AHRI Report #08007

MATERIAL COMPATIBILITY AND LUBRICANTS RESEARCH FOR LOW GWP REFRIGERANTS – PHASE II: CHEMICAL AND MATERIAL COMPATIBILITY OF LOW GWP REFRIGERANTS WITH HVACR MATERIALS OF CONSTRUCTION

Final Report

June 2014

Julie A. Majurin, Elyse Sorenson, Steven J. Staats, William Gilles, and Stephen A. Kujak

Trane
A Division of Ingersoll Rand
3600 Pammel Creek Road
La Crosse, Wisconsin 54601

Prepared for

AIR-CONDITIONING, HEATING AND REFRIGERATION INSTITUTE, INC.
2111 Wilson Boulevard, Suite 500, Arlington, Virginia 22201-3001

Table of Contents

ABSTRACT

AHRI Material Compatibility and Lubricants Research for Low GWP Refrigerants project #8007 was an 11-month research effort. The testing effort was initiated at Trane on March 1, 2013, and the draft summary report was completed in February, 2014.

The information contained in this report is designed to assist the air-conditioning and refrigeration industry in identification of potential chemical compatibility and material compatibility concerns that may result from interactions between new refrigerants and new refrigerant blends, and currently used HVACR system materials.

The project was divided into two sections: 1) chemical compatibility (evaluation of the impact of materials on the chemical stability of the fluids) and 2) material compatibility (evaluation of the impact of fluids on material properties). The material compatibility portion of the project was further divided into two sections: compatibility of elastomeric and polymeric materials, and compatibility of motor materials. Materials of interest were selected by the project monitoring committee to encompass the general range of components currently used in the HVACR industry.

ACKNOWLEDGMENTS

The authors would like to acknowledge the following people and companies for their contributions to this project. The people listed worked with the authors on the project. The companies listed provided materials, refrigerants, and lubricants without charge. A special thank you is extended to AHRI and the project monitoring committee for the sponsorship and administration of this project.

Companies	**Contact**	**People**	**Affiliation**
Altana/Elantas	Jeff Hasser	Daryl Steinke	Trane/Ingersoll Rand
	Mike Orcutt	Raymond Schafer	
	Steve Tuckwell	John Miller	
BASF	Chip Hayes	Bill Lapp	
Chevron-Phillips	Tom Giovannetti	Jay Field	
CPI/Lubrizol	Joe Karnaz	Mark Ezzo	
DuPont Teijin Films	Dickie Hardy		
EIS	John Wendel		
Emerson	Marc Scancarello		
Gottifredi Maffioli S.p.A.	Luigi Maffioli		
Grace	Bob Woods		
The Gund Company	Todd Midkiff		
Higbee	Jim Corbo		
Honeywell	Mark Spatz		
Henkel	Gregory Precup		
Nexeo	Michael Lastovica		
Parker	Tim Nelson		
Solvay	Dan Ireland		
UOP	Alan Cohen		

INTRODUCTION

Societal demands to control climate change are driving the development of new regulatory policies to restrict and lower the direct GWP (Global Warming Potential) impact of Fluorocarbons (F-gases). These regulations have prompted the technology development of unsaturated F-gas refrigerant chemistries, referred to as hydrofluoroolefins (HFOs). The new HFO chemistries are designed to facilitate refrigerant degradation in the atmosphere in days rather than years, and this presents the possibility that these refrigerants could be unstable with traditional construction materials and contaminants in HVACR systems. Chemical and material compatibility of refrigerants are important parameters given the expectation that HVACR products will have design lives of 10 to 20+ years.

Only a few studies have been published regarding the potential risks associated with using HFOs in HVACR systems. Fujitaka, Shimizu, Sato and Kawabe (2010) studied the chemical stability of R-1234yf with POE lubricant in the presence of air and water contaminants. The studies were conducted with copper, aluminum, and steel coupons in stainless steel containers with the refrigerant, lubricant, and contaminant(s) exposed for 14 days at 175°C (347°F). Test results indicated minor instability of R-1234yf when contaminants were not present. However, significant R-1234yf instability was observed in the presence of air, and it appeared to be accelerated even more in the presence of both air and moisture. It is important to note that the POE lubricant in the study was formulated with additives including an acid catcher and an antioxidant, which were measured after the exposures. Analyses of the lubricants from the R-410A baseline samples exposed to both air and moisture indicated that the acid catcher and antioxidant were nearly (approximately 90%) depleted. In the case of the corresponding R-1234yf exposures, the acid catcher was completely depleted, but the antioxidant was still present at significant concentrations. These results suggested that R-1234yf was preferentially reactive with air and that significant acids were formed, resulting in depletion of the acid catcher additive. A more recent study was facilitated by AHRTI (Rohatgi, Clark, and Hurst, 2012) in which the stabilities of R-1234yf, R-1234ze(E), and mixtures of R-1234yf blended with R-32 (50% of each by weight), with two POE lubricants and one PVE lubricant, were evaluated. R-134a and R-410A were evaluated as baseline controls for comparison with the HFOs and HFO/HFC blend refrigerants. This study constituted phase I of the Material Compatibility and Lubricant Research (MCLR) for Low GWP Refrigerants program, and involved preparation of samples in sealed glass tubes in accordance with ASHRAE standard 97-2007 with copper, aluminum, and steel catalysts. Prepared samples were aged for 14 days at 175°C (347°F) and the impacts of three contaminant conditions—air, water, and air with water—were evaluated. This study revealed evidence of refrigerant breakdown under specific scenarios and reinforced that additional work was required to understand the refrigerant system chemistry implications of using HFOs in HVACR systems.

The objectives of this two-part AHRI study were to expand upon the initial chemical stability work conducted in Phase I of the MCLR for Low GWP Refrigerants program, and to evaluate the compatibility of various materials with new low GWP refrigerants.

Chemical compatibility experiments were conducted in sealed glass tubes with a three-refrigerant composite blend of R-1234yf, R-1234ze(E), and R-32 (33 ⅓% by weight of each) in combination with one POE and one PVE lubricant, and 41 different materials of construction. Control baseline samples with the same materials and lubricants were prepared with R-134a for comparison. This work resulted in the preparation and analysis of 258 sealed glass tubes.

