Experimental and Theoretical Investigations of Oil Return in Vapor-Compression Refrigeration Installations], PhD thesis, Technische Universität Berlin, Germany, 1968 (in German, rdb4C47)

T. S. Dremluh, **Experimental Study of the Temperature-Pressure-Concentration Parameters of a Solution of Freon F-22 and the Oil KhF-22S-16**, *Kolloidnyi Tekhnika* [Refrigeration Technology], 6:48-50, 1968 (3 pages in Russian, rdb4334)

R-22

L. Haar, **Thermodynamic Properties of Ammonia as an Ideal Gas**, report NSDS-NBS 19, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, 1968 (rdb3968)

thermodynamic properties of R-717; thermophysical data

H. J. Löffler, **Density, Vapor Pressure, Dynamic and Static Viscosity of a R-114 - Refrigeration Oil Mixtures**, *Kältetechnik-Klimatisierung*, 20(5), 1968 (in German, rdb4260)

thermodynamic and transport properties of R-114/lubricant mixtures; refrigerant-lubricant (RL) properties; thermophysical data

L. Z. Meltser, Z. I. Geller, and B. V. Gunchuk, **Thermophysical Properties of Oil-Freon Solutions**, *Teplofiz. Svoistvam Zhidk.,* Teplofizik Konf.

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Svoistvam Veshchestv. Vys. Temp. (Third Meeting 1968), 42-45, 1970 (4 pages in Russian, rdb4275)

thermodynamic and transport properties of refrigerant-lubricant (RL) mixtures; thermophysical data

H. O. Spauschus and R. A. Sellers (General Electric Company), **Effect of Atmosphere on Aging of Electrical Insulation**, *Annual Report of the Conference on Electrical Insulation and Dielectric Phenomena*, publication 1578, National Academy of Sciences (NAS), Washington, DC, 132 ff, 1968 (rdb-6659)

compatibility, motor materials

K. Stephan and M. Körner (Technische Universität Berlin, Germany), **Calculation of Heat Transfer for Vaporizing Binary Mixtures**, summary translation by AlliedSignal Incorporated from German text published in *Chemie Ingenieur Technik*, VCH Verlagsgesellschaft mbH, Weinheim, Germany, 41(7):-409-417, 1968; includes notes on the document prepared by R. R. Singh, AlliedSignal Incorporated, 22 October 1990 (8 pages with 5 figures, available from JMC as RDB0905)

A. A. Vassermann and V. A. Rabinovich, **Thermophysical Properties of Air and its Components**, Standard, Moscow, Russia (then USSR), 1968 (in Russian, rdb8470)

thermodynamic properties of R-728 (nitrogen),, R-732 (oxygen), R-729 (air), R-740 (argon), and other components of air; thermophysical data

M. P. Vulkalovich and V. V. Altunin, **Thermophysical Properties of Carbon Dioxide**, Collet's Limited, London, UK, 1968 (rdb7107)

thermodynamic and transport properties of R-744; thermophysical data

M. Zander, **Pressure-Volume-Temperature Behavior of Chlorodifluoromethane (Freon 22) in the Gaseous and Liquid States**, *Proceedings of the Fourth Thermophysical Properties Symposium*, American Society of Mechanical Engineers (ASME), New York, NY, 114-123, 1968 (10 pages, rdb4325)

thermodynamic properties of R-22: PVT; thermophysical data

Refractive Index of 'Freon' Compounds, technical bulletin B-32a, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, March 1968 (4 pages with 1 table, RDB7C26)

calculation method using the Lorentz-Lorenz equation and calculated refractive indices for R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-23, R-112, R-113, R-114, R-114B2, R-115, R-116, R-123, R-214, R-215, R-216, R-C318, six compounds identified as Freon E 1 through E 5 and E 9; transport properties, thermophysical data

1967

H. L. Emmons (A. O. Smith Corporation), **Latest Technology for Hermetic Motor Insulation Testing - Part 4, Motorette-Autoclave for Systems Evaluation**, *Insulation*, 53-58, December 1967 (6 pages with 7 figures and 3 tables, RDB6C39)

compatibility, motor materials, test methods

D. J. David, **Use of Thermal Analysis to Reduce Magnet Wire Evaluation Time**, *Insulation*, 38 ff, November 1967 (rdb6658)

compatibility, motor materials, test methods

H. L. Emmons (A. O. Smith Corporation), **Latest Technology for Hermetic Motor Insulation Testing - Part 3, Sheet and Integral Insulation Cut-Through**, *Insulation*, 53-56, November 1967 (4 pages with 3 figures and 2 tables, RDB6657)

compatibility, motor materials, test methods

K. L. Snider (Union Carbide Corporation), **Thermal Stability of Several Fluorocarbons**, *ASHRAE Journal*, 9(11):54-58, November 1967 (5 pages, rdb3A06)

reactivity

H. O. Spauschus and R. A. Sellers (General Electric Company), **Apparatus and Procedures for Evaluating Dielectric Properties of Wire Enamels in Controlled Environments**, paper 32C79-66, *Proceedings of the Seventh Electrical Insulation Conference* (EIC, October 1967), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 191-193, 1967; republished in, *Journal of Electrical Insulation*, EI-3(3):82-87, August 1968 (6 pages with 7 figures and 1 table, RDB6650)

R-12, R-22, compatibility, dielectric properties, motor materials, varnishes

H. L. Emmons (A. O. Smith Corporation), **Latest Technology for Hermetic Motor Insulation Testing - Part 2, Magnet Wire Overload**, *Insulation*, 57-61, September 1967 (rdb2510)

compatibility, motor materials, test methods

C. P. Aroa, **Power Savings in Refrigerating Machines Using Mixed Refrigerants**, *Progress in Refrigeration Science and Technology* (proceedings of the XIIth International Congress of Refrigeration, Madrid, Spain, 30 August - 6 September

1967), International Institute of Refrigeration (IIR), Paris, France, 11:397-409, 1969 (13 pages, rdb6410)

blends, performance

H. O. Spauschus and R. A. Sellers (General Electric Company), **Electrical Properties of Wire Enamels in Refrigerant Environments**, paper 3.04, *Progress in Refrigeration Science and Technology* (proceedings of the XIIth International Congress of Refrigeration, Madrid, Spain, 30 August - 6 September 1967), International Institute of Refrigeration (IIR), Paris, France, II:1153-1160, 1969 (8 pages with 2 figures and 2 tables including discussion, RDB4A30)

R-12, R-22, polyvinyl formal, isocyanate modified polyvinyl formal, polyamide-imide, polyester-imide, polyimide

H. L. Emmons (A. O. Smith Corporation), **Latest Technology for Hermetic Motor Insulation Testing - Part 1, Varnishes**, *Insulation*, 42 ff, August 1967 (rdb6656)

compatibility, motor materials, test methods

F. S. Palmer and J. I. Qureshi, **Low-Temperature Refrigerants**, *ASHRAE Journal*, 9(7):50-52, July 1967 (3 pages, rdb4936)

refrigeration

Forced Convection Boiling of Refrigerants in Horizontal Tubes, research project 45-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, July 1963 - July 1967 (ASH0045)

The contractors for the project were Purdue University and Duke University, led by J. B. Chaddock; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow*.

S. Manabe and R. T. Wetherald (Geophysical Fluid Dynamics Laboratory, ESSA), **Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity**, *Journal of Atmospheric Sciences*, 24(3):241-259, May 1967 (19 pages with 31 figures and 11 tables, RDB8B29)

computation of the radiative convective equilibrium of the atmosphere; sensitivity to solar intensity and to the atmospheric concentrations of carbon dioxide (CO_2), ozone, and humidity; adjustment of atmospheric water vapor content with temperature variation of the atmosphere; one of the early predictions of atmospheric temperature sensitivity to changes in CO_2 content

R. D. Bennett, L. J. V. Earthy, and H. Heckmatt, **Lubrication of Refrigerant 22 Refrigeration Plant**, *Journal of Refrigeration*, *9*(9):211-215, 1967; republished in *Journal of the Institute of Petroleum*, 53:, 1967 (5 pages, rdb4337)

R-22, addition of R-12 to R-22 in naphthenic mineral oil to improve lubricant solubility and heat transfer

J. M. Chawla, **Wärmeübergang und Druckabfall in waagerechten Rohren bei der Stromung von verdampfenden Kältemitteln**, *Fortschritt-Berichte VDI*, VDI-Verlag, Düsseldorf, Germany, 523:, 1967 (rdb6423)

heat transfer, pressure drop

A. V. Kletskii, **Thermodynamic Properties of Freon 11**, *Kolloidnyi Tekhnika* [Refrigeration Technology], 44(1):18-21, 1967 (4 pages in Russian, rdb7A69)

thermodynamic properties of R-11; thermophysical data

H. J. Löffler and H. P. Jaeger, **Wie Verhalten Sich Öl-R23-Gemische in Kältemaschinen**? [How Do R-23/Oil Mixtures Behave in Refrigeration Machines?], *Kältetechnik-Klimatisierung*, Germany, 19(8):237-240, 1967 (4 pages in German, rdb4308)

R-23, lubricants

H. J. Löffler (Technische Universität Berlin, Germany), **Thermodynamische Eigenschaften Binärer Gemische aus Kältemittel 502 und Kältemaschinenölen** [Thermodynamic Properties of Binary Mixtures of R-502 and Refrigeration Oils], *Kältetechnik-Klimatisierung*, 19(7):201-207, 1967 (7 pages in German, RDB4261)

This paper presents solubility, density, vapor pressure, viscosity, and fluidity data for R-502 and mixtures of two naphthenic mineral oils and a lubricant mixture comprising naphthenic mineral oil and a synthetic. It also presents new thermodynamic property data for R-502.

