DOE/CE/23810-42G
NMERI OC 94/31

METHODS DEVELOPMENT FOR MEASURING AND CLASSIFYING FLAMMABILITY/COMBUSTIBILITY OF REFRIGERANTS

Interim Report
TASK 1 - ANNOTATED BIBLIOGRAPHY AND SUMMARY

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June 1994

Prepared for
The Air-Conditioning and Refrigeration Technology Institute
Under
ARTI MCLR Project Number 660-52400

This program is supported, in part, by U.S. Department of Energy (Office of Building Technology) grant number DE-FG02-91CE23810: Materials Compatibility and Lubricants Research (MCLR) on CFC-Refrigerant Substitutes. Federal funding supporting this program constitutes 93.67% of allowable costs. Funding from non-government sources supporting this program consists of direct cost sharing of 6.33% of allowable costs, and significant in-kind contributions from the air-conditioning and refrigeration industry.

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PREFACE

This report was prepared by the Center for Global Environmental Technologies (CGET), the New Mexico Engineering Research Institute (NMERI), The University of New Mexico, Albuquerque, New Mexico 87131-1376 under Contract 660-52400 for the Air-Conditioning and Refrigeration Technology Institute (ARTI), 4301 N. Fairfax Drive, Suite 425, Arlington, VA 22203.

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ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
ARI	Air-Conditioning and Refrigeration Institute
ARTI	Air-Conditioning and Refrigeration Technology Institute, Inc.
ASTM	American Society for Testing and Materials
CA	Chemical Abstracts
CAS	Chemical Abstract Service
CFC	Chlorofluorocarbon
CFR	Critical Flammability Ratio
DC	Direct Current
IR	Infrared
LFL	Lower Flammability Limit
MIE	Minimum Ignition Energy
NMERI	New Mexico Engineering Research Institute
NTIS	National Technical Information Service
PC	Personal Computer
UFL	Upper Flammability Limit
UV	Ultraviolet
VAC	Volts AC

1.0 DATABASE AND LITERATURE SEARCH

For Task 1 of the flammable refrigerant methods development contract, NMERI performed a literature search to identify references on the flammability of refrigerants. A database to store a bibliographic record of the literature search was then developed . This database is contained in the Microsoft Access® relational database management system for Windows™. Searches for applicable sources were made on-line using the STN® scientific and technical network; off-line using the National Technical Information Service (NTIS) database; WorldCat CD-rom database; the University of New Mexico library search; the Air-Conditioning and Refrigeration Institute (ARI) Refrigerant Database; and personal contacts. Three specific areas were searched: refrigerant properties, flammability test methods, and ignition technology. Many of the articles retrieved fall into multiple categories. Ignition technology was included as a separate category because of the importance of the ignition process to flammability and the vast amount of information available on ignition of gaseous fuels, especially hydrocarbons. It is believed that much of this data is applicable to ignition of the flammable refrigerants and will assist in selecting a repeatable and representative ignition source for Task 3 testing.

1.1 Database

The REFLIBRY (Refrigeration Library) database contains the table, forms, reports, and supporting software to allow data entry, modification, search, and report generation for all literature sources collected for this task. Two tables are included in this database–*APT Library* and *Publisher's Addresses* (Note: all table, form, and report names are italicized for ease of reference). *APT Library* consists of all data for the references, while the *Publisher's Address* form contains complete address information on the journal, book, or other source publisher. Appendix A describes the organization and operation of the database in detail.

1.2. Literature Search

Both on-line and off-line literature searches were made using personnel and facilities at The University of New Mexico Centennial Engineering and Science Library. Key words, which could be contained in the title, abstract, or the body of the document, were used for the search.

1.2.1. On-line Literature Searches

A preliminary "411" search identified the databases containing the most key word references in the STN information system for “flammabl?, combust?, or ignition” combined with “refrigerant?” with the ? representing additional letters on the end of each term. Many of the databases with the highest number of “hits” (matches) were either patent or business files that did not prove to be useful. The following on-line databases were searched:

a. CA (Chemical Abstracts)
b. Ei Compendex Plus (engineering)
c. Pascal (French engineering and science)
d. Energy SciTec (energy database)
e. Aerospace Database
f. Current Contents
g. Energyline(R)
h. Scisearch(R) (citations)

In general, only English-language articles with abstracts were searched, although several German, Japanese, and Russian language articles have been included in the annotated database. Copies of the weekly *Chemical Abstracts* published since the update of the CA database have also been searched to ensure that all recent articles relevant to this contract are included in the database; this process will continue to the end of the contract.

Key words included the individual refrigerants, referred by Chemical Abstract Service (CAS) registry number^{SM} in the Chemical Abstracts database and by refrigerant number elsewhere, and combinations of combustion, flammability, and ignition. Addition of specialized terms such as temperature, humidity, and pressure did not increase the number of hits or limit the number of documents, and searches for individual ASTM test methods did not result in any hits. A copy of all on-line data searches will be maintained with the program documentation.

As an example of the scope of the on-line search, the 11 million records of the Chemical Abstracts database were the first searched. Only 46 met the criteria of flammability or combustibility or ignition plus refrigerant. All 46 references were examined, but none were judged to be useful to this program.

1.2.2. Off-line Literature Searches

Several off-line databases residing on CD-roms or accessible from NMERI personal computers (PC) were also searched. Several databases did not include abstracts, thus limiting their usefulness. The following databases were searched:

a. Applied Science and Technology, 1983-present: 200 English language engineering journals.
b. General Science Index: Approximately 75 general science publications.
c. NTIS Bibliographic Database, 1990-1994: U.S. Government reports.
d. WorldCat: Millions of books, journals, magazines, plus other formats.
e. ARTI Refrigerant Database (resident on NMERI PC).
f. UNM Library Database (searched from NMERI PC through Telnet).

In addition to the direct literature searches, all applicable references cited in articles were examined. Experts in the refrigeration and flammability areas were personally contacted either by phone or at the May 1994 NMERI Halon Options Technical Working Conference at Albuquerque to gain their experience. Several additional contacts were obtained and additional references provided. We believe, based on the depth and breadth of the literature search and the comments of those experts contacted, that we have collected the majority of the available literature on flammable refrigerants and refrigerant test methods, as well as a representative sampling of flammability test methods and ignition technology. Some articles have been ordered and will be received shortly, and the process of identifying additional references will continue throughout the life of the contract. We have also obtained entries on chlorofluorocarbon (CFC) replacements from a database sponsored by the International Institute of Refrigeration.

1.3. Literature Search Results

Over 90 separate references have been entered into the database. Two separate report formats have been developed to display the results of the literature search. Appendix B is the short report format–without abstract, while Appendix C is the long format–with abstract.

2.0 SUMMARY OF LITERATURE SEARCH

Few of the documents in the bibliography directly concern the flammability of refrigerants. Many deal with investigations of flammability limits and test techniques used to determine these limits, while others are concerned primarily with the ignition of flammable materials by different types of sources, primarily electric sparks. All references in this section are footnoted, with a notation correlating the reference to the entry number in the REFLIBRY database.

2.1. Flammability Parameters

The following section discusses the nature of flammability and lists parameters to be investigated during the test phase of this project. There is still significant disagreement over what determines the flammability limit. For example, B. Lewis' comment to Gerstein and Stine's paper on analytic criteria for flammability limits[1], in which Lewis states that the true criterion for flammability limits is perturbations caused by flame stretch rather than energy loss from the incipient flame, illustrates some of the fundamental differences among researchers in this area. In reality, most of this debate in not critical to the work to be done in this program, but it should be kept in mind as techniques are developed.

Not all combustible mixtures are considered flammable, and one of the difficulties in determining flammability is the definition of what constitutes flammability. According to Zabetakis,

> A combustible gas-air mixture can be burned over a wide range of concentrations - when either subjected to elevated temperatures or exposed to a catalytic surface at ordinary temperatures. However, homogeneous combustible gas-air mixtures are flammable, that is, they can propagate flame freely within a limited range of compositions.[2]

We will use this definition for flammability, namely, that flames propagate freely through the gas-air mixture. The most dilute mixture that is flammable is known as the lower flammability limit (LFL) or lower limit, and the most concentrated mixture is known as the upper flammability limit (UFL) or upper limit. The paramount concept is that flame must propagate for the material to be flammable, and, with that in mind, we have borrowed liberally from the large body of combustion data.

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1. Gerstein, M., and Stine, W.B., Analytic Criteria for Flammability Limits, The Fourteenth Symposium (International) on Combustion, pages 1109-1118, The Combustion Institute, Pittsburgh, PA 15213, 1973. (Reference 90) (Note: Reference numbers refer to the NMERI/ARTI Flammable Refrigerants Database.)

2. Zabetakis, Michael G., Flammability Characteristics of Combustible Gases and Vapors, Bureau of Mines Report of Investigation 627, page 2, Bureau of Mines, Pittsburgh, PA, 1965. (Reference 15)

A second difficulty is the definition of the flammability limits themselves. Some researchers consider the LFL a unique fundamental material property[3] while others consider that there "is no convincing evidence for the existence of fundamental limits of inflammability, although theory suggests that there probably are such limits."[4] It is known that flames which can propagate upward may not always propagate downward, and that "carefully nurtured flames can be maintained well outside conventional limits"[5] using flat-flame burners. Pressure, temperature, catalytic effects, and other external factors influence flammability limits. One goal of this program is the development of a test technique that will determine realistic limits to reflect accurately the "true" flammability of refrigerants. One possible definition of "true" limits is that the limits should reflect the behavior of the flammable mixture in the environment in which the refrigerant is used.

Only recently have flammable refrigerants and blends containing flammable refrigerants started once again to be considered for use as refrigerants. Therefore, the amount of recent data available on flammable refrigerants, while becoming more available, is nonetheless somewhat limited. More data are available on the flammability of combustible gases, but the subject is almost always hydrocarbon fuels. Even more information is available on the ignition and propagation of flames through combustible mixtures. Therefore, the flammable refrigerant will be considered to have flammability properties similar to those of a hydrocarbon fuel, and other refrigerants in the mixture will be considered to be diluents or inertants. This concept will allow the application of vast amounts of combustion theory to the problem.

Combustion, and therefore flammability, generally cannot occur without the four legs of the fire tetrahedron–fuel, oxygen, heat, and sufficient free radicals to sustain the reaction. Unless sufficient fuel is available (at the LFL) or sufficient oxygen is available (at the UFL), the mixture is non-flammable. Unless the temperature reaches the ignition temperature, and heat is conveyed to the next layer of unburned gas, the mixture is non-flammable. And unless an adequate number of free radicals is available to sustain the reaction, the mixture is also non-flammable.

Gaseous fuels can burn in one of two ways. Fuel and air may be intimately mixed prior to burning (pre-mixed flames) or they may be initially separated and burned in the zone where they mix (diffusion flames).[6] While flammable refrigerants may burn under either condition, most testing uses a pre-mixed flame rather than the diffusion flame (flowing, constant pressure systems are the exception). In reality, a realistic scenario for a flammable refrigerant could be an unconfined vapor cloud, which is not truly representative of either type of testing. For the purpose of this test program, only pre-mixed flames will be investigated due to the general acceptance of flammability results based on this type of testing.

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3. Grossshandler, William, ARI Flammability Workshop , March 8-9, 1994, Chicago Illinois, Air Conditioning and Refrigeration Institute, Arlington, VA 22203, 1994. (Reference 27)

4. Linnett, J.W., and Simpson, J.S.M., Limits of Inflammability, Sixth Symposium (International) on Combustion, page 25, Reinhold Publishing Corporation, New York, NY, 1957. (Reference 44)

5. Lewis, B., and Von Elbe, G, Combustion, Flames, and Explosion of Gases, 3rd Ed., page 326, Academic Press, Inc., Orlando, FL 32887, 1987. (Reference 57)

6. Drysdale, D., An Introduction to Fire Dynamics, page 13, John Wiley and Sons, Chichester, UK, 1985. (Reference 80)

Visual indications are only one of many indications that may be used to verify flammability. It may not be the most reliable method due to reactions at low temperatures that may produce cool flames or low-temperature explosions that, while producing luminosity, do not propagate on their own and thus do not meet the definition of flammability. Other indications of flammability that could potentially prove to be more reliable include the following:

a. Temperature rise. Does the ignition source raise the temperature above the limiting flame temperature of the mixture, which is required to sustain combustion?

b. Light. Are there non-visual methods–infrared or ultraviolet (IR or UV)–that can be more reliable and repeatable than visual?

c. Pressure rise. Both the magnitude of the pressure rise and the rate of the rise can be indicators of flammability.

d. Presence of radicals. It is known that combustion cannot occur without the presence of an adequate number of free radicals to sustain the reaction.

e. Presence of combustion products. Combustion can be indicated by the ratio of certain combustion products in the mixture.

f. Heat of Reaction. Combustion can be indicated by the presence of a heat rise detected in bomb calorimetry.

g. Flame Velocity. Combustion waves travel with a specific flame velocity that can be measured and analyzed to determine combustion.

h. Electrical properties. Electrical conductivity, ionization potential, dipole moments, and other electrical properties of the mixture may change after combustion.

Conceivably, each of these techniques could result in different limits of flammability depending upon the criteria. It is the purpose of this test program to propose and assess one or more reliable and repeatable test techniques to determine the flammability of refrigerants and refrigerant blends. Any experimental method should minimize the following quantities:[7]

a. Natural convection

b. Conductive/convection losses to walls

c. Radiative losses to walls

d. Selective diffusional demixing

e. Non-linear flow gradients (flame stretch)

Many parameters affect flammability and must be considered in the design and analysis of test methodology. Each of the following factors could affect the flammability limits:

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7. Hertzberg, M., The Theory of Flammability Limits - Natural Convection, Bureau of Mines Report of Investigations 8127, page 1, Bureau of Mines, Pittsburgh, PA, 1976. (Reference 68)

a. Ignition source

b. Temperature of the mixture

c. Pressure of the mixture

d. Humidity of the air

e. Size and shape of the test vessel

f. Test vessel materials

g. Turbulence in the test vessel

h. Concentration of the components of the mixture

i. Reactivity of the components

j. Mixing of the components

k. Altitude of testing (may be a function of other factors such as pressure and air composition)

Each parameter will be discussed below.

2.1.1. Ignition Source

The ignition source may be the most critical parameter in determining repeatable flammability limits. Richard and Shankland[8] found differences of up to 12% in the LFL for R-32 when ignited with copper wire as compared to a match, and much greater differences have been found for more marginally flammable refrigerants such as R-141b. Except for autoignition, in which the temperature of the flammable gas is raised uniformly above the temperature required for ignition, most ignitions occur when a highly concentrated, but relatively small, region of high temperature raises the surrounding volume of flammable gas above its ignition temperature. If this reaction raises the temperature of the next layer of gas above its ignition temperature, the reaction continues and propagation of the flame occurs. If the next layer of gas is not ignited, the propagation is halted. Potential ignition sources, all of which provide this region of high temperature, include matches, pyrotechnic igniters (including electric matches), electric sparks, mechanical sparks, glowing wires, and hot surfaces. Alternating current (AC) sparks must be examined as well as the more traditional direct current (DC) sparks. Any potential source (for example, nichrome wire) must be examined to ensure that it does not have a catalytic effect on the reaction. Of the above sources, the two most likely to be repeatable are the match and the electric spark (AC or DC), and most flammability testing has been accomplished using those two ignition sources.

The electric spark is a very fast-acting ignition source, in the order of 10^{-8} to 10^{-7} seconds discharge time, and, therefore, the energy is highly concentrated. Sparks have

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8. Richard, Robert G., and Shankland, Ian, "Flammability of Alternative Refrigerants", ASHRAE Journal, Vol. 34, Number 4, page 22, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA 30329, 1992. (Reference 2)

been studied for years, primarily because of their importance in the internal combustion engine. Variables in this technique are given below:

a. AC vs. DC. Testing at NMERI involving inertion of propane and methane by Halon 1301 has indicated that 120 volts AC (VAC) boosted through a transformer can ignite mixtures that cannot be ignited by a DC spark at any energy up to 100 J. However, the duration of the spark was not controlled.

b. Electrodes. The shape, diameter, separation distance, and materials may be critical. Most references indicate that above the quenching distance ($d_{\parallel}$)–the maximum gap between electrodes that will successfully quench ignition–the shape of the ends of the electrodes is not important.[9] However, Lewis and von Elbe also state that for large spark energies, $d_{\parallel}$ actually increases, due to the increased heat transfer produced by the turbulence of the larger spark.[10]

c. Position of the ignition source. It appears that the majority of flammability testing, including the NMERI inertion work, has been conducted with the electrodes located approximately in the center of the apparatus. However, the procedures for testing in the ASTM flask do not specify a location of the electrodes, and the drawing of the apparatus indicates that the location as somewhat lower than the center of the flask. Since ignition is measured by the upward propagation of flame, this would seem logical. On the other hand, Crescitelli, et al., have shown a correlation between the vertical location of the electrodes and the location of the flame front as a function of time.[11] Therefore, the vertical location of the electrodes in the ASTM flask will be considered as a variable.

d. Energy. Most electric sparks are produced by a capacitive discharge with many also having an inductive component. The energy level in a capacitive spark is defined by the stored electrical energy in the capacitors ($\frac{1}{2}FV^2$) where F is the capacitance and V is the voltage to which the capacitors are charged (actually, the voltage before and after discharge must be considered). If there are no losses between the capacitor and the electrodes, all energy is transferred into the spark. However, it is possible that some energy will be required to initiate the spark and not all will be available to ignite the flammable mixture. The energy deposited at a sufficient temperature to initiate a freely propagating flame is called ε_{eff} and may be up to two orders of magnitude less than the stored energy, depending upon the voltage to which the

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9. Sheldon, M., Principles of Spark Ignition, Fire Protection, Volume 165, page 28, Fire Protection Association, London, England, UK, 1983. (Reference 55)

10. Lewis, B., and Von Elbe, G, op.cit., pages 337-340. (Reference 57)

11. Crescitelli, S., Russo, G., Tufano, V., Napolitano, F., and Tranchino, L., Flame Propagation in Closed Vessels and Flammability Limits, Combustion Science and Technology, Volume 15, Pages 201-212, Gordon and Breach Science Publishers, Inc., New York, NY, 1977. (Reference 89)

capacitors were charged and the chamber volume size.[12] The energy loss due to the high-voltage transformer has been estimated at 85%.

e. Circuit parameters. It is known that (1) inductance in the ignition circuit results in a different type of spark than that without inductance[13] and (2) there is a fundamental difference in circuits that employ inductors in parallel or series to the capacitor. It has also been recognized that ignition energy is dependent not only on the resistance and capacitance of the circuit, but also on the product of the two, i.e., the discharge time constant.[14]

Matches have also been used for flammability testing. Matches are easily ignited using low voltage batteries or power supplies. Under most test conditions, matches have a higher energy content (one source reported 176 J)[15] than a spark with a time duration much longer than a spark and have resulted in wider flammability limits than electric sparks or heated wires. It must be assessed whether matches provide a realistic ignition source in the small test volumes used in flammability testing.

Lewis and von Elbe describe ignition by hot-wires and heated metal bars.[16] These sources will be considered as potential ignition sources in this program.

The minimum ignition energy (MIE) for various hydrocarbons has been extensively studied for years.[17,18] According to Bradford and Finch,[19] "in all cases which have been examined, more electrical energy is necessary to bring about ignition of mixtures near the

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12. Hertzberg, Martin, Conti, Ronald, and Cashdollar, Kenneth, Spark Ignition Energies for Dust-Air Mixtures: Temperature and Concentration Dependencies, Twentieth Symposium (International) on Combustion, pages 1682-1683, The Combustion Institute, Pittsburgh, PA 15213, 1984. (Reference 20)

13. Allsop, G., and Guenault, E.M., The Incendivity of Electric Sparks in Relation to the Characteristics of the Circuit, Third Symposium (International) on Combustion, page 344, The Williams and Wilkins Co., Baltimore, MD, 1949. (Reference 47)

14. Li, G., and Wang, C., Comprehensive Study on Electric Spark Sensitivities of Ignitable Gases and Explosive Powders, Journal of Electrostatics, Volume 11, page 331, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, 1982. (Reference 56)

15. Skaggs, S.R., Heinonen, E.W., Moore, T.A., and Kirst, J.A., Low Ozone-Depleting Halocarbons as Total-Flood Agents: Volume 2: Laboratory-Scale Fire Suppression and Explosion Prevention (Draft Report), New Mexico Engineering Research Institute OC 92/26, page 46, New Mexico Engineering Research Institute, Albuquerque, NM 87106, Sep 1993. (Reference 35)

16. Lewis, B., and Von Elbe, G, op.cit., pages 373-380. (Reference 57)

17. Ballal, D.R., and Lefebvre, A.H., The Influence of Flow Parameters on Minimum Ignition Energy and Quenching Distances, Fifteenth Symposium (International) on Combustion, pages 1473-1481, The Combustion Institute, Pittsburgh, PA 15213, 1974. (Reference 40)

18. Blanc, M.V., Guest, P.G., Von Elbe, G., and Lewis, B., Ignition of Explosive Gas Mixtures by Electric Sparks III. Minimum Ignition Energies and Quenching Distances of Mixtures of Hydrocarbons and Ether with Oxygen and Inert Gases, Third Symposium (International) on Combustion, pages 363-367, The Williams and Wilkins Co., Baltimore, MD, 1949. (Reference 48)

19. Bradford, B.W., and Finch, G.I., The Mechanism of Ignition by Electric Discharges, Second Symposium on Combustion, pages 112-126, The Combustion Institute, Pittsburgh, PA 15213, 1965. (Reference 49)

limits than in the middle zone of inflammability." Therefore, the MIE must be examined not only at the stoichiometric fuel-to-air ratio, but at the limits as well. However, it is believed that rather than devote significant effort to determine the precise MIE for various concentrations of agents, it is more critical to develop a representative source that provides repeatable and reliable ignition of the mixture with a known energy.

2.1.2. Temperature.

In general, the higher the initial temperature, the wider the flammability limits. This occurs because less energy is required to bring the flammable mixture to its flame temperature. The mixture will ignite without an external source when raised to its auto-ignition temperature. Zabetekis[20] has suggested that the LFL of a hydrocarbon at any temperature can be estimated by drawing a line between the room temperature LFL and 0% concentration at 1300 ºC (Figure 1). If this estimation can be extrapolated to flammable refrigerants, or if a similar estimation can be made, the amount of testing at elevated temperature can be minimized.

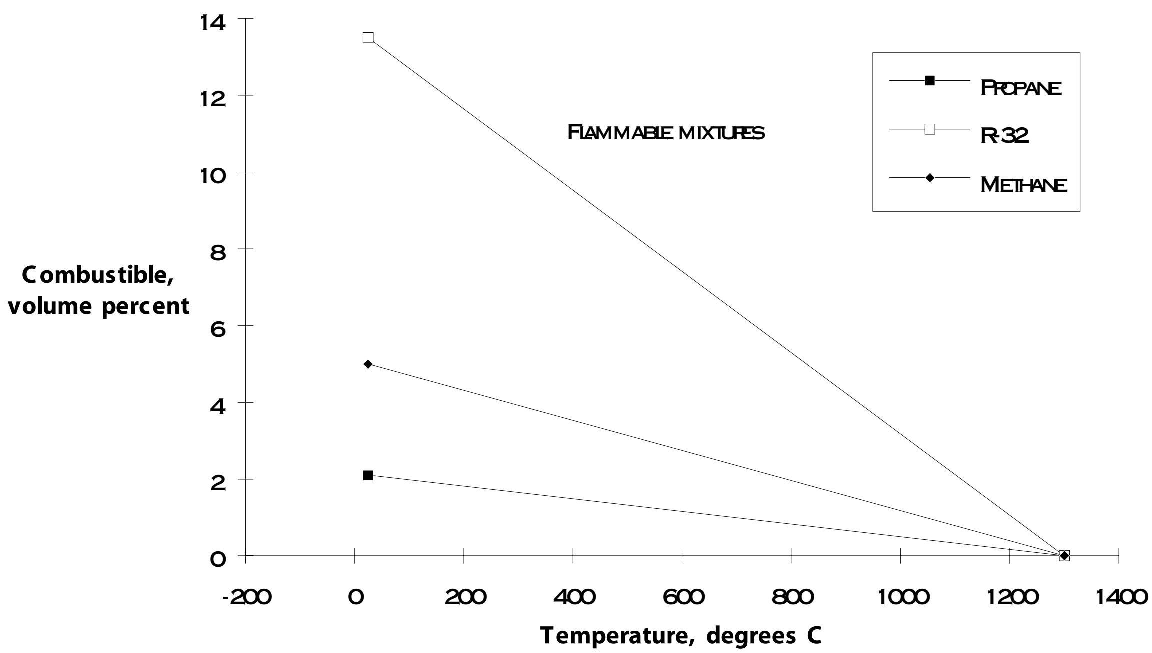

Figure 1. Effect of Temperature on Lower Limits of Paraffin Hydrocarbons in Air at Atmospheric Pressure

20. Zabetekis, op.cit., pages 22-24. (Reference 15)

2.1.3. Pressure.

Pressure effects are among the most difficult of all the factors affecting flammability to quantify, and in some cases trends presented in different sources are contradictory. It is fairly well understood that higher pressures affect the UFL much more than the LFL. For example, Drysdale reports the UFL of methane as 60% and the LFL as 4% at 200 atmospheres (as compared to 15% and 5% at 1 atm)[21], indicating a significant widening of the limits. On the other hand, Coward and Jones state that increases in pressure above that of atmospheric do not always widen the limits and for some mixtures, the range of flammability is lowered with increasing pressure.[22]

At lower pressures some disagreements also occur. Drysdale indicates that pressures below atmospheric do not affect the flammability limits providing that the pressure is above 10.1 kPa (0.1 atmosphere) and the compound remains either a gas or a liquid.[23] Egerton states that "a reduction of the pressure below 760 mm *(of Hg)* always causes both limits to converge until they coincide at some critical pressure below which no propagation can occur"[24] (although he doesn't state how rapidly this convergence occurs). However, Lovachev in 1973[25] has reported that Lewis and von Elbe were uncertain that a lower pressure limit independent of vessel size could exist. He also reported instances of flammability limits at extremely low pressures, although he concluded that ignition effects may have played a part in those tests. While these three statements may not be totally inconsistent (the conditions under which the conclusions were made were not described), the fact that some controversy appears to occur indicates that difficulty in measuring the flammability limits at low pressures exists. Therefore, care must be taken to define reasonable upper and lower pressure requirements that will not impact flammability limits.

2.1.4. Humidity

While it has long been known that water vapor can affect the kinetics of a reaction, it has been only recently that the flammability behavior of R-245ca has been analyzed with respect to the moisture content of the air.[26,27] It has been postulated that more than one

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21. Drysdale, D., op.cit., page 89. (Reference 80)

22. Coward, H.F., and Jones, G.W., Limits of Flammability of Gases and Vapors, Bureau of Mines Bulletin 503, pages 3-4, Bureau of Mines, Pittsburgh, PA, 1952. (Reference 14)

23. Drysdale, D., op.cit., page 88. (Reference 80)

24. Egerton, A.C., Limits of Inflammability, Fourth Symposium (International) on Combustion, page 10, The Williams and Wilkins Co., Baltimore, MD, 1953. (Reference 45)

25. Lovachev, L.A., Babkin, V.S., Bunev, V.A., V'yun, A.V., Krivulin, V.N., and Baratov, A.N. Flammability Limits: An Invited Review, Combustion and Flame, Volume 20, pages 281-282, Elsevier Science Publishing Co., New York, NY 10017, 1973. (Reference 71)

26. Smith, N.D., Ratanaphruks, K., Tufts, M., and Ng, A.S., R-245ca: A Potential Far-Term Alternative for R-11, ASHRAE Journal, Vol. 35, No. 2, pages 19-23, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA 30329, 1993. (Reference 73)

27. Smith, N.D., ARI Flammability Workshop, March 8-9, 1994, Chicago, Illinois, Air Conditioning and Refrigeration Institute, Arlington, VA 22203, 1994. (Reference 27)

combustion reaction is possible depending upon whether adequate water vapor is present. This dichotomy occurs primarily where the number of fluorine atoms is greater than the number of hydrogen atoms and the flammability of refrigerants, such as R-134a, R-245ca, and R-245fa, may be affected by this phenomenon. Effectively, as refrigerant concentration, temperature and pressure were kept constant, the flame characteristics intensified as the moisture content increased from 10 to 60% relative humidity. Therefore, any test methods developed must consider the relative humidity of the air.