The material compatibility studies were conducted in Parr pressure vessels with R-1234yf, R-1234ze(E), and a three-refrigerant composite blend of R-1234yf, R-1234ze(E), and R-32 (33 ⅓% by weight of each), with nine types of elastomers, three different gaskets, five types of polymers, and ten various motor materials. Material compatibility assessments were conducted in 100% refrigerant, 50% refrigerant:50% lubricant, and 100% lubricant baseline control conditions, to encompass the range of refrigerant and lubricant compositions that may be present in different areas of operating systems.

EXECUTIVE SUMMARY

Chemical Compatibility

A three-refrigerant blend consisting of two different HFO refrigerants and one HFC refrigerant exhibited little evidence of increased chemical reactivity relative to R-134a with several of the materials evaluated in this study. These materials included four polyester motor materials, two different magnet wires, and a water-borne motor varnish. All five of the desiccants, including four molecular sieve materials and one activated alumina, are included, as well as four out of five polymers, two different brass alloys, phosphor bronze, leaded and unleaded bearing materials, manganese phosphate, a powder metal alloy, and one of two Loctite formulations. Relative to R-134a, indications of increased chemical reactivity were observed between the three-refrigerant blend and several of the elastomers and gaskets. One of the Loctite formulations (Loctite 640), Nomex® 410, a mica glass cloth, nylon 6,6, and a solvent-based varnish also exhibited indications of increased chemical reactivity with the three-refrigerant blend in comparison to R-134a.

Eight materials (Nomex® 410 and mica glass cloth motor phase insulations, nylon 6,6 polymer, Loctite 640, Garlock® 3300 gasket material, and epichlorohydrin, butyl rubber, and nitrile-based NBR elastomers) were determined to contribute to significant (>500 ppm) fluoride concentrations in at least one of the three-refrigerant blend sample test conditions in this study. However, it was not confirmed in this study that the observed fluoride was due to refrigerant degradation, or that these fluoride concentrations were greater than what would be generated from material exposures with today's HFC refrigerants. Additional investigation may be required to understand the source(s) of fluoride, and the potential system implications of these findings relative to refrigerants in use today.

An interaction was noted between the three-refrigerant blend and the PVE lubricant that resulted in the detection of volatile compounds that were not observed in the corresponding R-134a control samples exposed with PVE lubricants. These compounds were detected at very low concentrations, and the relevance of this observation was not determined.

Overall, results of the chemical compatibility portion of this study suggest that the chemical stability of the three-refrigerant blend - and the implied chemical stability of the individual components - is similar to R-134a when in contact with many of today's common HVACR materials.

Material Compatibility

Material compatibility concerns were identified for specific elastomers and polymers with R-1234yf, R-1234ze(E), and the three-refrigerant blend.

The silicone and fluorocarbon elastomer formulations evaluated in this study exhibited material compatibility concerns due to significant swelling and material softening when these materials were exposed to R-1234yf, R-1234ze(E), and the three-refrigerant blend, both with and without lubricants present.

One of the two neoprene formulations also presented material compatibility concerns due to shrinkage and hardening of the material as a consequence of all of the refrigerant and refrigerant/lubricant exposures.

The butyl rubber elastomer formulation was identified as a concern when exposed to R-1234yf with lubricants and the three-refrigerant blend with lubricants, due to significant blistering that occurred when the refrigerant was removed via a post-exposure material bakeout process.

In the assessment of polymer compatibility, R-1234ze(E) and the three-refrigerant blend interacted unfavorably with polyester, both with and without lubricants present. Although the polyester material exhibited ≤3.0% weight change, significant impacts to the material tensile properties were observed as a consequence of interactions with R-1234ze(E) and the three-refrigerant blend.

Polyester materials are used prevalently in hermetic motors. During evaluation of polyester motor material films in this study, it was noted that R-1234ze(E) and the three-refrigerant blend, when exposed with lubricants, resulted in material being extracted from the Mylar® MO21 polyester material. This same observation was not noted in the Melinex® 238 polyester material that is specifically formulated for hermetic motor applications.

Future Studies

Future work is recommended to better understand the implications and risks associated with the compatibility concerns identified in this study. It is recommended to conduct further evaluations on the sources of fluoride observed in this study, and to compare the results with HFC refrigerants that are in use today. In addition, interactions between R-1234ze(E) and ester-based materials may require additional investigation to quantify the risks associated with the polyester material compatibility concerns.

There is also a need for understanding compatibility concerns associated with materials that are used prevalently in the industry but were not included in this study, such as process chemicals and joining materials.

1. MATERIALS

Details of the materials used in this study are summarized in Tables 1-5.

Table 1: Refrigerant and Lubricant Information

Fluid	Details
Refrigerant	
R-1234yf	Honeywell/Solstice 1234yf, CAS 754-12-1 (2,3,3,3-tetrafluoropropene)
R-1234ze(E)	Honeywell/Solstice 1234ze, CAS 29118-24-9 (trans (E) isomer of 1,3,3,3-tetrafluoropropene)
R-32	Arkema/Forane® 32, CAS 75-10-5 (difluoromethane)
Lubricant	
Polyol ester (POE)	CPI Engineering Services, Inc., EXP-4616
Polyvinyl ether (PVE)	Idemitsu, PVE32-A