J. J. Martin, **Equations of State**, *Industrial and Engineering Chemistry*, 59(12):34-52, 1967 (19 pages, rdb4226)

EOS, thermodynamic properties, thermophysical data

I. W. Mills and J. J. Melchoire, **Effect of Aromatics and Selected Additives on Oxidation Stability of Transformer Oils**, *Industrial and Engineering Chemistry*, 59(6):40 ff, 1967 (rdb4621)

lubricant stability, use of additives

1966

E. R. Larsen, **1,1,1,2-Tetrafluoroethane Anesthetic**, U.S. patent 3,261,748, 19 July 1966 (RDB-2B12)

historic interest in R-134a as an anesthetic

Heat Transfer and Fluid Flow Inside a Horizontal Tube Evaporator, research project 46-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1965 - September 1966 (ASH0046)

The contractor for the project was the Massachusetts Institute of Technology (MIT), led by Drs. Gouse and Coumou; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

G. C. Doderer and H. O. Spauschus (General Electric Company), **A Sealed Tube Gas Chromatograph Method for Measuring Reaction of Refrigerant 12 with Oil**, paper 2003, *Transactions* (Annual Meeting, Toronto, ON, Canada, 27-29 June 1966), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 72(II):IV.4.1-IV.4.5, 1966 (5 pages, rdb2326)

R-12

Condensing Refrigerants in Horizontal and Inclined Tubes, research project 1-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1966 (ASH0001)

This research developed correlations for heat transfer in smooth tubes, both horizontal and inclined, for condensing of R-12. Annular, dispersed and annular-dispersed, and wave and wave-annular flow regimes were identified. The heat transfer equations developed are applicable to condensation within the annular-flow regime. The contractor for the project was Kansas State University (KSU), led by R. G. Nevins; it was sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow.*

W. Barho, **Berechnung der Molwärme der Fluor-Chlor-Derivate von Methan und Äthan im Zustand idealer Gase** [Calculation of the Ideal Gas Molar Heats of Methane- and Ethane-Series Chlorofluorocarbons], dissertation, Technische Universität Karlsruhe, Karlsruhe, Germany, 1966 (in German, rdb5535)

CFC compounds, chlorocarbons, fluorocarbons, chlorofluorocarbons; ideal gas heat capacity

J. A. Brown, **Sulfur Hexafluoride**, *Kirk-Othmer Encyclopedia of Chemical Technology* (second edition), John Wiley and Sons, Incorporated, New York, 9:664 ff, 1966 (rdb5A37)

R-7146, properties, applications

J. C. Chen, **A Correlation for Boiling Heat Transfer to Saturated Fluids in Convective Flow**, *Industrial and Engineering Chemistry, Process Design and Development*, 5(3):322-329, 1966 (8 pages, rdb5223)

heat exchanger, heat transfer, evaporator

R. C. Downing (E. I. duPont de Nemours and Company), **Fluorinated Hydrocarbons**, *Kirk-Othmer Encyclopedia of Chemical Technology* (second edition), edited by A. Standen, John Wiley and Sons, Incorporated, New York, 9:739-751, 1966 (13 pages, rdb8138)

R. C. Downing (E. I. duPont de Nemours and Company), **History of the Organic Fluorine Industry**, *Kirk-0ihmer Encyclopedia of Chemical Technology* (second edition), John Wiley and Sons, Incorporated, New York, 9:704-707, 1966 (5 pages with 1 table, available from JMC as RDB2440)

This section of a popular reference outlines the history of fluorocarbon refrigerants, starting with the assignment of Dr. Thomas Midgley to find a new refrigerant, through their status in the mid-1960s. It recounts the 1928 events that led Dr. Midgley and his associates A. L. Henne and R. R. McNary to identify and synthesize R-12. The document describes the initial toxicity test, which might have delayed the birth of the organic fluorine industry except for a fortuitous, but random selection of reactant specimens. It then describes the joint venture between the Frigidaire Division of General Motors Corporation and E. I. duPont de Nemours and Company in 1930, to begin commercial production of R-11 and R-12 under Kinetic Chemicals, Incorporated. It notes the introduction of other fluorocarbon refrigerants including R-114 in 1933, R-113 in 1934, and R-22 in 1936; the development of related polymers; and production expansion in World War II. The document then describes entrance of other manufacturers, milestone developments in production methods, and the beginning of the aerosol industry based on fluorinated propellants. The document, written around 1965, identifies six producers of fluorocarbons in the USA and mentions that more than 20 manufacturing plants existed in other countries. It indicates that R-12 accounted for half the entire output and that more than 98% was confined to R-11, R-12, R-22, R-113, and R-114, with growing interest in plastics and elastomers. The document also notes related development of organic fluorine compounds as anesthetics, biocides, fire suppressants, solvents, and blowing agents; statistics on fluorocarbon sales are tabulated for the USA for 1958-1963.

H. G. Hirschberg (Gebrüder Sulzer AG, Switzerland), **Kältemittel** [Refrigerants], Verlag C. F. Müller, Karlsruhe, Germany, 1966 (in German, rdb5712)

refrigerant applications and data

L. M. Lagutina, **Experimental Investigation of PVT Properties of Freon-22**, *Kolloidnyi Tekhnika* [Refrigeration Technology], 43(12):25-28, 1966 (4 pages in Russian, rdb7C35)

R-22, thermodynamic properties, thermophysical data

A. Michels, T. Wassenaar, G. J. Wolkers, C. Prins, L. V. D. Klundert, **P-V-T Data and Thermodynamic Properties of Freon-12 (CCl_2F_2) and Freon-13 ($CClF_3$) Fluorocarbons** *Journal of Chemical and Engineering Data*, 11:449-452, 1966 (4 pages, rdb-7B37)

R-12 and R-13, thermodynamic properties, thermophysical data

D. N. Seshadri, D. S. Vishwanath, and N. R. Kuloor, **Thermodynamic Properties of Carbon Tetrachloride**, *Journal of the Indian Institute of Science*, 48(2-3):65-80, 1966 (16 pages, rdb4934)

R-10, thermodynamic properties, thermophysical data

H. Uchida and S. Yumaguchi, **Heat Transfer in Two-Phase Flow of Refrigerant 12 through Horizontal Tubes**, *Proceedings of the Third International Heat Transfer Conference*, V:69-79, 1966 (11 pages, rdb8442)

R-12 heat transfer

A. A. Vassermann, Y. Z. Kazavchinskij, and V. A. Rabinovich, **Thermophysical Properties of Air and its Components**, Nauka, Moscow, Russia (then USSR), 1966 (in Russian, rdb8471)

thermodynamic properties of R-728 (nitrogen), R-732 (oxygen), R-729 (air), R-740 (argon), and other components of air; thermophysical data

1965

H. O. Spauschus (General Electric Company), **Migration Rates for Refrigerant 22**, *ASHRAE Journal*, 7(10):77 ff, October 1965 (rdb4233)

R-22

J. F. Hesselberth and L. F. Albright, **Solubility of Mixtures of Refrigerants 12 and 22 in Organic Solvents of Low Volatility**, paper 1944, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 71(II), June 1965 (rdb4935)

R-12, R-22, refrigerant-lubricant properties

T. D. Armstrong, **Chloride Analyses as a Measure for the Evaluation of Sealed Tube Tests**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 71(I):150 ff, 1965 (rdb2325)

H. M. Elsey, **Small Sealed Tube Procedure for Quality Control of Refrigeration Oils**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 71(I):143-149, 1965 (7 pages, rdb2328)

D. E. Kvalnes, **The Sealed Tube Test for Refrigeration Oils**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 71(I):138-142, 1965 (5 pages, rdb2324)

R-12, metal catalysts

H. M. Parmelee (E. I. duPont de Nemours and Company), **Sealed-Tube Stability Tests on Refrigeration Materials**, paper 1924, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 71(I):154-161 and 167-168, 1965 (10 pages with 29 tables, RDB0013)

This paper summarizes an investigation into the stability of fluorocarbon refrigerants alone and in the presence of oils, metals, nonmetallic components of refrigeration systems, and residual cleaning and degreasing agents. It is based on sealed-tube stability tests, performed at elevated temperatures, for periods as long as three years. Results are reported for R-11, R-12, R-13B1, R-22, R-113, R-114, R-115, R-124, R-216, R-C318, R-500, and R-502. The testing included examination of decomposition products, specifically including the fraction converted into other refrigerants. The metals tested included aluminum, brass, cadmium, copper, iron, lead, magnesium, mercury, steel, and zinc. The effects of selected additives and inhibitors, including phenyl alpha naphthylamine, molybdenum disulfide, and tricresyl phosphate (TCP), also were examined. The paper concludes that the life of a system should be longer if made chemically simpler, because every added mate-

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rial provides a possibility of increased chemical reactions.

S. Rosen, A. A. Sakhnovsky (University of Miami), R. B. Tilney (Alco Valve Company), and W. O. Walker (University of Miami), **A Method of Evaluating Filtration and Flow Characteristics of Liquid Line Refrigeration Driers**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 71(I), 1965 (6 pages with 6 figures and 5 tables, RDB4A33)

This paper describes a test method for evaluating the filtration capabilities of a liquid-line, filter-driers. The method is based on measurement of the flow and pressure drop of R-113 with added grit through test filters. The grit used is a silicon carbide abrasive grain, selected because it is inexpensive, inert, nonporous, readily available, and easy to see in the refrigerant. The paper discusses the need for a test method, the rationale for use of R-113, the test loop, refrigerant circulation pump, and venturi flow meter. It describes the flow and pressure drop calibration, correlation of R-113 and R-22 flow data, selection of the grit, and the test procedure. A simplified schematic is provided for the apparatus. The paper then presents results for six different types of driers. Measured pressure drops are tabulated for the driers with varied flow rates and grit quantities for three grit sizes. The conclusions indicate a need for a standard rating method.

Fainberg and Miller, **Molar Refractivity in Fluorine Containing Perhalo Compounds**, *Journal of Organic Chemistry*, 30:864 ff , 1965 (rdb7C27)

refractive indices of fluorochemical refrigerants

R. B. Irmann, **A Simple Correlation Between Water Solubility and Structure of Hydrocarbons and Halohydrocarbons**, *Chem. Ing. Tech.*, 37:789-798, 1965 (10 pages, rdb8473)

materials compatibility

C. M. Knobler and C. J. Pings, **Saturated Liquid Density of Carbon Tetrafluoride from 90 to 150 K**, *Journal of Chemical and Engineering Data*, 10(2):129-130, 1965 (2 pages, rdb7B19)

thermodynamic properties of R-14 from -183 to -123 °C (-298 to -190 °F); thermophysical data

M. Kriebel and H. J. Löffler, **Thermodynamische Eigenschaften des binären Systems Difluormonochlormethan (R22) - Tetraäthylenglycoldimethyläther (E181)** [Thermodynamic Properties of Binary Mixtures of Chlorodifluoromethane (R-22) and Tetraethylene Glycol Dimethyl Ether (R-E181) [possibly R-E281], *Kältetechnik*, Germany, 17(9):-266-271, 1965 (6 pages, in German, rdb4916)

R-22 blends, R-22/TGDME

N. Sharpe, **Oil Migration in R-12 and R-22 Systems**, *ASHRAE Journal*, 7:, 1965 (rdb4C46)

H. Steinle (Robert Bosch GmbH, Germany), **Prüfung und Auswahl von Kunstoffen zur verwendung in gekapselten Kältemaschinen** [Test and Selection of Plastics for Use in Hermetic Refrigeration Machines], *Kältetechnik*, Germany, 16(11):334-341, 1965 (8 pages with 8 figures and 5 tables, in German, RDB6643)

R-12, R-22, laboratory tests of plastics

W. O. Walker (University of Miami), **Sealed-Tube Tests: A Comparison of Methods**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 71(I):134-137, 1965 (RDB6712)

catalytic effects, refrigerant lubricant reactions, compatibility

M. G. Zabetakis, **Flammability Characteristics of Combustible Gases and Vapors**, bulletin 627, Bureau of Mines, U.S. Department of the Interior, Washington, DC, 1965 (rdb4976)

LFL, UFL, test methods

Toxicity Studies with 1,1,2-Trichloro-1,2,2-trifluoroethane, bulletin S-24, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1965 (rdb5564)

R-113, health effects, safety, toxicity

1964

H. O. Spauschus and G. C. Doderer (General Electric Company), **Chemical Reactions of Refrigerant 22**, *ASHRAE Journal*, 54-58, October 1964; republished in *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 71(I):162-168, 1965 (7 pages, rdb2327)

R-22; stability; literature review on reactions; decomposition mechanisms; experimental study of decomposition in the presence of lubricants and metals (aluminum, copper, and iron); effect of temperature

H. L. Emmons (A. O. Smith Corporation), **Motorette-Autoclave Method for Evaluating Hermetic**

Motor Insulation Systems, *Insulation*, 10(3):30-32, March 1964 (3 pages, rdb6629)

compatibility, motor materials

H. G. Hirschberg (Gebrüder Sulzer AG, Switzerland), **Zur Ermittlung der Viskosität von Mineralöl-Kältemittel-Gemischen**, *Technische Rundschau Sulzer,* Winterthur, Switzerland, 46(2):89-93, February 1964; republished in English as **Determining the Viscosity of Mixtures of Mineral Oil and Refrigerants**, *Sulzer Technical Review*, Winterthur, Switzerland, 46(2):89-92, February 1964; republished in *Modern Refrigeration*, 711-713 (3 pages with 4 figures, RDB2501)

The viscosity of lubricating oils is substantially lowered by dissolved hydrocarbons. Determination of viscosity for refrigerant-lubricant mixtures, therefore, is very important in equipment and application design. The need is heightened by variations in the hydrocarbon content, related to the origin of the crude oil used, and the way in which it is refined. This paper outlines calculation methods to determine the viscosity based on ring analysis, mean molecular weight, viscosity-temperature relation, and density. The ring analysis determines the paraffins, cyclic paraffins (naphthenic substances, and benzene derivatives (aromatics) present in the oil. The molecular weight is a measure of the size of the oil molecules. The viscosity index, or alternative viscosity pole height, may be obtained from manufacturer data. The paper discusses viscosity equations developed by a number of investigators, including Arrhenius, E. R. Epperson and H. L. Dunlap, L. Grunberg and A. H. Nissan, and H. Umstätter. It illustrates comparative results based on a mixture of R-114 and mineral oil. It concludes that a modified version of the Grunberg and Nissan equation is useful for representing and calculating the viscosities of refrigerant-lubricant mixtures.