2.1.5. Test Vessel Size and Shape.

Many of the accepted flammability results were developed in the Bureau of Mines in the 150-cm high by 5-cm diameter explosion (flame) tube. In several studies it was determined that flammability limits were affected by the quenching effects of the vessel walls under 5 cm, but were generally unaffected over 5 cm.[28] Likewise, it was determined that explosion spheres of 5 liters (20.2 cm diameter) give similar results to larger vessels for R-32 flammability testing.[29]

However, the behavior of flammability limits in free space have not been studied extensively. Lovachev indicates that "the flammability limits of ammonia-air flames in free space were found to be wider than for a standard tube. This indicated that there are mixtures capable of burning in free space only."[30] Therefore, any limits determined in the confined spaces of the ASTM flask or explosion sphere must be regarded as approximate if the true flammability situation is an unconfined cloud of refrigerant.

2.1.6. Test Vessel Material.

Although for the most part, flammability has been determined by the time that the flame front has reached the walls of the test vessel, two different properties could affect the flame front after that point. First, different materials have different heat conduction values, affecting the temperature of the flame front. Second, various types of materials tend to affect the free radicals differently, promoting different kinetics at the wall of the vessel.

One additional parameter to be considered is the cleanliness and condition of the ASTM flask. Repeated testing may eventually etch the Pyrex®, affecting both the actual results of the flammability testing and the visual observation of the tests.

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28. Lewis, B., and Von Elbe, G, op.cit., page324. (Reference 57)

29. ICI Chemicals, KLEA 32 Blends: Flammability Characteristics, page 1, ICI Chemicals and Polymers, Mar 1992. (Reference 10)

30. Lovachev, L.A., Flammability Limits - a Review, Combustion Science and Technology, Volume 20, page 211, Gordon and Breach Science Publishers, Inc., New York, NY, 1979. (Reference 78)

2.1.7. Turbulence in the Test Vessel

Turbulence affects the development of the flame front. Drysdale[31] indicates that turbulence increases the rate of flame propagation through a mixture, but the effect is difficult to quantify. Significant research has been conducted on the effect of turbulence on coal dust explosions[32] and to a lesser extent flammable gases.[33] Any testing needs to consider that turbulence is a variable and should most likely reduce turbulence to as low a level as possible.

2.1.8. Composition of the Components of the Mixture

Two component factors determine the flammability of the mixture in air: (1) the weight (or volume) fraction of each constituent element in a binary or ternary mixture, especially when only one of the constituents is flammable, and (2) the total concentration of the mixture with air. Methods such as the critical flammability ratio (CFR)[34] can provide a good estimate of the flammability of any ratio of constituents if the weight percentage required to provide non-flammability to the flammable refrigerant is known for each individual constituent. One additional factor that must be considered is the purity of the individual constituents.

2.1.9. Reactivity of the Components

For the most part, the refrigerants used are very stable components; however, even stable components may react with outside chemicals such as lubricants or other fluids. In inertion testing using ethylene oxide and R-12 in the NMERI explosion sphere, a regular pressure decrease was noted prior to ignition. This was believed to be due to the ability of the ethylene oxide to polymerize. Reactivity is not considered to be a problem in either test or field situations and will be evaluated on a case-by-case basis rather than consequent to testing for each mixture.

2.1.10. Mixing of the Components

During initial inertion testing in the NMERI sphere, it was determined that repeatable results required thorough mixing of the fuel, air, and inertant. A electronic box fan was installed inside the sphere and allowed to run at least one (1) minute to ensure proper mixing. Total mixing is required in any test technique for consistency in the evaluation of flammability in a laboratory environment.

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31. Drysdale, op.cit., page 111-113. (Reference 80)

32. Pu, Y.K., Jarosinski, J., Johnson, V.G., and Kauffman, C.W., Turbulence Effects on Dust Explosions in the 20-Liter Spherical Vessel, Twenty-third Symposium (International) on Combustion, pages 843-849, The Combustion Institute, Pittsburgh, PA 15213, 1991. (Reference 32)

33. Coward, H.F., and Jones, G.W., op.cit. (Reference 14)

34. Dekleva, T.W., Lindley, A.A., and Powell, P., "Flammability and Reactivity of Select HFCs and Mixtures", ASHRAE Journal, Vol. 35, No. 12, page 46, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA 30329, 1993. (Reference 1)

2.1.11. Altitude

Altitude effects may be a function of other fundamental variables such as pressure as it varies with altitude and the composition of the air with respect to the altitude. Coward and Jones state that the normal variations of atmospheric pressures do not appreciably affect the limits of flammability.[35] However, any technique developed must be independent of the altitude at which the testing occurs to account for locations, such as Albuquerque, that have an altitude in excess of 1524 m (5000 ft). All NMERI sphere tests were performed at 101kPa (14.7 psia), which required the addition of approximately 17.2 kPa (2.5 psig) additional air to the sphere to compensate for the altitude. The effect of the reduced pressure due to altitude will be examined as part of the pressure factor.

2.2. Test Apparatus

The following test apparatuses have been identified as potential vehicles to develop a new test technique for determination of the flammability of refrigerants. A listing of pros, cons, and additional work required to utilize the apparatuses fully is provided.

2.2.1. NMERI Explosion Sphere

The NMERI explosion sphere[36] (Figure 2) was constructed to investigate the ability of halocarbons to inert propane and methane. It was designed to screen large numbers of halocarbons to determine which required the least weight and volume of inerting agent to reduce the explosive overpressure to 1 psi or less, which was considered the definition of an explosion. In addition to its intended use, it has also been used to test inertants using refrigerants such as R-32, R-152a, and R-142b as fuels. As part of this series of tests, upper and lower flammability limits were found for these flammable refrigerants, although precise limits were not determined due to time limitations. In all cases, however, the flammability limits were narrower than reported using other test facilities, reflecting the trend that less inerting agent was required in the NMERI flammability sphere than in other apparatuses. The difference in NMERI results was the subject of a paper presented in 1993.[37]

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35. Coward, H.F., and Jones, G.W., op.cit., page 3. (Reference 14)

36. Skaggs, S.R., Heinonen, E.W., Moore, T. A., and Kirst, J.A., op.cit. (Reference 35)

37. Heinonen, E.W., The Effect of Ignition Source and Strength on Sphere Ignition Results, Halon Alternatives Technical Working Conference 1993, pages 565-576, New Mexico Engineering Research Institute, Albuquerque, NM 87106, 1993. (Reference 34)

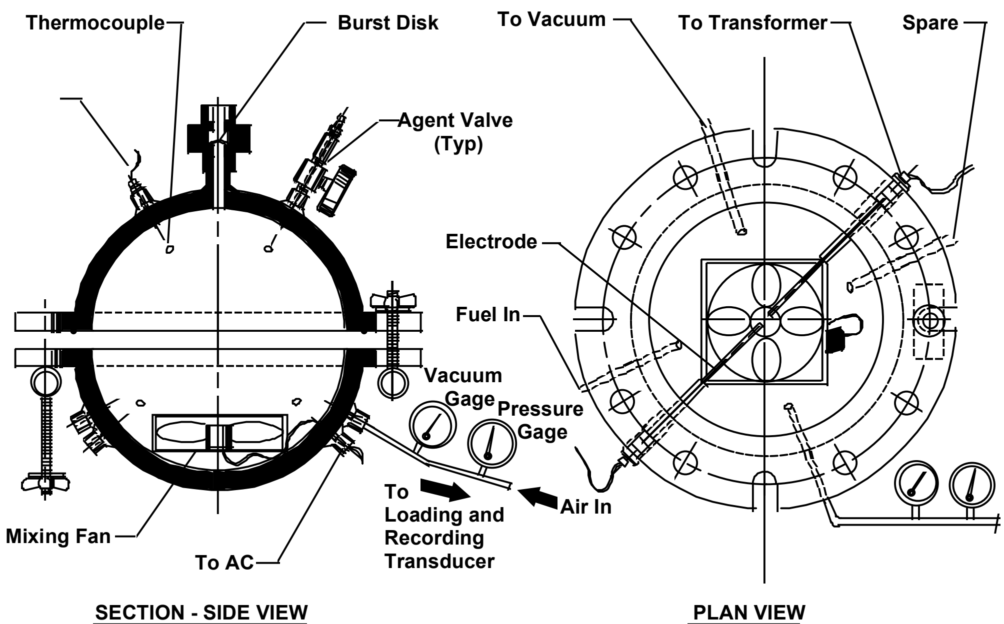

Figure 2. NMERI Explosion Sphere.

PROS: Procedures have been developed and results for inerting have been shown to be repeatable and reliable. Flammability limits for some flammable refrigerants have already been determined, although not to a great degree of accuracy. The measure of flammability–1 psi overpressure - is objective and repeatable. Because of the steel construction of the sphere, the effect of increased pressure can be examined.

CONS: An explosion sphere is not readily available for every user–it has to be custom-built. There is no indication that the chosen explosion limit of 1 psi, or any other arbitrary pressure limit, corresponds to a definition of flammability.

ADDITIONAL WORK: The ignition system has not been optimized. The electrodes have flat ends rather than the more efficient rounded or pointed, and the electrode separation was set at 6mm, similar to that of other test techniques but nonetheless not optimized. As part of the ignition research, many factors will be investigated.

The Hewlett-Packard computer system used for control and data collection is slow and limited in channels, and data cannot be transferred to a PC for analysis and plotting. Therefore, a PC-based control and data collection system will be developed and the software rewritten to work on a PC. This will allow additional pressure transducer, thermocouple, and humidity measuring channels to be connected and accelerate data collection and analysis significantly.

2.2.2. ASTM E-681 Flask

This apparatus[38] is the standard device used to determine flammability of refrigerants.

PROS: The standard is well accepted and many potential testers already have the equipment. The test is easy to run, and there is a vast body of data available. The effect of temperature can be measured easier in this device than with the sphere.

CONS: Results for this test are subjective, depending in part upon the visual indication of flammability. The ignition source is not precisely denoted. According to Reference 38, "Test data available at present are inadequate to establish any measure of repeatability or reproducibility."

ADDITIONAL WORK: Because of the general acceptance of this method, it appears logical that the test equipment and methodology should be modified using to the additional precision and automation available in the NMERI explosion sphere. This would involve a comparison of testing as prescribed in ASTM Standard E-681 with modifications to the test technique, including more precise measurement of the partial pressures of the components, measurement of the overpressure using a precise transducer, and better control of ignition. A comparison could then be made between visual indications and pressure and temperature increases to assess how well flammability is determined by a visual criteria. Size effects could also be examined by replacing the 5-liter flask by a 12-liter flask and repeating tests.

2.2.3. Bomb Calorimeter

Fedorko, et al. used a bomb calorimeter in their evaluation of the flammability of R-22.[39] They did not consider the small size of the bomb (65 mm in diameter and 342 mL in volume) a handicap because they reported 50 mm (5 cm) as the limit of the quenching effects of the walls. Bomb calorimetry is a simple method to determine the heat of combustion, and it appears logical that the LFL and UFL can also be determined by noting the lowest and highest concentrations under which combustion occurs. NMERI has a Paar 1341 plain jacket oxygen bomb calorimeter available,[40] which is apparently the same model used by Fedorko.

PROS: Test procedures are well defined, results are precise and many testers would have access to such a device.

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38. ASTM Standard E-681-85 (Reapproved 1991) Standard Test Method for Concentration of Flammability of Chemicals, American Society for Testing and Materials, Philadelphia, PA 19103, 1991. (Reference 16)

39. Fedorko, G., Fredrick, L.G., and Hansel, J.G., Flammability Characteristics of Chlorodifluoromethane (R-22)-Oxygen-Nitrogen Mixtures, ASHRAE Transactions, Number 3097, pages 716-724, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA 30329, 1993. (Reference 3)

40. Instructions for the 1341 Plain Jacket Oxygen Bomb Calorimeter, Manual Number 147, Parr Instrument Corporation, Moline, IL.

CONS: Both the explosion sphere and the ASTM flask have been extensively used to measure the limits of flammability for numerous materials, but the bomb calorimeter has apparently been used by only a few researchers. It is uncertain to what degree of accuracy the LFL and UFL can be calculated and how well they compare with the results seen from other apparatuses. The volume in this particular bomb is small. Precise measurement of the refrigerant would be required. Most testing is done at pressures above atmospheric, although atmospheric testing is possible.

ADDITIONAL WORK: For pressures above atmospheric, an analysis must be made to determine whether the refrigerants to be tested can generate adequate partial pressures to allow concentrations equal to the UFL or LFL to be injected in the bomb.

2.2.4. Light Emission Detection Device

This device would involve measuring individual photons as they are generated after the ignition. A schematic is shown below:

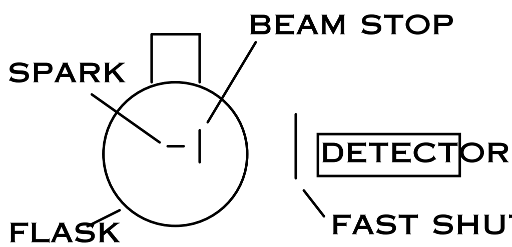

Figure 3. Light Emission Detection Device.

A photon detector would be aimed at the ignition point. A fast shutter would block the spark at the time of ignition but open to allow viewing immediately afterward. Photons emitted from the gas would be counted and combustion indicated.

PROS: This could be a precise indication of whether a combustion event has occurred.

CONS: The apparatus is not yet constructed and may not be practical. There has been no correlation between photon emission and flammability, and photon emission may occur long before visible ignition indications.

ADDITIONAL WORK: NMERI will investigate the feasibility of such a device, and construct a device if cost allows. The University of New Mexico Chemistry Department has several additional devices that may prove to be better suited to this work, and we will research these as well.

2.2.5. Other Test Vessels

Many of the early flammability results were obtained in flame tubes or other such devices. During the course of testing, design and construction of an apparatus similar to one of those early devices may prove useful to compare results.

PROS. It could prove useful to repeat some early tests with more sophisticated instrumentation to investigate whether accurate, repeatable results could be generated using a simple, inexpensive test apparatus.

CONS. This would add another complexity to the test program. It is uncertain at this point whether the data could add to the understanding of the flammability of refrigerants.

ADDITIONAL WORK. Planning, construction, and test method development would be required. Instrumentation, ignition, and gas inlet procedures will have to be developed to fit the new vessel.

2.3. Alternate Refrigerants Flammability Test Results

As was mentioned above, few articles deal directly with measurements of the flammability of refrigerants. Several of the key articles in the database describing the flammability of the refrigerants specified in this project and other refrigerants are summarized below:

a. Dekleva, Lindley, and Powell.[41] The flammability of R-134a, R-32, and blends of those refrigerants with R-125 were tested. In a binary blend of R-32/R-125, a minimum of 35 wt% of R-125 was required to provide non-flammability on dilution with air. In a similar binary blend of R-32/R-134a, the R-134a percentage was 44%. The critical flammability parameter methodology was applied to a ternary blend of the three refrigerants, leading to a means of determining whether any proportion of components would be non-flammable. An analysis of temperature effects on 80% filled cylinders indicated that both a 30/10/60 wt% ternary blend of R-32/R-125/R-134a and a 25/75 wt % binary blend of R-32/R-134a remain non-flammable to less than -50 ºC (-58 ºF). However, if the cylinders are liquid discharged to complete emptiness, the remaining vapor is enriched with R-32, and the 25/75 blend would have a flammable vapor below -15 ºC (5 ºF), while the ternary blend would remain non-flammable down to -50 ºC (-58 ºF). Intermediate fill ratios yield intermediate flammability characteristics.

b. Richard and Shankland.[42] This article describes refrigerant flammability test results for many pure refrigerants, including the three proposed for the mixture in this program. Both R-125 and R-134a are considered non-flammable at room temperature using a match as an ignition source, while the flammability of R-32 ranges from 12.7% to 33.5% at room temperature depending on the ignition source, and from 11.4% to 33.8% at 95 ºC. The Critical Flammability

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41. Dekleva, T.W., Lindley, A.A., and Powell, P., op.cit. (Reference 1)

42. Richard, Robert G., and Shankland, Ian, op.cit. (Reference 2)

Ratio for several binary blends is also presented, including that for R-32/R-125 (81.6/18.4 mol%, 65.6/34.2 wt%). This compares favorably with the 65/35 wt% results reported by Dekleva, et al.

c. Sand and Andrjeski.[43] Refrigerants R-22, R-12 and R-11 were tested in a Paar 1108 bomb calorimeter to determine whether they were combustible. The conclusions were that R-12 and R-11 were not combustible, while pressurized gas mixtures of R-22 and air containing at least 50 5 air are combustible and capable of increasing the pressure in a closed container by a factor of six to eight times.

d. Fedorko, Fredrick, and Hansel.[44] The flammability envelopes for R-22 in air and enriched air up to 100% oxygen have been measured up to 1380 kPa (200 psia). The lowest pressure at which R-22 was flammable in air was 518 kPa (75 psia), while relatively wide limits were established (20% to 85% by volume) in 100% O_2 at even 101 kPa (14.7 psia).

e. Grob.[45] Flammability tests run in a 5-liter flask using the ASTM E-681 method at nominal room temperature and 1 atmosphere indicate that the addition of approximately 29% by volume of R-134a would inert any mixture of R-32 and R-134a. The value for R-125 is 18% by volume. This compares favorably to the 29 and 19 vol% presented by Dekleva, et al.

f. ICI Chemicals and Polymers.[46] The flammability of R-32 is reported for various test equipment. The LFL and UFL at room temperature and atmospheric pressure are reported as 18.9% and 26.9%, respectively, for a 2-inch flame tube, and 13.6% and 32.2% for a 6-inch diameter autoclave. The LFL and UFL for a 5-liter sphere are 14.0% and 31.0%, which are the quoted ICI values. The CFR values for R-32/R-134a are 29% by volume and 44% by weight, identical to those presented by Dekleva and for R-32/125 are 18.4% by volume and 34.3% by weight, also in agreement with Dekleva.

g. Reed and Rizzo.[47] The authors investigated six pure refrigerants and several blends to determine whether the chemicals were flammable. Under the conditions specified by the protocol for the test, specifically 0 to 2-volume percent air and 82 ºC to 177 ºC, all refrigerants were non-flammable in a 1.7-liter reactor. At test conditions with air exceeding 60-volume percent at elevated pressures, R-134a was combustible, and at test conditions with air exceeding 80-volume percent, blends containing R-22/R-152a/R-114 and R-124 were combustible at any pressure.

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43. Sand, James R., and Andrjeski, D.L., "Combustibility of Chlorodifluoromethane", ASHRAE Journal, Volume 24, Issue 5, pages 38-40, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA 30329, 1982. (Reference 8)

44. Fedorko, G., Fredrick, L.G., and Hansel, J.G., op.cit. (Reference 3)

45. Grob, Don, Flammability Characteristics of R-32 and R-32 Mixtures, Underwriter's Laboratories, Inc., Northbrook, IL 60062, March 1991. (Reference 11)

46. KLEA 32 Blends: Flammability Characteristics, ICI Chemicals and Polymers, March 1992. (Reference 10)

47. Reed, Paul R., and Rizzo, Joseph J., Combustibility and Stability Studies of CFC Substitutes with Simulated Motor Failures in Hermetic Refrigeration Equipment, XVIII International Congress of Refrigeration, 18th International Institute of Refrigeration, 10-17 Aug 1991. (Reference 33)

h. Borchart and Gilbaugh.[48] The flammability of the mixture R-22/R-142b (42 wt % R-22) was investigated with respect to its potential use in automotive air conditioning. It was identified that while the mixture itself was non-flammable, with any composition containing more that 36 wt % R-22 being non-flammable, a flammable residue can form if R-22 rich vapor is lost via a vapor phase leak. A large-scale test using 1 pound of charge of a 75/25 R-142b/R-22 mixture discharged in the liquid phase resulted in the entire 40 ft^3 test compartment being completely engulfed in flames. A polyethylene panel blew off and flames shot several feet above the compartment. The concentration of refrigerant to air prior to ignition was approximately 10 vol percent. However, when only vapor was discharged, simulating a vapor phase discharge during servicing, ignition did not occur.

Two additional articles have been identified but not received. The first, by Ohnishi and others, describes the relationship between flammability and composition ratio of R-32/R-134a blends. The second, by Shaoqiang and others, reports results from R-152a flammability testing. In general, all results available to date are consistent with each other and indicate a flammability range of R-32 in the range of 14 to 31%, with some differences reported for vessel size and initial conditions.

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48. Borchardt, H.J., and Gilbaugh, R.C., Hazard of FC22/142b Flammability, KSS-8274, E.I. du Pont Nemours & Co., Wilmington DE, 1979. (Reference 58)

APPENDIX A: REFLIBRY DATABASE DESCRIPTION

The REFLIBRY Database is designed to operate using the Microsoft Access® database. The database is user friendly, permitting the user to enter and modify data through the use of forms. The user can also print individual records or the entire bibliography on the local printer. A series of switchboards is provided for ease of navigation throughout the database.

a. Main Switchboard

Upon selection of the REFLIBRY database from the Access®, the main switchboard screen (Figure A-1) is displayed giving the user the choice to select any of the forms or reports, return to the database window (for forms maintenance and modification), or exit the database.

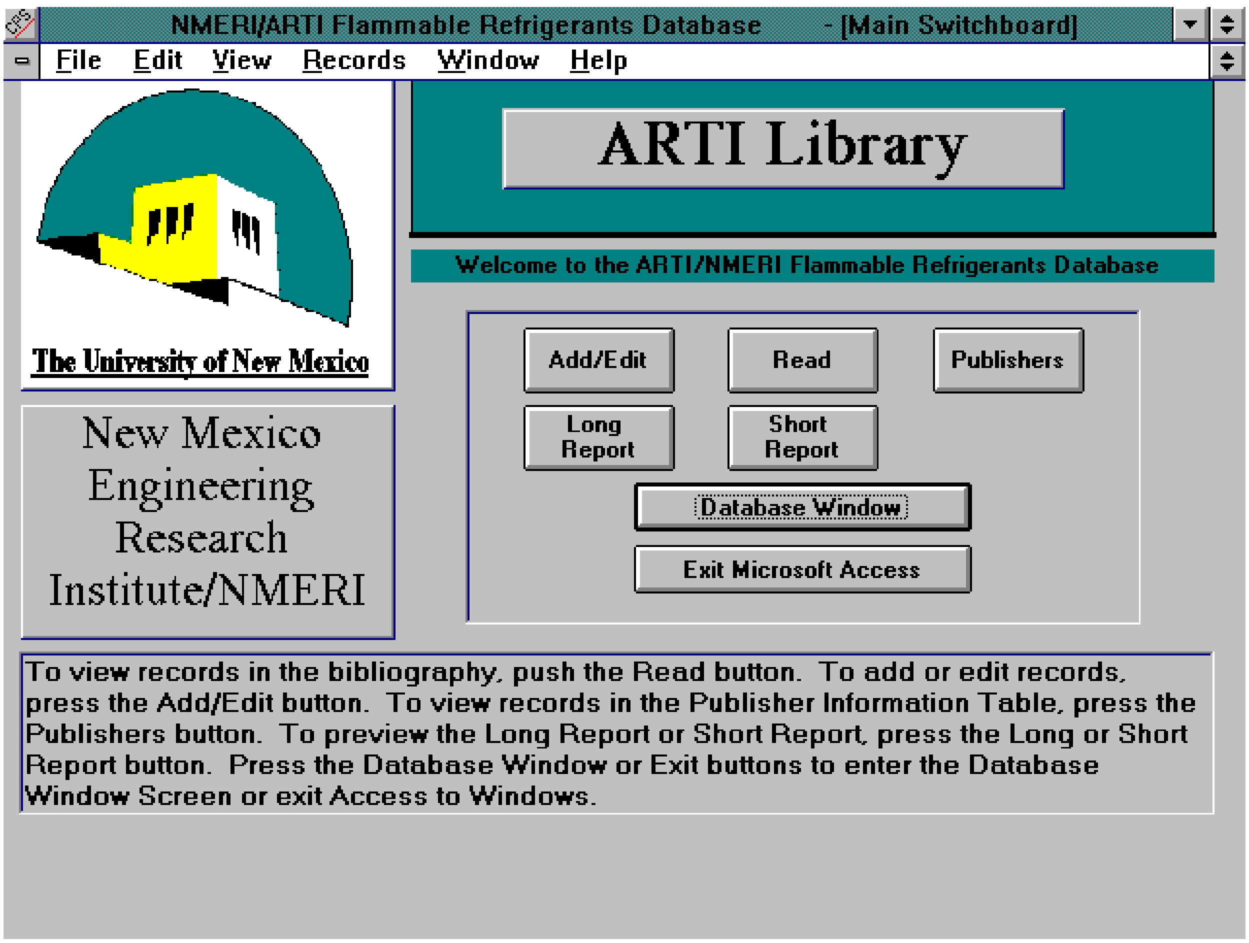

Figure A-1. Main Switchboard.

33 Seven buttons are provided:

1. Add/Edit. Opens *Add/Edit* form and allows viewing of all records plus addition of new record and modification to existing ones.
2. Read. Opens *Add/Edit* form as above but with read-only access. It does not allow any data entry or updates of the data.

3. Publishers. Opens *Publishers Address* form and allows addition or modification of the publisher's address.
4. Long Report. Previews long report format, which includes all data including abstract. The report can be printed from this screen.
5. Short Report. Preview short report format, which includes limited data, but does not include abstract.
6. Database Window. Returns to the Database Window. From this window, tables, queries, forms, reports, macros and modules can be selected for creation or modification.
7. Exit Microsoft Access. Exits Microsoft Access.

b. *Add/Edit* Form

The *Add/Edit* form displays all data in the table in screen format plus allows data entry or modification (Figure A-2). Attachment A-1 explains each of the fields in this form. Six buttons on the top right of the form allow selection of various functions:

1. New. Increases the index counter and allows addition of a new record.
2. Publ. Allows selection of the *Publisher Information* form to add or edit data on the publisher of the document.
3. Find. Allows selection of records containing a specific term in a field.
4. Print. Prints the current record, without header information, on a single sheet.
5. Delete. Allows deletion of the current record.
6. Close. Close the form and return to the window from which the form was opened (for example, the forms switchboard or the database window).