Table 2: Motor Materials Information

Material Name	Details
Unvarnished Motor Materials	
Mylar® MO21	Polyester sample film with a thickness of 0.010 inches (250 µm)
Melinex® 238	Hermetic motor grade polyester sample film with a thickness of 0.010 inches (250 µm)
Nomex® 410	Aramid sample film with a thickness of 0.020 inches (500 µm)
Mica Glass Cloth[1]	Cloth insulation consisting of mica splittings bonded between varnished glass plied composite, NEMA #311, 0.020 inches (500 µm)
Polyester Tie Cord	Threaded polyester 16-plait braid of 250 Denier fibers having 8 interlacings per cm
Varnishes	
Pedigree® 923 Solvent-Based Varnish	Elantas Pedigree® 923 hermetic epoxy impregnating resin, 50% solids (magnet wire samples) and 35% solids (varnish pucks)
Guardian™ Water-Borne Varnish	Elantas Guardian™ EM GRC 59-50 hermetic epoxy impregnating resin, 50% solids
Magnet Wires	
Film Insulated Round Magnet Wire	Rea Super Hyslik 200® film insulated round copper wire for hermetic applications, 18 AWG; thermal class 200, per Section MW 73-C of ANSI/NEMA Standard MW 1000
Fibrous Covered Round Magnet Wire	Rea Single Daglas over HTAI (Heavy Therm-Aimid) round copper wire with an epoxy varnish, 18 AWG; thermal class 180, per Section MW 51-C of ANSI/NEMA Standard MW 1000
Other	
Polyester Connector Block[2]	BASF Ultradur® B 2550 polybutylene terephthalate (unfilled), received as molded ASTM Type 1 tensile bars

[1]Information and samples from motor suppliers were unable to be acquired for this type of material. This material may not be representative of specific materials currently used in hermetic compressor motors.

[2]Note that the polyester connector block is a motor material, but was tested in conjunction with the structural polymer samples due to similarities between the prescribed test protocols.

Table 3: Seals and Polymers Information

Material Name	Material Details
Elastomers	
Neoprene 1	Parker C0873-70 neoprene O-rings, size 2-362
Neoprene 2	Parker C1276-70 neoprene O-rings, size 2-345
Nitrile-Based HNBR	Parker N1173-70 nitrile (hydrogenated nitrile-butadiene rubber) O-rings, size 2-361
Nitrile-Based NBR	Parker NA151-70 nitrile (nitrile-butadiene rubber) O-rings, size 2-367
Fluorocarbon	Parker V0747-75 fluorocarbon O-rings, size 2-362
EPDM	Parker E0893-80 EPDM (ethylene propylene diene monomer) O-rings, size 2-358
Epichlorohydrin	Parker YB146-75 epichlorohydrin O-rings, size 2-363
Butyl Rubber	Parker B0612-70 butyl rubber O-rings, size 2-358
Silicone	Parker L1120-70 silicone O-rings, size 2-354
Gaskets	
Garlock® 3300	Blue-Gard® style 3300 flat gasket comprised of aramid fibers with a neoprene binder, 1/32 inch
Armstrong N-8092	Flat gasket comprised of reinforced cellulose fibers with a fully cured nitrile butadiene binder, 1/32 inch
Klingersil® C-4401	Thermoseal® flat gasket material comprised of synthetic fibers and a nitrile binder, 1/32 inch
Polymers	
Nylon 6,6 (unfilled)	BASF Ultramid® A 3K BK00464 Nylon 6,6 (unfilled) molded ASTM Type 1 tensile bars
PEEK (unfilled)	Solvay Specialty Polymers Ketaspire® PEEK 820NT, polyether ether ketone (unfilled) molded ASTM Type 1 tensile bars
PPS (filled)	Chevron Phillips Chemical Company Ryton® R-7-120NA, polyphenylene sulfide (glass/mineral filled) molded ASTM Type 1 tensile bars
PAI (unfilled)	Solvay Specialty Polymers Torlon® 4203L HF, polyamide-imide (unfilled) molded ASTM Type 1 tensile bars (cured for 17 days by the supplier)
PTFE (unfilled)	Parker 0100 polytetrafluoroethylene (unfilled) material, received as a skived strip, 3 inches wide by 0.055 inches thick

Table 4: Desiccant Materials Information

Material Name	Material Details
3A Molecular Sieve 1	Grace, type 594 3A molecular sieve
3A Molecular Sieve 2	UOP, type XH11 3A molecular sieve
3A Molecular Sieve 3	UOP, type XH5 3A molecular sieve
4A Molecular Sieve	Grace, type 504 4A molecular sieve
Activated Alumina	UOP, type D-201 activated alumina

Table 5: Other HVACR Materials Information

Material Name	Material Details
Free Cutting Brass	Brass CDA C36000
Cartridge Brass	Brass CDA 26000
Phosphor Bronze	Bronze CDA C52400
Manganese Phosphate	Strips of low carbon steel subjected to a manganese phosphate conversion coating process
Lead-Free Polymer Bearing	"DP-31" bearing material from GGB
Leaded Polymer Bearing	"DU" bearing material from GGB
Powder Metal Alloy	Iron sinter material, steam treated
Loctite 620	Methacrylate ester one-component retaining compound
Loctite 640	Urethane methacrylate one-component retaining compound

1.1 CHARACTERIZATION OF MATERIALS

Where applicable, unexposed materials were analyzed by FTIR to obtain characteristic spectra of the materials as received. The moisture concentrations of the materials were also measured, and the results are summarized in Table 6. In the various materials evaluated, moisture concentrations ranged from <0.01 weight % (PTFE) to 3.65 weight % (Nomex® 410).

Table 6: Moisture Concentrations of Unexposed Materials

Material	Average Moisture (weight %), n=3	Material	Average Moisture (weight %), n=3
Motor Materials		**Polymers**	
Mylar® MO21	0.18	Nylon 6,6 (unfilled)	1.75
Melinex® 238	0.16	PEEK (unfilled)	0.09
Nomex® 410	3.65	PPS (filled)	0.04
Mica Glass Cloth	0.14	PAI (unfilled)	1.98
Polyester	0.11	PTFE (unfilled)	<0.01
Elastomers and Gaskets			
Neoprene 1	0.38		
Neoprene 2	0.37		
Nitrile-Based HNBR	0.16		
Nitrile-Based NBR	0.28		
Fluorocarbon	0.13		
EDPM	0.61		
Epichlorohydrin	1.19		
Butyl Rubber	0.36		
Silicone	0.16		
Garlock® 3300	0.61		
Armstrong N-8092	1.32		
Klingersil® C-4401	0.79		

2. CHEMICAL COMPATIBILITY

Chemical compatibility of refrigerants and lubricants with materials was evaluated by preparing samples in sealed glass tubes, subjecting the prepared samples to accelerated thermal aging conditions, and performing detailed analyses on the exposed refrigerants and lubricants. All of the material samples detailed in Tables 1-5 were evaluated in this portion of the study.