E. Jones, **Determining Pressure Drop and Refrigerant Flow Capacities of Liquid Line Driers**, *ASHRAE Journal*, 6(2):70 ff, February 1964 (RDB-4A34)

filter-driers, test method

R. T. Divers and W. West (Carrier Corporation), **Hermetic Compressors in Modern Applications**, *Transactions* (Semiannual Meeting, New Orleans, LA, 27-29 January 1964), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 70:, 1964; republished in *ASHRAE Journal*, 6(4):55-61, April 1964 (7 pages with 9 figures and 3 tables, RDB6634)

R-22, motor cooling methods in reciprocating-piston compressors, motor insulation materials

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mass flow, heat transfer, heat exchanger, evaporator

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history of mineral oil lubricant standards in Germany, Philipp test for stability, copper plating, life test, wear test: high temperatures in compressor bearings, discharge valves, and motor windings promote chemical reactions of refrigerants and lubricants; the reactivity of oil mixtures, metal corrosion, and copper plating are caused by oleoresins; DIN standard 51 503 prescribes tests for these phenomena; includes discussion by H. O. Spauschus (General Electric Company, USA)

K. Stephan (Technische Universität Berlin, Germany), **Einfluß von Öl auf den Wärmeübergang von siedendem Frigen 12 und Frigen 22** [The Effect of Oil on Heat Transfer of Boiling R-12 and R-22], *Kältetechnik*, Germany, 16(6):162-166, 1964 (5 pages in German, rdb3B25)

heat transfer, lubricant effects

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R-12, thermophysical data

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R-12, R-22, heat transfer, lubricant effects

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W. O. Walker (University of Miami), **Latest Ideas in Use of Desiccants and Driers**, *Refrigerating Service and Contracting* (RSC), 24-30, August 1963 (7 pages with 4 figures, RDB4B58)

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H. Steinle (Robert Bosch GmbH, Germany), **Kältemachinenöle, Mindestanforderungen, Neufassung Juli 1963** [Refrigeration Machine Oils, Minimum Requirements, July 1963 Revision], *Kältetechnik*, Germany, 15(7):204 ff, 1963; republished in *Erdöl und Kohle* [Petroleum and Coal], Germany, 16(8):867 or 1867 ff, 1963 (in German, RDB6679)

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R-218, thermodynamic properties, thermophysical data

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pressure drop in evaporators from frictional forces in the two-phase flow region and from a momentum change from acceleration of the increasing vapor mass

D. L. McClenahan, **The Significance of Hydrolysis Tests on Film-Insulated Magnet Wire in Predicting Suitability in Hermetically-Sealed Units**, paper CP63-500, *IEEE Conference*, Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 1963 (rdb6636)

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thermodynamic properties, thermophysical data, service

R. E. Gundarson and H. W. Millet, **Polyglycols in Synthetic Lubricants**, *Synthetic Lubricants*, edited by R. E. Gundarson and A. W. Hart, Reinholt Publishing, New York, NY, 1962 (rdb4354)

J. M. Hamilton, Jr. (E. I. duPont de Nemours and Company, USA), **The Organic Fluorochemicals Industry**, *Advances in Fluorine Chemistry*, 3:117-180, 1962 (64 pages with 12 figures and 9 tables, RDB7601)

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I. I. Perelshtein, **Thermodynamic Properties of the Azeotropic Mixture of R-124 and R-C318**, *Inzhenerno-Fizicheskii Zhurnal* [Journal of Engineering Physics], Minsk, Belarus (then USSR), 12:27-33, 1962 (7 pages probably in Russian, rdb4901)

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R-11, R-12, R-22, R-113, R-114, R-114a, R-500, naphthenic and paraffinic mineral oils, lubricants, aluminum, copper, steel, metal catalysts, compatibility

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oil floc points in refrigerants

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Solubility Relationships of the Freon Fluorocarbon Compounds, technical bulletin B-7, E. I. duPont de Nemours and Company, Wilmington, DE, September 1961 (rdb6624)

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D. J. Bushouse (General Electric Company), **Degradation of Polyester Films by Alcohols when Used as Additives in Refrigeration Systems**, Annual Meeting (Denver, CO, June 1961), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA; republished in *ASHRAE Journal*, 3(9):61-64, September 1961 (4 pages with 7 figures and 2 tables, RDB-2301)

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L. Gardner, J. Lowe, and R. B. Whyte, **Investigation of the Stability Test for Refrigerator Oils**, Mechanical Engineering Report MP-20A, National Research Council of Canada (NRCC), Ottawa, ON, Canada, March 1961 (rdb7108)

lubricants, compatibility, test methods

H. Braunisch, **Untersuchungen Über die (R)Frigen-Durchlässigkeit von Kunstoff-Folien** [Investigations of the Permeability of Plastic Films by Refrigerants], *Kältetechnik*, Germany, 13:59 ff, February 1961 (in German, rdb7644)

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Y-T. Hwang, **The Constant Volume Heat Capacities of Gaseous Tetrafluoromethane, Chlorofluoromethane, Dichlorotetrafluoroethane, and Chloropentafluoroethane**, PhD dissertation, University of Michigan, Ann Arbor, MI, 1961 (rdb6809)

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R-12, R-22, 4Å molecular sieve desiccants

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Quality Specifications and Methods of Analysis for the Freon Fluorocarbon Refrigerants, technical bulletin B-8, E. I. duPont de Nemours and Company, Wilmington, DE, November 1960 (rdb6625)

R-11, R-12, R-22, R-113, R-114: specifications, water content, nonadsorbable gases, boiling range, high-boiling impurities, chloride ion content, cloud point

W. O. Walker, S. Rosen (University of Miami), and S. L. Levy (Allied Chemical Corporation), **A Study of the Factors Influencing the Stability of the Mixtures of Refrigerant 22 and Refrigerating Oils**, paper 1728, *Transactions* (Annual Meeting, Vancouver, BC, 13-15 June 1960), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 66:445-464, 1960 (20 pages with 23 figures, rdb2323)

R-22, compatibility, lubricants

J. L. Ditzler (Westinghouse Electric Corporation), **Better Methods for Evaluating Hermetic Motor Insulation**, *Air Conditioning, Heating, and Ventilating*, 57:64-68, April 1960 (5 pages with 2 figures and 3 tables, RDB6651)

R-22, compatibility, motor materials, evaluation of insulation systems for hermetic compressors, test results for tested wire-twist samples in R-22 and mineral oil: stressing of insulation systems under starting conditions contributes to motor failures; R-22 may reduce the strength of insulated conductors; simulated starting conditions by frequent motor reversals correlate with actual experience; short-time locked-rotor tests under controlled conditions indicate the quality of motor winding systems

P. Worsoe-Schmidt, **Some Characteristics of Flow Pattern and Heat Transfer of Freon 12 Evaporating in Horizontal Tubes,** *Journal of Refrigeration*, 40:40-44, March/April 1960 (5 pages, rdb4972)

R-12; influences of added oil on the refrigerant-side flow regime

M. Altman, R. H. Norris, and F. N. Staub, **Local and Average Heat Transfer and Pressure Drop for Refrigerants Evaporating in Horizontal Tubes**, *Journal of Heat Transfer*, 82:189-198, 1960 (10 pages, rdb6421)

J. A. Brown, **Effect of Propellants on Plastic Valve Components**, *Soap and Chemical Specialties*, (3):87 ff, 1960 (rdb7A03)

R-11, R-12, R-21, R-22, R-30, R-113, and R-114a compatibility with plastics: cellulose acetate, cellulose nitrate, methyl methacrylate resin, nylon, phenol formaldehyde resin, polyethylene, polystyrene, polytetrafluoroethylene, polyvinyl alcohol, polyvinyl chloride, and polyvinylidene chloride as reported in RDB7A01

L. D. Kaplan, **The Influence of Carbon Dioxide Variations on the Atmospheric Heat Balance**, *Tellus*, 12:204-208, 1960 (5 pages, rdb8B25)

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K. Y. Kondratiev and H. I. Niilisk, **On the Question of Carbon Dioxide Heat Radiation in the Atmosphere**, *Geofis. Pura Appl.*, 46-216-230, 1960 (15 pages, rdb8B26)

role of atmospheric carbon dioxide (CO_2) in global temperature; greenhouse gas (GHG) effects; global warming; one of the early predictions of climate sensitivity to changes in CO_2 content

H. J. Löffler, **Einige Eigenschaften des Binären Systems Frigen 12 - Frigen 22 und des Ternären Systems F 12 - F 22 - Naphthenbasisches Mineralöl** [Some Properties of the Binary System R-12 / R-22 and the Ternary System R-12 / R-22 / Naphthenic Mineral Oil], *Kältetechnik-Klimatisierung*, 12(9):256-260, 1960 (5 pages with 6 figures and 3 tables, in German, rdb4262)

This paper presents tabular data and a vapor-pressure diagram for R-22/12 mixtures at low temperatures based on new measurements and published data from other studies. It covers the temperature range of -80 to 50 °C (-112 to 122 °F). The paper also presents miscibility, low-temperature fluidity, viscosity, and vapor pres-

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sure data for high oil concentrations with R-501 [an azeotrope of R-22/12 (75/25)] and for up to 25% by weight R-12 in R-501.