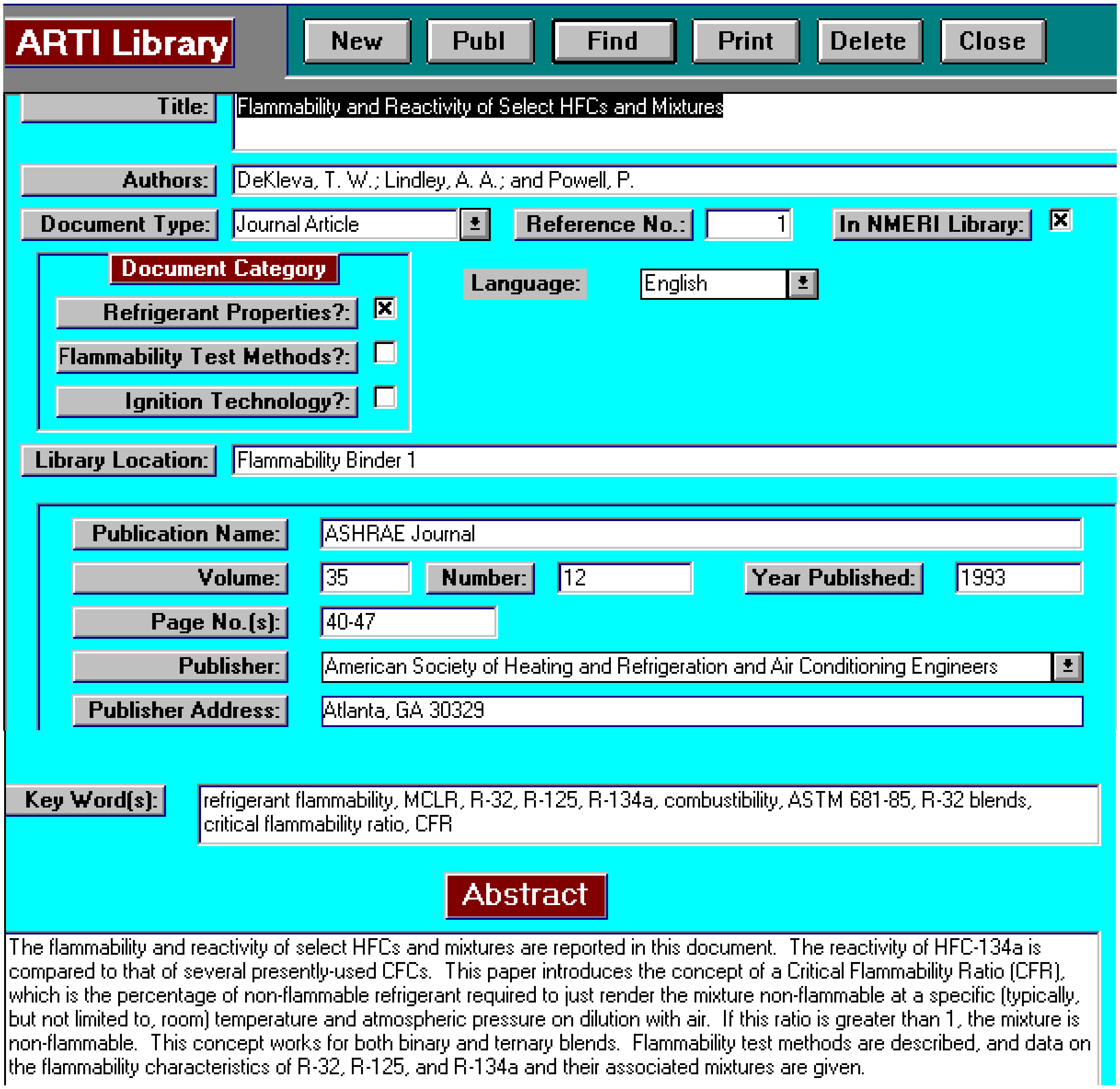

Figure A-2. *Add/Edit* Form.

c. *Publisher's Information* Form

The *Publisher Information* form (Figure A-3) allows editing and addition to the Publisher's Addresses Table. This form is designed to provide additional information on the publisher. The City, State, and Zip field is also included in the *Add/Edit* form under Publisher's Address. Attachment A-2 describes each of the fields.

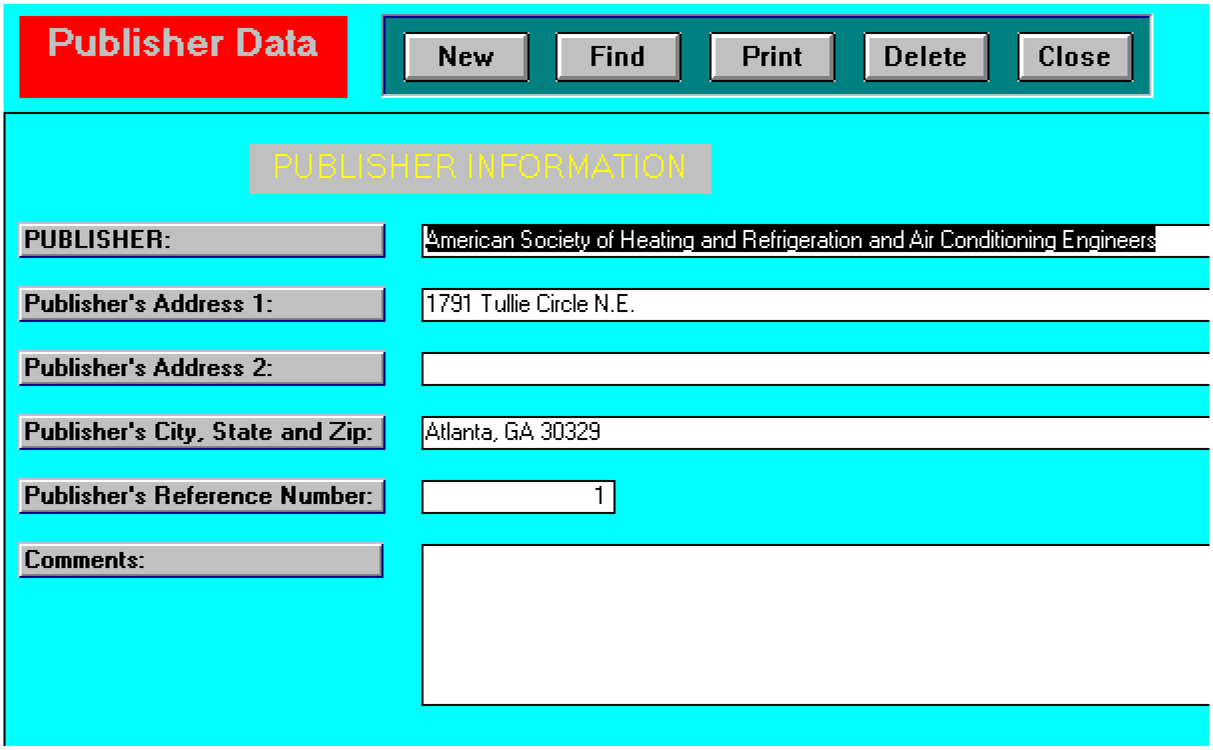

Figure A-3. *Publisher's Information* Form.

e. *Long Report*

The *Long Report* (Figure A-4) prints the bibliography in format more adapted to the printed page that the form. All fields except for document category and library location are included in this report.

AUTHOR: **Allsop, G.; and Guenault, E.M.**

TITLE: **The Incendivity of Electric Sparks in Relation to the Characteristics of the Circuit**

DOC TYPE: Conference Proceeding
DOCUMENT: Third Symposium (International) on Combustion
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
VOL NO: 3rd
ISSUE:
YEAR: 1949
PAGE NO: 341-353
LANGUAGE: English

KEYWORDS:
spark ignition, flammability

REFERENCE NUMBER: 47 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The concept of how spark ignition ignites flammable mixtures is examined. The composition of the gas or vapor, the circuit voltage, circuit inductance, the rate of separation of the electrodes, the frequency of the voltage supply, and the size and material of the electrodes are discussed. The effect of these factors on mine safety is further discussed.

Figure A-4. *Long Report* Format.

f. *Short Report*

The *Short Report* (Figure A-5) is a shortened version of the *Long Form* with only author, title, document type, document, reference number, keyword, and library information included.

Refrigeration Flammability References

AUTHORS: **Abbud-Madrid, Angel; and Ronney, Paul D.**
TITLE: **Effects of Radiative and Diffusive Transport Processes on Premixed Flames Near the Flammability Limits**

DOC TYPE: Conference Proceedings **REF NO:** 30
DOCUMENT: Twenty-third Symposium (International) on Combustion
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 423-431
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English

KEYWORDS:
flammability limits, flame extinguishment, transport properties

IN NMERI LIBRARY: Yes

Figure A-5. *Short Report* Format.

ATTACHMENT A-1. *ADD/ENTRY* FORM

a. Title. Title of Journal Article, book, or other publication.

b. Authors. Last name and initials of all authors.

c. Document Type. A Combo Box containing six choices: Journal Article, Book, Conference Proceeding, Standard, Report, or Other.

d. Reference No. The internal reference number that serves as the key for the database. It is also the number referred to in the NMERI library.

e. In NMERI Library. Indicates whether there is a copy of this document in the NMERI library.

f. Document Category. Indicates which of the three categories this document falls into.

g. Language. The language of the document. Most documents are in English.

h. Library Location. The location of the document within the NMERI Library System. Most documents are located in binders.

i. Publication Name. For journals and conferences, the name of the publication containing the document. For books and other documents, this is left blank.

j. Volume, number, year, and page number. Identification data for the document.

k. Publisher. Publisher of the document.

l. Publisher's Address. City, state, and zip code of the document publisher. These data are taken from the *Publisher's Address* Table, and full address information, where available, can be found in the *Publisher's Address* table and form.

m. Key Words. Key words were developed for all documents. Rather than limiting key words to a limited number, judgment was used to select several representative words for each document.

n. Abstract. Abstracts included with documents are presented. Abstracts were written for those documents without abstracts attached.

ATTACHMENT A-2. *PUBLISHER'S INFORMATION* FORM

a. Publisher. The name of the publisher of the document.

b. Publisher's Address 1. The first line of the publisher's address.

c. Publisher's Address 2. The second line of the publisher's address.

d. Publisher's City, State, and Zip. The city, state, and postal code of the publisher. This is also displayed on the *Add/Edit* form.

e. Comments. This section contains comments on the publisher (for example, if it is longer in business, etc.)

APPENDIX B. SHORT FORM PRINTOUT

Refrigeration Flammability References

AUTHORS: **Abbud-Madrid, Angel; and Ronney, Paul D.**
TITLE: **Effects of Radiative and Diffusive Transport Processes on Premixed Flames Near the Flammability Limits**

DOC TYPE: Conference Proceedings — REF NO: 30
DOCUMENT: Twenty-third Symposium (International) on Combustion
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 423-431
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English — IN NMERI LIBRARY: Yes

KEYWORDS: flammability limits, flame extinguishment, transport properties

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AUTHORS: **Allsop, G.; and Guenault, E.M.**
TITLE: **The Incendivity of Electric Sparks in Relation to the Characteristics of the Circuit**

DOC TYPE: Conference Proceedings — REF NO: 47
DOCUMENT: Third Symposium (International) on Combustion
VOL NO: 3rd
ISSUE:
YEAR: 1949
PAGE NO: 341-353
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
LANGUAGE: English — IN NMERI LIBRARY: Yes

KEYWORDS: spark ignition, flammability

AUTHORS: **Andrews, G.E.; and Bradley, D.**
TITLE: **Limits of Flammability and Natural Convection for Methane-Air Mixtures**

DOC TYPE: Conference Proceedings — REF NO: 91
DOCUMENT: Fourteenth Symposium (International) on Combustion
VOL NO: 14
ISSUE:
YEAR: 1973
PAGE NO: 1119-1128
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English — IN NMERI LIBRARY: Yes

KEYWORDS: flammability limits, velocity, convection

AUTHORS: **ASTM**
TITLE: **E 582 - 76 (Reapproved 1981) Standard Test Method for Minimum Ignition Energy and Quenching Distance in Gaseous Mixtures**

DOC TYPE: Standard — REF NO: 66
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1985
PAGE NO:
PUBLISHER: American Society for Testing and Materials
ADDRESS: Philadelphia, PA 19103
LANGUAGE: English — IN NMERI LIBRARY: Yes

KEYWORDS: minimum ignition energy, test technique

AUTHORS: ASTM
TITLE: **E 659-78 (Reapproved 1989) Standard Test Method of Autoignition Temperature of Chemicals**
DOC TYPE: Standard
REF NO: 17
DOCUMENT: ASTM
VOL NO:
ISSUE:
YEAR: 1989
PAGE NO:
PUBLISHER: American Society for Testing and Materials
ADDRESS: Philadelphia, PA 19103
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS:
autoignition temperature, ignition

AUTHORS: ASTM
TITLE: **E 918-83 (Reapproved 1988) Standard Practice for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure**
DOC TYPE: Standard
REF NO: 18
DOCUMENT: ASTM
VOL NO:
ISSUE:
YEAR: 1988
PAGE NO:
PUBLISHER: American Society for Testing and Materials
ADDRESS: Philadelphia, PA 19103
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS:
E 918, flammability, limits of flammability, LFL, UFL, UEL, LEL, flame propagation, elevated temperature

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AUTHORS: ASTM
TITLE: **E-681-85 (Reapproved 1991) Standard Test Method for Concentration of Flammability of Chemicals**
DOC TYPE: Standard
REF NO: 16
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1991
PAGE NO:
PUBLISHER: American Society for Testing and Materials
ADDRESS: Philadelphia, PA 19103
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS:
E 681, flammability, limits of flammability, LFL, UFL, UEL, LEL, flame propagation

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AUTHORS: Ballal, D.R.; and Lefebvre, A.H.
TITLE: **The Influence of Flow Parameters on Minimum Ignition Energy and Quenching Distances**
DOC TYPE: Conference Proceedings
REF NO: 40
DOCUMENT: Fifteenth Symposium (International) on Combustion
VOL NO: 15th
ISSUE:
YEAR: 1974
PAGE NO: 1473-1481
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS:
ignition, minimum ignition energy

AUTHORS: Bartknecht, W.
TITLE: Explosions

DOC TYPE: Book | **REF NO:** 12
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1981
PAGE NO:
PUBLISHER: Springer-Verlag
ADDRESS: New York, NY
LANGUAGE: English | **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, combustibility, explosion, inerting, ignition energy, explosion pressure, rate of pressure rise, Kg

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AUTHORS: Bartknecht, W.
TITLE: Ignition Capabilities of Hot Surfaces and Mechanically Generated Sparks in Flammable Gas and Dust/Air Mixtures
DOC TYPE: Journal Article | **REF NO:** 51
DOCUMENT: Plant/Operations Progress
VOL NO: 7
ISSUE: 2
YEAR: 1988
PAGE NO: 114-121
PUBLISHER: American Institute of Chemical Engineers
ADDRESS: New York, NY 10017
LANGUAGE: English | **IN NMERI LIBRARY:** Yes

KEYWORDS: sparks, ignition, flammable gas

AUTHORS: Bartknecht, Wolfgang
TITLE: Dust Explosions

DOC TYPE: Book | **REF NO:** 13
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1989
PAGE NO:
PUBLISHER: Springer-Verlag
ADDRESS: New York, NY
LANGUAGE: English | **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, combustibility, explosion, inerting, ignition energy, explosion presssure, rate of pressusre rise, Kg

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AUTHORS: Berthold, W.; Conrad, D.; Grewer, T.; Grosse-Wortmann, T.; Redeker, T.; and Schake, H.
TITLE: Entwicklung einer Standard-Apparat zur Messung von Explosiongrenzen (Development of a Standard Apparatus for Measurement of Explosive Limits)
DOC TYPE: Journal Article | **REF NO:** 86
DOCUMENT: Chem-Ing.-Tech
VOL NO: 56
ISSUE: 2
YEAR: 1984
PAGE NO: 126-127
PUBLISHER: Verlag Chemie Gmbh
ADDRESS: D-6940 Weinheim Germany
LANGUAGE: German | **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, flammability limits

Refrigeration Flammability References

AUTHORS: Bier, K.; Crone, M.; and Turk, M.
TITLE: Undersuchen zur thermischen Stabilitat sowie zum Zund- und Brennverhalten der Kaltemittell R152a and R-134a (Thermal Stability and Ignition and Combustion Behavior or Refrigerants R-152a and R-134a)
DOC TYPE: Journal Article **REF NO:** 98
DOCUMENT: DKV Tagungsbericht
VOL NO: 17
ISSUE: 2
YEAR: 1990
PAGE NO: 169-191
PUBLISHER: N/A
ADDRESS:
LANGUAGE: German **IN NMERI LIBRARY:** Yes
KEYWORDS:

AUTHORS: Bier, K.; Oellrich, L.; Turk, M.; Zhai, J.; Dressner, M.; Leisenheimer, B.; and Leukel, W.
TITLE: Investigation of mixtures of refrigerants 152a and 134a as an alternative to refrigerant 12 (Untersuchen des Stoffpaares R134a/R152a als ozonunschadliche Alternative zum Kaltemittel R12)
DOC TYPE: Report **REF NO:** 54
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1993
PAGE NO:
PUBLISHER: BMFT/DKV-Verbundvorhaben Minderung von FCKW-Emissionen in der Klima-und Kaltetechnik
ADDRESS: Karlsruhe Germany
LANGUAGE: German **IN NMERI LIBRARY:** Yes
KEYWORDS: R-152a, R-134a, ignition, flammability

AUTHORS: Bivens, D.B.; Shiflett, M.B.; Shealy, G.S.; et.al.
TITLE: HCFC-22 Alternative for Air Conditioner and Heat Pumps
DOC TYPE: Report **REF NO:** 92
DOCUMENT: ASHRAE Transactions 1994
VOL NO: 100
ISSUE: 2
YEAR: 1994
PAGE NO:
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English **IN NMERI LIBRARY:** Yes
KEYWORDS: R-22, R-32, R-125, R-134a, flammability, leakage

AUTHORS: Blanc, M.V.; Guest, P.G.; Von Elbe, G.; and Lewis, B.
TITLE: Ignition of Explosive Gas Mixtures by Electric Sparks III. Minimum Ignition Energies and Quenching Distances of Mixtures of Hydrocarbons and Ether with Oxygen and Inert Gases
DOC TYPE: Conference Proceedings **REF NO:** 48
DOCUMENT: Third Symposium (International) on Combustion
VOL NO: 3rd
ISSUE:
YEAR: 1949
PAGE NO: 363-367
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
LANGUAGE: English **IN NMERI LIBRARY:** Yes
KEYWORDS: minimum ignition energy, flammability limit

Refrigeration Flammability References

AUTHORS: Borchardt, H.J.; and Gilbaugh, R.C.
TITLE: Hazard of FC22/142b Flammability

DOC TYPE: Report
REF NO: 58
DOCUMENT: KSS-8274
VOL NO:
ISSUE:
YEAR: 1979
PAGE NO:
PUBLISHER: E.I. du Pont Nemours & Co.
ADDRESS: Wilmington DE
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: flammability, R-22, R-142b

AUTHORS: Bradford, B.W.; and Finch, G.I.
TITLE: The Mechanism of Ignition by Electric Discharges

DOC TYPE: Conference Proceedings
REF NO: 49
DOCUMENT: Second Symposium on Combustion
VOL NO: 2nd
ISSUE:
YEAR: 1965
PAGE NO: 112-126
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: ignition, limits of flammability, diluent

AUTHORS: Britton, L.G.
TITLE: Using Material Data in Static Hazard Assessment

DOC TYPE: Journal Article
REF NO: 59
DOCUMENT: Plant/Operations Progress
VOL NO: 11
ISSUE: 2
YEAR: 1992
PAGE NO: 56-70
PUBLISHER: American Institute of Chemical Engineers
ADDRESS: New York, NY 10017
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: mnimum ignition energy, flammability

AUTHORS: Cashdollar, K.L.; Hertzberg, M.; Zlochower, I.A.; Lucci, C.; Green, G.M.; and Thomas, R.A.
TITLE: Laboratory Flammability Studies of Mixtures of Hydrogen Nitrous Oxide and Air

DOC TYPE: Report
REF NO: 83
DOCUMENT: WHC-SD-WM-ES--219
VOL NO:
ISSUE:
YEAR: 1992
PAGE NO:
PUBLISHER: Westinghouse Hanford Company
ADDRESS: Richland, WA
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: flammability, spark ignition, turbulence

AUTHORS: Coward, H.F.; and Jones, G.W.
TITLE: Limits of Flammability of Gases and Vapors

DOC TYPE: Report
REF NO: 14
DOCUMENT: Bureau of Mines Bulletin 503
VOL NO:
ISSUE: 503
YEAR: 1952
PAGE NO:
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: flammability, UEL, LEL, explosion, inertion

AUTHORS: Crescitelli, S.; Russo, G.; Tufano, V.; Napolitano, F.; and Tranchino, L.
TITLE: Flame Propagation in Closed Vessels and Flammability Limits

DOC TYPE: Journal Article
REF NO: 89
DOCUMENT: Combustion Science and Technology
VOL NO: 15
ISSUE:
YEAR: 1977
PAGE NO: 201-212
PUBLISHER: Gordon and Breach Science Publishers, Inc.
ADDRESS: New York, NY
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: flammability, UFL, LFL, flame extinction

AUTHORS: Deguingand, B.; and Galant, S.
TITLE: Upper Flammability Limits of Coal Dust-Air Mixtures

DOC TYPE: Conference Proceedings
REF NO: 37
DOCUMENT: Eighteenth Symposium (International) on Combustion
VOL NO: 18th
ISSUE:
YEAR: 1981
PAGE NO: 705-715
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: UFL, ignition, ignition energy

AUTHORS: Dekleva, T. W.; Lindley, A. A.; and Powell, P.
TITLE: Flammability and Reactivity of Select HFCs and Mixtures

DOC TYPE: Journal Article
REF NO: 1
DOCUMENT: ASHRAE Journal
VOL NO: 35
ISSUE: 12
YEAR: 1993
PAGE NO: 40-47
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: refrigerant flammability, MCLR, R-32, R-125, R-134a, combustibility, ASTM 681-85, R-32 blends, critical flammability ratio, CFR

AUTHORS: **Devotta, S.; and Gopichand, S.**
TITLE: **Comparative Assessment of some Flammable Refrigerants as Alternatives to CFC-12**

DOC TYPE: Conference Proceedings **REF NO:** 77
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 249-257
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
LANGUAGE: English **IN NMERI LIBRARY:** No

KEYWORDS:
flammable, refrigrants,

AUTHORS: **Dieckmann, J.T.; Bentley, J.; and Varone, A.**
TITLE: **Non-Inert Refrigerant Study for Automotive Applications - Final Report**

DOC TYPE: **REF NO:** 85
DOCUMENT: DOE/CE/50274-TI DE92 041034
VOL NO:
ISSUE:
YEAR: 1991
PAGE NO:
PUBLISHER: U.S. Department of Energy
ADDRESS: Washington, DC
LANGUAGE: **IN NMERI LIBRARY:** Yes

KEYWORDS:
refrigerants, flammable refrigerants, HFC-134a, HFC-152a, propane, ignition

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AUTHORS: **DiNenno, P.E.**
TITLE: **The SPFE Handbook of Fire Protection Engineering**

DOC TYPE: Book **REF NO:** 52
DOCUMENT:
VOL NO: 1st
ISSUE:
YEAR: 1988
PAGE NO:
PUBLISHER: National Fire Protection Association
ADDRESS: Quincy, MA 02269
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS:
flammability, ignition

AUTHORS: **Dixon-Lewis, G.; and Isles, G.L.**
TITLE: **Limits of Inflammability**

DOC TYPE: Conference Proceedings **REF NO:** 43
DOCUMENT: Seventh Symposium (International) on Combustion
VOL NO: 7th
ISSUE:
YEAR: 1959
PAGE NO: 475-483
PUBLISHER: Butterworth's Scientific Publisher's
ADDRESS: London, England
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS:
flammability limits

AUTHORS: **Drysdale, D.**
TITLE: **An Introduction to Fire Dynamics**

DOC TYPE: Book
REF NO: 80
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1985
PAGE NO: 78-113
PUBLISHER: John Wiley and Sons
ADDRESS: Chichester, UK
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: flammability limits, ignition, UFL, LFL

AUTHORS: **Eckhoff, R.K.**
TITLE: **Generation, Ignition, Combustion, and Explosion of Sprays and Mists of Flammable Liquids in Air - A Literature Survey**

DOC TYPE: Report
REF NO: 84
DOCUMENT: CMI-R--91/A25014 DE93 721651
VOL NO:
ISSUE:
YEAR: 1991
PAGE NO:
PUBLISHER: Chr. Michelsen Institute
ADDRESS: N-5036 Fantoft Norway
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: ignition, spray mists, flame propagation

AUTHORS: **Egerton, A.C.**
TITLE: **Limits of Inflammability**

DOC TYPE: Conference Proceedings
REF NO: 45
DOCUMENT: Fourth Symposium (International) on Combustion
VOL NO: 4th
ISSUE:
YEAR: 1953
PAGE NO: 4-13
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: flammability, inflammability, diluent

AUTHORS: **Fedorko, G.; Fredrick, L.G.; and Hansel, J.G.**
TITLE: **Flammability Characteristics of Chlorodifluoromethane (R-22)-Oxygen-Nitrogen Mixtures**

DOC TYPE: Journal Article
REF NO: 3
DOCUMENT: ASHRAE Transactions
VOL NO: 2
ISSUE: 3097
YEAR: 1993
PAGE NO:
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: flammability envelope, flammability limit, R-22, heats of reaction

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Refrigeration Flammability References

AUTHORS: Fisher, S.K.; and Sand, J.R.
TITLE: Screening Analysis for Chlorine-Free Alternative Refrigerants to Replace R-22 in Air-Conditioning Applications
DOC TYPE: Report **REF NO:** 87
DOCUMENT: ASHRAE Technical Data Bulletin
VOL NO: 9
ISSUE: 4
YEAR: 1993
PAGE NO: 12-20
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, R-32, R-125, R-134a,

AUTHORS: Fluorochemicals Division, Isotron Department, Atochem North America Inc.
TITLE: Flammability Characteristics of ISOTRON 142b
DOC TYPE: Other **REF NO:** 9
DOCUMENT:
VOL NO:
ISSUE:
YEAR:
PAGE NO:
PUBLISHER: Atochem North America, Inc.
ADDRESS: Philadelphia, PA 19102
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: limits of flammability, flammability limits, explosion pressure, rate of pressure rise, flash point, LEL, UEL, autoignition temperature, heat of combustion

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AUTHORS: Fukutani, Seishiro; Yamamoto, Satoru; and Jinno, Hiroshi
TITLE: Propagation of Unsteady Hydrogen Premixed Flames Near Flammability Limits
DOC TYPE: Conference Proceedings **REF NO:** 28
DOCUMENT: Twenth-third Symposium (International) on Combustion
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 405-411
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability limits, flame propagation, LFL

AUTHORS: Gann, R.G
TITLE: Halogenated Fire Suppressants
DOC TYPE: Conference Proceedings **REF NO:** 79
DOCUMENT: Halogenated Fire Suppressants
VOL NO:
ISSUE:
YEAR: 1990
PAGE NO:
PUBLISHER: University Microfilms International
ADDRESS: Ann Arbor, MI 48106
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, ignition

AUTHORS: **Gerstein, M.; and Stine, W.B.**
TITLE: **Analytic Criteria for Flammability Limits**

DOC TYPE: Conference Proceedings — REF NO: 90
DOCUMENT: Fourteenth Symposium (International) on Combustion
VOL NO: 14
ISSUE:
YEAR: 1973
PAGE NO: 1109-1118
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English — IN NMERI LIBRARY: Yes

KEYWORDS: flammability limits, quenching distance, limit criteria

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AUTHORS: **Gray, P.; Griffiths, J.P.; and Bond, J.R.**
TITLE: **Carbon Monoxide Oxidation: Chemiluminescence and Ignition**

DOC TYPE: Conference Proceedings — REF NO: 38
DOCUMENT: Seventeenth Symposium (International) on Combustion
VOL NO: 17th
ISSUE:
YEAR: 1979
PAGE NO: 811-819
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English — IN NMERI LIBRARY: Yes