2.1 SAMPLE PREPARATION AND EXPOSURES

Sealed tubes were prepared according to the general procedure in ASHRAE Standard 97-2007 (Sealed Glass Tube Method to Test the Chemical Stability of Materials for Use within Refrigerant Systems). In contrast to ASHRAE Standard 97, the glass tubes that were used in this study were larger than those specified in the Standard to facilitate sufficient fluid volumes for multiple analyses to be performed on the contents from a single tube.

Investigations were conducted using a three-refrigerant blend of R-1234yf, R-1234ze(E), and R-32 (33 ⅓% by weight of each) with both a polyol ester (POE) lubricant and a polyvinyl ether (PVE) lubricant. The goal of this study was to better understand potential chemical compatibility concerns between these fluids and typical HVACR materials of construction. For comparison purposes, sealed tubes were prepared with R-134a using the same lubricants and sample materials.

Each tube contained 0.5 grams of refrigerant, 9.5 grams of lubricant, and the material of interest, as detailed in Appendix I, Tables 20-25. It is acknowledged that historically sealed glass tubes have been prepared at 50% by weight refrigerant instead of 5%, as was conducted in this study. Following are the reasons why these test conditions were selected for the chemical compatibility study: 1) at 5% refrigerant by weight, there is sufficient refrigerant for interaction with the materials and for the required post-exposure refrigerant analyses, 2) at 95% by weight, there is sufficient lubricant in one tube for all of the required analyses, and 3) use of one tube for all tests minimizes variability that may be observed from tube to tube. With the exception of the desiccant and Loctite samples, the materials were added to the tubes without additional processing or drying. The desiccants were dried for 4 hours at 300°C prior to addition to the tubes. Loctite samples were prepared by curing the material between two sheets of copper for 24 hours at ambient conditions, separating the copper sheets, and subsequently removing the Loctite with a clean, sharp blade. Metal coupons were not included in any of the tubes. Materials from the following categories were evaluated: motor construction materials, elastomers, gaskets, polymers, desiccants, and miscellaneous materials common to HVACR applications.

The material under investigation was added to the tube first, followed by the lubricant. Prior to addition to the sealed tube, the lubricant was tested for moisture by Karl Fischer coulometry and Total Acid Number (TAN) by titration. Lubricant moisture concentration requirements were ≤50 ppm and TAN requirements were ≤0.05 mg KOH/gram of oil. The TAN requirements were met in all instances throughout the duration of this project. When the lubricant moisture result exceeded the requirement, the lubricant was dried and degassed prior to use. Lubricant was added accurately to each tube with a syringe and cannula. Subsequently, the tube was evacuated to <200 microns prior to introduction of the refrigerant.

Refrigerant samples were assessed for purity by gas chromatography and moisture by Karl Fischer coulometry prior to charging the tubes. Accurate charging of refrigerant was conducted through condensation from a gas handling system while the tube was submerged in liquid nitrogen. After addition of the refrigerant, the tube neck was sealed and annealed. Batches of sealed tube samples were placed in Parr bombs for the exposures.

Exposures were conducted in air circulating ovens. The majority of the sealed tube samples were aged for 28 days at 150°C; however, samples with desiccants were aged for 28 days at 100°C due to prior research demonstrating instability of refrigerants and lubricants with desiccant materials at elevated temperatures (Field, 1995; Rohatgi, 1998).

2.2 SAMPLE ANALYSES

Digital pictures of the tubes were taken before and after aging. The aged samples were examined for visual changes of the fluids and materials, particulate formation, and film formation on the tube walls. The tube contents were also analyzed by high performance liquid chromatography (HPLC) to quantify inorganic anions, by gas chromatography-mass spectrometry (GC-MS) to identify and semi-quantify volatile components, by Karl Fischer coulometry to determine the post-exposure lubricant moisture concentration, by titration to determine the lubricant acidity (Total Acid Number, or TAN), by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) to quantify dissolved elements in the lubricants, and by gas chromatography (GC) with flame ionization detection (FID) to quantify specific organic acids in the POE lubricant samples.

A separate tube was prepared for inorganic anion determinations. Because of the large number of materials included in the study, inorganic anion determinations were conducted only on samples with the three-refrigerant blend to screen for the presence of fluoride in the exposed fluids. Additional sealed tubes were not prepared to evaluate the presence of fluoride in R-134a control samples.

Organic acid analyses were conducted only on the POE lubricant samples. POE lubricants, which have an ester backbone, are known to generate organic acids as byproducts of hydrolysis reactions (i.e., reactions with water). If POE degradation occurs and lubricant organic acid concentrations rise, an increase in the lubricant total acid number will be observed. Due to their different chemical structures, polyvinyl ether (PVE) lubricants follow different degradation pathways than POE lubricants. A specific analytical method of test for monitoring PVE lubricant breakdown products in HVACR applications has not been established for use in the industry. Potential options to consider are reaction methods that would target specific functional groups (such as alcohols) followed by spectroscopic or colorimetric analyses, or chromatographic methods such as gas or liquid chromatography. Further review of PVE chemistry and relevant testing technologies would be necessary to identify an appropriate testing strategy.

2.3 DETAILED SAMPLE ANALYSIS PROCEDURES

2.3.1 INORGANIC ANIONS BY HIGH PERFORMANCE LIQUID CHROMATOGRAPHY (HPLC)

HPLC analysis was conducted to determine the inorganic anion concentrations, including fluoride, chloride, and bromide. It should be noted that chloride and bromide are not constituents of the refrigerants, but were included in the analyses to evaluate the potential for these anions to be extracted from materials. The entire contents of the sealed tube were transferred into a vessel containing deionized water and the mixture was stirred continuously for 24 hours at room temperature to maximize extraction of water-soluble anions. The water extract was filtered through a syringe filter prior to analysis.