H. J. Löffler (Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Germany), **Die Viskosität von Öl-Kältemittel-Gemischen** [Viscosity of Oil-Refrigerant Mixtures], *Kältetechnik,* Germany, 12(3):71-75, 1960 (5 pages with 12 figures in German, rdb4263)

This paper presents viscosity data for R-11, R-12, and R-22 with five different lubricants. The experimental apparatus used to measure the viscosities is described and shown schematically. Plots show the kinematic viscosity of oil refrigerant mixtures for the three refrigerants with 75-100% mineral oil by weight and for R-22 with a synthetic silicate lubricant (Bayer Fluisil(R) S 55 K), at temperatures of -20 to 70 °C (-4 to 158 °F). Additional plots show the relationship between solution vapor pressure and concentration for the same temperatures. The results are compared with those published by other investigators. Based on the comparisons, the paper presents a simple method to estimate the viscosities of oil-refrigerant mixtures containing R-11, R-12, or R-22.

D. Madinabeitia, **The Effect of Pressure and Temperature on the Azeotropic Composition of the R22 and R12 Binary System**, MS thesis, University of Delaware, Newark, DE, 1960 (rdb4C11)

R-12, R-22, R-22/12, R-501, thermophysical data, blends

I. Sauerbrunn, **Elastomere in Kälteanlagen mit halogenierten Kohlenwasserstoffen als Kältemittel** [Elastomers in Refrigeration Equipment with Halogenated Hydrocarbons as Refrigerant], *BBC-Nachtrichten,* Brown, Boveri und Cie AG, Mannheim, Germany, 1:10 ff, 1960 (in German, rdb6660)

compatibility

H. Steinle (Robert Bosch GmbH), **Über der Oberflächenpannung von Kältemitteln, Kältemaschinenölen, und deren Gemischen** [On the Surface Tension of Refrigerants, Refrigeration Lubricants, and their Mixtures], *Kältetechnik*, Germany, 12(11):334-339, 1960 (6 pages in German, RDB-4913)

A. Thelen and H. J. Löffler, **Die Schmierung von zylindrischen Gleitlagern mit Öl-Kältemittel-Gemischen** [Lubrication of Cylindrical Bearings with Oil-Refrigerant Mixtures], *Abhandlung des DKV* [DKV Transactions], Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Verlag C. F. Müller, Karlsruhe, Germany, 15:, 1960 (in German, rdb4665)

KULENE(R) 131, Bromotrifluoromethane (CF_3Br), A New Low Temperature Refrigerant, technical bulletin, Eston Chemicals, Incorporated, Los Angeles, CA, circa 1960 (8 pages with 1 figure and 4 tables, RDB3743)

R-13B1, $CBrF_3$, physical properties, application information, solubility in lubricants (Capella Oil D), thermodynamic properties including tabular pressure-volume-temperature (PVT), density, latent heat, and entropy data; performance comparisons to R-12, R-22, R-40, and R-717, pressure-temperature plot for the same refrigerants

J. P. Hurtgen and A. R. Mounce (General Electric Company), **New Insulation Systems for Hermetic Refrigeration Motors**, *ASHRAE Journal*, 1(7):60-62, July 1959 (3 pages, rdb6630)

compatibility, motor materials

R. C. Downing, **Aluminum and the 'Freon' Refrigerants**, bulletin D-52, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, June 1959 (rdb4113)

compatibility, metals

L. F. Albright (Purdue University) and J. D. Lawyer (University of Oklahoma), **Viscosity-Solubility Characteristics of Mixtures of Refrigerant-13B1 and Lubricating Oils**, *ASHRAE Journal*, 1(4):67-70, April 1959 (4 pages with 12 figures and 1 table, RDB2207)

R-13B1, naphthenic mineral oil, paraffinic mineral oil, viscosity reduction due to refrigerants

J. P. Harrington and R. J. Ward, **Polyester Film Insulation for Hermetic Motors**, *ASHRAE Journal*, 1(4):75 ff, April 1959 (rdb2302)

compatibility, motor materials

J. F. Harris and C. B. Sonnino, **New Insulating Media for Hermetic Motors Require New Tests**, *ASHRAE Journal*, 1:49 ff, 1959 (rdb6652)

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C. Z. Kamien and O. W. Witzell (Purdue University), **Effects of Pressure and Viscosity of Refrigerants in the Vapor Phase**, paper 1693, *Transactions* (Annual Meeting, Lake Placid, NY, 22-24 June 1959, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 65:663-674, 1959 (12 pages with 9 figures and 7 tables, RDB4A56) viscosity measurements of R-12, R-13, R-14, R-21, R-22, R-23, R-114, R-115, and R-C318 with a rolling ball, Hoeppler type viscometer for 30-90 °C (86-194 °F) and pressures up to 2000 kPa (290 psia); thermophysical data

H. Kelker, **Determination of Inert Gas Components in Refrigerants by Means of Gas Chromatography**, *Kältetechnik*, Germany, 11:101-103, 1959 (3 pages, rdb4746)

W. McMahon, H. A. Birdsall, G. R. Johnson, and C. T. Camilli (Bell Telephone Laboratories, Incorporated), **Physical Properties Evaluation of Compounds and Materials, Part II: Degradation Studies of Polyethylene Terephthalate**, *Journal of Chemical and Engineering Data*, 4(1):57-69, January 1959 (13 pages with 23 figures and 22 tables, rdb6628)

compatibility, motor materials, rates of hydrolysis, oxidation, and thermal degradation of PET as functions of temperature, relative humidity, and film thickness; hydrolysis found to be faster than the other two reactions; provides a relation between extents of chemical and physical degradation to determine the time required for the polymer to reach a given degree of degradation; identifies materials and experimental methods with data for DuPont Mylar(R) film and Dacron(R) yarn

H. J. Löffler (Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Germany), **Die Kältefließfähigkeit von Öl-Frigen 22-Mischungen** [The Fluidity of Oil/R-22 Mixtures at Low Temperatures], *Kältetechnik*, Germany, 11(8):258-262, 1959 (5 pages with 10 figures and 2 tables, in German, RDB4264)

This paper presents data on the fluidity of R-22/lubricant mixtures at low temperatures.

H. J. Löffler (Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Germany) **Das spezifische Gewicht von Öl-Kältemittel-Gemischen** [The Specific Gravity of Oil-Refrigerant Mixtures], *Kaltetechnik*, Germany, 11(3):70-74, 1959 (5 pages, in German, rdb4620)

density of refrigerant-lubricant mixtures

J. J. Martin, R. M. Kapoor, and N. De Nevers, **An Improved Equation of State: Application to Eight Fluorine Compounds**, *AIChE Journal*, 5(2):159-160, 1959 (2 pages, rdb5622)

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J. J. Martin (University of Michigan), **Correlations and Equations Used in Calculating Thermodynamic Properties of 'Freon' Refrigerants**, *Thermodynamic and Transport Properties of Gases, Liquids, and Solids*, American Society of Mechanical Engineers (ASME), New York, NY, 110 ff. 1959 (rdb7A57)

equations of state (EOS), thermodynamic and transport properties, thermophysical data

I. Sauerbrunn (Brown, Boveri und Cie AG, Germany), **Methods of Testing and Selection of Non-cellulosic Insulating Materials to be Used in Hermetically-Sealed Refrigerating Machinery**, *Proceedings of the XIIth International Congress of Refrigeration* (Copenhagen, Denmark), International Institute of Refrigeration (IIR), Paris, France, 11:76 ff, 1959 (rdb6655)

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R. T. Divers (Carrier Corporation), **Better Standards Are Needed for Refrigeration Lubricants**, *Refrigerating Engineering*, 66(10):40 ff, October 1958 (rdb4619)

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W. W. Wareham, **Screening Tests for Hermetic Wire**, *Proceedings of the First Electrical Insulation Conference* (EIC, September 1958), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 1958 (rdb6662)

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E. T. Neubauer, **Compressor Crankcase Heaters Reduce Oil Foaming**, *Refrigerating Engineering*, 66(6):52 ff, June 1958 (rdb4637)

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J. P. Barger, W. M. Rohsenow, and K. M. Treadwell, **A Comparison of Refrigerants When Used in Vapor Compression Cycles over an Extended Temperature Range**, *Transactions of the ASME*, American Society of Mechanical Engineers (ASME), New York, NY, 79:681 ff, April 1957 (rdb4352)

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W. A. Pennington (Carrier Corporation), **Progress in Refrigerants, Part II**, *World Refrigeration*, 8(3):151-160, March 1957 (10 pages, rdb2446)

W. O. Walker, A. A. Sakhnovsky, and S. Rosen, **Behavior of Refrigerant Oils and Genetron-141**, *Refrigeration Engineering*, 65(3):38-45, March 1957 (8 pages, rdb4330)

R-22, addition of 15% R-12 to R-22 in naphthenic mineral oil to improve lubricant solubility by reducing the phase separation temperature by 20 °C (68 °F)

W. A. Pennington (Carrier Corporation), **Progress in Refrigerants, Part I**, *World Refrigeration*, 8(2):85-91, February 1957 (6 pages, rdb2437)

R. S. Barnes and M. Z. Fainman**, Synthetic Ester Lubricants**, *Lubrication Engineering*, 13:454 ff, 1957 (rdb7705)

historical development and need polyolester (POE) lubricants to replace mineral oils

G. G. Haselden and L. Klimek (University of Leeds, UK), **An Experimental Study of the Use of Mixed Refrigerants for Nonisothermal Refrigeration**, *Proceedings of the Institute of Refrigeration*, 54:129-148, 1957 (20 pages with 10 figures and 1 table, RDB2C02)

This paper reviews the history of zeotrope application, beginning with efforts by R. Pictet to use a blend of R-744 (carbon dioxide) and R-764 and (sulfur dioxide) in 1888. Subsequent efforts by A. Stradelli with the same blend in 1933, G. Maiuri with R-50 (methane) and R-1150 (ethene) in 1939, M. Ruhemann in 1947, and finally F. Carr using a ternary blend in 1949 also are noted. The paper reports a partially successful experiment to demonstrate the previously predicted performance benefits. It notes, however, that the power savings claimed may also be partially achieved with multistage operation with a pure refrigerant. The paper discusses the phase behavior of mixtures, concluding that concurrent condensation and evaporation of the components - with complete mixing - is necessary to achieve the low power consumption. It then describes experiments using R-290/600 (propane/butane), first with tubular and then plate heat exchangers. A power savings of 7% was achieved, less than predicted due to deterioration in heat transfer and to separation and remixing of the components during phase change. The paper postulates that improved performance might result with correct selection and sizing of the heat exchangers and use of herring-bone packing to promote phase mixing. The paper also compares the benefits and costs of use of mixtures to conventional cycles using R-12 or R-717 (ammonia). Figures illustrate the modes of binary mixture condensation, cycle modifications to utilize zeotrope benefits, cycle diagrams, and the plate heat exchanger. Additional figures depict the change in pressure ratio resulting from addition of R-600 to R-290, temperature profiles of the blend in condensation and evaporation, and boiling and condensing heat transfer coefficients for compositions ranging from 0-30% propane.

H. J. Löffler (Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Germany), **Refrigerants and Mixtures of Oils and Refrigerants**, *Kältetechnik-Klimatisierung*, 9(11):358-360, 1957 (3 pages in German, rdb4266)

H. J. Löffler (Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Germany), **Separation of Substances Which Are Insoluble in Frigen 22 from Mineral Oil/Frigen 22 Mixtures**, *Kältetechnik-Klimatisierung*, 9(9):103-105, 1957 (5 pages in German, rdb4269)

R-22

H. J. Löffler (Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Germany), **Der Einfluß der physikalischen Eigenschaften von Mineralölen auf deren Mischbarkeit mit dem Kältemittel Frigen 22** [The Influence of Physical Properties of Mineral Oils on Their Miscibility with Refrigerant R-22 ($CHClF_2$)], *Kältetechnik*, Germany, 9(9):282-286, 1957 (5 pages with 11 figures and 2 tables, in German, RDB4267)

This paper presents solubility plots for R-22 with 18 mineral oils. The experimental apparatus used for the measurements is described and shown schematically. The paper also presents regression relations to enable estimation of miscibility with naphthenic and paraffinic mineral oils.