KEYWORDS: ignition, chemiluminescence

AUTHORS: **Grob, Don**
TITLE: **Flammability Characteristics of R-32 and R-32 Mixtures**

DOC TYPE: Other — REF NO: 11
DOCUMENT:
VOL NO:
ISSUE:
YEAR: Mar 1991
PAGE NO:
PUBLISHER: Underwriter's Laboratories, Inc.
ADDRESS: Northbrook, IL 60062
LANGUAGE: English — IN NMERI LIBRARY: Yes

KEYWORDS: Westerberg, pressure, humidity, flammability diagram, flammability, R-32, R-134a, ASTM-681

AUTHORS: **Hansel, J.G.; Mitchell, J.W.; and Klotz, H.C.**
TITLE: **Predicting and Controlling Flammability of Multiple Fuel and Multiple Inert Mixtures**

DOC TYPE: Journal Article — REF NO: 60
DOCUMENT: Plant/Operations Progress
VOL NO: 11
ISSUE: 4
YEAR: 1992
PAGE NO: 213-217
PUBLISHER: American Institute of Chemical Engineers
ADDRESS: New York, NY 10017
LANGUAGE: English — IN NMERI LIBRARY: Yes

KEYWORDS: flammability, UFL, LFL

AUTHORS: **Hashiguchi, Y.**
TITLE: **Explosions of Combustible Gases and Vapors**

DOC TYPE: Journal Article **REF NO:** 70
DOCUMENT: Journal of Synthetic Organic Chemistry Japan
VOL NO: 37
ISSUE: 6
YEAR: 1979
PAGE NO: 501-506
PUBLISHER: N/A
ADDRESS:
LANGUAGE: Japanese **IN NMERI LIBRARY:** No

KEYWORDS: N/A

AUTHORS: **Heinonen, E.W.**
TITLE: **The Effect of Ignition Source and Strength on Sphere Ignition Results**

DOC TYPE: Conference Proceedings **REF NO:** 34
DOCUMENT: Halon Alternatives Technical Working Conference 1993
VOL NO:
ISSUE:
YEAR: 1993
PAGE NO: 565-576
PUBLISHER: New Mexico Engineering Research Institute
ADDRESS: Albuquerque, NM 87106
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: ignition, explosion sphere, halocarbons, flammability, flammability curves

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AUTHORS: **Hertzberg, M.**
TITLE: **The Theory of Flammability Limits - Natural Convection**

DOC TYPE: Report **REF NO:** 68
DOCUMENT: Bureau of Mines Report of Investigations 8127
VOL NO: 8127
ISSUE:
YEAR: 1976
PAGE NO:
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability limits

AUTHORS: **Hertzberg, M., Cashdollar, K.L.; and Opferman, J.J.**
TITLE: **The Flammability of Coal Dust-Air Mixtures**

DOC TYPE: Report **REF NO:** 67
DOCUMENT: Bureau of Mines Report of Investigations 8360
VOL NO: 8360
ISSUE:
YEAR: 1979
PAGE NO:
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, ignition, ignition energy

AUTHORS: Hertzberg, Martin; Cashdollar, Kenneth; and Zlochower, Issac
TITLE: Flammability Limit Measurements for Dusts and Gases: Ignition Energy Requirements and Pressure Dependences
DOC TYPE: Conference Proceedings **REF NO:** 19
DOCUMENT: Twenty-first Symposium (International) on Combustion
VOL NO: 21st
ISSUE:
YEAR: 1986
PAGE NO: 303-313
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability limits, ignition strength, methane, dusts, pressure dependence

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AUTHORS: Hertzberg, Martin; Cashdollar, Kenneth; Lazzara; Charles, and Smith, Alex
TITLE: Inhibition and Extinction of Coal Dust and Methane Explosions
DOC TYPE: Report **REF NO:** 22
DOCUMENT: Bureau of Mines Report of Investigations 8708
VOL NO:
ISSUE: 8708
YEAR: 1982
PAGE NO:
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, powdered inhibitors, coal dust, methane, alkali halides, quenching, nitrogen, Halon 1301

AUTHORS: Hertzberg, Martin; Conti, Ronald; and Cashdollar, Kenneth
TITLE: Electrical Ignition Energies and Thermal Autoignition Temperatures for Evaluating Explosive Hazards of Dusts
DOC TYPE: Report **REF NO:** 21
DOCUMENT: Bureau of Mines Report of Investigation 8988
VOL NO:
ISSUE: 8988
YEAR: 1985
PAGE NO:
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: spark ignition, autoignition, effective spark energy, minimum ignition energy, explosion

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AUTHORS: Hertzberg, Martin; Conti, Ronald; and Cashdollar, Kenneth
TITLE: Spark Ignition Energies for Dust-Air Mixtures: Temperature and Concentration Dependencies
DOC TYPE: Conference Proceedings **REF NO:** 20
DOCUMENT: Twentieth Symposium (International) on Combustion
VOL NO: 20th
ISSUE:
YEAR: 1984
PAGE NO: 1681-1690
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: ignition strength, ignition source, effective spark energy, autoignition

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AUTHORS: Hilado, Carlos; and Cumming, Heather
TITLE: The HC Value: A Method for Estimating the Flammability of Mixtures of Combustible Gases

DOC TYPE: Journal Article — **REF NO:** 4
DOCUMENT: Fire Technology
VOL NO:
ISSUE:
YEAR:
PAGE NO: 195-198
PUBLISHER: National Fire Protection Association
ADDRESS: Quincy, MA 02269
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability limit, Le Chatelier's law, HC value

AUTHORS: Hustad, J.E.; and Sønju, O.K.
TITLE: Experimental Studies of Lower Flammability Limits of Gases and Mixture of Gases at Elevated Temperatures

DOC TYPE: Journal Article — **REF NO:** 62
DOCUMENT: Combustion and Flame
VOL NO: 71
ISSUE:
YEAR: 1988
PAGE NO: 283-294
PUBLISHER: Elsevier Science Publishing Co.
ADDRESS: New York, NY 10017
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, LFL, gas, mixtures

AUTHORS: Ishii, K.; Tsukamoto, T.; Ujiie, Y.; and Kono, M.
TITLE: Analysis of Ignition Mechanisms of Combustible Mixtures by Composite Sparks

DOC TYPE: Journal Article — **REF NO:** 74
DOCUMENT: Combustion and Flame
VOL NO: 91
ISSUE: 2
YEAR: 1992
PAGE NO: 153-164
PUBLISHER: Elsevier Science Publishing Co.
ADDRESS: New York, NY 10017
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: ignition, flammability, combustible mixture, spark

AUTHORS: Kono, M.; Kumagai, S.; and Sakai, T.
TITLE: The Optimum Condition for Ignition of Gases by Composite Sparks

DOC TYPE: Conference Proceedings — **REF NO:** 39
DOCUMENT: Sixteenth Symposium (International) on Combustion
VOL NO: 16th
ISSUE:
YEAR: 1977
PAGE NO: 757-766
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: ignition, composite sparks, spark duration

AUTHORS: Lakshima, K.N.; Paul, P.J.; and Mukunda, H.S.
TITLE: On the Flammability Limit and Heat Loss in Flames with Detailed Chemistry

DOC TYPE: Conference Proceedings **REF NO:** 31
DOCUMENT: Twenth-third Symposium (International) on Combustion
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 433-440
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability limit, LFL

AUTHORS: Law, C.K.; and Egolfopolous, F.N.
TITLE: A Kinetic Criterion of Flammability Limits: The C-H-O-Inert System

DOC TYPE: Conference Proceedings **REF NO:** 29
DOCUMENT: Twenth-third Symposium (International) on Combustion
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 413-421
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability limits, LFL, UFL, C-H-O-inert system

AUTHORS: Levy, A.
TITLE: An Optical Study of Flammability Limits

DOC TYPE: Journal Article **REF NO:** 72
DOCUMENT: Proceedings of The Royal Society (London), Vol A
VOL NO: 283
ISSUE:
YEAR: 1965
PAGE NO: 134-145
PUBLISHER: Royal Society (London)
ADDRESS: London, SW1Y 5AG England
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, flammability limits, flame propagation, lower flammability limit

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AUTHORS: Lewis, B.; and Von Elbe, G
TITLE: Combustion, Flames, and Explosion of Gases, 3rd Ed.

DOC TYPE: Book **REF NO:** 57
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1987
PAGE NO:
PUBLISHER: Academic Press, Inc.
ADDRESS: Orlando, FL 32887
LANGUAGE: English **IN NMERI LIBRARY:** No

KEYWORDS: flammability, flammability limits, combustion, LFL, UFL,

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AUTHORS: Li, G.; and Wang, C.
TITLE: Comprehensive Study on Electric Spark Sensitivities of Ignitable Gases and Explosive Powders

DOC TYPE: Journal Article | REF NO: 56
DOCUMENT: Journal of Electrostatics
VOL NO: 11
ISSUE:
YEAR: 1982
PAGE NO: 319-332
PUBLISHER: Elsevier Scientific Publishing Company
ADDRESS: Amsterdam, The Netherlands
LANGUAGE: English | IN NMERI LIBRARY: Yes

KEYWORDS: flammability, ignition, minimum ignition energy, spark ignition, humidity

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AUTHORS: Linnett, J.W.; and Simpson, J.S.M
TITLE: Limits of Inflammability

DOC TYPE: Conference Proceedings | REF NO: 44
DOCUMENT: Sixth Symposium (International) on Combustion
VOL NO: 6th
ISSUE:
YEAR: 1957
PAGE NO: 20-27
PUBLISHER: Reinhold Publishing Corporation
ADDRESS: New York, NY
LANGUAGE: English | IN NMERI LIBRARY: Yes

KEYWORDS: flammability limits

AUTHORS: Litchfield, E.L.; Hay, M.H.; Kubala, T.A.; and Monroe, J.S.
TITLE: Minimum Ignition Energy and Quenching Distance in Gaseous Mixtures - techniques and Apparatus

DOC TYPE: Report | REF NO: 81
DOCUMENT: Bureau of Mines Report of Investigation 7009
VOL NO: 7009
ISSUE:
YEAR: 1967
PAGE NO:
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
LANGUAGE: English | IN NMERI LIBRARY: Yes

KEYWORDS: minimum ignition energy, quenching distance, ignition

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AUTHORS: Lovachev, L.A.
TITLE: Flammability Limits - a Review

DOC TYPE: Journal Article | REF NO: 78
DOCUMENT: Combustion Science and Technology
VOL NO: 20
ISSUE:
YEAR: 1979
PAGE NO: 209-224
PUBLISHER: Gordon and Breach Science Publishers, Inc.
ADDRESS: New York, NY
LANGUAGE: English | IN NMERI LIBRARY: Yes

KEYWORDS: flammability limits, ignition

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AUTHORS: Lovachev, L.A.; Babkin, V.S.; Bunev, V.A.; V'yun, A.V.; Krivulin, V.N.; and Baratov, A.N.
TITLE: Flammability Limits: An Invited Review

DOC TYPE: Journal Article
REF NO: 71
DOCUMENT: Combustion and Flame
VOL NO: 20
ISSUE:
YEAR: 1973
PAGE NO: 259-289
PUBLISHER: Elsevier Science Publishing Co.
ADDRESS: New York, NY 10017
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: flammability, flammability limits, flames, inhibition, ignition

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AUTHORS: McLinden, Mark O.; and Didion, David A.
TITLE: Quest for Alternatives

DOC TYPE: Journal Article
REF NO: 6
DOCUMENT: ASHRAE Journal
VOL NO: 29
ISSUE: 12
YEAR: 1987
PAGE NO: 32-42
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: R-12, alternative refrigerants, CFC, thermodynamic, flammability, toxicity,

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AUTHORS: Multiple
TITLE: 1993 ASHRAE Handbook Fundamentals SI Edition

DOC TYPE: Book
REF NO: 53
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1993
PAGE NO:
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: refrigerant, refrigerant properties

AUTHORS: Multiple
TITLE: ARI Flammability Workshop March 8-9 1994 Chicago Illinois

DOC TYPE: Conference Proceedings
REF NO: 27
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1994
PAGE NO:
PUBLISHER: Air Conditioning and Refrigeration Institute
ADDRESS: Arlington, VA 22203
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: refrigerant, flammability, ASTM E682, UEL, LEL, test methods

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AUTHORS: N/A
TITLE: **Hoechst Suffers Explosion at Frankfurt 134a Facility**

DOC TYPE: Journal Article **REF NO:** 26
DOCUMENT: Chemical Marketing Reporter
VOL NO: 245
ISSUE: 12
YEAR: March 28 1994
PAGE NO: 1, 40
PUBLISHER: Chemical Marketing Reporter
ADDRESS: New York, NY 10004
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS:
R-134a, explosion, Hoechst

AUTHORS: N/A
TITLE: **KLEA 32 Blends: Flammability Characteristics**

DOC TYPE: Report **REF NO:** 10
DOCUMENT:
VOL NO:
ISSUE: 1
YEAR: Mar 92
PAGE NO:
PUBLISHER: ICI Chemicals and Polymers
ADDRESS:
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS:
R-32, flammability, ignition, heat of combustion, blends, R-134a, critical flammability ratio, leakage, lubricant, elastomer, R-125, ASHRAE

AUTHORS: **Ohnishi, H.; Izutani, N.; Inagaki, S.; Karasawa, K.; Ishida, S.; and Kataoka, O.**
TITLE: **Relationship between Flammability and Composition Ratio of HFC-32/HFC-134a Blend**

DOC TYPE: Conference Proceedings **REF NO:** 23
DOCUMENT: ASHRAE/NIST Refrigerants Conference on R-22/R-502 Alternatives
VOL NO:
ISSUE: August
YEAR: 1993
PAGE NO:
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English **IN NMERI LIBRARY:** No

KEYWORDS:

AUTHORS: **Pannock, J.; Didion, D.A.; and Radermacher, R.**
TITLE: **Performance Evaluation of Chlorine Free Zeotropic Refrigerant Mixtures in Heat Pumps - Computer Study and Tests**
DOC TYPE: Conference Proceedings **REF NO:** 95
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 25-34
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS:
refrigerants, R-32, R-134a

Refrigeration Flammability References

AUTHORS: **Powell, F.**
TITLE: **Ignition of Gases and Vapors**

DOC TYPE: Journal Article **REF NO:** 50
DOCUMENT: Industrial and Engineering Chemistry
VOL NO: 61
ISSUE: 12
YEAR: 1969
PAGE NO: 29-37
PUBLISHER: American Chemical Society Publications
ADDRESS: Washington DC 20036
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: ignition, gases, friction, impact

AUTHORS: **Pu, Y.K.; Jarosinski, J.; Johnson, V.G.; and Kauffman, C.W.**
TITLE: **Turbulence Effects on Dust Explosions in the 20-Liter Spherical Vessel**

DOC TYPE: Conference Proceedings **REF NO:** 32
DOCUMENT: Twenty-third Symposium (International) on Combustion
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 843-849
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: explosion sphere, burning rate

AUTHORS: **Radermacher, R.; and Jung, D.**
TITLE: **Theoretical Analysis of Replacement Refrigerants for R-22 for Residential Uses**

DOC TYPE: Report **REF NO:** 75
DOCUMENT: US EPA Report EPA/400/1-91/041
VOL NO:
ISSUE:
YEAR: 1991
PAGE NO:
PUBLISHER: US Environmental Protection Agency
ADDRESS: Washington, DC
LANGUAGE: English **IN NMERI LIBRARY:** No

KEYWORDS:

AUTHORS: **Reed, Paul R.; and Rizzo, Joseph J.**
TITLE: **Combustibility and Stability Studies of CFC Substitutes with Simulated Motor Failures in Hermetic Refrigeration Equipment**
DOC TYPE: Conference Proceedings **REF NO:** 33
DOCUMENT: XVIII International Congress of Refrigeration
VOL NO: 18th
ISSUE:
YEAR: 10-17 Aug 1991
PAGE NO:
PUBLISHER: International Institute of Refrigeration
ADDRESS:
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability of refrigerants, HFC-134a, combustibility

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Refrigeration Flammability References

AUTHORS: Richard, R.G.; and Shankland, I.R.
TITLE: Flammability of Alternative Refrigerants

DOC TYPE: Conference Proceedings **REF NO:** 25
DOCUMENT: Proceedings of the XVIII International Congress of Refrigeration
VOL NO: II
ISSUE: Paper #42
YEAR: 1991
PAGE NO:
PUBLISHER: Unknown
ADDRESS:
LANGUAGE: English **IN NMERI LIBRARY:** No

KEYWORDS: refrigerant flammability, CFCs, HFCs, ASTM E-681, ignition, R-32, R-152a

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AUTHORS: Richard, Robert G.; and Shankland, Ian
TITLE: Flammability of Alternative Refrigerants

DOC TYPE: Journal Article **REF NO:** 2
DOCUMENT: ASHRAE Journal
VOL NO: 34
ISSUE: 4
YEAR: 1992
PAGE NO: 20-24
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: refrigerant flammability, CFCs, HFCs, ASTM E-681, ignition, R-32, R-152a

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AUTHORS: Rose, H.E.; and Priede, T.
TITLE: An Investigation of the Characteristics of Spark Discharges as Employed in Ignition Experiments

DOC TYPE: Conference Proceedings **REF NO:** 42
DOCUMENT: Seventh Symposium (International) on Combustion
VOL NO: 7th
ISSUE:
YEAR: 1959
PAGE NO: 454-463
PUBLISHER: Butterworth's Scientific Publisher's
ADDRESS: London, England
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: ignition, minimum ignition energy

AUTHORS: Rose, H.E.; and Priede, T.
TITLE: Ignition Phenomena in Hydrogen-Air Mixtures

DOC TYPE: Conference Proceedings **REF NO:** 41
DOCUMENT: Seventh Symposium (International) on Combustion
VOL NO: 7th
ISSUE:
YEAR: 1959
PAGE NO: 436-445
PUBLISHER: Butterworth's Scientific Publisher's
ADDRESS: London, England
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS: ignition, minimum ignition energy

AUTHORS: **Roth, W.; Guest, P.G.; Von Elbe, G.; and Lewis, B.**
TITLE: **Heat Generation by Electrical Sparks and Rate of Heat Loss to the Spark Electrodes**

DOC TYPE: Journal Article — **REF NO:** 82
DOCUMENT: The Journal of Physical Chemistry
VOL NO: 19
ISSUE: 12
YEAR: 1953
PAGE NO: 1530-1535
PUBLISHER: The Journal of Physical Chemistry
ADDRESS:
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: ignition, spark ignition, minimum ignition energy

AUTHORS: **Sand, James R.; and Andrjeski, D.L.**
TITLE: **Combustibility of Chlorodifluoromethane**

DOC TYPE: Journal Article — **REF NO:** 8
DOCUMENT: ASHRAE Journal
VOL NO: 24
ISSUE: 5
YEAR: 1982
PAGE NO: 38-40
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: R-22, refrigerant-22, combustibility, flammability, heat of combustion,

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AUTHORS: **Sanvordenker, K.S.**
TITLE: **Experimental Evaluation of an R-32/R-134a Blend as a Near Drop-in Substitute for R-22**

DOC TYPE: Report — **REF NO:** 88
DOCUMENT: ASHRAE Technical Data Bulletin
VOL NO: 9
ISSUE: 4
YEAR: 1993
PAGE NO: 34-39
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, R-32, R-134a

AUTHORS: **Shankland, Ian R.**
TITLE: **Some Issues Related to Flammability Classification of Refrigerants, or When is a Refrigerant Flammable? How Flammable is Flammable?**
DOC TYPE: Conference Proceedings — **REF NO:** 7
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1993
PAGE NO:
PUBLISHER: AlliedSignal Chemicals
ADDRESS: Buffalo, NY 14210
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: refrigerant flammability standards, codes, regulations, ASTM-E-681, flammable,

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Refrigeration Flammability References

AUTHORS: Shaoqiang, H.; Xiaoping, L.; and Chunfei, X.
TITLE: Refrigerant HCR-152a Flammability Test Results

DOC TYPE: Report
REF NO: 76
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1991
PAGE NO:
PUBLISHER: Wanbao Refrigerator Industrial Corporation
ADDRESS: China
LANGUAGE: English
IN NMERI LIBRARY: No

KEYWORDS:

AUTHORS: Sheldon, M.
TITLE: Principles of Spark Ignition

DOC TYPE: Journal Article
REF NO: 55
DOCUMENT: Fire Protection
VOL NO: 165
ISSUE:
YEAR: 1983
PAGE NO: 27-31
PUBLISHER: Fire Protection Association
ADDRESS: London, England, UK
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: ignition, spark ignition, flammability, flammable vapors, flammable gases

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AUTHORS: Sherbo, H.N.; Korolchenko, A.Y.; Eremenko, O.Y.; Tsarickenko, S.G; Navtshenya, V.Y.; and Ilin, A.B.
TITLE: Concentration Limits of Flammability in Vapor-Gas Mixtures Based on Halohydrocarbons

DOC TYPE: Journal Article
REF NO: 69
DOCUMENT: Zhurnal Fizicheskoi Khimii
VOL NO: 64
ISSUE: 5
YEAR: 1991
PAGE NO: 1327-1331
PUBLISHER: N/A
ADDRESS:
LANGUAGE: Russian
IN NMERI LIBRARY: No

KEYWORDS: N/A

AUTHORS: Shiflett, M.B.; Yokozeki, A.; and Bivens, D.B.
TITLE: Refrigerant Mixtures as HCFC-22 Alternatives

DOC TYPE: Conference Proceedings
REF NO: 96
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 35-44
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
LANGUAGE: English
IN NMERI LIBRARY: Yes

KEYWORDS: flammability, refrigerant, R-32, R-134a,

AUTHORS: Shiflett, M.B.; Yokozeki, A.; and Reed, P.R.
TITLE: Property and Performance Evaluation of "Suva" HP Refrigerants as R-502 Alternatives
DOC TYPE: Conference Proceedings | **REF NO:** 94
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 15-24
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
LANGUAGE: English | **IN NMERI LIBRARY:** Yes
KEYWORDS: flammability, refrigerants, leakage

AUTHORS: Sicars, S.; Hesse, U.; and Kruse, H.
TITLE: Theoretische Undersuchungen zur Brennbarkeit von Kaltemitteln und Kaltemittelgemischen (Theoretical Investigation of the Combustion of Refrigerants and Refrigerant Blends)
DOC TYPE: Journal Article | **REF NO:** 97
DOCUMENT: N/A
VOL NO: N/A
ISSUE: N/A
YEAR: N/A
PAGE NO:
PUBLISHER: N/A
ADDRESS:
LANGUAGE: German | **IN NMERI LIBRARY:** Yes
KEYWORDS: N/A

AUTHORS: Singh, A.K.
TITLE: Spark Ignition of Aerosols
DOC TYPE: Conference Proceedings | **REF NO:** 36
DOCUMENT: Twenty-first Symposium (International) on Combustion
VOL NO: 21st
ISSUE:
YEAR: 1986
PAGE NO: 513-519
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
LANGUAGE: English | **IN NMERI LIBRARY:** Yes
KEYWORDS: ignition, flame propagation

AUTHORS: Skaggs, S.R.; Heinonen, E.W.; Moore, T. A.; and Kirst, J.A.
TITLE: Low Ozone-Depleting Halocarbons as Total-Flood Agents: Volume 2: Laboratory-Scale Fire Suppression and Explosion Prevention (Draft Report)
DOC TYPE: Report | **REF NO:** 35
DOCUMENT: New Mexico Engineering Research Institute OC 92/26
VOL NO:
ISSUE:
YEAR: Sep 1993
PAGE NO:
PUBLISHER: New Mexico Engineering Research Institute
ADDRESS: Albuquerque, NM 87106
LANGUAGE: English | **IN NMERI LIBRARY:** Yes
KEYWORDS: explosion sphere, inerting concentration, ignition

AUTHORS: **Smith, N.D.; Ratanaphruks, K.; Tufts, M.; and Ng, A.S.**
TITLE: **R-245ca: A Potential Far-term Alternative for R-11**

DOC TYPE: Journal Article — **REF NO:** 73
DOCUMENT: ASHRAE Journal
VOL NO: 35
ISSUE: 2
YEAR: 1993
PAGE NO: 19-23
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, R-245ca, moisture, humidity

AUTHORS: **Sokolik, A.S.**
TITLE: **Self-Ignition, Flame and Detonation in Gases**

DOC TYPE: Book — **REF NO:** 65
DOCUMENT: NASA TT F-125
VOL NO:
ISSUE:
YEAR: 1963
PAGE NO:
PUBLISHER: Unknown
ADDRESS:
LANGUAGE: English — **IN NMERI LIBRARY:** No

KEYWORDS: ignition, combustion, gases

AUTHORS: **Sorenson, S.C.; Savage, L.D.; and Strehlow, R.A.**
TITLE: **Flammability Limits - A New Technique**

DOC TYPE: Journal Article — **REF NO:** 63
DOCUMENT: Combustion and Flame
VOL NO: 24
ISSUE:
YEAR: 1975
PAGE NO: 347-355
PUBLISHER: Elsevier Science Publishing Co.
ADDRESS: New York, NY 10017
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, flammability limits, premixed flames

AUTHORS: **Sundaresan, S.G.**
TITLE: **Near Azeotrope Refrigerants to Replace R502 in Commercial Refrigeration**

DOC TYPE: Conference Proceedings — **REF NO:** 93
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 1-13
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
LANGUAGE: English — **IN NMERI LIBRARY:** Yes

KEYWORDS: flammability, refrigerants, fractionation

AUTHORS: Swift, I.
TITLE: Developments in Explosion Protection
DOC TYPE: Report | **REF NO:** 61
DOCUMENT: Plant/Operations Progress
VOL NO: 7
ISSUE: 3
YEAR: 1988
PAGE NO: 159-168
PUBLISHER: American Institute of Chemical Engineers
ADDRESS: New York, NY 10017
LANGUAGE: English | **IN NMERI LIBRARY:** Yes

KEYWORDS: explosion, gas, dust, ignition

AUTHORS: Underwriter's Laboratory
TITLE: File USNC181, Project 89NK14414, Report on Alternatives to Currently-Used Chlorofluorocarbon (CFC) Refrigerants
DOC TYPE: Report | **REF NO:** 5
DOCUMENT:
VOL NO:
ISSUE:
YEAR: 1989.
PAGE NO:
PUBLISHER: Underwriter's Laboratories, Inc.
ADDRESS: Northbrook, IL 60062
LANGUAGE: English | **IN NMERI LIBRARY:** Yes

KEYWORDS: R-12, flammable refrigerants, fire, explosion, alternative refrigerants, ASTM E681-85, ASTM E981-83, ignition, products of combustion, toxicity, leakage

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AUTHORS: Von Elbe, G.
TITLE: The Problem of Ignition
DOC TYPE: Conference Proceedings | **REF NO:** 46
DOCUMENT: Fourth Symposium (International) on Combustion
VOL NO: 4th
ISSUE:
YEAR: 1953
PAGE NO: 13-20
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
LANGUAGE: English | **IN NMERI LIBRARY:** Yes

KEYWORDS: ignition, spark ignition, minimum ignition energy

AUTHORS: Von Lavante, E.; and Strehlow, R.A.
TITLE: The Mechanism of Lean Limit Flame Extinction
DOC TYPE: Journal Article | **REF NO:** 64
DOCUMENT: Combustion and Flame
VOL NO: 49
ISSUE:
YEAR: 1983
PAGE NO: 123-140
PUBLISHER: Elsevier Science Publishing Co.
ADDRESS: New York, NY 10017
LANGUAGE: English | **IN NMERI LIBRARY:** Yes

KEYWORDS: flame extinction, flammability, flammability limits

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AUTHORS: Zabetakis, M.G.; and Richmond, J.K.
TITLE: The Determination and Graphic Representation of the Limits of Flammability of Complex Hydrocarbon Fuels at Low Temperatures and Pressures
DOC TYPE: Conference Proceedings **REF NO:** 24
DOCUMENT: Fourth Symposium (International) on Combustion
VOL NO: 4th
ISSUE:
YEAR: 1953
PAGE NO: 121-126
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
LANGUAGE: English **IN NMERI LIBRARY:** No

KEYWORDS:
flammability, flammability limits, ignition, ignition source

AUTHORS: Zabetakis, Michael G.
TITLE: Flammability Characteristics of Combustible Gases and Vapors
DOC TYPE: Report **REF NO:** 15
DOCUMENT: Bureau of Mines 627
VOL NO:
ISSUE: 627
YEAR: 1965
PAGE NO:
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
LANGUAGE: English **IN NMERI LIBRARY:** Yes

KEYWORDS:
flammability, UEL, LEL, explosion, inertion, autoignition, burning-rate

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APPENDIX C. LONG FORM PRINTOUT

AUTHOR: Abbud-Madrid, Angel; and Ronney, Paul D.