Liquid chromatography was used to analyze the water extracts. The HPLC system consisted of a high pressure pump to push the sample through the system, a polymeric reversed phase column to separate the ions in the sample, and a conductivity detector to indicate how much of each ion was present in the sample.

The mobile phase, the solution flowing through the machine that the sample becomes entrained in after injection, was a dilute solution of p-hydroxybenzoic acid mixed with 2.5% methanol. In the analytical column, negatively charged ions were separated by their individual affinity for the column stationary phase, producing a predictable time and order of elution from the column. The concentrations of anions were obtained by calibrating the chromatograph with standard solutions so that the peak area was proportional to the anion concentration.

The quantitation limit for fluoride was validated at 20 ppm in a sample prior to dilution. Results are reported in ppm based on the mass of refrigerant used (not the total mass of the tube contents).

2.3.2 VOLATILE COMPOUND ANALYSIS BY GAS CHROMATOGRAPHY-MASS SPECTROMETRY (GC-MS)

After aging and recording the appearance changes of a sample, the tube contents were frozen and the tube was fitted with a valve. The gas phase of each sample was analyzed by connecting the valve on the tube to an evacuated gas sampling loop and filling the loop on the gas chromatograph to equalize with the pressure of the glass tube. Gas chromatography was conducted using a capillary column with a nonpolar stationary phase and helium as the carrier gas. A column temperature program was employed to separate the components on the GC column, and volatile chemicals were ionized by electron ionization at 70 eV. The ions were then filtered in a single quadrupole mass filter, and ions in the range between 33 and 500 m/z (mass/charge) units were detected. The total ion chromatograms were integrated and the results are expressed as percent area of the total MS response.

This method allowed for semi-quantitation of organic gas species with a molecular mass of at least 33 g/mole. The mass spectrum for each individual peak in the chromatography was reviewed and identifications were assigned by comparison to mass spectral libraries and/or interpretation of the spectra. Additional confirmations of the assigned component identities, such as retention time verification with standards or different types of analyses, were not conducted.

This GC-MS analysis procedure has sufficient sensitivity to detect very low concentrations of volatile organic compounds. In the analyses conducted, components present at concentrations in the range of 0.001% total peak area or less were able to be readily distinguished from the baseline and identified.

After GC-MS analysis had been completed, and residual refrigerant had evaporated from the lubricant samples, the lubricants were analyzed for moisture, acidity (TAN), dissolved elements (ICP-OES), and organic acids (GC-FID).

2.3.3 LUBRICANT MOISTURE BY KARL FISCHER COULOMETRY

Lubricant moisture concentrations were determined by Karl Fischer coulometry immediately after removing the valves from the tubes. The quantitation limit for lubricant moisture determinations is 10 ppm.

2.3.4 LUBRICANT ACIDITY BY TOTAL ACID NUMBER (TAN) TITRATION

The method used for measuring TAN is based on ASTM D664 (Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration) with modifications to accommodate small sample sizes. Total acid number values of ≥0.05 mg KOH/g of oil are able to be accurately quantified.

2.3.5 DISSOLVED ELEMENTS BY INDUCTIVELY COUPLED PLASMA-OPTICAL EMISSION SPECTROSCOPY (ICP-OES)

Dissolved elements in the lubricants were quantified using ICP-OES. Lubricant samples were diluted in kerosene and an internal standard was utilized to account for any matrix interferences in the exposed samples. The diluted samples were filtered through a syringe filter prior to analysis. External calibration curves were prepared from a stock multi-element oil-based standard. Sample responses at select wavelengths were compared to standards prepared at known concentrations to determine the concentrations of each dissolved element in the sample. Elements that were evaluated include silver (Ag), aluminum (Al), boron (B), barium (Ba), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), silicon (Si), tin (Sn), titanium (Ti), vanadium (V), and zinc (Zn).

Quantitation limit of this method is ≤5 ppm for each of the elements analyzed.

2.3.6 ORGANIC ACIDS BY GAS CHROMATOGRAPHY WITH FLAME IONIZATION DETECTION (GC-FID)

Lubricants from the POE-containing samples were analyzed by GC-FID. Gas chromatography was conducted using a capillary column with an acid-modified polar stationary phase and helium as the carrier gas. An FID detector with air and hydrogen fuel was utilized to ionize and detect the carbon-containing components eluting from the analytical column. Organic acids were separated by their boiling points, producing a predictable time and order of elution from the column. The concentrations of organic acids in the sample lubricants were determined by comparing individual peak areas to external calibration curves prepared for isobutyric, isovaleric, valeric, hexanoic, heptanoic, branched nonanoic, and linear nonanoic acids.

The quantitation limits were determined experimentally for each of the acids (concentration in the lubricant prior to dilution), and are summarized in Table 7.

Table 7: GC-FID Organic Acid Quantitation Limits

Analyte	Quantitation Limit (ppm, or µg acid/g of lubricant)
Isobutyric Acid	150
Isovaleric Acid	200
Valeric Acid	300
Hexanoic Acid	200
Heptanoic Acid	300
Branched Nonanoic Acid	500
Nonanoic Acid	300

2.4 CHEMICAL COMPATIBILITY RESULTS AND DISCUSSION

2.4.1 RESULTS OF INORGANIC ANION ANALYSIS BY HPLC

As summarized in Appendix I, Tables 26-31, inorganic anions including fluoride were detected in many of the samples. Fluoride concentration results are ordered from highest to lowest concentrations in Table 8. Eight materials were found to contribute to >500 ppm fluoride concentrations in at least one of the sample test conditions. One potential source of fluoride in the samples is from refrigerant degradation, but the materials themselves may also have fluoride-containing constituents. The fluoride concentrations of individual materials, and the potential contribution of the materials to the results, were not evaluated. Additional studies are recommended to confirm the source of fluoride, to compare the three-refrigerant blend fluoride results with R-134a, and to further investigate the potential system impacts associated with the presence of fluoride.