H. J. Löffler (Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Germany) **Die Mischbarkeit der synthetischen Öle 'Fluisil S55K' und 'Polyran M15' mit den Kältemitteln Frigen 13, Frigen 22, bzw. mit Gemischen as Frigen 13 und Frigen 22** [The Mixing Abilities of the Synthetic Oils Fluisil S55K and Polyran M15 with Refrigerants R-22, R-13, or Mixtures of R-22 and R-13], *Kältetechnik*, Germany, 9(5):135-137, 1957 (3 pages with 2 figures and 1 table in German, RDB4268)

R-13, R-22, R-13/22, synthetic silicate butyl ester (polykieselsäurebutylester) lubricant (Bayer Fluisil(R) S 55 K), synthetic polyether (Bayer Polyran M15)

E. F. Nielson and D. White, **The Heat Capacity, Heat of Fusion, Heat of Transition, and Heat of Vaporization of Chlorodifluoromethane Between 16 K and the Boiling Point**, *Journal of the American Chemical Society*, 79:5618-5621, 1957 (4 pages, rdb4312)

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R. Schubert, **Determination of Fluidity of Oils at Low Temperatures by Means of Extrapolation**, *Kältetechnik*, Germany, 9(2):40-43, 1957 (4 pages in German, rdb4556)

B. Pierre, **The Coefficient of Heat Transfer for Boiling Freon-12 in Horizontal Tubes**, *Heating and Air Treatment Engineer*, 302-310, December 1956 (9 pages, rdb3B45)

please see page 6 for ordering information

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L. F. Albright (Purdue University) and A. S. Mendelbaum (Atlantic Refinery Company), **Solubility and Viscosity Characteristics of Mixtures of Lubricating Oils and 'Freon-13' or '-115'**, presented at the 43rd Semiannual Meeting of the American Society of Refrigerating Engineers (ASRE, New Orleans, LA, 26-28 November 1956; republished in *Refrigerating Engineering*, 64(10):37-47 and 106, October 1956 (12 pages with 17 figures and 2 tables, RDB2208)

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N. Thorp and R. L. Scott (University of California at Los Angeles), **Fluorocarbon Solutions at Low Temperatures. II. The Liquid Mixtures of C_2H_6-C_2F_6, C_2F_6-CHF_3, CH_2F_2-CHF_3, C_2H_6-CHF_3 and Xe-CHF_3**, *Journal of Physical Chemistry*, 60(10): 1441-1443, October 1956 (3 pages with 4 figures and 3 tables, RDB4A35)

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S. F. Murray, R. L. Johnson, and M. A. Swikert, **Difluorodichloromethane as a Boundary Lubricant for Steel and Other Metals**, *Mechanical Engineering*, 78(3):233-236, March 1956 (4 pages, rdb4636)

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J. Kuprianoff, R. Plank, and H. Steinle, **Die Kältemittel** [Refrigerants], *Handbuch der Kältetechnik* [Handbook of Refrigeration], Springer Verlag, Berlin, Germany, 4:, 1956 (in German, rdb4668)

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H. J. Löffler, **Der Einfluß der physikalischen Eigenschaften von Mineralölen auf deren Mischbarkeit mit dem Kältemittel R22 (CHF_2Cl)** [The Influence of Physical Properties of Mineral Oils on Their Miscibility with Refrigerant R-22 (CHClF2)], dissertation, Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Karlsruhe, Germany, 1956; republished in *Abhandlung des DKV* [DKV Transactions], Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Verlag C. F. Müller, Karlsruhe, Germany, 12:, 1957 (in German, rdb4265)

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H. Steinle (Robert Bosch GmbH), **Schmiermittel für Kältemaschinen mit Frigen 22** [Lubricants for Refrigerating Machines with R-22], *Kältetechnik,* Germany, 8(1):12-14, 1956 (3 pages, in German, rdb4286)

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J. F. Dexter (Dow Corning Corporation), **Simple Test Uses One Criterion, Few Samples to Evaluate Impregnating Varnishes**, *Insulation*, 12-19, September 1955 (8 pages with 6 figures and 6 tables, RDB6666)

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R-12, mineral oil

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G. Bambach, **A Contribution to the Information on Physical and Thermodynamic Properties of R-12/Mineral Oil Mixtures**, dissertation, Technische Universität Karlsruhe, Karlsruhe, Germany, 1955 (in German, rdb4245)

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Solubility Relationships of the Freon Compounds, technical bulletin B-7, Kinetic Chemicals Division, E. I. duPont de Nemours and Company, Wilmington, DE, 1 May 1954 (rdb6621)

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N. Luft, **Assignment of Torsional Frequencies in Some Halogenated Ethanes**, *Journal of Chemical Physics*, 22:155 ff, 1954 (rdb7963)

R-123 and others, ideal gas heat capacity, thermodynamic properties, thermophysical data

T. Makita, **The Viscosity of Freons under Pressure**, *Review of Physical Chemistry of Japan*, (2):74 ff, 1954 (rdb7718)

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H. Steinle (Robert Bosch GmbH, Germany), **Bestimmung der Kältemittel-Beständigkeit von Kältemachinenölen (Philipp Test), Entwurf DIN 51 593** [Determination of Refrigerant Stability with Refrigeration Machine Oils (Philipp Test), Preliminary German Institute for Normalization Standard 51 593], *Kältetechnik*, Germany, 6(12):342 ff, 1954 (in German, RDB6677)

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Monochlorodifluoromethane - Freon-22 (F-22) Analysis for Sales Specification, Kinetic Chemicals Division, E. I. duPont de Nemours and Company, Wilmington, DE, 7 July 1953 (rdb6618)

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P. G. T. Fogg, P. A. Hanks, and J. D. Lambert, **Ultrasonic Dispersion in Halomethane Vapours**, *Proceedings of the Royal Society*, 219:490-499, 1953 (10 pages, rdb5484)

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J. L. Little (Texaco Incorporated, then the Texas Company), **Viscosity of Lubricating Oil – Freon-22 Mixtures**, presented at the 48th Annual Meeting of the American Society of Refrigerating Engineers (ASRE, New York, NY, 30 November - 3 December 1952); republished in *Refrigerating Engineering*, 60(11):1191-1195, November 1952 (5 pages with 11 figures and 4 tables, RDB2214)

This paper presents a study of the viscosity of lubricant-refrigerant mixtures for R-22 with mineral oils. It notes that the viscosity of liquid fluorocarbons is very low, and that absorption of even a small amount of these refrigerants reduces the viscosity of lubricating oils. The paper notes that the amount of R-22 absorbed by the oil depends on the vapor pressure, temperature, rate of absorption, and time. Further, that rate largely depends on the amount of agitation in the oil reservoir, which varies with the compressor design and mode of operation. Two schematics show and the paper explains the separate apparatus used to measure the amount of R-22 absorbed by a lubricating oil and the viscosity of the resultant mixture. A table summarizes the physical characteristics of two viscosity grades each of naphthenic and paraffinic mineral oils. The paper outlines the measurements and provides plots of the measured data, including the volume reduction when the refrigerant and lubricant are mixed. Two more plots show the viscosities at 25, 38, and 54 °C (77, 100, and 130 °F) as a function of the absorbed refrigerant concentration. The paper explains a predictive method based on Bell & Sharp "H" values, which are a function of kinematic viscosity and are additive at any given temperature. The "H" values were found to be proportional to the R-22 concentration. The paper notes that the actual concentration in the compressor is usually not known, that a relatively small increase in temperature may reduce the viscosity as much as a sizeable dilution with R-22, and that the viscosity of the R-22/oil mixture varies far less with temperature increase than undiluted oil. The paper presents plotted absorption and viscosity measurements, the combination of which make it possible to estimate the viscosity of a mixture of R-22 and oil, if the vapor pressure of the R-22 is known.

H. M. Elsey, L. C. Flowers, and J. B. Kelley, **A Method of Evaluating Refrigeration Oils**, *Refrigerating Engineering*, 60(7):737 ff, July 1952 (rdb-2321)

R-12, lubricants: factors that influence R-12-oil reactions

C. M. Bosworth (Carrier Corporation), **Predicting the Behavior of Oils in Refrigeration Systems**, *Refrigerating Engineering*, 60(6):617-620 and 654-655, June 1952 (7 pages with 12 figures and 5 tables, RDB2503)

This paper discusses the solubility of lubricating oils in refrigerants, absorption of refrigerants, solvent effects on nonmetallic materials, and stability of oils. Differences among paraffinic, intermediate, and naphthenic lubricants are discussed, and recommendations are presented for selection of oil types for specific applications. Solubility curves are presented for R-12, R-22, and R-114 in four oils. The paper notes that the volumes of refrigerant-lubricant mixtures do not necessarily correspond to the sum of their separate volumes due to absorption; data on increases and decreases are provided for several examples.

B. J. Eiseman, Jr., **Kinetic Technical Memorandum**, number KTM-7, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, June 1952 (rdb4919)

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H. F. Coward and G. W. Jones, **Limits of Flammability of Gases and Vapors**, bulletin 503, Bureau of Mines, U.S. Department of the Interior, Washington, DC, 1952 (rdb4908)

LFL, UFL, test methods

A. T. E. Gibbes, **Effects of Mutual Solubilities of Refrigerant and Oil in Low Pressure Systems,** *Refrigeration Journal*, 19-28, 1952 (10 pages, rdb-4341)

L. H. Horsley, **Azeotropic Data**, report 6, Advances in Chemistry, American Chemical Society, Washington, DC, 1952 (rdb4605)

P. Laine, **Kältemaschinen und -apparate: Prüfung von Kältemaschineteilen auf Dichtheit** [Refrigeration Machines and Apparatus: Tests of Refrigeration Machine Components for Density], paper 55:129 presented at the 4th Congress Internationale des Chauffage Industr. (Paris, September-October 1952), *Kältetechnik*, Germany, 6:173, 1953 (1 page, rdb7947)

R-717 (ammonia), density, viscosity, thermodynamic properties, thermophysical data

D. R. Lide, **The Microwave Spectrum and Structure of Methylene Fluoride**, *Journal of the American Chemical Society*, 74:3548-3552, 1952 (4 pages, rdb4361)

R-32

D. C. Smith, G. M. Brown, J. R. Nielsen, R. M. Smith, and C. Y. Liang, **Infrared and Raman Spectra of Fluorinated Ethanes, III, the Series of CH_3CF_3, CH_3CF_2Cl, CH_3CFCl_2, and CH_3CCl_3**, *Journal of Chemical Physics*, 20:473-486, 1952 (14 pages, rdb4318)

R-143a, R-142b, R-141b, and R-140a (methyl chloroform)

W. M. Rohsenow, **A Method of Correlating Heat Transfer Data for Surface Boiling of Liquids**, *Transactions of the ASME*, 74:969 ff, 1952 (rdb4546)

mass flow, heat transfer, heat exchanger, evaporator

H. Steinle (Robert Bosch GmbH, Germany), **Die Temperaturbeständigkeit nichtmetallischer Stoffe in Kältemaschinen** [The Thermal Stability of Nonmetallic Materials in Refrigeration Machines], *Kältetechnik,* Verlag C. F. Müller, Karlsruhe, Germany, 4:28 ff, February 1952; republished in *Werkstoffe und Korrosion*, 3:419 ff, 1952 (in German, RDB6622)

compatibility with nonmetallic materials

This article presents a method to measure small amounts of noncondensable material in liquified gases and applies it to measurement of air solubility in R-12 and R-22. Plots show the solubility of air as functions its partial pressure and temperature for these refrigerants. The solubility relationship is shown to obey Henry's Law; the solubility coefficients are tabulated. Further plots and empirical relations examine the vari-

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ability of solubility with total pressure, variability with temperature, and distribution of air between the vapor and liquid phases - the last based on Raoult's Law. The article then examines the effect of the liquid discharge rate on air concentration in the liquid and the rate at which air dissolves in the refrigerants, the latter occurring very slowly. The article describes and schematically shows a method and apparatus to analyze air concentrates in refrigerants. Plots show the time required for air to mix with R-12 without agitation and the radical acceleration achieved with agitation by the apparatus presented. The article concludes that the solubility of air in R-12 and R-22 is proportional to the partial pressure of the air and to the total pressure. Moreover, the solubility coefficient increases with decreasing temperature. The findings and apparatus developed afford a practical means to determine small concentrations of air from refrigerant samples.