TITLE: Effects of Radiative and Diffusive Transport Processes on Premixed Flames Near the Flammability Limits

DOC TYPE: Conference Proceeding
DOCUMENT: Twenty-third Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 423-431
LANGUAGE: English

KEYWORDS: flammability limits, flame extinguishment, transport properties

REFERENCE NUMBER: 30 **IN NMERI LIBRARY:** Yes

ABSTRACT:

A study of the mechanisms of flammability limits and the dynamics of flame extinguishment in premixed gas flames is described, a novel feature of which is the use of diluent gases having a wide range of radiative and diffusive transport properties. This feature enables an assessment of the importance of volumetric heat losses and Lewis number effects on these mechanisms Additionally, effects of flame dynamics and flame front curvature are studied by employing spherically expanding flames obtained in a microgravity environment whereby natural convection is eliminated. New diagnostics include chamber pressure measurements and the first reported species concentration measurements in a microgravity combustion experiment. The limit mechanisms and extinguishment phenomena are found to be strongly influenced by the combined effects of radiant heat loss, Lewis number and flame curvature. Two new and as yet not well understood phenomena are reported: "double flames" in rich H2-O2-CO2 mixtures and "inverse flammability region" in rich C3H8-O2-CO2 mixtures.

AUTHOR: Allsop, G.; and Guenault, E.M.

TITLE: The Incendivity of Electric Sparks in Relation to the Characteristics of the Circuit

DOC TYPE: Conference Proceeding
DOCUMENT: Third Symposium (International) on Combustion
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
VOL NO: 3rd
ISSUE:
YEAR: 1949
PAGE NO: 341-353
LANGUAGE: English

KEYWORDS: spark ignition, flammability

REFERENCE NUMBER: 47 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The concept of how spark ignition ignites flammable mixtures is examined. The composition of the gas or vapor, the circuit voltage, circuit inductance, the rate of separation of the electrodes, the frequency of the voltage supply, and the size and material of the electrodes are discussed. The effect of these factors on mine safety is further discussed.

AUTHOR: Andrews, G.E.; and Bradley, D.

TITLE: Limits of Flammability and Natural Convection for Methane-Air Mixtures

DOC TYPE: Conference Proceeding
DOCUMENT: Fourteenth Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 14
ISSUE:
YEAR: 1973
PAGE NO: 1119-1128
LANGUAGE: English

KEYWORDS: flammability limits, velocity, convection

REFERENCE NUMBER: 91 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The existing methods of measuring the limits of flammability are critically reviewed. Experimental results are presented that were obtained with a cylindrical vessel equipped with windows. Flame propagation was recorded using a laser source, schlieren-interferometric techniques, and a high-speed camera. Gas velocities ahead of the flame front were measured with a hot-wire anemometer. These techniques also provided information on hot-gas kernels produced by the spark, but with no flame propagation. Limits of flammability were observed for upward and downward propagation, and burning velocities in near limit flames were measured, together with hot-gas convective rise velocities.

A theory is developed for the effects of natural convection, in which the buoyancy force acting on the hot kernel is equated to the kernel's rate of change of momentum. The reasons for the neglect of drag in the early stages are discussed. The theory gives the time for the top of the flame to move a given distance, and the convective rise velocity. There is fair agreement with the experimental results.

The role of natural convection in determining the limit for downward propagation is discussed. The limit for upward. propagation is discussed in terms of wall quenching, gas-phase quenching, and initial failure to ignite the mixture.

AUTHOR: ASTM

TITLE: E 582 - 76 (Reapproved 1981) Standard Test Method for Minimum Ignition Energy and Quenching Distance in Gaseous Mixtures

DOC TYPE: Standard
DOCUMENT:
PUBLISHER: American Society for Testing and Materials
ADDRESS: Philadelphia, PA 19103
VOL NO:
ISSUE:
YEAR: 1985
PAGE NO:
LANGUAGE: English

KEYWORDS: minimum ignition energy, test technique

REFERENCE NUMBER: 66 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This method covers the determination of minimum energy for ignition (initiation of deflagration) and associated flat-plate ignition quenching distances. While the complete description is specific to alkane or alkene fuels with air at normal ambient temperatures and pressures, it can be extended to other fuel-oxidizer combinations and to other temperatures and pressures under certain conditions.

AUTHOR: ASTM

TITLE: E 659-78 (Reapproved 1989) Standard Test Method of Autoignition Temperature of Chemicals

DOC TYPE: Standard
DOCUMENT: ASTM
PUBLISHER: American Society for Testing and Materials
ADDRESS: Philadelphia, PA 19103
VOL NO:
ISSUE:
YEAR: 1989
PAGE NO:
LANGUAGE: English

KEYWORDS: autoignition temperature, ignition

REFERENCE NUMBER: 17 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This standard test method covers the determination of hot- and cool-flame autoignition temperatures of a liquid chemical in air at atmospheric pressure in a uniformly heated vessel. Both the apparatus and technique are described.

AUTHOR: ASTM

TITLE: E 918-83 (Reapproved 1988) Standard Practice for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure

DOC TYPE: Standard

DOCUMENT: ASTM

PUBLISHER: American Society for Testing and Materials

ADDRESS: Philadelphia, PA 19103

VOL NO:

ISSUE:

YEAR: 1988

PAGE NO:

LANGUAGE: English

KEYWORDS: E 918, flammability, limits of flammability, LFL, UFL, UEL, LEL, flame propagation, elevated temperature

REFERENCE NUMBER: 18 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This standard practice covers the determination of the lower and upper concentration limits of flammability of combustible vapor-oxidant mixtures at temperatures up to 200C and initial pressures up to as much as 1.38 MPa (200 psia). Both equipment and technique are described.

AUTHOR: ASTM

TITLE: E-681-85 (Reapproved 1991) Standard Test Method for Concentration of Flammability of Chemicals

DOC TYPE: Standard

DOCUMENT:

PUBLISHER: American Society for Testing and Materials

ADDRESS: Philadelphia, PA 19103

VOL NO:

ISSUE:

YEAR: 1991

PAGE NO:

LANGUAGE: English

KEYWORDS: E 681, flammability, limits of flammability, LFL, UFL, UEL, LEL, flame propagation

REFERENCE NUMBER: 16 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This standard test method covers the determination of the lower and upper concentration limits of chemicals having sufficient vapor pressure to form flammable mixtures in air at one atmosphere pressure for the test temperature. Test equipment and technique are described.

AUTHOR: Ballal, D.R.; and Lefebvre, A.H.

TITLE: The Influence of Flow Parameters on Minimum Ignition Energy and Quenching Distances

DOC TYPE: Conference Proceeding
DOCUMENT: Fifteenth Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 15th
ISSUE:
YEAR: 1974
PAGE NO: 1473-1481
LANGUAGE: English

KEYWORDS: ignition, minimum ignition energy

REFERENCE NUMBER: 40 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Experiments have been carried out on the effects of pressure, velocity, mixture strength, turbulence intensity and turbulence scale on minimum ignition energy and quenching distance. Tests were conducted at room temperature in a specially designed closed-circuit tunnel in which a fan was used to drive propane/air mixtures at subatmospheric pressures through a 9 cm square working section at velocities up to 50 m/sec. Perforated plates located at the upstream end of the working section provided near-isotropic turbulence in the ignition zone ranging from 1 to 22 percent in intensity, with values of turbulence scale up to 0.8 cm. Ignition was effected using capacitance sparks whose energy and duration could be varied independently.

The results of these tests showed that rectangular, arc-type sparks of 60 microsecond duration gave lower than previously reported values of ignition energy for both stagnant and flowing mixtures. It was found that both quenching distance and minimum ignition energy increased with (a) increase in velocity, (b) reduction in pressure, (c) departures from stoichiometric fuel/air ratio, and (d) increase in turbulence intensity. Increase in turbulence intensity. Equations based on an idealized model of the ignition process satisfactorily predicted all the experimental data on minimum ignition energy.

AUTHOR: Bartknecht, W.

TITLE: Explosions

DOC TYPE: Book
DOCUMENT:
PUBLISHER: Springer-Verlag
ADDRESS: New York, NY
VOL NO:
ISSUE:
YEAR: 1981
PAGE NO:
LANGUAGE: English

KEYWORDS: flammability, combustibility, explosion, inerting, ignition energy, explosion pressure, rate of pressure rise, Kg

REFERENCE NUMBER: 12 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This book describes the features of explosion, detonations, and deflagrations such as the violence of explosions (overpressure and rate of pressure rise) and how they are affected by environmental conditions such as ignition sources. Flammable limits are discussed for both dusts and gases.

AUTHOR: Bartknecht, W.

TITLE: Ignition Capabilities of Hot Surfaces and Mechanically Generated Sparks in Flammable Gas and Dust/Air Mixtures

DOC TYPE: Journal Article
DOCUMENT: Plant/Operations Progress
PUBLISHER: American Institute of Chemical Engineers
ADDRESS: New York, NY 10017
VOL NO: 7
ISSUE: 2
YEAR: 1988
PAGE NO: 114-121
LANGUAGE: English

KEYWORDS:
sparks, ignition, flammable gas

REFERENCE NUMBER: 51 **IN NMERI LIBRARY:** Yes

ABSTRACT:

A review with 5 refs. on tests which show that hot surfaces are the most frequent ignition sources. not mechanically produced sparks. An electrically equivalent energy is defined to correlate ignition temperature of a mechanically produced spark to the electrical energy in a capacitance spark.

AUTHOR: Bartknecht, Wolfgang

TITLE: Dust Explosions

DOC TYPE: Book
DOCUMENT:
PUBLISHER: Springer-Verlag
ADDRESS: New York, NY
VOL NO:
ISSUE:
YEAR: 1989
PAGE NO:
LANGUAGE: English

KEYWORDS:
flammability, combustibility, explosion, inerting, ignition energy, explosion presssure, rate of pressusre rise, Kg

REFERENCE NUMBER: 13 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This book discusses the flammability of dusts. It also describes flammable limits and minimum ignition energies for explosions.

AUTHOR: Berthold, W.; Conrad, D.; Grewer, T.; Grosse-Wortmann, T.; Redeker, T.; and Schak

TITLE: Entwicklung einer Standard-Apparat zur Messung von Explosiongrenzen (Development of a Standard Apparatus for Measurement of Explosive Limits)

DOC TYPE: Journal Article
DOCUMENT: Chem-Ing.-Tech
PUBLISHER: Verlag Chemie Gmbh
ADDRESS: D-6940 Weinheim Germany
VOL NO: 56
ISSUE: 2
YEAR: 1984
PAGE NO: 126-127
LANGUAGE: German

KEYWORDS: flammability, flammability limits

REFERENCE NUMBER: 86 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This document describes a method of determining flammability limits. Results from this method are indicate that flammability limits are wider than for other methods. For example, for methane, the LFL was measured as being between 4.3 and 4.4% and the UFL was measured between 15.9 and 17.4% at room temperature (as compared to 5% and 15% for most other publications. Ethylene limits were listed at 2.1 to 2.4% for the LFL and 31.5 to 32.7% for the UFL (as compared to 2.75 to 28.6%).

AUTHOR: Bier, K.; Crone, M.; and Turk, M.

TITLE: Undersuchen zur thermischen Stabilitat sowie zum Zund- und Brennverhalten der Kaltemittell R152a and R-134a (Thermal Stability and Ignition and Combustion

DOC TYPE: Journal Article
DOCUMENT: DKV Tagungsbericht
PUBLISHER: N/A
ADDRESS:
VOL NO: 17
ISSUE: 2
YEAR: 1990
PAGE NO: 169-191
LANGUAGE: German

KEYWORDS:

REFERENCE NUMBER: 98 **IN NMERI LIBRARY:** Yes

ABSTRACT:

AUTHOR: Bier, K.; Oellrich, L.; Turk, M.; Zhai, J.; Dressner, M.; Leisenheimer, B.; and Leukel,

TITLE: Investigation of mixtures of refrigerants 152a and 134a as an alternative to refrigerant 12 (Untersuchen des Stoffpaares R134a/R152a als ozonunschadliche

DOC TYPE: Report

DOCUMENT:

PUBLISHER: BMFT/DKV-Verbundvorhaben Minderung von FCKW-Emissionen in der Klima-und Kaltetechnik

ADDRESS: Karlsruhe Germany

VOL NO:

ISSUE:

YEAR: 1993

PAGE NO:

LANGUAGE: German

KEYWORDS: R-152a, R-134a, ignition, flammability

REFERENCE NUMBER: 54 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The thermal stability has been investigated for refrigerants 134a and 152a as well as for mixtures of both substances. The tests were performed in combination with the materials of a commercial refrigeration compressor and with a suitable compressor oil. The thermal stability of an equimolar mixture of 134a and 152a is at least equivalent to that of refrigerant 12.

It has been shown that the combustion behaviour of R152a in mixture with air is similar to that of methane. Admixing of R134a leads to a remarkable increase in the minimum ignition energy and of the maximum burning velocity. The combustion properties of an equimolar mixture of refrigerants 134a and 152a are comparable to those of ammonia. Mixtures with more than 82 mole percent R134a are not ignitable in air.

In a refrigeration cycle, mixtures of R134a and R152a can be treated nearly the same way as a pure substance. The boiling point curve and the thermal properties of the superheated vapour are more favorable for a mixture than for the pure refrigerants. Therefore, a somewhat lower energy consumption of a compression refrigeration cycle is to be expected.

The investigation shows that mixtures of R134a and R152a can be employed as an alternative to refrigerant 12. An advantage would be the lower global warning potential compared to that of pure R134a. On the other hand, the flammability of mixtures with less than 82 mole percent of R134a has to be taken into consideration.

AUTHOR: Bivens, D.B.; Shiflett, M.B.; Shealy, G.S.; et.al.

TITLE: HCFC-22 Alternative for Air Conditioner and Heat Pumps

DOC TYPE: Report
DOCUMENT: ASHRAE Transactions 1994
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
VOL NO: 100
ISSUE: 2
YEAR: 1994
PAGE NO:
LANGUAGE: English

KEYWORDS: R-22, R-32, R-125, R-134a, flammability, leakage

REFERENCE NUMBER: 92 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The mixture of 23% HFC-32/25% HFC-125/52% HFC-134a is a nonflammable, chlorine-free alternative to HCFC-22 that is a close match in capacity and energy efficiency in tests with current design air conditioners and heat pumps. Additional performance, improvements are possible through optimization of the expansion device and other system components, including use of liquid line/suction line heat exchange and counterflow evaporators and condensers. Energy efficient values that are 6% to 7% higher than those of HCFC-22 are predicted with the mixture in modified equipment. A study of mixture vapor leakage followed by recharging with the initial composition demonstrated a maximum loss of 9% capacity after five cycles, representing a worst-case effect of leakage. This document also discusses the flammability of various compositions of the refrigerants and of compositional changes that could occur during normal and abnormal system operation and leakage.

Note: This is a preprint for discussion purposes only. It will be replaced with the published document when available

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AUTHOR: Blanc, M.V.; Guest, P.G.; Von Elbe, G.; and Lewis, B.

TITLE: Ignition of Explosive Gas Mixtures by Electric Sparks III. Minimum Ignition Energies and Quenching Distances of Mixtures of Hydrocarbons and Ether with Oxygen and

DOC TYPE: Conference Proceeding
DOCUMENT: Third Symposium (International) on Combustion
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
VOL NO: 3rd
ISSUE:
YEAR: 1949
PAGE NO: 363-367
LANGUAGE: English

KEYWORDS: minimum ignition energy, flammability limit

REFERENCE NUMBER: 48 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The minimum ignition energies of hydrocarbon gases, with various oxygen-nitrogen atmospheres fraction of stoichiometric percentage of combustible air and quenching distances vs. percent propane and ethane presented. The smallest minimum energy for ignition is practically identical for all the compounds studied.

AUTHOR: Borchardt, H.J.; and Gilbaugh, R.C.

TITLE: Hazard of FC22/142b Flammability

DOC TYPE: Report
DOCUMENT: KSS-8274
PUBLISHER: E.I. du Pont Nemours & Co.
ADDRESS: Wilmington DE
VOL NO:
ISSUE:
YEAR: 1979
PAGE NO:
LANGUAGE: English

KEYWORDS:
flammability, R-22, R-142b

REFERENCE NUMBER: 58 IN NMERI LIBRARY: Yes

ABSTRACT:

The mixture FC22/142b (42 wt. % R22) has been considered as a replacement for R12 in automotive air conditioning. Although this mixture is nonflammable (compositions containing less than approximately 36 wt. % R22 are flammable), a flammable residue can form if R22 rich vapor is lost via a vapor phase leak. The object of this project is to identify the hazards associated with FC22/142b flammability in automotive air conditioning use. Flammable refrigerant was discharged into an open 6' by 10' room. Eight candles and two propane torches, located various distances from the discharge site and at various heights, served as the ignition sources. In five attempts, including one with pure FC-142b, no ignition occurred. A second scenario was similar to the first except that the cylinder containing the refrigerant was inverted so that the liquid rather than the gas discharged. A third scenario involved the release of one pound of the mixture into a 40 cu. ft. compartment to simulate the release of mixture into a passenger compartment. Under the test conditions described, no hazard was found with the vapor phase release of flammable refrigerant residue under simulated servicing conditions. Under otherwise identical conditions, a fire hazard of minor-to-modest proportions may develop if the discharge is in the liquid phase. A very serious fire hazard develops when flammable refrigerant is discharged into a closed simulated passenger compartment.

AUTHOR: Bradford, B.W.; and Finch, G.I.

TITLE: The Mechanism of Ignition by Electric Discharges

DOC TYPE: Conference Proceeding
DOCUMENT: Second Symposium on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 2nd
ISSUE:
YEAR: 1965
PAGE NO: 112-126
LANGUAGE: English

KEYWORDS:
ignition, limits of flammability, diluent

REFERENCE NUMBER: 49 IN NMERI LIBRARY: Yes

ABSTRACT:

This early article (1937) explores the precise sequence of events by which a potential explosive gaseous mixture is caused to ignite. The thermal theory of electrical ignition is discussed. Ignition by different electrical sources is also discussed. The conclusion is that the view that electrical ignition is attributable to purely thermal effects of the spark is dismissed, and that excitation of the gases is possible, heat being only one source.

AUTHOR: Britton, L.G.

TITLE: Using Material Data in Static Hazard Assessment

DOC TYPE: Journal Article
DOCUMENT: Plant/Operations Progress
PUBLISHER: American Institute of Chemical Engineers
ADDRESS: New York, NY 10017
VOL NO: 11
ISSUE: 2
YEAR: 1992
PAGE NO: 56-70
LANGUAGE: English

KEYWORDS:
mnimum ignition energy, flammability

REFERENCE NUMBER: 59 IN NMERI LIBRARY: Yes

ABSTRACT:

Minimum ignition energy (MIE) test methods for gases, liquid mists and dust suspensions are reviewed. A compilation of gas MIEs is given and applications described both in assessing static ignition risks for flammable liquids and the basic requirements for static grounding. The relevance of liquid electrical properties is discussed and a large compilation provided. MIE interpretation problems are discussed with emphasis on dust suspensions.

AUTHOR: Cashdollar, K.L.; Hertzberg, M.; Zlochower, I.A.; Lucci, C.; Green, G.M.; and Thomas

TITLE: Laboratory Flammability Studies of Mixtures of Hydrogen Nitrous Oxide and Air

DOC TYPE: Report
DOCUMENT: WHC-SD-WM-ES-219
PUBLISHER: Westinghouse Hanford Company
ADDRESS: Richland, WA
VOL NO:
ISSUE:
YEAR: 1992
PAGE NO:
LANGUAGE: English

KEYWORDS:
flammability, spark ignition, turbulence

REFERENCE NUMBER: 83 **IN NMERI LIBRARY:** Yes

ABSTRACT:

At the request of the Department of Energy and the Westinghouse Hanford Company, the Bureau of Mines has investigated the flammability of mixtures of hydrogen, nitrous oxide, and air. This work is relevant to the possible hazards of flammable gas generation from nuclear waste tanks at Hanford, WA. The tests were performed in a 120-L spherical chamber under both quiescent and turbulent conditions using both electric spark and pyrotechnic ignition sources.

The data reported here for binary mixtures of hydrogen in air generally confirm the data of previous investigators, but they are more comprehensive than those reported previously. The results clarify to a greater extent the complications associated with buoyancy, turbulence, and selective diffusion. The data reported here for ternary mixtures of hydrogen and nitrous oxide in air indicate that small additions of nitrous oxide (relative to the amount of air) have little effect, but that higher concentrations of nitrous oxide (relative to air) significantly increase the explosion hazard.

AUTHOR: Coward, H.F.; and Jones, G.W.

TITLE: Limits of Flammability of Gases and Vapors

DOC TYPE: Report
DOCUMENT: Bureau of Mines Bulletin 503
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
VOL NO:
ISSUE: 503
YEAR: 1952
PAGE NO:
LANGUAGE: English

KEYWORDS:
flammability, UEL, LEL, explosion, inertion

REFERENCE NUMBER: 14 IN NMERI LIBRARY: Yes

ABSTRACT:

This bulletin presents a critical review of all figures published on the limits of flammability of combustible gases and vapors when admixed with air, oxygen, or other "atmosphere". Part I discusses the conditions for propagation of flame in mixtures of gases. Conditions discussed include the source of ignition, direction of propagation, diameter and length of vessel, effects of small changes in atmospheric conditions, pressure, temperature, turbulence, comparison of limits in air with those in oxygen, effect of chemically inert substances, mixtures, and suppression of flammability. Experimental conditions are described. Part II presents theoretical considerations about flammability, while Part III reports the limits of individual gases and vapors. A bibliography of 368 entries is also included.

AUTHOR: Crescitelli, S.; Russo, G.; Tufano, V.; Napolitano, F.; and Tranchino, L.

TITLE: Flame Propagation in Closed Vessels and Flammability Limits

DOC TYPE: Journal Article
DOCUMENT: Combustion Science and Technology
PUBLISHER: Gordon and Breach Science Publishers, Inc.
ADDRESS: New York, NY
VOL NO: 15
ISSUE:
YEAR: 1977
PAGE NO: 201-212
LANGUAGE: English

KEYWORDS:
flammability, UFL, LFL, flame extinction

REFERENCE NUMBER: 89 IN NMERI LIBRARY: Yes

ABSTRACT:

Flame propagation in near-limit mixtures of ethylene and air has been investigated by using a spherical vessel. A model of the flame behavior in closed vessels has been formulated, which takes into account the complete motion equation and the heat losses by the flame to the surroundings. The model forecasts two possible mechanisms of flame failure: the "homogeneous" flame extinction due to conductive heat losses to the walls after flame impingement on the vessel top. The theory and the experimental data fairly agree; in particular the dependence of the measured "heterogeneous" limit on the igniter position is explained.

AUTHOR: Deguingand, B.; and Galant, S.

TITLE: Upper Flammability Limits of Coal Dust-Air Mixtures

DOC TYPE: Conference Proceeding
DOCUMENT: Eighteenth Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 18th
ISSUE:
YEAR: 1981
PAGE NO: 705-715
LANGUAGE: English

KEYWORDS:
UFL, ignition, ignition energy

REFERENCE NUMBER: 37 IN NMERI LIBRARY: Yes

ABSTRACT:

The present paper is a progress report on a comprehensive study of upper flammability limits of coal dust-air mixtures. The study was undertaken in the context of safety in pneumatic conveying systems. An improved 8-liter combustion chamber was designed which allows dispersal of combustible particles up to concentrations around 5 kg/kg air. The study includes:

i) use of two narrow size distributions of a high volatile content coal (vis. 13 and 50 micron)
ii) measurement of ignition energy requirements
iii) measurement of the extent of flame propagation based on the pressure attained at constant volume, and the residual O2, CO2 and CO content after combustion.

Flame propagation was obtained up to concentrations around 3 kg/kg air (30 times the stoichiometric concentration), weakly dependent upon particles size. Electrical ignition energies of hundreds of Joules were required. Although no direct dust concentration measurements were carried out at such elevated values, good reproducibility of pressure traces and residual O2, CO2 and CO concentrations measurements up to 2.5 kg/kg air was obtained. This might be interpreted as a proof of constant coal-air dispersion characteristics around the energy source. A discussion of the underlying physical phenomena is presented, with some evidence of a radiation enhanced propagation rate.

Direct implications for safety in pneumatic conveying systems are drawn, together with an appraisal for future experimental studies concerning various industrial combustible dusts in a simulated pneumatic conveying environment.

AUTHOR: Dekleva, T. W.; Lindley, A. A.; and Powell, P.

TITLE: Flammability and Reactivity of Select HFCs and Mixtures

DOC TYPE: Journal Article
DOCUMENT: ASHRAE Journal
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
VOL NO: 35
ISSUE: 12
YEAR: 1993
PAGE NO: 40-47
LANGUAGE: English

KEYWORDS:
refrigerant flammability, MCLR, R-32, R-125, R-134a, combustibility, ASTM 681-85, R-32 blends, critical

REFERENCE NUMBER: 1 IN NMERI LIBRARY: Yes

ABSTRACT:

The flammability and reactivity of select HFCs and mixtures are reported in this document. The reactivity of HFC-134a is compared to that of several presently-used CFCs. This paper introduces the concept of a Critical Flammability Ratio (CFR), which is the percentage of non-flammable refrigerant required to just render the mixture non-flammable at a specific (typically, but not limited to, room) temperature and atmospheric pressure on dilution with air. If this ratio is greater than 1, the mixture is non-flammable. This concept works for both binary and ternary blends. Flammability test methods are described, and data on the flammability characteristics of R-32, R-125, and R-134a and their associated mixtures are given.

AUTHOR: Devotta, S.; and Gopichand, S.

TITLE: Comparative Assessment of some Flammable Refrigerants as Alternatives to CFC-12

DOC TYPE: Conference Proceeding
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 249-257
LANGUAGE: English

KEYWORDS: flammable, refrigrants,

REFERENCE NUMBER: 77 **IN NMERI LIBRARY:** No

ABSTRACT:

The theoretical performance of some flammable refrigerants, namely, propane (HC290), butane (HC600), isobutane (HC600a), cyclopropane (HCC270), HFC152a and HCFC142b have been comparatively assessed as alternatives to CFC12. This has been done for a range of evaporating temperatures by using some standard refrigeration parameters like pressure ratio, specific compressor displacement, theoretical Rankine coefficient of performance, shaft per ton of refrigeration. Cyclopropane (HC270), which would require smaller compressors than CFC12 and may offer superior energy performance, appears to be a potential candidate. If a suitable weighting is to be given for non-flammability and experience, then HFC152a is perhaps a better alternative.