Table 8: Post-Exposure Fluoride Concentrations from the Three-Refrigerant Blend Samples

Category	Material	Fluoride Concentrations (ppm)	
		Exposure	
		Three-Refrigerant Blend:POE	Three-Refrigerant Blend:PVE
Fluoride concentrations ≥1000 ppm in at least one exposure condition	Nomex® 410	2850	3680
	Nylon 6,6 (unfilled)	3210	1240
	Loctite 640	450	1550
	Epichlorohydrin	1030	<20
Fluoride concentrations ≥500 but ≤1000 ppm in at least one exposure condition	Butyl Rubber	80	780
	Garlock® 3300	770	<20
	Mica Glass Cloth	610	90
	Nitrile-Based NBR	510	600
Fluoride concentrations ≤500 but ≤20 ppm in at least one exposure condition	Neoprene 1	240	280
	Guardian™ Water-Borne Varnish	240	250
	Polyester Tie Cord	<20	240
	Neoprene 2	200	190
	Lead-free Polymer Bearing	180	100
	Armstrong N-8092	170	<20
	Polyester Connector Block	40	100
	PAI (unfilled)	<20	100
	Loctite 620	40	800
	Leaded Polymer Bearing	70	<20
	Film Insulated Round Magnet Wire	<20	60
	Fibrous Covered Round Magnet Wire	<20	60
	Phosphor Bronze	<20	60
	Pedigree® 923 Solvent-Based Varnish	30	40
	Manganese phosphate	<20	30
	EDPM	30	20
	Klingersil® C-4401	<20	20
Fluoride concentrations <20 ppm in both exposure conditions	Mylar® MO21 Melinex® 238 Nitrile-Based HNBR Fluorocarbon Silicone PEEK (unfilled) PPS (filled) PTFE (unfilled)	3A Molecular Sieve 1 3A Molecular Sieve 2 3A Molecular Sieve 3 4A Molecular Sieve Activated Alumina Free Cutting Brass Cartridge Brass Powder Metal Alloy	

2.4.2 RESULTS OF VOLATILE COMPOUND ANALYSIS BY GC-MS

Example chromatograms from GC-MS analyses of refrigerant samples from tubes containing the three-refrigerant blend and R-134a are shown in Figures 1 and 2, respectively. The chromatogram in Figure 1 demonstrates that the three components of the refrigerant blend exhibit resolution between each component peak and that elution order follows boiling point (i.e., compounds with lower boiling points elute earlier than those with higher boiling points).

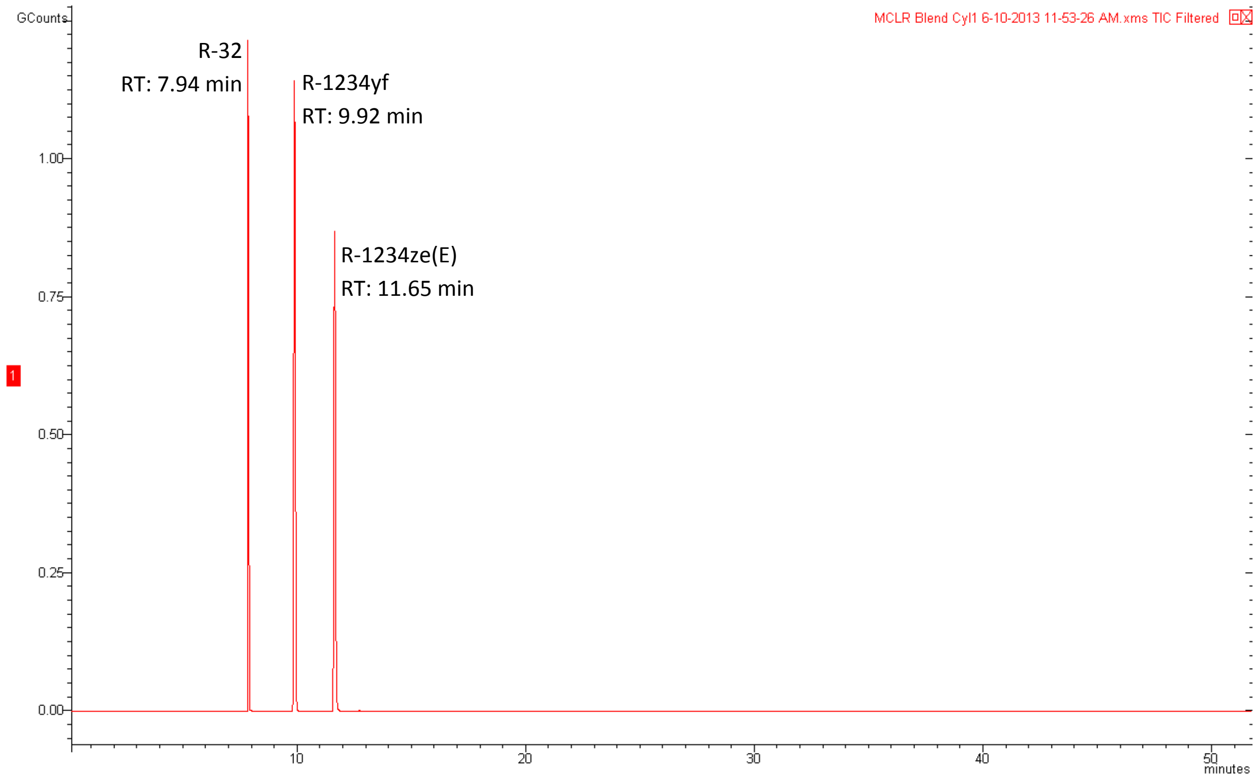


Figure 1. Total ion chromatogram of the three-refrigerant blend.