H.. M. Parmelee (E. I. duPont de Nemours and Company), **Solubility of Air in Freon-12 and Freon-22**, presentation (ASRE Spring Meeting, Detroit, MI, 27-30 May 1951); republished in the *Journal of the American Society of Refrigerating Engineers* (ASRE), 573-577, June 1951 (5 pages with 11 figures and 1 table, RDB5702)

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C. W. Huskins, P. Tarrant, J. F. Bruesch, and J. J. Padbury, **Thermal Dehydrohalogenation of Some Chlorofluoroethanes**, *Industrial and Engineering Chemistry*, 43:1253-1256, 1951 (4 pages, rdb7C34)

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H. Steinle (Robert Bosch GmbH, Germany), **Prüfung der Kältemittel-Beständigkeit nichtmetallischer Stoffe in Kältemaschinen** [Stability Testing of Nonmetallic Materials in Refrigerants in Refrigeration Machines], *Kältetechnik*, Germany, 3(5 pages 110 ff and number 6 pages 139 ff, 1951 (in German, RDB6641)

testing of refrigerant compatibility with nonmetallic materials in refrigeration systems

K. Van Nes and H. A. Weston, **Aspects of the Constitution of Mineral Oils**, Elsevier Publishing Company, Incorporated, New York, NY, 1951 (rdb-4649)

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N. E. Hopkins, **Rating the Restrictor Tube**, *Refrigerating Engineering*, 48(11):1087-1095, November 1950 (rdb3417)

Specifications and Methods of Analysis of Dichlorodifluoromethane - Freon-12 (F-12), technical paper 8, Kinetic Chemicals Division, E. I. duPont de Nemours and Company, Wilmington, DE, 1 July 1950 (rdb6620)

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W. A. Pennington (Carrier Corporation), **Refrigerant Sampling**, *Refrigerating Engineering*, 58(2):261-265, March 1950 (5 pages with 3 figures and 5 tables, RDB6604)

techniques for obtaining a representative sample of refrigerant for analysis

E. Altenkirch, **Der Einfluß endlicher Temperaturdifferenzen auf die Betriebskosten von Kompressionskälteanlagen mit und ohne Lösungskreislauf** [Influence of the Temperature Glides on the Operating Costs of Vapor-Compression Cycles with and without Solution Circuit], *Kältetechnik,* Germany, 3:201-205, 229-234, and 225-259, 1950 (45 pages in German, rdb5653)

E. Altenkirch, **Kompressionskältemaschine mit Lösungskreislauf** [Vapor-Compression Cycle with Solution Circuit], *Kältetechnik,* Germany, (2):251-259, 279-284, and 310-315, 1950 (9 pages in German, rdb5654)

H. Steinle (Robert Bosch GmbH, Germany), **Entwurf DIN 6553, Kältemachinenölen** [Preliminary German Institute for Normalization Standard 6553, Refrigeration Machine Oils], *Erdöl und Kohle* [Petroleum and Coal], Germany, 3:334 ff, 1950 (in German, RDB6678)

test methods, refrigeration lubricants

B. J. Eiseman, Jr. (E. I. duPont de Nemours and Company, Incorporated), **Effect on Elastomers of Freon Compounds and Other Halohydrocarbons**, *Refrigerating Engineering*, 57(12):1171 ff, December 1949 (rdb7A05)

R-11, R-12, R-13, R-13B1, R-21, R-22, R-30, R-40, R-113, R-114, R-502, and R-600 (n-butane) compatibility with elastomers: include nitrile butyl rubber (Buna(TM) N), butadiene styrene (Buna(TM) S, GR-S), Butyl(TM) (GR-1), natural rubber, neoprene GN, polysulfide rubber (Thiokol(R) FA), fluoroelastomer (DuPont Viton(R) B), and silicone as reported in RDB7A01

H. M. Elsey and L. C. Flowers, **Equilibria in Freon-12 Water Systems**, *Refrigerating Engineering*, 57:153 ff, 1949 (rdb6605)

R-12, water content

L. Grunberg and A. H. Nissan, **Mixture Law for Viscosity**, *Nature*, 164(4175):799-800, 1949 (2 pages, rdb4609)

W. A. Pennington (Carrier Corporation), **Determination of Water in Freon-12**, *Analytical Chemistry*, 21:766 ff, 1949 (rdb6606)

R-12, water content

H. Steinle (Robert Bosch GmbH, Germany), **Schwefeldioxyd-Beständigkeit und Harzgehalt von Kältemachinenölen** [Stability with Sulfur Dioxide and Resin Content of Refrigeration Machine Lubricants], *Kältetechnik*, 1:14 ff, 1949 (in German, rdb6676)

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R-12, water content

C. C. Roberts, **Proper Instrumentation Assures Dehydration of Hermetic Units**, *Refrigerating Engineering*, 56:231 ff, 1948 (rdb6640)

drying processes for refrigeration systems

J. M. Russ, *Lubrication Engineering*, 2:151 ff, 1947 (rdb2265)

discusses potential use of polyglycol lubricants for ice-making equipment circa 1944 - as reported In RDB2218

G. Scratchard et al., **Thermodynamic Properties - Saturated Liquid and Vapor of Ammonia-Water Mixtures**, *Refrigerating Engineering*, 55:413 ff, 1947 [possibly 53:413 ff, 1945] (rdb3231)

absorption, R-717, R-717/718, thermophysical data

I. W. Mills et al., **Molecular Weight-Physical Property Correlations for Petroleum Fractions**, *Industrial and Engineering Chemistry*, 38:442 ff, 1946 (rdb4622)

W. A. Cook, **Maximum Allowable Concentrations of Industrial Atmospheric Contaminants**, *Industrial Medicine*, 14:936 ff, 1945 (rdb6168)

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A. F. Benning and R. C. McHarness, **Thermodynamic Properties of Freon 114 Refrigerant**, technical bulletin T-114B, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1944 (rdb3639)

R-114, thermophysical data

T. R. Rubin, B. H. Levendahl, and D. M. Yost, **The Heat Capacity, Heat of Transition, Vaporization, Vapor Pressure, and Entropy of 1,1,1-Trichloroethane**, *Journal of the American Chemical Society*, 66:279-282, 1944 (4 pages, rdb8453)

thermodynamic properties of R-140a; thermophysical data

J. N. Friend and W. D. Hargreaves, **Viscosity at the Boiling Point - the Rheocor**, *Philos. Magazine*, 643-650, 1943 (8 pages, rdb4342)

W. A. Grant (Carrier Corporation), **A History of the Centrifugal Refrigeration Machine**, *Refrigerating Engineering*, 82-86, 120, and 122, February 1942 (7 pages with 6 figures and 3 tables, RDB4147)

This article recaps the history of centrifugal refrigeration through 1941. It attributes the first "competent analysis and experimental groundwork" to the old idea of centrifugal compression to Maurice LeBlanc in France, in 1910-1915. LeBlanc experimented with R-10 (carbon tetrachloride or tetrachloromethane) and R-718 (water vapor) as refrigerants, but was unsuccessful due to impeller design and seal problems. The paper describes analyses of hydraulic compression by Dr. Willis H. Carrier in 1916, which led to investigation of the centrifugal compression concept using R-1130 ("dielene"). It reviews subsequent development efforts by Carrier and others, and tabulates the refrigerants used. They included R-1120 ("trielene"), R-717 (ammonia), R-30 (methylene chloride), R-160B1 (ethyl bromide), R-160 (ethyl chloride), R-718 (water vapor), R-11, R-12, and R-113. The article discusses design problems with early machines and development of improved heat transfer surfaces, including "Lo-Fin" tubing by Carrier and Wolverine. It notes that the impetus for centrifugal refrigeration grew out of inadequacies of the primary alternatives, namely ammonia compression and absorption, which were deemed hazardous, and carbon dioxide compression, deemed inefficient and expensive. The article also provides a perspective of the refrigeration industry during the war years, noting a total installed capacity of centrifugal refrigeration of approximately 1 GW (300,000 tons) worldwide. It cites such interesting applications as cooling "blackout" plants and air conditioning blast furnaces, the latter to increase steel production.

E. S. Ross, **Mineral Lubricating Oils**, *Refrigerating Engineering*, 42:27 ff, 1942, and 50:129 ff, 1945 (rdb6675)

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G. H. Wagner, G. C. Bailey, and W. G. Eversole, **Determining Liquid and Vapor Densities in**

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Closed Systems, *Industrial and Engineering Chemistry*, 14(2):129-131, 1942 (3 pages, RDB4288)

D. W. Osborne, C. S. Garner, R. N. Doescher, and D. M. Yost, **The Heat Capacity, Entropy, Heats of Fusion and Vaporization, and Vapor Pressure of Fluorotrichloromethane**, *Journal of the American Chemical Society*, 63:3496-3499, 1941 (4 pages, rdb7A63)

R-11, thermodynamic properties, thermophysical data

L. Riedel**, Bestimmung der thermischen und kalorischen Eigenschaften von Difluormonochloräthan** [Determination of the Thermal and Caloric Properties of Chlorodifluoroethane], *Zeitschrift für die gesamte Kälte Industrie* [Journal of the Combined Refrigeration Industry], Germany, 48(7):105-107, 1941 (3 pages in German, rdb7C42)

R-142b (possibly also R-142 and/or R-142a), vapor pressure, density, thermodynamic properties, thermophysical data

Trump, Safford, and Cloud, **DC Breakdown Strength of Air and of Freon in a Uniform Field at High Pressures**, *Transactions*, American Institute of Electrical Engineers (AIEE), 60:, 1941 (rdb6623)

dielectric strength of refrigerants

1931-1940

R. E. Dufour and A. J. Perkins**, The Comparative Life, Fire, and Explosion Hazards of Tetrafluoromonochloroethane ('Freon-124')**, Miscellaneous Hazard Report 3135, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 23 October 1940 (22 pages with 7 tables, RDB5176)