The paper also discusses the need for the assessment of flammable fluids and the implications of using these fluids as alternatives to CFC12.

AUTHOR: Dieckmann, J.T.; Bentley, J.; and Varone, A.

TITLE: Non-Inert Refrigerant Study for Automotive Applications - Final Report

DOC TYPE:
DOCUMENT: DOE/CE/50274-TI DE92 041034
PUBLISHER: U.S. Department of Energy
ADDRESS: Washington, DC
VOL NO:
ISSUE:
YEAR: 1991
PAGE NO:
LANGUAGE:

KEYWORDS: refrigerants, flammable refrigerants, HFC-134a, HFC-152a, propane, ignition

REFERENCE NUMBER: 85 IN NMERI LIBRARY: Yes

ABSTRACT:

Alternatives to CFC-12 for automobile air conditioning were examined. The list of candidate fluids included flammable as well as non-flammable substances. HFC-134a was taken as the baseline alternative given current industry plans to convert automobile air conditioning systems to this fluid over the next several years. Three flammable (non-inert) alternative refrigerants - HFC-152a, HC-290 (propane) and HC-270 (cyclopropane) were identified. Air conditioning cycle efficiency, ozone depletion potential, and global warming impacts of these three fluids and HFC-134a were compared, with the three non-inert fluids all having higher COP and lower global warming impact. The ozone depletion potential of each of these fluids is zero. The fire safety implications of the flammable alternatives being used in otherwise conventional automobile air conditioning systems were examined in preliminary fashion. The results, which are subject to more extensive verification indicate that the additional passenger compartment fire risk would be very small, while the incidence of engine compartment fires would increase modestly. The engine compartment of fire hazard could be minimized by modest design changes to reduce the occurrence of ignition sources and condenser punctures in front end collisions.

AUTHOR: DiNenno, P.E.

TITLE: The SPFE Handbook of Fire Protection Engineering

DOC TYPE: Book
DOCUMENT:
PUBLISHER: National Fire Protection Association
ADDRESS: Quincy, MA 02269
VOL NO: 1st
ISSUE:
YEAR: 1988
PAGE NO:
LANGUAGE: English

KEYWORDS: flammability, ignition

REFERENCE NUMBER: 52 IN NMERI LIBRARY: Yes

ABSTRACT:

This handbook integrates fire protection theory and practice. Much of the basics of ignition are described, especially Section 1/Chapter 17, "Flammability Limits of Premixed and Diffusion Flames" and Section 1/Chapter 20, "Ignition of Liquid Fuels".

AUTHOR: Dixon-Lewis, G.; and Isles, G.L.

TITLE: Limits of Inflammability

DOC TYPE: Conference Proceeding
DOCUMENT: Seventh Symposium (International) on Combustion
PUBLISHER: Butterworth's Scientific Publisher's
ADDRESS: London, England
VOL NO: 7th
ISSUE:
YEAR: 1959
PAGE NO: 475-483
LANGUAGE: English

KEYWORDS: flammability limits

REFERENCE NUMBER: 43 IN NMERI LIBRARY: Yes

ABSTRACT:

This paper describes some work which has been aimed at clarifying the position of limits of inflammability. The properties of ethylene-air flames near the lower limit were investigated on a modified flat flame burner in which the top of the chimney was closed by an electrically heated, perforated stainless steel plate. Results reported included that the limits of inflammability in the burner are essentially functions of the apparatus and environment, and the more work is required to investigate hydrocarbon oxidation in flames.

AUTHOR: Drysdale, D.

TITLE: An Introduction to Fire Dynamics

DOC TYPE: Book
DOCUMENT:
PUBLISHER: John Wiley and Sons
ADDRESS: Chichester, UK
VOL NO:
ISSUE:
YEAR: 1985
PAGE NO: 78-113
LANGUAGE: English

KEYWORDS: flammability limits, ignition, UFL, LFL

REFERENCE NUMBER: 80 IN NMERI LIBRARY: Yes

ABSTRACT:

This book describes the mechanics of fire dynamics. Chapter 3, "Limits of Flammability and Premixed Flames" and Chapters 6 and 7, "Ignition: the Initiation of Flaming Combustion" and "Spread of Flame", respectively, provide a good basis for understanding the phenomena of ignition in flammable gases, including refrigerants.

AUTHOR: Eckhoff, R.K.

TITLE: Generation, Ignition, Combustion, and Explosion of Sprays and Mists of Flammable Liquids in Air - A Literature Survey

DOC TYPE: Report
DOCUMENT: CMI-R-91/A25014 DE93 721651
PUBLISHER: Chr. Michelsen Institute
ADDRESS: N-5036 Fantoft Norway
VOL NO:
ISSUE:
YEAR: 1991
PAGE NO:
LANGUAGE: English

KEYWORDS: ignition, spray mists, flame propagation

REFERENCE NUMBER: 84 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The spray/mist explosion hazard is illustrated by reported accidents. Experimental and theoretical studies of generation and physical behaviour of spray/mists, of ignition and flame propagation, including detonation, and of diagnostic methods in experimentation, are reviewed. Some topics requiring further investigation are mentioned. Includes 247 references.

AUTHOR: Egerton, A.C.

TITLE: Limits of Inflammability

DOC TYPE: Conference Proceeding
DOCUMENT: Fourth Symposium (International) on Combustion
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
VOL NO: 4th
ISSUE:
YEAR: 1953
PAGE NO: 4-13
LANGUAGE: English

KEYWORDS: flammability, inflammability, diluent

REFERENCE NUMBER: 45 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This survey paper describes flammability limits for gases. It investigates both upper and lower limits and how they differ for various gases. Various definitions of "flammability" are compared and contrasted. A method of determining the upper limit in oxygen based on the upper limit in air is discussed. Effects of additives on the upper flammability limit are also discussed. One conclusion reached was that chain-branching reactions are important in governing the minimum flame temperature and hence limits of inflammability. "Cool flames", which have temperatures of only 400C and are maintained thermally, and decomposition flames can cause visible light but not be true flammability; they can, however, lead to hot flames. As of the date of this paper (1953) no theory describing the propagation of flames had yet been found that could predict the upper or lower flammability limits.

AUTHOR: Fedorko, G.; Fredrick, L.G.; and Hansel, J.G.

TITLE: Flammability Characteristics of Chlorodifluoromethane (R-22)-Oxygen-Nitrogen Mixtures

DOC TYPE: Journal Article

DOCUMENT: ASHRAE Transactions

PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers

ADDRESS: Atlanta, GA 30329

VOL NO: 2

ISSUE: 3097

YEAR: 1993

PAGE NO:

KEYWORDS: flammability envelope, flammability limit, R-22, heats of reaction

LANGUAGE: English

REFERENCE NUMBER: 3 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The flammability envelopes for R-22 in air and enriched air up to 100% O2 have been measured up to 200 psia (1380 kPa) and ambient temperature. Flammability limits were established from heat of reaction measurements in a bomb calorimeter. The lowest pressure at which R-22 was flammable in air was approximately 75 psia (518 kPa). Relatively wide limits were established in 100% O2 at even 14.7 psia (101 kPa). (Generally, somewhat wider limits may be established in larger vessels.) Measured heats of reaction revealed that regardless of the O2/N2 mixture, flammable compositions between about 30% and 45% R-22 provided peak heats of reaction. The flammability envelopes were able to predict the outcome of R-22 flammability tests of other investigators who used similar apparatus but fewer values of the O2/N2 ratio.

AUTHOR: Fisher, S.K.; and Sand, J.R.

TITLE: Screening Analysis for Chlorine-Free Alternative Refrigerants to Replace R-22 in Air-Conditioning Applications

DOC TYPE: Report

DOCUMENT: ASHRAE Technical Data Bulletin

PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers

ADDRESS: Atlanta, GA 30329

VOL NO: 9

ISSUE: 4

YEAR: 1993

PAGE NO: 12-20

LANGUAGE: English

KEYWORDS: flammability, R-32, R-125, R-134a,

REFERENCE NUMBER: 87 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The potential health and environmental effects of the depletion of stratospheric ozone from refrigerants containing chlorine have resulted in international treaties, laws, and nonbinding agreements to phase out and eliminate many common refrigerants. R-22 is one of these compounds. A study was conducted to evaluate the potential of 22 chlorine-free compounds in refrigerant mixtures of up to three components as substitutes for R-22. The selection or screening of blends was based on vapor compression cycle COP at the 95°F (35°C) cooling condition, the volumetric cooling capacity of the blend, evaporator and condenser temperature glides, and the "estimated" flammability of the blend. Promising results were obtained for nine ternary blends containing E-125 and eleven ternary blends that exclude E-125. Recommendations are made to obtain further experimental data on E-125 since the mixtures with the best performance contain that compound. Results from this study will be used in an in-depth follow-on analysis.

AUTHOR: Fluorochemicals Division, Isotron Department, Atochem North America Inc.

TITLE: Flammability Characteristics of ISOTRON 142b

DOC TYPE: Other

DOCUMENT:

PUBLISHER: Atochem North America, Inc.

ADDRESS: Philadelphia, PA 19102

VOL NO:

ISSUE:

YEAR:

PAGE NO:

LANGUAGE: English

KEYWORDS: limits of flammability, flammability limits, explosion pressure, rate of pressure rise, flash point, LEL, UEL,

REFERENCE NUMBER: 9 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This document provides technical data on Isotron 142b (1-chloro-1,1-difluoroethane), including flammability limits, maximum explosion pressure and maximum rate of pressure rise, flash point, and comparison of properties.

AUTHOR: Fukutani, Seishiro; Yamamoto, Satoru; and Jinno, Hiroshi

TITLE: Propagation of Unsteady Hydrogen Premixed Flames Near Flammability Limits

DOC TYPE: Conference Proceeding
DOCUMENT: Twenth-third Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 405-411
LANGUAGE: English

KEYWORDS: flammability limits, flame propagation, LFL

REFERENCE NUMBER: 28 IN NMERI LIBRARY: Yes

ABSTRACT:

The structure and propagation mechanisms of spherically propagating hydrogen-air premixed flames were investigated under the conditions of various fuel concentrations and initial temperatures to elucidate the essential factors influencing propagation of the flames near the lean flammability limit. Measurements of the burning velocity indicated that flames with adiabatic flame temperatures lower than 890 K cannot extend up to 100 mm in diameter. In addition, they showed appreciable dependence of the burning velocity on the initial temperature. The structure and the propagation mechanism of hydrogen flames near the lean flammability limits differ from the flames having large burning velocity such as unsteady stoichiometric hydrogen flames.

AUTHOR: Gann, R.G

TITLE: Halogenated Fire Suppressants

DOC TYPE: Conference Proceeding
DOCUMENT: Halogenated Fire Suppressants
PUBLISHER: University Microfilms International
ADDRESS: Ann Arbor, MI 48106
VOL NO:
ISSUE:
YEAR: 1990
PAGE NO:
LANGUAGE: English

KEYWORDS: flammability, ignition

REFERENCE NUMBER: 79 IN NMERI LIBRARY: Yes

ABSTRACT:

This book was originally published by the American Chemical Society in 1975. It reports results of a symposium held in April 1975 at the Southwest Research Institute in San Antonio. Although the main purpose of the symposium was to discuss halogenated compounds for use in fire suppression, several articles have direct bearing on flammable refrigerants. The first article entitled "An Overview of Halon 1301 Systems" by C.L. Ford traces the history of Halon 1301 testing and provides significant data on ignition sources relative to fire suppression. Articles by R.G. Gann entitled "Initial Reactions in Flame Inhibition by Halogenated Halocarbons" and N.J. Brown entitled "Halogen Kinetics Pertinent to Flame Suppression: A Review" provide insight into the mechanisms by which halogenated compounds suppress flames.

AUTHOR: Gerstein, M.; and Stine, W.B.

TITLE: Analytic Criteria for Flammability Limits

DOC TYPE: Conference Proceeding
DOCUMENT: Fourteenth Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 14
ISSUE:
YEAR: 1973
PAGE NO: 1109-1118
LANGUAGE: English

KEYWORDS:
flammability limits, quenching distance, limit criteria

REFERENCE NUMBER: 90 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The one-dimensional laminar flame equations with single-step Arrhenius kinetics, including both conduction and radiation heat loss to the surroundings, have been integrated. Adiabatic and nonadiabatic burning velocity, quenching distance, and an "apparent" flammability limit are calculated. It is shown that a fundamental flammability limit, independent of heat loss, does not exist even when radiation loss is included. The experimentally observed flammability limits are explained on the basis of the insensitivity of the critical fuel concentration for flame propagation to changes in tube diameter, when the radiation loss exceeds conduction loss. Flame thickness and inflection temperature are discussed as other possible criteria for "apparent" flammability limits. It is pointed out that safety criteria, based on flammability limits, should take into account the possible reduction of limits for very large systems.

Comparison is made with experimental values, in which pressure and diluent type and concentration are varied.

AUTHOR: Gray, P.; Griffiths, J.P.; and Bond, J.R.

TITLE: Carbon Monoxide Oxidation: Chemiluminescence and Ignition

DOC TYPE: Conference Proceeding
DOCUMENT: Seventeenth Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 17th
ISSUE:
YEAR: 1979
PAGE NO: 811-819
LANGUAGE: English

KEYWORDS: ignition, chemiluminescence

REFERENCE NUMBER: 38 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The present work is a study in carbon monoxide oxidation of the instabilities ignition, glow, oscillation and of slow reaction. It pertains to the region of the upper limit in an acid-washed quartz vessel. The key range of conditions is that achieved by varying proportions of H2 in CO+O2 from 1% to 200 ppm, and isolated experiments have been performed in extremely "dry" compositions of CO+O2. Experimentally, stress is laid on quantitative measurements not only of pressure change but also of light intensities, extents of reaction and, in some experiments, temperature change.

Ignition is identified by its intensity, completeness and brevity. Chemiluminescent glow is distinguished from ignition by its duration and its incompleteness of reaction: light intensity-time records show a peak (smaller than that of ignition) followed by a protracted tail. Oscillatory chemiluminescence can occur wherever glow is seen. It is dependent for its occurrence on the previous history of the vessel surface.

The modes of behavior that can be detected and distinguished from one another depend crucially on the amount of hydrogenous material: when more than 0.2% H2 is present, only slow reaction and ignition are observed. In mixtures containing between 0.2% (2000 ppm) and 0.02% (200 ppm), chemiluminescent glow and oscillations occur as well, and they are quite distinct from slow reaction and ignition. The boundary between slow reaction and chemiluminescence (glow and oscillation) is sharp. In very dry mixtures, which contain about 10 ppm of hydrogenous material, only chemiluminescence and dark, slow reaction can be observed. Previous locations of ignition limits in very "dry" CO + O2 mixtures are those for chemiluminescent glow.

AUTHOR: Grob, Don

TITLE: Flammability Characteristics of R-32 and R-32 Mixtures

DOC TYPE: Other
DOCUMENT:
PUBLISHER: Underwriter's Laboratories, Inc.
ADDRESS: Northbrook, IL 60062
VOL NO:
ISSUE:
YEAR: Mar 1991
PAGE NO:
LANGUAGE: English

KEYWORDS:
Westerberg, pressure, humidity, flammability diagram, flammability, R-32, R-134a, ASTM-681

REFERENCE NUMBER: 11 IN NMERI LIBRARY: Yes

ABSTRACT:

This document reports the maximum pressure development of common refrigerants in the Westerberg apparatus. Also reported are the flammability diagrams for HFC-32/HFC-125 and HFC-32/HFC-134a.

AUTHOR: Hansel, J.G.; Mitchell, J.W.; and Klotz, H.C.

TITLE: Predicting and Controlling Flammability of Multiple Fuel and Multiple Inert Mixtures

DOC TYPE: Journal Article
DOCUMENT: Plant/Operations Progress
PUBLISHER: American Institute of Chemical Engineers
ADDRESS: New York, NY 10017
VOL NO: 11
ISSUE: 4
YEAR: 1992
PAGE NO: 213-217
LANGUAGE: English

KEYWORDS:
flammability, UFL, LFL

REFERENCE NUMBER: 60 IN NMERI LIBRARY: Yes

ABSTRACT:

Le Chatelier's Rule is in wide use for predicting the flammability of mixtures with multiple fuels present. The rule does not conveniently handle multiple inerts or elevated temperatures and FLAMCHECK(TM), which conveniently handles these variables. This method for predicting flammability is based upon the commonality of the adiabatic flame temperature of a wide variety of fuels at their upper and lower flammable limits. The method, if PC based, can be extended to automatically control the addition of inerts, fuels, or oxidizers in order to avoid flammable conditions. The concept may be extended to more involved applications. such as within an oil well with fuel gas mixtures containing oxygen. In this case, the location from which a gas sample Is obtained for analysis (well-head) may have a different fuel analysis and flammability condition than the location where an explosion is likely to initiate (bottom of well). Hence a correction of the fuels analysis is required.

AUTHOR: Hashiguchi, Y.

TITLE: Explosions of Combustible Gases and Vapors

DOC TYPE: Journal Article
DOCUMENT: Journal of Synthetic Organic Chemistry Japan
PUBLISHER: N/A
ADDRESS:
VOL NO: 37
ISSUE: 6
YEAR: 1979
PAGE NO: 501-506
LANGUAGE: Japanese

KEYWORDS:
N/A

REFERENCE NUMBER: 70 **IN NMERI LIBRARY:** No

ABSTRACT:

N/A

AUTHOR: Heinonen, E.W.

TITLE: The Effect of Ignition Source and Strength on Sphere Ignition Results

DOC TYPE: Conference Proceeding
DOCUMENT: Halon Alternatives Technical Working Conference 1993
PUBLISHER: New Mexico Engineering Research Institute
ADDRESS: Albuquerque, NM 87106
VOL NO:
ISSUE:
YEAR: 1993
PAGE NO: 565-576
LANGUAGE: English

KEYWORDS:
ignition, explosion sphere, halocarbons, flammability, flammability curves

REFERENCE NUMBER: 34 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The New Mexico Engineering Research Institute (NMERI) has conducted testing to determine the amount of halogenated agents required to inert common flammable fuels in its inertion sphere facility. The source of ignition is a capacitive discharge spark which is formed between two electrodes inside the sphere. This apparatus has also been used to determine the upper and lower flammability limits of several alternative refrigerants. Differences between the concentrations of Halon 1301 required to inert methane and propane were seen between NMERI results and other researchers, and the flammability limits on alternative refrigerants are narrower than reported elsewhere. This paper investigates whether the energy contained in the spark, nominally 70 joules using the stored capacitance, is actually far lower than that reported. An explanation based on effective spark energy indicates that the effective energy in the spark may be in the order of 1 joule, which would be in accordance with other researcher's work. Reasons for the lower energy are discussed, and other work compared to support this premise.

AUTHOR: Hertzberg, M.

TITLE: The Theory of Flammability Limits - Natural Convection

DOC TYPE: Report
DOCUMENT: Bureau of Mines Report of Investigations 8127
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
VOL NO: 8127
ISSUE:
YEAR: 1976
PAGE NO:
LANGUAGE: English

KEYWORDS:
flammability limits

REFERENCE NUMBER: 68 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The concept of limit burning velocities is used to formulate a qualitative theory of flammability limits. Competing processes dissipate power from a combustion wave and quench propagation at some characteristically low limit velocity. There are four competing processes and one complication: (a) Free, buoyant convection, (b) conductive-convective wall losses, (c) radiation, (d) selective, diffusional demixing (the complication), and (e) flow gradient effects (flame stretch). These complexities are unraveled by creating an idealization that is initially freed from these competing processes. The ideal serves as a standard, and its burning velocity (su)*sub*ideal is a unique function of the initial thermodynamic variables of state. By adding each process individually, it is possible to evaluate their significance, quantitatively, in terms of a limit velocity (Su)*sub*a,b,c,cr,e, and to explore the nature of their cooperative interactions. The larger the limit velocity, the more significant process. The apparently diverse observations of flammability behavior are readily unified within this simple, conceptual framework.

AUTHOR: Hertzberg, M., Cashdollar, K.L.; and Opferman, J.J.

TITLE: The Flammability of Coal Dust-Air Mixtures

DOC TYPE: Report
DOCUMENT: Bureau of Mines Report of Investigations 8360
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
VOL NO: 8360
ISSUE:
YEAR: 1979
PAGE NO:
LANGUAGE: English

KEYWORDS:
flammability, ignition, ignition energy

REFERENCE NUMBER: 67 **IN NMERI LIBRARY:** Yes

ABSTRACT:

A comprehensive study of the flammability behavior of air-dispersed coal dust was made using an 8-liter Bureau of Mines system which included the following: (1) An optical probe to continuously monitor the dust concentration; (2) measurements of ignition energy requirements; (3) the use of several narrow size distributions ranging from 3 to 65 microns in average diameter, (4) measurements of the extent of flame propagation based on pressure attained at constant volume, residual O2 content after combustion, and flame and dust surface temperatures.

The measured lean limit for near-horizontal propagation of Pittsburgh coal dust was about 135 mg/1 (milligrams per liter), virtually independent of particle size. Required ignition energies were hundreds of joules and measured limit flame temperatures were 1,450 to 1,600K. Data on inerting requirements with KHCO3, rock dust, and NaCl gave approximately the same results as full-scale explosion tests. The good agreement suggests that the cause of earlier discrepancies between small-scale laboratory data and full-scale mine experiments may not have been the difference in size, but were rather a problem of proper care in isolating and controlling the significant experimental variables and in consistently defining the extent of flame propagation at the limits.

AUTHOR: Hertzberg, Martin; Cashdollar, Kenneth; and Zlochower, Issac

TITLE: Flammability Limit Measurements for Dusts and Gases: Ignition Energy Requirements and Pressure Dependences

DOC TYPE: Conference Proceeding

DOCUMENT: Twenty-first Symposium (International) on Combustion

PUBLISHER: The Combustion Institute

ADDRESS: Pittsburgh, PA 15213

VOL NO: 21st

ISSUE:

YEAR: 1986

PAGE NO: 303-313

LANGUAGE: English

KEYWORDS: flammability limits, ignition strength, methane, dusts, pressure dependence

REFERENCE NUMBER: 19 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Data are presented for the flammability limits of Pittsburgh Seam bituminous coal dust, polyethylene powder, and methane in air at pressures in the range 0.5 to 3 bar. Explosibility test chambers of 20 and 120 L were used, and ignitability limitations were overcome with efficient pyrotechnic ignitors with nominal energies of 500 to 5,000 J. The propagation criterion used was based on the maximum explosion pressure and the size-normalized maximum rate of pressure rise. The latter is a dynamic criterion that tends to minimize "overdriving" effects as the 20-L data are taken to their asymptotic limits at high ignition energies. The measured lean limits in air at atmospheric pressure are 90 g/m3 for the coal dust, 35 g/m3 for polyethylene, and 4.9 vol pct for methane. The rich limit for methane is 18-19 vol pct, whereas the dusts have no rich limits out to concentrations as high as 4,000 g/m3.

A linear, lean-limit pressure dependence was measured for the dusts which was essentially the same as the pressure dependence measured for methane when all are expressed in comparable units: namely, mass concentration of fuel per unit volume of air. This observation further confirms a lean limit dust flame propagation mechanism that is controlled by the gas-phase reaction rate. The limit concentrations are then determined by the dust loading required to generate a lean limit concentration of pyrolysis products in the volatiles-air mixture, and the dust behaves as an equivalent "homogeneous," premixed gas, regardless of the initial pressure.

AUTHOR: Hertzberg, Martin; Cashdollar, Kenneth; Lazzara; Charles, and Smith, Alex

TITLE: Inhibition and Extinction of Coal Dust and Methane Explosions

DOC TYPE: Report
DOCUMENT: Bureau of Mines Report of Investigations 8708
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
VOL NO:
ISSUE: 8708
YEAR: 1982
PAGE NO:
LANGUAGE: English

KEYWORDS:
flammability, powdered inhibitors, coal dust, methane, alkali halides, quenching, nitrogen, Halon 1301

REFERENCE NUMBER: 22 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The Bureau of Mines 8-liter flammability system was used to study the effectiveness of a variety of powdered inhibitors in preventing the propagation of explosions of coal dust or methane in air. Over 35 different chemical additives were evaluated against Pittsburgh seam pulverized coal. The least effective inhibitors were the carbonates, which required mass additions in the range of two to there parts inhibitor to one part of coal dust in order to prevent propagation. The most effective inhibitors were the derivatives of ammonium phosphate, which were effective quenching agents at additions of only one part inhibitor to four parts of coal dust. Alkali halide powders were of intermediate effectiveness. These laboratory-scale results are in good agreement with full-scale mine experiments in all cases where detailed comparisons have been made.

Data were also obtained for the effectiveness of several of the same powdered inhibitors against methane-air explosions. Their relative order of effectiveness and the concentration ranges required for quenching the gas explosion are comparable to those measured for coal dust explosions. Data are also presented for the effectiveness of N2 and CF3Br.

Some preliminary data are also presented for powder addition to methane burner flames. Those data are compared with other burner data and evaluated in terms of their relevance to explosion tests.

AUTHOR: Hertzberg, Martin; Conti, Ronald; and Cashdollar, Kenneth

TITLE: Electrical Ignition Energies and Thermal Autoignition Temperatures for Evaluating Explosive Hazards of Dusts

DOC TYPE: Report

DOCUMENT: Bureau of Mines Report of Investigation 8988

PUBLISHER: Bureau of Mines

ADDRESS: Pittsburgh, PA

VOL NO:

ISSUE: 8988

YEAR: 1985

PAGE NO:

LANGUAGE: English

KEYWORDS: spark ignition, autoignition, effective spark energy, minimum ignition energy, explosion

REFERENCE NUMBER: 21 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The Bureau of Mines measured the energy requirements for the spark ignition in air of Pittsburgh seam bituminous coal dust, lycopodium spores, and polyethylene powder with a 1.2-L furnace and 8-L and 20-L chambers. Thermal autoignition temperatures of the same dusts were measured in the 1.2-L furnace. Electrical ignition requirements are given in terms of both effective spark gap energies, epsilon*sub*eff, and stored circuit energies, 1/2 CE*super*2.

The measured order of electrical ignitability for the three dusts is consistent with the data of other researchers; however, the absolute values are systematically higher, probably because of higher flow and turbulence levels in the chambers used and lower electrical efficiency in the circuit.

The temperature dependence of the lean limit of flammability for lycopodium was measured with the 1.2-L system, and those measurements confirm the applicability of the modified Burgess-Wheeler law to a dust.

Due to experimental complexities, the minimum ignition energies for dusts may not reflect intrinsic flammability behavior. However, some valuable information may be obtained from the relative ignition energies of various dusts at ambient and elevated temperatures. In addition, the concept of minimum electrical ignition energies for homogeneous gas mixtures is reevaluated theoretically.

AUTHOR: Hertzberg, Martin; Conti, Ronald; and Cashdollar, Kenneth

TITLE: Spark Ignition Energies for Dust-Air Mixtures: Temperature and Concentration Dependencies

DOC TYPE: Conference Proceeding

DOCUMENT: Twentieth Symposium (International) on Combustion

PUBLISHER: The Combustion Institute

ADDRESS: Pittsburgh, PA 15213

VOL NO: 20th

ISSUE:

YEAR: 1984

PAGE NO: 1681-1690

LANGUAGE: English

KEYWORDS: ignition strength, ignition source, effective spark energy, autoignition

REFERENCE NUMBER: 20 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Energy requirements for the spark ignition in air of polyethylene powder, lycopodium spores, and Pittsburgh seam bituminous coal dust were measured in a 1.2-L furnace and a 20-L chamber. Dust concentrations and initial temperatures were carefully controlled (at ambient pressure) so that the mixtures were above their lean limits of flammability and below their spontaneous autoignition temperatures. Electrical ignition energy requirements are given in terms of both effective spark gap energies, epsilon*sub*eff, and stored capacitor energies, 1/2 CE*super*2.