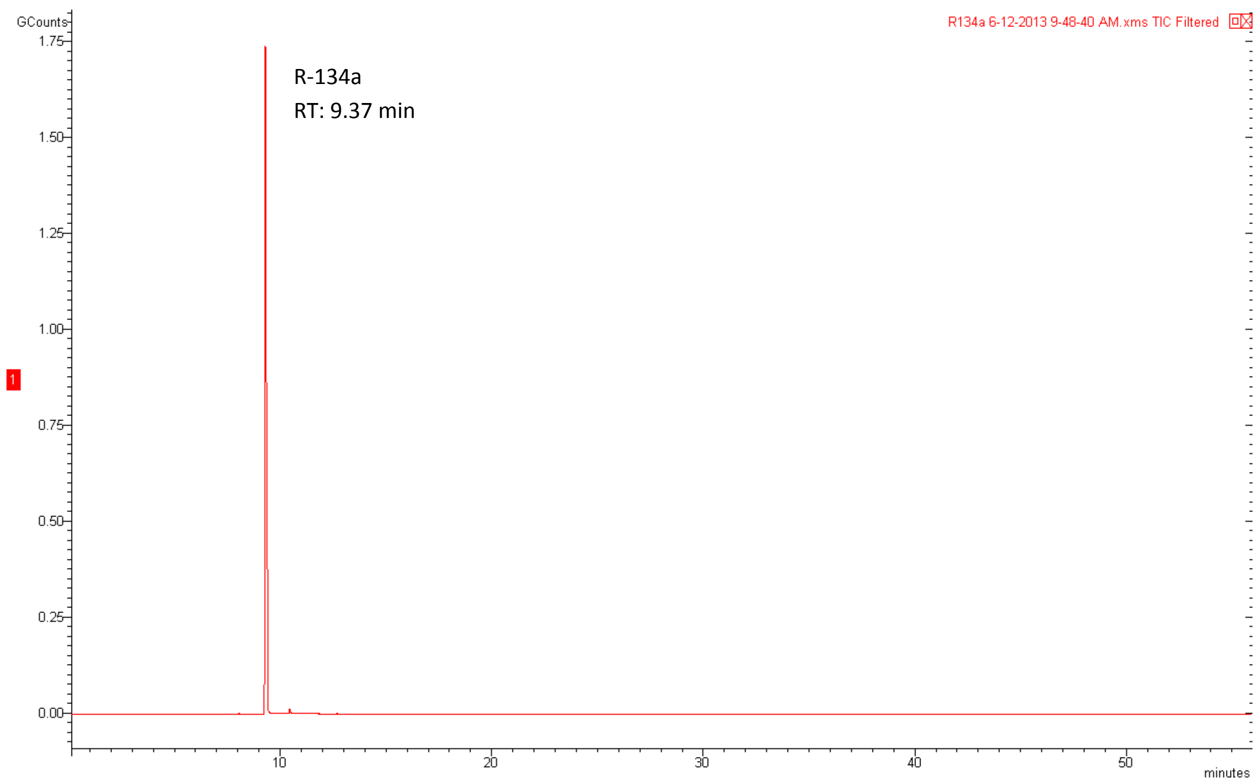


Figure 2. Total ion chromatogram of R-134a.

Example mass spectra of each of the refrigerants under study are shown in Figures 3 – 6. Mass spectra of each of the components in the three-refrigerant blend are presented in Figures 3-5, and the mass spectrum of R-134a is displayed in Figure 6.

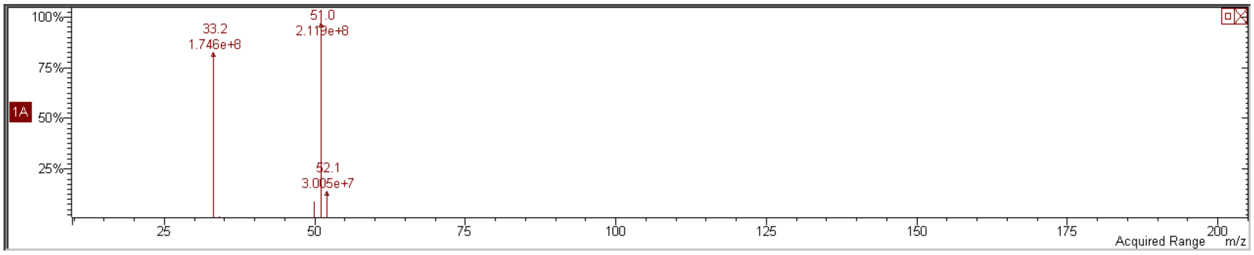


Figure 3. Mass spectrum of R-32.

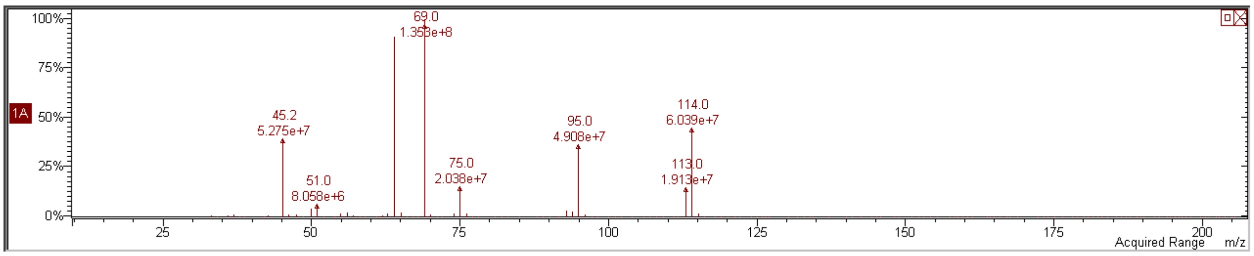


Figure 4. Mass spectrum of R-1234yf.

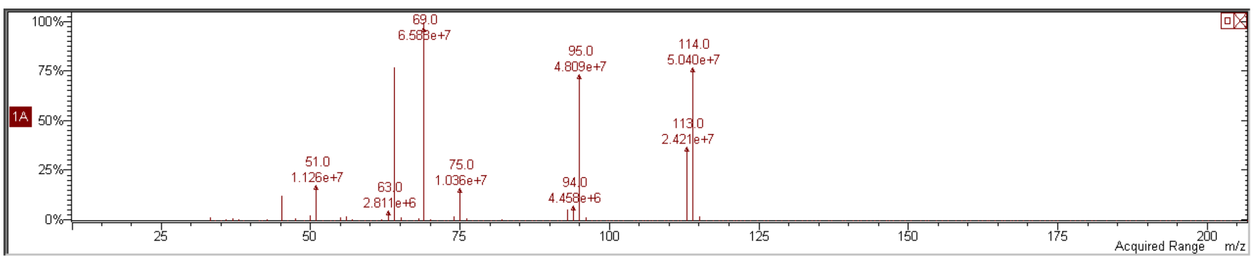


Figure 5. Mass spectrum of R-1234ze(E).