R-124, toxicity, flammability, stability

R. E. Dufour and A. J. Perkins, **The Comparative Life, Fire, and Explosion Hazards of Difluoromonochloromethane ('Freon-22')**, Miscellaneous Hazard Report 3134, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 26 September 1940 (22 pages with 7 tables, RDB5175)

R-22, toxicity, flammability, stability

A. F. Benning and R. C. McHarness, **Thermodynamic Properties of Fluorochloromethanes and -Ethanes**, *Industrial and Engineering Chemistry*, 32:976 ff, July 1940 (rdb7A64)

R-21, R-113, and others: thermodynamic properties, thermophysical data

A. F. Benning and R. C. McHarness, **Thermodynamic Properties of Fluorochloromethanes and -Ethanes. Orthobaric Densities and Critical Constants of Three Fluorochloromethanes and Trifluorotrichloroethane**, *Industrial and Engineering Chemistry*, 32:814-816, June 1940 (3 pages, rdb7A65)

R-11, R-21, R-22, and R-113 (trichlorotrifluoroethane): thermodynamic properties, thermophysical data

F. Benning and R. C. McHarness, **Thermodynamic Properties of Fluorochloromethanes and -Ethanes**, *Industrial and Engineering Chemistry*, 32:698 ff, May 1940 (rdb7A66)

R-21, R-113, and others: thermodynamic properties, thermophysical data

M. Benedict, G. B. Webb, and L. C. Rubin, **An Empirical Equation for Thermodynamic Properties of Light Hydrocarbons and their Mixtures, I: Methane, Ethane, Propane, n-Butane**, *Journal of Chemical Physics*, 8(4):334-345, April 1940 (12 pages, rdb2350)

thermodynamic properties of R-50, R-170, R-290, and R-600; BWR equation of state (EOS), thermophysical data

A. F. Benning and R. C. McHarness, **Thermodynamic Properties of Fluorochloromethanes and -Ethanes: Vapor Pressure of Three Fluorochloromethanes and Trifluorotrichloroethane**, *Industrial and Engineering Chemistry*, 32:497-499, April 1940 (3 pages, rdb7A67)

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J. S. Kazarnowsky, **Die Kompressibilität von Ammoniak bet hohen Temperaturen und hohen Drücken** [The Compressibility of Ammonia at High Temperatures and High Pressures], *Acta. Phys. Chim. URSS*, 12:513-521, 1940 (9 pages, RDB9307)

thermodynamic properties of R-717 (ammonia); thermophysical data

A. F. Benning and W. M. Markwood, Jr., **The Viscosities of 'Freon' Refrigerants**, *Refrigerating Engineering*, 38(4):243 ff [possibly 37(4)], April 1939 (rdb7717)

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F. Musgrave, **Oils for Domestic and Commercial Refrigeration**, *Refrigeration and Air Conditioning*, 5(9):19 ff , 1939 (rdb6674)

O. C. Rutledge (General Electric Company), **Viscosity of Oils Diluted with Refrigerants**, presented at 33rd Annual Meeting of the American Society of Refrigerating Engineers (ASRE, New York, NY, 25 January 1938); republished in *Refrigerating Engineering*, 31-36, January 1938 (6 pages with 10 figures and 5 tables, RDB4281)

R-12, R-611 (methyl formate), and R-764 (sulfur dioxide) viscosity dilution of mineral oils, viscometer

R. M. Fuoss, **Dielectric Constants of Some Fluorine Compounds**, *Journal of the American Chemical Society*, 1633 ff, 1938 (rdb7A06)

R-11, R-12, R-13, R-14, R-22, R-114, R-116, R-133a, R-142b, and R-143a: dielectric constant as reported in RDB7A01

B. H. Jennings and F. P. Shannon, **The Thermodynamics of Absorption Refrigeration**, *Refrigerating Engineering*, 35(5):333 ff, 1938 (rdb3230)

L. Riedel, **Bestimmung der thermischen Eigenschaften von Trifluortrichloräthan** [Determination of the Thermal Properties of Trichlorotrifluoroethane], *Zeitschrift für die gesamte Kälte Industrie* [Journal of the Combined Refrigeration Industry], Germany, 45:221-225, 1938 (5 pages in German, rdb7C43)

R-113 (possibly also R-113a): vapor pressure, density, thermodynamic properties, thermophysical data

M. Benedict, **Pressure, Volume, and Temperature Properties of Nitrogen at High Density, I and II**, *Journal of the American Chemists Society*, 59(11):224 ff, November 1937 (rdb7A23)

R-728 (nitrogen), equation of state (EOS), thermodynamic data, thermophysical data

W. O. Walker and K. S. Willson (Ansul Chemical Company), **The Action of Methyl Chloride on Aluminum**, *Refrigerating Engineering*, 89, 90, 126 ff, August 1937 (rdb6632)

R-40, compatibility, reactivity

T. Midgley, Jr. (Ethyl Gasoline Corporation and Kinetic Chemicals, Incorporated), **From the Periodic Table to Production**, *Industrial and Engineering Chemistry*, 29(2):239-244, February 1937 (6 pages with 5 figures, RDB2438)

personal account of the discovery of organic fluorides (fluorocarbons) as refrigerants; acknowledges the roles of A. L. Henne and C. F. Kettering in the research; recounts the use of a periodic table of the elements, to identify those suitable, and the resultant eight that led to discovery fluorochemical refrigerants; describes the synthesis of the first fluorochemical, R-21, from antimony trifluoride; also describes the initial toxicity test and fortuitous outcome, based on chance use of the only uncontaminated sample of antimony trifluoride from the five bottles obtained; includes an address by R. E. Wilson for award of the Perkins Medal of the Society of Chemical Industry to T. Midgley; this address recalls some of Midgley's background [Wilson proposed the novel arrangement of the periodic table used by Midgley and his colleagues]

E. E. Charlton and F. S. Cooper**, Dielectric Strength of Insulating Fluids**, *General Electric Review*, General Electric Company, 865(9):438 ff, 1937 (rdb7A04)

R-11, R-12, R-13, R-14, R-22, R-113, R-114, R-717 (ammonia), R-744 (carbon dioxide), and R-1150 (ethene): relative dielectric strength as reported in RDB7A01

A. L. Henne (Ohio State University), **Fluorinated Derivatives of Methane**, *Journal of the American Chemical Society*, 59:1400-1401, 1937 (2 pages with 1 table, RDB5779)

revised boiling points and synthesis yields for R-21, R-22, R-31, and R-32; toxicity tests for R-21 and R-31 show that they cannot be tolerated by guinea pigs for long periods in concentrations "greater than a few percent" and are "inferior anesthetic agents"; R-22 and R-32 yield no toxic effect in guinea pigs following inhalation of 200,000 ppm v/v in air "for hours" and have no anesthetic effect

A. Perlick, **Calorimetric Investigations on Dichloromethane, Difluoromonochloroethane, and Tetrafluorodichloroethane**, annex to the *Bulletin of the International Institute of Refrigeration*, (1):, 1937 (rdb7C46)

R-30, R-142b (possibly R-142 or R-142a), and R-114 (possibly R-114a), thermodynamic properties, thermophysical data

A. L. Henne and D. M. Hubbard (Ohio State University), **Fluorochloroethanes and Fluorochloroethylenes. III**, *Journal of the American Chemical Society*, 58:404-406, March 1936 (3 pages with 3 figures and 3 tables, RDB7803)

synthesis and properties of R-130a, R-131a, R-132b, R-140, R-140a, R-150a

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preferential course of fluorination during synthesis with one hydrogen atom present, properties of R-121, R-121B2, R-121a, R-122, R-122a, R-122b,

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R-122B2, R-123a, R-124, R-1121a, R-1122a [note: R-123 is conspicuously omitted from the progression]

R. I. Thompson, **Thompson Warns of Dangers and Problems in Attempts to Change Refrigerants**, *Electric Refrigeration News*, 23 October 1935 (rdb6672)

R-12, compatibility

R. E. Dufour, **The Comparative Life, Fire, and Explosion Hazards of Dichloromonofluoromethane (F21)**, Miscellaneous Hazard Report 2630, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 15 January 1935 (22 pages with 7 tables, RDB5173)

R-21, toxicity, flammability, stability

R. I. Thompson, **The Chemical Activity of Freon-12**, *Refrigerating Engineering*, 29:139 ff, 1935 (rdb-6673)

R-12, compatibility

J. K. L. Webling, **Refrigerating Practice with Reference to Lubricants**, *Refrigerating Engineering*, October 1934 (rdb3738)

refrigerant lubricants, oils

F. S. Stevens, **Oil with Common Refrigerants**, *Refrigerating Engineering*, September 1934 (rdb-3737)

L. S. Philipp and B. E. Tiffany, **Thermodynamics of Sulfur-Dioxide-Oil Systems**, *Refrigerating Engineering*, 27:248 ff, May 1934 (rdb3736)

R-764 (sulfur dioxide), thermodynamic properties, thermophysical data

A. A. Durrant, T. G. Pearson, P. L. Robinson, **Physical Relationships Amongst the Hydrides of Elements of the Fifth Group with Special Reference to Association in these Compounds**, *Journal of the American Chemical Society*, (1):730-735, 1934 (6 pages, rdb7606)

R-717 (ammonia), surface tension, transport properties, thermophysical data

E. G. Locke, W. R. Brode, and A. L. Henne (Ohio State University), **Fluorochloroethanes and Fluorochloroethylenes**, *Journal of the American Chemical Society*, 56:1726-1728, 1934 (3 pages with 4 tables, RDB7801)

synthesis, purification, properties, differences in boiling points, and molecular refractions for R-111, R-111B2, R-112, R-112B2, R-112a, R-112aB2, R-113, R-113B2, R-113a, R-114, R-114B2, R-114a, R-115, R-116, R-1111, R-1112, R-1112-cis, R-1112-trans, R-1113, and R-1114

A. H. Nuckolls, **The Comparative Life, Fire, and Explosion Hazards of Common Refrigerants**, Miscellaneous Hazard Report Number 2375, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 13 November 1933 (134 pages with 20 figures and 29 tables, RDB4B64)

This report presents a detailed examination of the comparative safety of then common refrigerants. They included R-11, R-12, R-30, R-40, R-40B1, R-114, R-160, R-160B1, R-170 (ethane), R-290 (propane), R-600 (butane), R-611 (methyl formate), R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), and R-1130. Data also are provided for R-10 (carbon tetrachloride), R-20 (chloroform), gasoline, and "illuminating gas" for comparison. The report discusses the nature of "life," fire, and explosion hazards and outlines salient concerns for investigation. It then describes the samples tested and documents tests and findings for identification, toxicity before decomposition, toxicity of decomposition products, analytical identification of decomposition products, ignition temperature, limits of flammability, explosion pressure and kinetics, and flame propagation. A summary presents the comparative health hazards, health hazards in the presence of flames, health hazards in the presence of surfaces at high temperatures, and fire and explosion hazards. Interspersed tables and plots illustrate the findings. A summary table recaps the toxicity, fire, explosion, and other hazards of the substances investigated. It includes safety classifications based on a relative scale of toxicity.