At ambient temperature and pressure, the average minimum *eff-values for the three dusts were: 40 mJ for lycopodium, 50 mJ for polyethylene, and 160 mJ for the coal dust. The concentrations at which those minima were observed were 300, 500, and 750 g/m3, respectively. The measured electrical ignitability ranking is consistent with the data of other researchers but the measured values are systematically higher, probably because of the higher flow and turbulence levels used here. For lycopodium, its ease of ignition allowed its lean limit to be approached readily with spark sources, and measurements of its temperature dependence confirm the validity of the modified Burgess-Wheeler law for a dust.

While the concept of a minimum electrical ignition enemy for homogeneous gas mixtures is well established, the data reported here, and their analysis, suggest that the concept may not be particularly useful for heterogeneous dust-air mixtures. So many contradictory requirements are involved in experimental conditions, and such extraordinary difficulties and complexities are encountered for dusts, that a reliable determination of a minimum ignition energy that reflects intrinsic flammability behavior is dubious.

AUTHOR: Hilado, Carlos; and Cumming, Heather

TITLE: The HC Value: A Method for Estimating the Flammability of Mixtures of Combustible Gases

DOC TYPE: Journal Article
DOCUMENT: Fire Technology
PUBLISHER: National Fire Protection Association
ADDRESS: Quincy, MA 02269
VOL NO:
ISSUE:
YEAR:
PAGE NO: 195-198
LANGUAGE: English

KEYWORDS:
flammability limit, Le Chatelier's law, HC value

REFERENCE NUMBER: 4 IN NMERI LIBRARY: Yes

ABSTRACT:

The authors discuss the use of the ratio of gas concentration to its lower flammability limit in estimating the flammability of combustible gas mixtures. The lower limit of flammability of any mixture of paraffin hydrocarbons can be calculated by Le Chatelier's law. Experimental values of the HC are compared with theoretical.

AUTHOR: Hustad, J.E.; and Sønju, O.K.

TITLE: Experimental Studies of Lower Flammability Limits of Gases and Mixture of Gases at Elevated Temperatures

DOC TYPE: Journal Article
DOCUMENT: Combustion and Flame
PUBLISHER: Elsevier Science Publishing Co.
ADDRESS: New York, NY 10017
VOL NO: 71
ISSUE:
YEAR: 1988
PAGE NO: 283-294
LANGUAGE: English

KEYWORDS:
flammability, LFL, gas, mixtures

REFERENCE NUMBER: 62 IN NMERI LIBRARY: Yes

ABSTRACT:

Experimental studies of lower flammability limits for methane, butane, hydrogen, carbon monoxide, in addition to the mixtures of these gases are performed at temperatures of up to 450C and at atmospheric pressure. The experimental tests are mostly carried out for upward propagation. The flammability limits for each gas are found to decrease linearly with increasing temperature in the temperature range tested. A new mixing rule for calculating lower flammability limits for mixtures at elevated temperatures is suggested The mixing rule is a simplification of that of Le Chatelier's and is based on the established equations for each gas component in the mixture.

AUTHOR: Ishii, K.; Tsukamoto, T.; Ujiie, Y.; and Kono, M.

TITLE: Analysis of Ignition Mechanisms of Combustible Mixtures by Composite Sparks

DOC TYPE: Journal Article
DOCUMENT: Combustion and Flame
PUBLISHER: Elsevier Science Publishing Co.
ADDRESS: New York, NY 10017
VOL NO: 91
ISSUE: 2
YEAR: 1992
PAGE NO: 153-164
LANGUAGE: English

KEYWORDS:
ignition, flammability, combustible mixture, spark

REFERENCE NUMBER: 74 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Formation process of flame kernels produced by composite sparks in a quiescent propane-air mixture is numerically simulated by using a set of partial differential equations on two-dimensional cylindrical coordinates. Simulation is done with emphasis on physical effects such as gas movements generated by spark discharge and heat transfer from the flame kernel to spark electrode surfaces. Although chemical reaction is considered only by an overall reaction, the present simulation is found to be useful for understanding of physical effects in the following points: the flow pattern near spark gaps is an important factor that governs the flame kernel structure, the flow pattern is affected by the spark electrode diameter, gap width, and spark duration, and the calculated variation in the minimum ignition energy agrees qualitatively with the experimental variation, and the existence of the optimum spark duration is well confirmed. As for composite sparks, it is found that the superiority in ignition ability of composite sparks over capacitance sparks depends on spark electrode diameter and flap width.

AUTHOR: Kono, M.; Kumagai, S.; and Sakai, T.

TITLE: The Optimum Condition for Ignition of Gases by Composite Sparks

DOC TYPE: Conference Proceeding
DOCUMENT: Sixteenth Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 16th
ISSUE:
YEAR: 1977
PAGE NO: 757-766
LANGUAGE: English

KEYWORDS:
Ignition, composite sparks, spark duration

REFERENCE NUMBER: 39 **IN NMERI LIBRARY:** Yes

ABSTRACT:

To determine the optimum ignition condition for sparks consisting of a capacitance spark followed by a dc- (glow) or ac-discharge (1 MHz), the effects of gap width, electrode configuration, mixture strength, spark duration, and energy distribution between the two components on the minimum ignition energy were investigated, using a quiescent propane-air mixture. The condition in question is conveniently characterized by the optimum spark duration for which the minimum ignition energy is lowest and the corresponding energy value. For a dc-discharge spark, the well-defined optimum spark duration varies from about 50 to 300 microseconds and the minimum ignition energy for spark durations larger than the optimum increases in different modes, depending on the mixture strength and the quenching effect of spark electrodes. For an ac-discharge spark, the optimum condition for ignition is much the same as for a dc-discharge spark, but the minimum ignition energy and the spark duration are always proportional to each other above the optimum, and therefore the optimum spark duration is easily obtained up to about 5 msec. Flash-schlieren photographic observations of the initial behavior of the spark kernel confirmed that such differences in the mode of minimum ignition energy are related to electrostatic attraction by the negative electrode.

AUTHOR: Lakshima, K.N.; Paul, P.J.; and Mukunda, H.S.

TITLE: On the Flammability Limit and Heat Loss in Flames with Detailed Chemistry

DOC TYPE: Conference Proceeding
DOCUMENT: Twenth-third Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 433-440
LANGUAGE: English

KEYWORDS:
flammability limit, LFL

REFERENCE NUMBER: 31 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This paper reports a computational study of one-dimensional, planar, premixed, nonadiabatic flames near lean flammability limits, considering detailed chemistry and variable properties. Calculations made for CH4/air mixtures of varying leanness between 4.5 - 6.0% of CH4 show that (1) steady propagation is obtained for all lean mixtures when heat loss is not considered, and (2) with the inclusion of a distributed heat loss a steady propagation is predicted above a certain CH4 fraction; below this critical CH4 fraction the solution decays, indicating nonflammability. The limit so determined varies from 5.18 - 5.6% of CH4, with the magnitude of heat loss raised by a factor of 3. This small change in the limit for a large variation in heat loss factor is argued to indicate the fundamental nature of limit. The limiting fuel composition and flame speed found are nonzero and compare well with the results of zero-gravity experiments. The critical heat loss factor and flame speed at the limit obtained from the present work confirm the results of asymptotic theory. The principal effect of detailed chemistry is argued to be the correct reproduction of heat release rate vs. mixture ratio.

AUTHOR: Law, C.K.; and Egolfopolous, F.N.

TITLE: A Kinetic Criterion of Flammability Limits: The C-H-O-Inert System

DOC TYPE: Conference Proceeding
DOCUMENT: Twenth-third Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 413-421
LANGUAGE: English

KEYWORDS:
flammability limits, LFL, UFL, C-H-O-inert system

REFERENCE NUMBER: 29 **IN NMERI LIBRARY:** Yes

ABSTRACT:

An experimental and theoretical Investigation has been conducted on the determination of the flammability limits of the C-H-O-inert system and on the understanding of limit phenomena in general. Experimentally, flammability limits have been determined by first measuring the extinction limits of stretched, counterflow flames and extrapolating the results to zero stretch. Consequently, lean and rich flammability limits have been determined for mixtures of methane, ethane, ethylene, acetylene, and propane with air, for mixtures of H2, H2/CH4, and H2/CO2 with O2/N2, and for the effects of dilution, inert substitution, chemical additives such as CH3Br and H2, and radiative heat loss due of flame broadening. By further hypothesizing that the limit phenomena are primarily controlled by the kinetic processes of chain branching versus termination, a predictive theory has been advanced for the a priori determination of flammability limits. The study shows that H + O2 – O + OH is the dominant branching reaction for all lean and rich limits, that H + O2 + M – HO2 + M is the dominant terminal reaction for all lean limits, that the dominant termination reaction for rich limits can be mixture specific, and as the flammability limit is approached the maximum termination rate occurs in the same physical region as that of the maximum branching rate, thereby allowing for the most efficient radical scavenging. Pressure effects on rich limits and the concept of limit temperature are also interpreted based on the present theory and understanding.

AUTHOR: Levy, A.

TITLE: An Optical Study of Flammability Limits

DOC TYPE: Journal Article
DOCUMENT: Proceedings of The Royal Society (London), Vol A
PUBLISHER: Royal Society (London)
ADDRESS: London, SW1Y 5AG England
VOL NO: 283
ISSUE:
YEAR: 1965
PAGE NO: 134-145
LANGUAGE: English

KEYWORDS:
flammability, flammability limits, flame propagation, lower flammability limit

REFERENCE NUMBER: 72 IN NMERI LIBRARY: Yes

ABSTRACT:

Divergent views on the fundamental cause of flammability limits suggest insufficient knowledge of the mechanism of flame failure. Direct and schlieren photography have been applied to a study of flame failure in tubes at the fuel-lean limit of flammability. Results show that a bubble of hot exhaust gas rises in contact with upward propagating flames and continues to rise even after the visible flame has failed. Downward propagating flames show no evidence of such a mechanism. Comparison with fluid dynamical calculations shows that the exhaust bubble and attached flame rise in accordance with a relation involving only the tube diameter and the local gravitational acceleration. It is deduced that the bubble plays a major part in assisting the stability of a rising flame, hence accounting for the difference between flammability limits for upward and downward propagation. Further discussion suggests that this mechanism itself causes flammability limits as conventionally defined and shows how limits for different fuels are related. The final conclusion is that the limit of flammability, as commonly measured, is not a fundamental combustion parameter of a fuel.

AUTHOR: Lewis, B.; and Von Elbe, G

TITLE: Combustion, Flames, and Explosion of Gases, 3rd Ed.

DOC TYPE: Book
DOCUMENT:
PUBLISHER: Academic Press, Inc.
ADDRESS: Orlando, FL 32887
VOL NO:
ISSUE:
YEAR: 1987
PAGE NO:
LANGUAGE: English

KEYWORDS:
flammability, flammability limits, combustion, LFL, UFL,

REFERENCE NUMBER: 57 IN NMERI LIBRARY: No

ABSTRACT:

This book is the third edition of Combustion, Flames and Explosions of Gases. It provides the chemist, physicist, and engineer with the scientific basis for understanding combustion phenomena. It deals with systems of gases that are capable of spontaneously accelerating chemical reactions with large energy releases such as may be found in the combustion of flammable refrigerants. It is divided into four parts: chemistry and kinetics of the reactions between gaseous fuels and oxidants; flame propagation; state of the unburned gas; and technical combustion processes. Of particular interest are Chapter IV in Part I, The Reaction Between Hydrocarbons and Oxygen and Chapter V in Part II, Combustion Waves in Laminar Flow. Among other topics, Chapter V covers ignition by electric sparks, limits of flammability, and combustion waves in closed vessels. Chapter VI covers combustion waves in turbulent flow.

AUTHOR: Li, G.; and Wang, C.

TITLE: Comprehensive Study on Electric Spark Sensitivities of Ignitable Gases and Explosive Powders

DOC TYPE: Journal Article
DOCUMENT: Journal of Electrostatics
PUBLISHER: Elsevier Scientific Publishing Company
ADDRESS: Amsterdam, The Netherlands
VOL NO: 11
ISSUE:
YEAR: 1982
PAGE NO: 319-332
LANGUAGE: English

KEYWORDS: flammability, ignition, minimum ignition energy, spark ignition, humidity

REFERENCE NUMBER: 56 IN NMERI LIBRARY: Yes

ABSTRACT:

The present paper reports experimental results of a systematic study on electric spark sensitivity of ignitable gases and explosive powders with a new type of sensitivity testing apparatus, which consists of a test bomb, a dual switch spark circuit and a photoengraved electrode sheet. The ranking of electric spark sensitivity of hydrogen typical if ignitable gases and lead styphnate typical of explosive powders has been obtained for the first time. Through careful sensitivity comparison tests, the conclusion has been drawn that hydrogen is more sensitive than lead styphnate. In addition, the electric spark sensitivity of black powder was investigated in depth and the minimal value (26.4 mJ) of the minimum energy for 50% ignition was obtained.

In systematic studies on the optimum ignition condition of hydrogen, lead styphnate and black powder, the minimal vale of the ignition energy was found existing regularly for different materials; whereas in the study of the effects of ambient temperature and humidity on the ignition energy, linear elation was discovered.

AUTHOR: Linnett, J.W.; and Simpson, J.S.M

TITLE: Limits of Inflammability

DOC TYPE: Conference Proceeding
DOCUMENT: Sixth Symposium (International) on Combustion
PUBLISHER: Reinhold Publishing Corporation
ADDRESS: New York, NY
VOL NO: 6th
ISSUE:
YEAR: 1957
PAGE NO: 20-27
LANGUAGE: English

KEYWORDS: flammability limits

REFERENCE NUMBER: 44 IN NMERI LIBRARY: Yes

ABSTRACT:

This paper investigates the theory of the limits of flammability. Various test results using methane and ethylene plus air are reported with respect to the direction of the propagation of the flame; significant differences are recorded, especially for ethylene. Burning velocities, pressure, and other factors affecting the limits are discussed. Conclusions included that there is no convincing evidence for the existence of fundamental limits although theory suggests that there probably are such limits.

AUTHOR: Litchfield, E.L.; Hay, M.H.; Kubala, T.A.; and Monroe, J.S.

TITLE: Minimum Ignition Energy and Quenching Distance in Gaseous Mixtures - techniques and Apparatus

DOC TYPE: Report

DOCUMENT: Bureau of Mines Report of Investigation 7009

PUBLISHER: Bureau of Mines

ADDRESS: Pittsburgh, PA

VOL NO: 7009

ISSUE:

YEAR: 1967

PAGE NO:

LANGUAGE: English

KEYWORDS: minimum ignition energy, quenching distance, ignition

REFERENCE NUMBER: 81 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Descriptions are given of the techniques and apparatus used by the Bureau of Mines for determinations of flat plate ignition quenching distance and minimum spark ignition energy. The descriptions include discussions of reaction vessel materials, shapes, and sizes and discussions of electrode configurations. Spherical, hemispherical, or flat plate electrodes are recommended. The preferred metal in electrodes and electrode supports is stainless steel; the flat plate electrodes incorporate flanges of low electrical conductivity which are most frequently formed from glass. Various aspects of the electrical energy supply system are discussed and suitable arrangements of components are indicated. The concept of a thermal relaxation time is introduced as a basis for the choice of a minimum interspark time during the testing of a gas mixture. The following indicate the varied conditions under which these techniques were utilized: Mixture pressures between 10 mm Hg and 45 psig, initial temperatures between -78 degrees and +198 degrees C, and gaseous mixtures representing wide ranges of chemical reactivity and corrosiveness. Minimum ignition energies were determined which varied from about 10 *super*-7 joule to nearly 10*super*3 joule.

AUTHOR: Lovachev, L.A.

TITLE: Flammability Limits - a Review

DOC TYPE:	Journal Article
DOCUMENT:	Combustion Science and Technology
PUBLISHER:	Gordon and Breach Science Publishers, Inc.
ADDRESS:	New York, NY
VOL NO:	20
ISSUE:	
YEAR:	1979
PAGE NO:	209-224
LANGUAGE:	English

KEYWORDS:
flammability limits, ignition

REFERENCE NUMBER: 78 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The definition of a flammability limit still remains a most important fundamental problem of the combustion theory. The data on limits are needed in practice in determining the fire- and explosion-proof conditions. However, there is yet no universal answer to the main question of the applicability of the data obtained in standard tubes to large confined and unconfined clouds. This paper is concerned with results obtained after the publishing of the first review by Lovachev et al. in 1973 (Flammability 71).

AUTHOR: Lovachev, L.A.; Babkin, V.S.; Bunev, V.A.; V'yun, A.V.; Krivulin, V.N.; and Baratov,

TITLE: Flammability Limits: An Invited Review

DOC TYPE:	Journal Article
DOCUMENT:	Combustion and Flame
PUBLISHER:	Elsevier Science Publishing Co.
ADDRESS:	New York, NY 10017
VOL NO:	20
ISSUE:	
YEAR:	1973
PAGE NO:	259-289
LANGUAGE:	English

KEYWORDS:
flammability, flammability limits, flames, inhibition, ignition

REFERENCE NUMBER: 71 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This review deals with problems of flammability limits for gaseous mixtures: the theory of convective flammability limits, flame behaviour near the limits, near-limit phenomena in large vessels, inhibition of flammability limits, definition of flammability limit, certain aspects of ignition, and flammability limits at high pressures and temperatures.

AUTHOR: McLinden, Mark O.; and Didion, David A.

TITLE: Quest for Alternatives

DOC TYPE: Journal Article
DOCUMENT: ASHRAE Journal
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
VOL NO: 29
ISSUE: 12
YEAR: 1987
PAGE NO: 32-42
LANGUAGE: English

KEYWORDS:
R-12, alternative refrigerants, CFC, thermodynamic, flammability, toxicity,

REFERENCE NUMBER: 6 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This document describes the CFC/atmospheric problem and defines requirements for refrigerants which replacement refrigerants must satisfy. It describes a database search for compounds which are capable of meeting thermodynamic, toxicological, flammability and other criteria. Although there are a large number of compounds in the halocarbon family, only a few are simultaneously nonflammable, environmentally acceptable and of low toxicity. R-134 and R-134a were identified as potential refrigerants in this early (1987) study. Mixtures were recommended, along with equipment modifications, as the prudent course to follow, as well as refrigerant conservation and recycling.

AUTHOR: Multiple

TITLE: 1993 ASHRAE Handbook Fundamentals SI Edition

DOC TYPE: Book
DOCUMENT:
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
VOL NO:
ISSUE:
YEAR: 1993
PAGE NO:
LANGUAGE: English

KEYWORDS:
refrigerant, refrigerant properties

REFERENCE NUMBER: 53 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This book covers fundamentals of refrigeration. Chapter 15 describes combustion and fuels, Chapter 16 describes refrigerants, and Chapter 17 presents tables of refrigerant properties.

AUTHOR: Multiple

TITLE: ARI Flammability Workshop March 8-9 1994 Chicago Illinois

DOC TYPE: Conference Proceeding
DOCUMENT:
PUBLISHER: Air Conditioning and Refrigeration Institute
ADDRESS: Arlington, VA 22203
VOL NO:
ISSUE:
YEAR: 1994
PAGE NO:
LANGUAGE: English

KEYWORDS:
refrigerant, flammability, ASTM E682, UEL, LEL, test methods

REFERENCE NUMBER: 27 IN NMERI LIBRARY: Yes

ABSTRACT:

The briefing from the ARI-sponsored flammability workshop held in Chicago on 8-9 March 1994. Experimental data, regulatory updates, flammability test methods, and risk assessment were among the topics discussed.

AUTHOR: N/A

TITLE: Hoechst Suffers Explosion at Frankfurt 134a Facility

DOC TYPE: Journal Article
DOCUMENT: Chemical Marketing Reporter
PUBLISHER: Chemical Marketing Reporter
ADDRESS: New York, NY 10004
VOL NO: 245
ISSUE: 12
YEAR: March 28 1994
PAGE NO: 1, 40
LANGUAGE: English

KEYWORDS:
R-134a, explosion, Hoechst

REFERENCE NUMBER: 26 IN NMERI LIBRARY: Yes

ABSTRACT:

An explosion in the Hoechst 134a facility in Frankfurt Germany on March 18, 1994 may shut production down for six months. The cause of the explosion is unknown, but the blast may have occurred in the caustic soda cleaning process. "The vessel in which the explosion occurred contained 134a with a purity of greater than 97 percent. It is possible an explosive mixture formed as a result of air getting into the vessel." DuPont believes that the substance was not at fault in the explosion, and suggests Hoechst had problems in its manufacturing process. "The fact that you can get 134a at high temperatures to show some flammability is not new information, but this only occurs at very high temperatures and pressures (See Dekleva, et al, Ref 1).

AUTHOR: N/A

TITLE: KLEA 32 Blends: Flammability Characteristics

DOC TYPE: Report
DOCUMENT:
PUBLISHER: ICI Chemicals and Polymers
ADDRESS:
VOL NO:
ISSUE: 1
YEAR: Mar 92
PAGE NO:
LANGUAGE: English

KEYWORDS:
R-32, flammability, ignition, heat of combustion, blends, R-134a, critical flammability ratio, leakage, lubricant,

REFERENCE NUMBER: 10 IN NMERI LIBRARY: Yes

ABSTRACT:

This document supplies flammability data on KLEA 32 (R-32). It describes the effects of different test equipment on the flammability limits. For blends, it states critical flammability ratios, the effect of temperature on vapour composition in cylinders, leakage from systems, and lubricant effects.

AUTHOR: Ohnishi, H.; Izutani, N.; Inagaki, S.; Karasawa, K.; Ishida, S.; and Kataoka, O.

TITLE: Relationship between Flammability and Composition Ratio of HFC-32/HFC-134a Blend

DOC TYPE: Conference Proceeding
DOCUMENT: ASHRAE/NIST Refrigerants Conference on R-22/R-502 Alternatives
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
VOL NO:
ISSUE: August
YEAR: 1993
PAGE NO:
LANGUAGE: English

KEYWORDS:

REFERENCE NUMBER: 23 IN NMERI LIBRARY: No

ABSTRACT:

AUTHOR: Pannock, J.; Didion, D.A.; and Radermacher, R.

TITLE: Performance Evaluation of Chlorine Free Zeotropic Refrigerant Mixtures in Heat Pumps - Computer Study and Tests

DOC TYPE: Conference Proceeding
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 25-34
LANGUAGE: English

KEYWORDS: refrigerants, R-32, R-134a

REFERENCE NUMBER: 95 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Fifteen binary zeotropic refrigerant mixtures consisting of the components R23, R32, R125, R134a, R143a, and R152a are investigated as possible replacement fluids for R22. The two mixtures of R32/R134a and R32/R152a showed COP improvements over R22 of up to 24% (depending on the operating condition and mixture composition) at the same capacity as with R22 while using counter flow heat exchange in evaporator and condenser. The use of a liquid line to suction line heat exchanger proved to be advantageous for both mixtures. The overall conductance for both mixtures is evaluated to be equal to or up to 22% greater (R32/R152a) than that of R22. Therefore, the heat exchanger size used with R22 should be sufficient to achieve performance increases with these zeotropic mixtures.

AUTHOR: Powell, F.

TITLE: Ignition of Gases and Vapors

DOC TYPE: Journal Article
DOCUMENT: Industrial and Engineering Chemistry
PUBLISHER: American Chemical Society Publications
ADDRESS: Washington DC 20036
VOL NO: 61
ISSUE: 12
YEAR: 1969
PAGE NO: 29-37
LANGUAGE: English

KEYWORDS: ignition, gases, friction, impact

REFERENCE NUMBER: 50 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The ignition of flammable gases and vapors in the presence of hot surfaces, and (or) sparks produced by friction or impact of solids (e.g. metals, rocks) is reviewed with 82 references.

AUTHOR: Pu, Y.K.; Jarosinski, J.; Johnson, V.G.; and Kauffman, C.W.

TITLE: Turbulence Effects on Dust Explosions in the 20-Liter Spherical Vessel

DOC TYPE: Conference Proceeding
DOCUMENT: Twenty-third Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 23rd
ISSUE:
YEAR: 1991
PAGE NO: 843-849
LANGUAGE: English

KEYWORDS:
explosion sphere, burning rate

REFERENCE NUMBER: 32 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The method of collecting a large amount of data and taking ensemble average over all measurement periods using computer is employed to determine the turbulence parameters during the transient dispersion process in the 20 liter spherical vessel. The system studied is typical for laboratory pneumatic dispersion systems in explosion test vessels. Measurements show that a decaying turbulence feature is generated by the dispersion system and characterized by a decay period of 150-300 ms with the integral scale of about 1 cm and initial intensity of about 3 m/s, which has no analogue with the expected natural conditions of accidental explosions in industry. Two kinds of dust-air mixtures (aluminum and cornstarch) and methane-air mixtures, three different sizes of aluminum dust particle (5, 15, 30 μm) and one average size of cornstarch dust (15 μm) are tested in this sphere. The maximum burning velocity is used instead of Kst factor to characterize the highest combustion rate occurred during the explosion process in the closed vessel for both dust and gas-air mixtures. The present experimental results demonstrate that the maximum burning velocities determined as a linear function of the initial rms turbulence velocity produced by the pneumatic dispersion system in the aluminum- and cornstarch-air mixtures. The experimental results also demonstrate that the reduction of dust particle size will increase significantly the turbulent burning velocity in dust-air mixtures, but the kind of dust seems to have no significant influence on explosion data, if their particle sizes are the same. These suggest that the dispersion induced turbulence may play more important role in formation of dust-air mixtures than in direct effect dust combustion process, and that the influence of the above turbulence on the combustion characteristics mainly enters through the mechanisms of creating uniform suspension of dust clouds.

AUTHOR: Radermacher, R.; and Jung, D.

TITLE: Theoretical Analysis of Replacement Refrigerants for R-22 for Residential Uses

DOC TYPE: Report
DOCUMENT: US EPA Report EPA/400/1-91/041
PUBLISHER: US Environmental Protection Agency
ADDRESS: Washington, DC
VOL NO:
ISSUE:
YEAR: 1991
PAGE NO:
LANGUAGE: English

KEYWORDS:

REFERENCE NUMBER: 75 **IN NMERI LIBRARY:** No

ABSTRACT:

AUTHOR: Reed, Paul R.; and Rizzo, Joseph J.

TITLE: Combustibility and Stability Studies of CFC Substitutes with Simulated Motor Failures in Hermetic Refrigeration Equipment

DOC TYPE: Conference Proceeding
DOCUMENT: XVIII International Congress of Refrigeration
PUBLISHER: International Institute of Refrigeration
ADDRESS:
VOL NO: 18th
ISSUE:
YEAR: 10-17 Aug 1991
PAGE NO:
LANGUAGE: English

KEYWORDS: flammability of refrigerants, HFC-134a, combustibility

REFERENCE NUMBER: 33 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Alternative refrigerants tested to date are non-flammable at ambient temperature and pressure. In addition, these refrigerants are non-combustible at elevated temperatures and pressure if minimal air is present. However, with large quantities of air, both HFC-134a and blends containing HCFC-22/HFC-152a/HCFC-124 or CFC-114 were combustible.

AUTHOR: Richard, R.G.; and Shankland, I.R.

TITLE: Flammability of Alternative Refrigerants

DOC TYPE: Conference Proceeding
DOCUMENT: Proceedings of the XVIII International Congress of Refrigeration
PUBLISHER: Unknown
ADDRESS:
VOL NO: II
ISSUE: Paper #42
YEAR: 1991
PAGE NO:
LANGUAGE: English

KEYWORDS:
refrigerant flammability, CFCs, HFCs, ASTM E-681, ignition, R-32, R-152a

REFERENCE NUMBER: 25 **IN NMERI LIBRARY:** No

ABSTRACT:

This document is an earlier version of the April 1992 Richard-Shankland ASHRAE article (Flammability 2). Nothing additional is available in this document (phone conversation with Richard, April, 1994).

AUTHOR: Richard, Robert G.; and Shankland, Ian

TITLE: Flammability of Alternative Refrigerants

DOC TYPE: Journal Article
DOCUMENT: ASHRAE Journal
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
VOL NO: 34
ISSUE: 4
YEAR: 1992
PAGE NO: 20-24
LANGUAGE: English

KEYWORDS:
refrigerant flammability, CFCs, HFCs, ASTM E-681, ignition, R-32, R-152a

REFERENCE NUMBER: 2 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The flammability of non-CFC refrigerants were measured using the ASTM E-681 flammability method. Six different ignition sources were investigated: spark, fused wire, electric squib and three household matches. Vessel size, moisture and temperature effects were also investigated and results compared for several compounds. The flammability range for thirty-one pure refrigerants was presented, both for room temperature and at 95C. The match ignition source is more vigorous, and is recommended for halocarbons which are marginally flammable, while materials which are easy to ignite (e.g., hydrocarbons) all ignition sources produce the same flame limits within experimental error.

AUTHOR: Rose, H.E.; and Priede, T.

TITLE: An Investigation of the Characteristics of Spark Discharges as Employed in Ignition Experiments

DOC TYPE: Conference Proceeding

DOCUMENT: Seventh Symposium (International) on Combustion

PUBLISHER: Butterworth's Scientific Publisher's

ADDRESS: London, England

VOL NO: 7th

ISSUE:

YEAR: 1959

PAGE NO: 454-463

LANGUAGE: English

KEYWORDS: ignition, minimum ignition energy

REFERENCE NUMBER: 42 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This paper investigates capacitive discharge and their energy release characteristics in relation to the ignition of explosive gaseous mixtures. The investigation concerns a detailed inquiry into the characteristics of spark discharges range of capacitance from 1000 micro-micro-farads down to a few micro-micro farads. Tentative conclusions included that the proportion of stored energy which is released into the spark gap depends upon the ratio of the spark gap resistance to other resistance in the circuit, which means for small capacitances (gap resistance high - of the order of 150 to 300 ohms) resistances up to 10 ohms have almost negligible effect on the energy release. In many experimental circuits a circuit resistance of below 0.1 ohm is practical and for such cases the expression 1/2 CV*super*2 can be accepted as a good criterion for the electrical energy released at the spark gap. With circuit resistances of 10 ohms and upwards, the proportion of the total stored energy that is released at the spark gap decreases with increasing series resistance, with increasing capacitance, and with increasing hydrogen concentration.

AUTHOR: Rose, H.E.; and Priede, T.

TITLE: Ignition Phenomena in Hydrogen-Air Mixtures

DOC TYPE: Conference Proceeding
DOCUMENT: Seventh Symposium (International) on Combustion
PUBLISHER: Butterworth's Scientific Publisher's
ADDRESS: London, England
VOL NO: 7th
ISSUE:
YEAR: 1959
PAGE NO: 436-445
LANGUAGE: English

KEYWORDS:
ignition, minimum ignition energy

REFERENCE NUMBER: 41 IN NMERI LIBRARY: Yes

ABSTRACT:

This paper investigates various parameters, such as the electrode configuration, electrode material and the rate of energy release which affect the ignition energy required to ignite a hydrogen-air mixture. It was found that for capacitive discharges, with a gap distance greater than the quenching distance of the mixture, changes in the gap geometry and in the circuit conditions can produce two to fivefold changes in the experimentally derived values of the minimum energy to be liberated in the gap in order to produce ignition. The minimum ignition energy, expressed as electrical energy released at the spark gap, decreases with the following factors: (a) a reduction of the electrode size; (b) with the electrode material in the order platinum, aluminum, silver cadmium; (c) the increase in the value of the series resistance in the discharge circuit. Electrical influences affecting ignition are the time intervals during which the spark channel remains in a conducting state, after the energy release, and the voltage level at which the energy is being released; both these factors also being dependent upon the parameters of the circuit.

AUTHOR: Roth, W.; Guest, P.G.; Von Elbe, G.; and Lewis, B.

TITLE: Heat Generation by Electrical Sparks and Rate of Heat Loss to the Spark Electrodes

DOC TYPE: Journal Article
DOCUMENT: The Journal of Physical Chemistry
PUBLISHER: The Journal of Physical Chemistry
ADDRESS:
VOL NO: 19
ISSUE: 12
YEAR: 1953
PAGE NO: 1530-1535
LANGUAGE: English

KEYWORDS:
ignition, spark ignition, minimum ignition energy

REFERENCE NUMBER: 82 **IN NMERI LIBRARY:** Yes

ABSTRACT:

In a capacitance spark the gas between the electrodes is heated almost instantaneously; subsequently, the spark-generated heat flows from the gas to the materials of the electrodes. In the present experiments sparks of 0.1 to 2 millijoules were passed between Pt electrodes in a bulb containing helium or argon or xenon, and either the pressure change, delta p, at constant volume v or the volume change, delta v, at constant pressure p was recorded, the former by means of a sensitive diaphragm and the latter by the movement of a droplet in a capillary tube attached to the bulb. The spark-generated heat H residing in the gas at any instant was computed from the equations H =1.5 delta p and H = 2.5p delta v, which apply to constant volume and pressure, respectively, and are derived from the gas law and the energy equation, using the heat capacity of monoatomic gases. From the values of H and the discharge energy corresponding to the measured capacitance and breakdown voltage, the percentage of spark-generated heat residing in the gas was obtained. Immediately after discharge the percentage was found to exceed 95. The rate at which the percentage decreases with time was found to be independent of total energy and vessel diameter above a critical value of the latter. It was found to become smaller with decreasing heat conductivity of the gas, decreasing diameter of the spherical electrodes, and increasing gap length, as expected on the basis of heat loss from the gas to the electrodes. With electrode diameters of 1 mm, the heat loss after about 30 milliseconds ranged from a few percent for xenon and 10 mm gap length to 75 percent for helium and 1 mm gap length. An increase of the electrode diameter to 3 and 4.6 mm caused a substantial increase of the rate of heat loss; for example, for xenon and 10 mm gap length the heat loss after about 30 milliseconds was 28 percent and 35 percent, respectively. It was found that for constant electrode diameter the data for the several gases and gap lengths could be combined in a plot of percentage heat loss against a dimensionless parameter, theta, representing the product of thermal diffusivity and time elapsed since discharge, divided by the square of the gap length. By means of the latter parameter, one may estimate an upper bound of the heat loss during the formation of a combustion wave from a spark in an explosive gas, i.e., during the process of spark ignition, on the basis that the combustion wave is formed in a time interval smaller than the time required for the wave to travel in a distance equal to its width. It is found that the loss of spark energy during the ignition process is always rather small.

AUTHOR: Sand, James R.; and Andrjeski, D.L.

TITLE: Combustibility of Chlorodifluoromethane

DOC TYPE: Journal Article
DOCUMENT: ASHRAE Journal
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
VOL NO: 24
ISSUE: 5
YEAR: 1982
PAGE NO: 38-40
LANGUAGE: English

KEYWORDS:
R-22, refrigerant-22, combustibility, flammability, heat of combustion,

REFERENCE NUMBER: 8 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Laboratory tests have confirmed the combustibility of pressurized mixtures containing chlorodifluoromethane (Refrigerant-22, R-22) and air or oxygen. The investigation was instituted after a fatal industrial explosion which occurred during the weld repair of a compressor shell which apparently contained a 50:50 air:R-22 mixture at about 200 psia. Previous references to the combustibility and explosivity of R-22 suggest that it is non-flammable and quite safe, although an Underwriter's laboratory test report states that under certain laboratory conditions it may form a weakly explosive mixture with air. This work presents experimental evidence that pressurized gas mixtures of R-22 containing at least 50% air are combustible and that the heat generated by this reaction is capable of increasing the pressure in a closed contained by a factor of from 6 to 8 times. Refrigerants-12 and -11 are not combustible under similar conditions.

AUTHOR: Sanvordenker, K.S.

TITLE: Experimental Evaluation of an R-32/R-134a Blend as a Near Drop-in Substitute for R-22

DOC TYPE: Report
DOCUMENT: ASHRAE Technical Data Bulletin
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
VOL NO: 9
ISSUE: 4
YEAR: 1993
PAGE NO: 34-39
LANGUAGE: English

KEYWORDS:
flammability, R-32, R-134a

REFERENCE NUMBER: 88 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Based on thermodynamic properties and environmental acceptability, a 30%/70% blend by mass of R-32 and R-134a was evaluated as a near drop-in alternative to R-22 for use in unitary hermetic compressors.

Calorimeter data based on ASHRAE and ARI standard test methods were determined and results interpreted according to ARI Standard 540-91. Results indicate that this blend is as close as can be expected to being a "drop-in" replacement for R-22.

Aspects of environmental acceptability as well as those of materials compatibility are discussed. The flammability of R-32 and R-134a blends is also discussed.

AUTHOR: Shankland, Ian R.

TITLE: Some Issues Related to Flammability Classification of Refrigerants, or When is a Refrigerant Flammable? How Flammable is Flammable?

DOC TYPE: Conference Proceeding
DOCUMENT:
PUBLISHER: AlliedSignal Chemicals
ADDRESS: Buffalo, NY 14210
VOL NO:
ISSUE:
YEAR: 1993
PAGE NO:
LANGUAGE: English

KEYWORDS:
refrigerant flammability standards, codes, regulations, ASTM-E-681, flammable,

REFERENCE NUMBER: 7 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This paper outlines flammability standards, codes, and regulations, and defines various classes of flammability. It states that the answer to the question, is it flammable, is not simple, but can depend on the test condition (vessel size, ignition source, temperature, pressure, humidity, etc.). It also suggests that additional information (e.g. minimum ignition energy, maximum explosion pressure, rate of pressure rise) is required to ascertain whether these materials are viable refrigerants.

AUTHOR: Shaoqiang, H.; Xiaoping, L.; and Chunfei, X.

TITLE: Refrigerant HCR-152a Flammability Test Results

DOC TYPE: Report
DOCUMENT:
PUBLISHER: Wanbao Refrigerator Industrial Corporation
ADDRESS: China
VOL NO:
ISSUE:
YEAR: 1991
PAGE NO:
LANGUAGE: English

KEYWORDS:

REFERENCE NUMBER: 76 IN NMERI LIBRARY: No

ABSTRACT:

AUTHOR: Sheldon, M.

TITLE: Principles of Spark Ignition

DOC TYPE: Journal Article
DOCUMENT: Fire Protection
PUBLISHER: Fire Protection Association
ADDRESS: London, England, UK
VOL NO: 165
ISSUE:
YEAR: 1983
PAGE NO: 27-31
LANGUAGE: English

KEYWORDS:
ignition, spark ignition, flammability, flammable vapors, flammable gases

REFERENCE NUMBER: 55 IN NMERI LIBRARY: Yes

ABSTRACT:

This article describes factors affecting spark ignition of flammable gases and vapors. It describes several factors which influence spark ignition, including the electrodes, gas movement, temperature, pressure, oxygen enrichment and depletion, as well as determining the minimum ignition energy. It contains little which is not published elsewhere, but is a good simple review of the ignition process.

AUTHOR: Sherbo, H.N.; Korolchenko, A.Y.; Eremenko, O.Y.; Tsarickenko, S.G; Navtshenya, V.

TITLE: Concentration Limits of Flammability in Vapor-Gas Mixtures Based on Halohydrocarbons

DOC TYPE: Journal Article
DOCUMENT: Zhurnal Fizicheskoi Khimii
PUBLISHER: N/A
ADDRESS:
VOL NO: 64
ISSUE: 5
YEAR: 1991
PAGE NO: 1327-1331
LANGUAGE: Russian

KEYWORDS:
N/A

REFERENCE NUMBER: 69 **IN NMERI LIBRARY:** No

ABSTRACT:

N/A

AUTHOR: Shiflett, M.B.; Yokozeki, A.; and Bivens, D.B.

TITLE: Refrigerant Mixtures as HCFC-22 Alternatives

DOC TYPE: Conference Proceeding
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 35-44
LANGUAGE: English

KEYWORDS:
flammability, refrigerant, R-32, R-134a,

REFERENCE NUMBER: 96 **IN NMERI LIBRARY:** Yes

ABSTRACT:

A recent international assessment of the atmospheric science has provided a basis to accelerate the chlorofluorocarbon (CFC) phase-out. In addition, the assessment provided a basis for advancing the phase-out schedule for long-lived hydrochlorofluorocarbons (HCFCs) such as chlorodifluoromethane (HCFC-22). The objective of this study was to identify potential alternatives to HCFC-22 and evaluate their performance in a room air conditioner. Computer model simulations of a theoretical refrigeration cycle suggested that a mixture of hydrofluorocarbons (HFCs) might perform the same as HCFC-22. The air conditioner test results indicate that mixtures may be used as alternatives to HCFC-22.

AUTHOR: Shiflett, M.B.; Yokozeki, A.; and Reed, P.R.

TITLE: Property and Performance Evaluation of "Suva" HP Refrigerants as R-502 Alternatives

DOC TYPE: Conference Proceeding
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 15-24
LANGUAGE: English

KEYWORDS: flammability, refrigerants, leakage

REFERENCE NUMBER: 94 **IN NMERI LIBRARY:** Yes

ABSTRACT:

Impending reductions in chlorofluorocarbon production, with an accelerated phase-out by January 1, 1996, made it necessary to develop alternatives for R-502. A family of R-502 alternatives ("SUVA" HP Refrigerants) have been developed providing significant reductions in ozone depletion and global warming potential, plus cooling performance essentially the same as R-502.

AUTHOR: Sicars, S.; Hesse, U.; and Kruse, H.

TITLE: Theoretische Undersuchungen zur Brennbarkeit von Kaltemitteln und Kaltemittelgemischen (Theoretical Investigation of the Combustion of Refrigerants

DOC TYPE: Journal Article
DOCUMENT: N/A
PUBLISHER: N/A
ADDRESS:
VOL NO: N/A
ISSUE: N/A
YEAR: N/A
PAGE NO:
LANGUAGE: German

KEYWORDS: N/A

REFERENCE NUMBER: 97 **IN NMERI LIBRARY:** Yes

ABSTRACT:

N/A

AUTHOR: Singh, A.K.

TITLE: Spark Ignition of Aerosols

DOC TYPE: Conference Proceeding
DOCUMENT: Twenty-first Symposium (International) on Combustion
PUBLISHER: The Combustion Institute
ADDRESS: Pittsburgh, PA 15213
VOL NO: 21st
ISSUE:
YEAR: 1986
PAGE NO: 513-519
LANGUAGE: English

KEYWORDS: ignition, flame propagation

REFERENCE NUMBER: 36 **IN NMERI LIBRARY:** Yes

ABSTRACT:

An experimental investigation was carried out to determine the minimum spark ignition energy of monodisperse tetraline aerosols in a laminar gas flow. Results, presented in terms of spark ignition frequency, and for droplet sizes between 6.7 microns and 40 microns showed: a relatively weak dependence on spark duration, an optimum spark gap width between 3 and 4 mm, an increase in minimum spark ignition energy with decreasing oxygen concentration in the gas, a decrease in spark ignition energy as the gas to fuel ratio decreased from lean to stoichiometric, a maximum ignition frequency depending on droplet size, and an optimum droplet size between 22 and 26 microns for minimum spark ignition energy. A model of droplet motion and vaporization allowed an estimation of the non-reactive fuel vapor concentration and droplet motion due to the spark discharge and was used for qualitative discussion of the experimental results.

AUTHOR: Skaggs, S.R.; Heinonen, E.W.; Moore, T. A.; and Kirst, J.A.

TITLE: Low Ozone-Depleting Halocarbons as Total-Flood Agents: Volume 2: Laboratory-Scale Fire Suppression and Explosion Prevention (Draft Report)

DOC TYPE: Report
DOCUMENT: New Mexico Engineering Research Institute OC 92/26
PUBLISHER: New Mexico Engineering Research Institute
ADDRESS: Albuquerque, NM 87106
VOL NO:
ISSUE:
YEAR: Sep 1993
PAGE NO:
LANGUAGE: English

KEYWORDS: explosion sphere, inerting concentration, ignition

REFERENCE NUMBER: 35 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This report presents results from flame suppression and inertion testing of alternatives to Halon 1301 for use on the North Slope of Alaska. The NMERI explosion sphere, which was used to determine the inerting concentration and which has also been used to determine the flammability range of alternative refrigerants, is described along with the test technique required to determine whether a material is flammable or not.

AUTHOR: Smith, N.D.; Ratanaphruks, K.; Tufts, M.; and Ng, A.S.

TITLE: R-245ca: A Potential Far-term Alternative for R-11

DOC TYPE: Journal Article
DOCUMENT: ASHRAE Journal
PUBLISHER: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ADDRESS: Atlanta, GA 30329
VOL NO: 35
ISSUE: 2
YEAR: 1993
PAGE NO: 19-23
LANGUAGE: English

KEYWORDS:
flammability, R-245ca, moisture, humidity

REFERENCE NUMBER: 73 IN NMERI LIBRARY: Yes

ABSTRACT:

R-245ca was tested as a possible replacement for R-11. The flammability behavior was found to be sensitive to the moisture content of the mixtures. While R-245ca was found to be non-flammable at 30C and 50C with no moisture or up to 25 microliters of water, it was found to be flammable at the equivalent of 43% humidity at 30C. The flammability range was between 7.0% and 14.4%. In a separate test, flame characteristics intensified as the humidity was increased. Additionally, when the spark ignition was replaced with a matchhead, the mixture was non-flammable under conditions which were flammable using the spark ignition. This is unexpected as most flammable mixtures become more flammable as the ignition energy is increased, as in replacing the spark ignition with the match.

AUTHOR: Sokolik, A.S.

TITLE: Self-Ignition, Flame and Detonation in Gases

DOC TYPE: Book
DOCUMENT: NASA TT F-125
PUBLISHER: Unknown
ADDRESS:
VOL NO:
ISSUE:
YEAR: 1963
PAGE NO:
LANGUAGE: English

KEYWORDS:
ignition, combustion, gases

REFERENCE NUMBER: 65 IN NMERI LIBRARY: No

ABSTRACT:

This document is a translation of a Russian document (1960) detailing combustion processes, especially the kinetic problems of combustion. Topics covered include thermal and chain-thermal explosions, self-ignition of hydrocarbons, hydrocarbon ignition at high pressures, laminar flames, turbulent combustion, and shock and detonation. While most of the discussion centers around the internal combustion engine, this document is nonetheless a good treatise on ignition in general.

AUTHOR: Sorenson, S.C.; Savage, L.D.; and Strehlow, R.A.

TITLE: Flammability Limits - A New Technique

DOC TYPE: Journal Article
DOCUMENT: Combustion and Flame
PUBLISHER: Elsevier Science Publishing Co.
ADDRESS: New York, NY 10017
VOL NO: 24
ISSUE:
YEAR: 1975
PAGE NO: 347-355
LANGUAGE: English

KEYWORDS: flammability, flammability limits, premixed flames

REFERENCE NUMBER: 63 IN NMERI LIBRARY: Yes

ABSTRACT:

A technique has been developed to study the extinguishment of premixed laminar flames. The technique utilizes a steady state burner with a tent flame surrounded by a separate stream of ignition gases, which are the product gases of another premixed flame using the same fuel. Extinguishment is determined by observation of the shape of the tent flame as the composition of the test mixture of fuel-suppressant-air is changed so as to move toward a composition region of extinguishment. Results are reported for five methane-air flames and methane-suppressant-air flames containing the suppressants Helium, Argon, Nitrogen, carbon dioxide and Halon 1301 (CF3Br). The technique yields a slightly broader flammability region than other techniques previously used. The relation between the results of this technique and the standard flammability techniques is discussed.

AUTHOR: Sundaresan, S.G.

TITLE: Near Azeotrope Refrigerants to Replace R502 in Commercial Refrigeration

DOC TYPE: Conference Proceeding
DOCUMENT: Proceedings of the 1992 International Refrigeration Conference
PUBLISHER: Purdue University
ADDRESS: West Layfayette, IN
VOL NO: 1
ISSUE:
YEAR: 1992
PAGE NO: 1-13
LANGUAGE: English

KEYWORDS: flammability, refrigerants, fractionation

REFERENCE NUMBER: 93 IN NMERI LIBRARY: Yes

ABSTRACT:

The refrigerant R502, an azeotrope of CFC115 and HCFC22, is an important refrigerant in commercial refrigeration, especially for low temperature applications using single stage compressors. Current users of R502 are faced with an earlier than anticipated phase-out and are under great pressure to find suitable alternates for retrofit and O.E.M. (new) applications. Single components like HCFC125, HFC143a, and HFC32 are not viable candidates. Some candidates which are being evaluated are near azeotropes containing HCFC22 and propane as components. This paper discusses the challenges involving the near azeotropes and also includes status on lubricants and materials compatibility requirements. The final solution for R502 involves finding a suitable zero ozone depletion potential refrigerant candidate with an appropriate lubricant.

AUTHOR: Swift, I.

TITLE: Developments in Explosion Protection

DOC TYPE: Report
DOCUMENT: Plant/Operations Progress
PUBLISHER: American Institute of Chemical Engineers
ADDRESS: New York, NY 10017
VOL NO: 7
ISSUE: 3
YEAR: 1988
PAGE NO: 159-168
LANGUAGE: English

KEYWORDS:
explosion, gas, dust, ignition

REFERENCE NUMBER: 61 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The current state of testing and research programs regarding present developments relating to deflagrations of gases and dusts.

AUTHOR: Underwriter's Laboratory

TITLE: File USNC181, Project 89NK14414, Report on Alternatives to Currently-Used Chlorofluorocarbon (CFC) Refrigerants

DOC TYPE: Report
DOCUMENT:
PUBLISHER: Underwriter's Laboratories, Inc.
ADDRESS: Northbrook, IL 60062
VOL NO:
ISSUE:
YEAR: 1989
PAGE NO:
LANGUAGE: English

KEYWORDS:
R-12, flammable refrigerants, fire, explosion, alternative refrigerants, ASTM E681-85, ASTM E981-83, ignition,

REFERENCE NUMBER: 5 **IN NMERI LIBRARY:** Yes

ABSTRACT:

CFC-12 is a widely used refrigerant in household and small commercial refrigerant equipment. It is among the substances banned by the Montreal Protocol. Several alternatives, either single fluids or binary or ternary blends, have been suggested as possible CFC replacements, including R-123, R-134a, R-142b, R-152a, propane, butane, and dimethyl ether. With the possible exception of R-123 and R-134a, these refrigerants are flammable to some degree. Because of the safety concerns over the use of flammable refrigerants, this report reviews available information on refrigerant properties, discusses flammability characteristics, explores several factors relating to refrigeration system leakage, and examines some of the details that need to be considered in connection with system charging at the factory and in the field.

Refrigeration Flammability References

AUTHOR: Von Elbe, G.

TITLE: The Problem of Ignition

DOC TYPE: Conference Proceeding
DOCUMENT: Fourth Symposium (International) on Combustion
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
VOL NO: 4th
ISSUE:
YEAR: 1953
PAGE NO: 13-20
LANGUAGE: English

KEYWORDS:
ignition, spark ignition, minimum ignition energy

REFERENCE NUMBER: 46 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This survey paper investigates the mechanisms of igniting a flammable mixture. The initial portion describes ignition by an electric spark, and discusses flame front propagation and minimum ignition energies. Ignition by other sources is described, and the concept that lower temperatures can ignite a mixture if the heat is applied for a longer period of time. It also states that high temperature sources may not ignite a mixture if the time period is too short.

AUTHOR: Von Lavante, E.; and Strehlow, R.A.

TITLE: The Mechanism of Lean Limit Flame Extinction

DOC TYPE: Journal Article
DOCUMENT: Combustion and Flame
PUBLISHER: Elsevier Science Publishing Co.
ADDRESS: New York, NY 10017
VOL NO: 49
ISSUE:
YEAR: 1983
PAGE NO: 123-140
LANGUAGE: English

KEYWORDS:
flame extinction, flammability, flammability limits

REFERENCE NUMBER: 64 **IN NMERI LIBRARY:** Yes

ABSTRACT:

The extinction of lean limit methane-air flames was experimentally studied in a vertical variable-geometry flammability tube with rectangular cross section. Four tube configurations have been investigated: 50 x 50, 100, 200 x 200, and 20 x 200 mm, using schlieren photography, visual observation, measurement of heat flux to the wall, and image intensifier photography. Extinction of the lean limit flame which did not involve unstable flame fluctuations occurred only for upward propagation in the tube sizes 50 x a50 and 100 x 100 mm. In all the other tube geometries, the extinction was preceded by unstable flame motions.

The flow field characteristics ahead of the flame for an upward propagating flame have been calculated numerically using a finite difference method. The results were applied to the determination of flame stretch. The comparison of the theoretically calculated Karlovitz number and the experimental observations suggest that flame stretch is the primary mechanism of extinction in the flammability tube when the flame is stable prior to extinction. Preferential diffusivity was found to have significant effects on the lean limit flame behavior. Preferential diffusion ahead of the flame lowered the lean limits in smaller tubes and caused cellular structures to appear in larger tubes.

AUTHOR: Zabetakis, M.G.; and Richmond, J.K.

TITLE: The Determination and Graphic Representation of the Limits of Flammability of Complex Hydrocarbon Fuels at Low Temperatures and Pressures

DOC TYPE: Conference Proceeding
DOCUMENT: Fourth Symposium (International) on Combustion
PUBLISHER: The Williams and Wilkins Co.
ADDRESS: Baltimore, MD
VOL NO: 4th
ISSUE:
YEAR: 1953
PAGE NO: 121-126
LANGUAGE: English

KEYWORDS:
flammability, flammability limits, ignition, ignition source

REFERENCE NUMBER: 24 **IN NMERI LIBRARY:** No

ABSTRACT:

This paper describes the effects of test conditions on the measurement of flammability limits at low temperatures and pressures. The careful selection of test chamber size and ignition source is critical and requires more exploratory tests than at room temperature and pressure. The experimental setup and block diagram of the U.S. Bureau of Mines surge generator and spark ignition measurement apparatus is described. Combustible liquid mixtures should be handled carefully before testing as vaporization losses may affect the results obtained. Experiments conducted on typical aviation gasolines and jet fuels illustrate these points.

AUTHOR: Zabetakis, Michael G.

TITLE: Flammability Characteristics of Combustible Gases and Vapors

DOC TYPE: Report
DOCUMENT: Bureau of Mines 627
PUBLISHER: Bureau of Mines
ADDRESS: Pittsburgh, PA
VOL NO:
ISSUE: 627
YEAR: 1965
PAGE NO:
LANGUAGE: English

KEYWORDS:
flammability, UEL, LEL, explosion, inertion, autoignition, burning-rate

REFERENCE NUMBER: 15 **IN NMERI LIBRARY:** Yes

ABSTRACT:

This is a summary of the available limit of flammability, autoignition, and burning-rate data for more than 200 combustible gases and vapors in air and other oxidants, as well as of empirical rules and graphs that can be used to predict similar data for thousands of other combustibles under a variety of environmental conditions Specific data are presented on the paraffinic, unsaturated, aromatic, and alicyclic hydrocarbons, alcohol, ether, aldehydes, ketones, and sulfur compounds, and an assortment of fuels, fuel blends, hydraulic fluids, engine oils, and miscellaneous combustible gases and vapors. It also discusses the limits of flammability and ignition, and the formation of flammable mixtures.