F. Hovorka and F. E. Geiger, **Thermodynamic Properties of Trifluorotrichloroethane and Difluorotetrachloroethane**, *Journal of the American Chemical Society*, 55:4759-4761, 1933 (3 pages, rdb7C47)

R-112, R-112a, R-113, R-113a, vapor pressure, density, thermophysical data

V. M. Menzel and F. Mohry, **Die Dampfdrucke des CF_4 and NF_3** [Vapor Pressures of CF_4 and NF_3], *Zeitschrift für Anorg. Allgem. Chem.*, 210:257-263, 1933 (7 pages, rdb7B21)

thermodynamic properties of R-14 and R-771; thermophysical data

N. Thornton, A. B. Burg, and H. I. Schlesinger, **The Behavior of Dichlorodifluoromethane and of Chlorotrifluoromethane in the Electric Discharge**, *Journal of the American Chemical Society*, 55:3177-3182, 1933 (6 pages, rdb6645)

R-12, R-13

E. R. Epperson and H. L. Dunlap, **Relationship Between Mole Fractions and Absolute Viscosi-**

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H. S. Booth and E. M. Bixby, **Fluorine Derivatives of Chloroform**, *Industrial and Engineering Chemistry*, 24(6):637-641, June 1932 (5 pages, rdb5137)

R-20, R-21, R-22, R-23, anesthesia, physiological effect, toxicity: R-21 ALC = 200,000 ppm (duration and species not indicated) and R-22 ALC = 490,000 ppm as reported in RDB5147

W. S. Calcott and R. A. Kehve, **Tests to Show Toxic, Irritant, and Fire Characteristics of Certain Well Known Refrigerants**, Kinetic Chemicals Incorporated, December 1931 (rdb6670)

safety, flammability, toxicity

Bichowski and W. K. Gilkey (Kinetic Chemicals Incorporated), **The Thermodynamic Properties of Dichlorodifluoromethane, A New Refrigerant, III,** *Industrial and Engineering Chemistry*, 23:366 ff, 1931 (rdb8229)

thermodynamic properties of R-12: liquid density; thermophysical data

R. M. Buffington and H. M. Fellows, **The Stability and Corrosive Properties of Freon-12**, technical paper 5, Kinetic Chemicals Incorporated, 1931 (rdb6669)

R-12, compatibility

R. M. Buffington and Fleischer (Kinetic Chemicals Incorporated), **The Thermodynamic Properties of Dichlorodifluoromethane, A New Refrigerant, IV**, *Industrial and Engineering Chemistry*, circa 1931 (rdb8232)

thermodynamic properties of R-12: specific heat of the vapor at atmospheric pressure; thermophysical data

R. M. Buffington and W. K. Gilkey (Kinetic Chemicals Incorporated), **Thermodynamic Properties of Dichlorodifluoromethane (F-12)**, circular 12, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, 1931 (12 pages with 2 tables, RDB8230)

thermodynamic properties of R-12: pressure, volume, density, enthalpy, and entropy as functions of temperature for saturated and superheated vapor; equation of state (EOS) and ancillary equations for the latent heat of vaporization, heat capacity, and entropy; thermophysical data

R. M. Buffington and W. K. Gilkey (Kinetic Chemicals Incorporated), **The Thermodynamic Properties of Dichlorodifluoromethane, A New Refrigerant, I**, *Industrial and Engineering Chemistry*, 23:254 ff, 1931 (rdb8231)

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W. K. Gilkey, Gerard, and Bixler (Kinetic Chemicals Incorporated), **The Thermodynamic Properties of Dichlorodifluoromethane, A New Refrigerant, II**, *Industrial and Engineering Chemistry*, 23:364-365, 1931 (2 pages, rdb8233)

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F. G. Keyes, **The Pressure-Volume-Temperature Values for Ammonia to 1000 Atmospheres from 30 to 200 °C**, *Journal of the American Chemical Society*, 53:965-967, 1931 (3 pages, rdb9705)

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Dittus-Boelter equation for heat transfer coefficients

T. Midgley, Jr., and A. L. Henne (Frigidaire Corporation, Division of General Motors Corporation), **Organic Fluorides as Refrigerants**, *Industrial and Engineering Chemistry*, 22(5):542-545, May 1930 (4 pages with 3 figures and 2 tables, RDB2439)

landmark publication on the introduction of fluorochemical refrigerants: announces discovery of "fluoro-halo derivatives of aliphatic hydrocarbons;" identifies the essential properties of a refrigerant as being stable and noncorrosive, having suitable vapor-pressure characteristics, and - for certain uses - being nontoxic and nonflammable; provides a tabular, qualitative comparison for these properties for R-40 (methyl chloride), R-40B1 (methyl bromide), R-600 (butane) R-717 (ammonia), R-718 (water), R-729 (air), R-744 (carbon dioxide), and R-764 (sulfur dioxide); presents physical and toxicity data for R-12; provides a tabular comparison of the acute toxicity of R-12, R-40, R-717, and R-744;

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shows how selective chlorination and fluorination of hydrocarbons can be applied to obtain desired boiling points with some influence on flammability and toxicity; reviews and illustrates the a batch, Swarts process for manufacture of R-12

Chemists Discover New Refrigerant, *Ice and Refrigeration*, Nickerson and Collins Company, Chicago, IL, 78(4):369, April 1930 (1 page with no figures or tables, RDB3520)

possibly the first report of fluorochemical refrigerants - described as "aliphatic compounds containing fluorine and chlorine" - to the refrigeration industry; its discovery is predicted to "bring about a vast improvement in the world's environment" and described as "an outstanding event in the development of automatic refrigeration"; the "as yet unnamed" refrigerant [R-12] is described as "not-toxic, non-inflammable, and it was said, has very desirable engineering characteristics"; the report notes that "this class of the fluor-chloro-methanes will replace all present refrigerants, chief among which at present are ammonia and sulphur dioxide"; describes investigations of toxicity at the University of Cincinnati and U.S. Bureau of Mines; projects commercial manufacture in two years; cites potential uses in air conditioning, mining, and submarines; notes acknowledgement by the discovers, Thomas Midgley, Jr., and A. L. Henne of the Frigidaire Corporation of General Motors, of the contribution of Frederic Swarts of the University of Ghent, "whose pioneering work on fluorine derivatives forms the basis from which the present production methods have been derived"

J. A. Beattie and C. K. Lawrence, **Some of the Thermodynamic Properties of Ammonia. I. The Compressibility of and an Equation of State for Gaseous Ammonia**, *Journal of the American Chemical Society*, 52:6-14, 1930 (9 pages, rdb9306)

thermodynamic properties of R-717; equation of state (EOS); thermophysical data

C. C. Coffin and O. Maass, **The Preparation and Physical Properties of Alpha-, Beta- and Gamma-Butylene and Normal and Isobutane**, *Journal of the American Chemical Society*, 50:1427-1437, 1928 (11 pages, rdb7952)

R-600 (n-butane) and R-600a (isobutane), thermodynamic and transport properties, thermophysical data

H. Inokuty, **Graphical Method of Finding Compression Pressure of CO_2 Refrigerating Machines for Maximum Coefficient of Performance**, *Proceedings of the 5th International Congress of Refrigeration (*Rome, Italy, 9-15 April 1928), International Institute of Refrigeration (IIR), Paris, France, III:185-192, 1928 (8 pages, rdb8336)

method to determine the high-side pressure to optimize efficiency in transcritical cycles for R-744 (carbon dioxide use): pressure in the gas cooler is determined by the refrigerant charge rather than the condensing temperature

H. Inokuty, **Optimum Operating Conditions for Carbon Dioxide**, *Refrigerating Engineering*, 16(4):-122-123, 1928 (2 pages, rdb8337)

method to determine the high-side pressure to optimize efficiency in transcritical cycles for R-744 (carbon dioxide use): pressure in the gas cooler is determined by the refrigerant charge rather than the condensing temperature

F. Lehmann, **Über Konstitution und Wirkung: Untersuchungen an aromatischen Fluorverbindungen**, *Archiv für Experimentelle Pathologie und Pharmakologie*, 130:250 ff, 1928 (rdb6167)

pharmacological action and influence of the trifluoromethyl group, narcotic properties, toxicity

J. C. Goosman, **The Progressive Development of Carbon Dioxide Refrigerating Methods**, *Refrigerating Engineering*, 14(6):188-189, 1927 (2 pages, rdb6925)

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W. H. Carrier (Carrier Corporation, then Carrier Engineering Corporation), **Centrifugal Compression as Applied to Refrigerants**, *Refrigerating Engineering*, February 1926 (rdb4146)

P. Le Beau and A. Damiens, **Chimie Minérale sur le Tetrafluorure de Carbone** [Inorganic Chemistry of Carbon Tetrafluoride], *Compte Rendu* [Proceedings], 182:1340 ff, 1926 (rdb3247)

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J. C. Goosman, **History of Refrigeration - Part 3**, *Ice and Refrigeration*, 68:413-414, May 1925 (3 pages, rdb2118)

J. C. Goosman, **History of Refrigeration - Part 2**, *Ice and Refrigeration*, 68:335-336, April 1925 (2 pages, rdb2117)

J. C. Goosman, **History of Refrigeration - Part 1**, *Ice and Refrigeration*, 67:428-430, December 1924 (3 pages, rdb2116)

W. H. Carrier and R. W. Waterfill (Carrier Corporation, then Carrier Engineering Corporation), **Comparison of Thermodynamic Characteristics**

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F. Haber, **Zur Gesichte des Gaskrieges**, *Fünf Vorträge aus den Jahren 1920-1923* [Five Discourses from the Years 1920-1923], Springer-Verlag, Berlin, Germany, 75-92, 1924 (18 pages, rdb6306)

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C. S. Cragoe, E. C. McKelvy, and G. F. O'Connor, **Specific Volume of Saturated Ammonia Vapor**, *Scientific Papers of the National Bureau of Standards*, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), 18:707-735, 1922 (29 pages, rdb9703)

thermodynamic properties of R-717, thermophysical data

A. G. White, **Limits for the Propagation of Flame at Various Temperatures in Mixtures of Ammonia with Air and Oxygen**, *Journal of the American Chemical Society*, (121):1688-1695, 1922 (7 pages, rdb6357)

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C. S. Cragoe and D. R. Harper III, **Specific Volume of Liquid Ammonia** *Scientific Papers of the National Bureau of Standards*, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), 17:287-315, 1921 (29 pages, rdb9704)

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O. Maass and C. H. Wright, **Some Physical Properties of Hydrocarbons Containing Two and Three Carbon Atoms**, *Journal of the American Chemical Society*, 43:1098-1111, 1921 (14 pages, rdb7954)

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S. Young, **The Vapour Pressures, Specific Volumes, Heats of Vaporization, and Critical Constants of Thirty Pure Substances**, *Scientific Proceedings of the Royal Dublin Society*, New Series 12, Dublin, Ireland, 374-443, 1909-1910 (70 pages, rdb4933)

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H. Lorenz, **Die Ausnutzung der Brennstoffe in den Kühlmaschinen** [The Utilization of Combustible Substances in Refrigeration Machines], *Zeitschrift für die gesamte Kälte Industrie* [Journal of the Combined Refrigeration Industry], Germany, 1:10-15, 1894 (6 pages in German, rdb4870)

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R-744, R-764, R-744/764, zeotropic blends; possibly the first patent for use of refrigerant mixtures

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