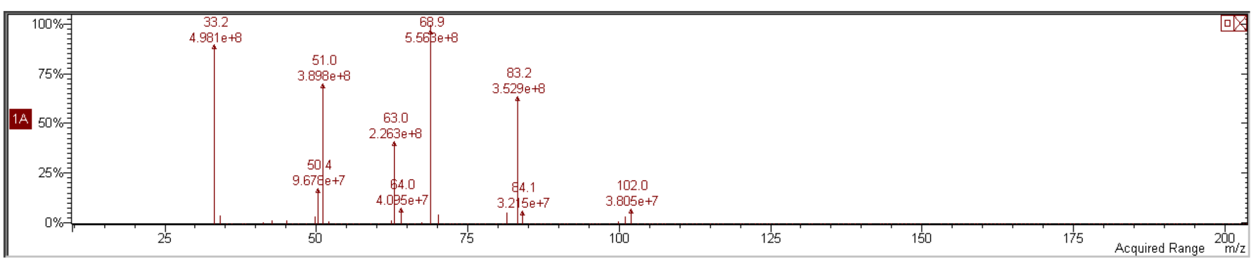


Figure 6. Mass spectrum of R-134a.

As summarized in Appendix I, Tables 26-31, GC-MS results indicate that the majority of samples had peak areas consisting of at least 99.9% of the base refrigerants. Under the conditions of analysis, no appreciable concentrations of volatile degradation products were detected in either the three-refrigerant blend samples or the R-134a samples.

Because of the high sensitivity of GC-MS, refrigerant impurities and degradation products were able to be detected and identified even when present at very low concentrations. For instance, R-1243zf (1,1,1-trifluoropropene) and R-1234ze(Z) (the cis (Z) isomer of 1,3,3,3-tetrafluoropropene) were detected as degradation products at low concentrations (<0.05%) in some samples. Example mass spectra for components identified as R-1243zf and R-1234ze(Z) are shown in Figures 7 and 8, respectively.

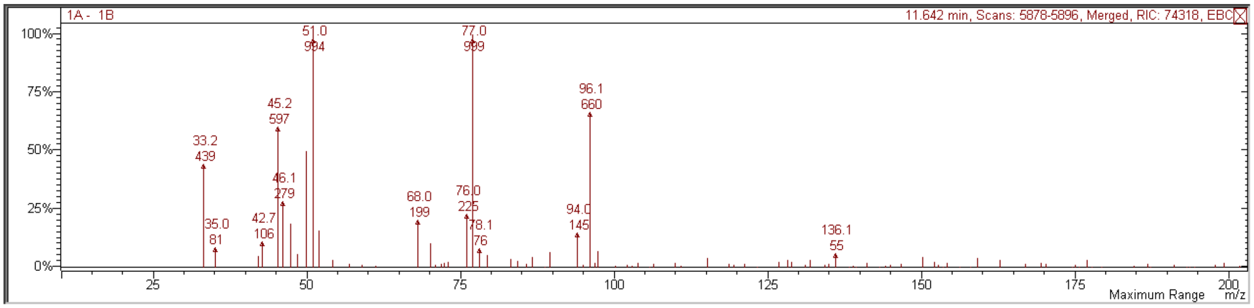


Figure 7. Mass spectrum of compound identified as R-1243zf.

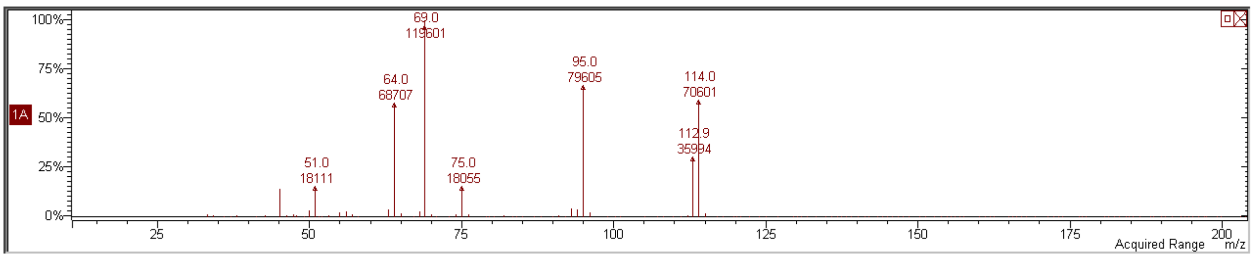


Figure 8. Mass spectrum of compound identified as R-1234ze(Z).

In addition to low concentrations of refrigerant breakdown products being observed, some volatile compounds were observed in all of the samples from exposures of the three-refrigerant blend with PVE lubricant (except the desiccant samples which were exposed at lower temperatures). These compounds were not observed in the samples exposed with R-134a and PVE lubricant, and are thus attributed to an interaction between the PVE lubricant and the three-refrigerant blend that is not occurring between R-134a and PVE under the same conditions.   Comparison of a three-refrigerant blend:PVE sample chromatogram and an R-134a:PVE sample chromatogram is shown in Figure 9. Example mass spectra of the components present only in the three-refrigerant blend samples that were exposed with PVE are shown in Figure 10. Although consistently observed in the three-refrigerant blend:PVE sample exposures, the total area of these peaks was <0.05% in all of these sample analyses.

The identity of Unknown A was unable to be determined in this study. Unknown B had spectral similarities to 2-fluoro-2-methylpropane, and is likely a higher molecular weight compound consisting of a CH_3CFCH_3- ion fragment or other ion fragment with a mass/charge ratio of 61. Unknown C was consistent with 2-methylpropanal. Additional studies would be required to confirm the identities of these compounds, and to understand the significance of these observations.

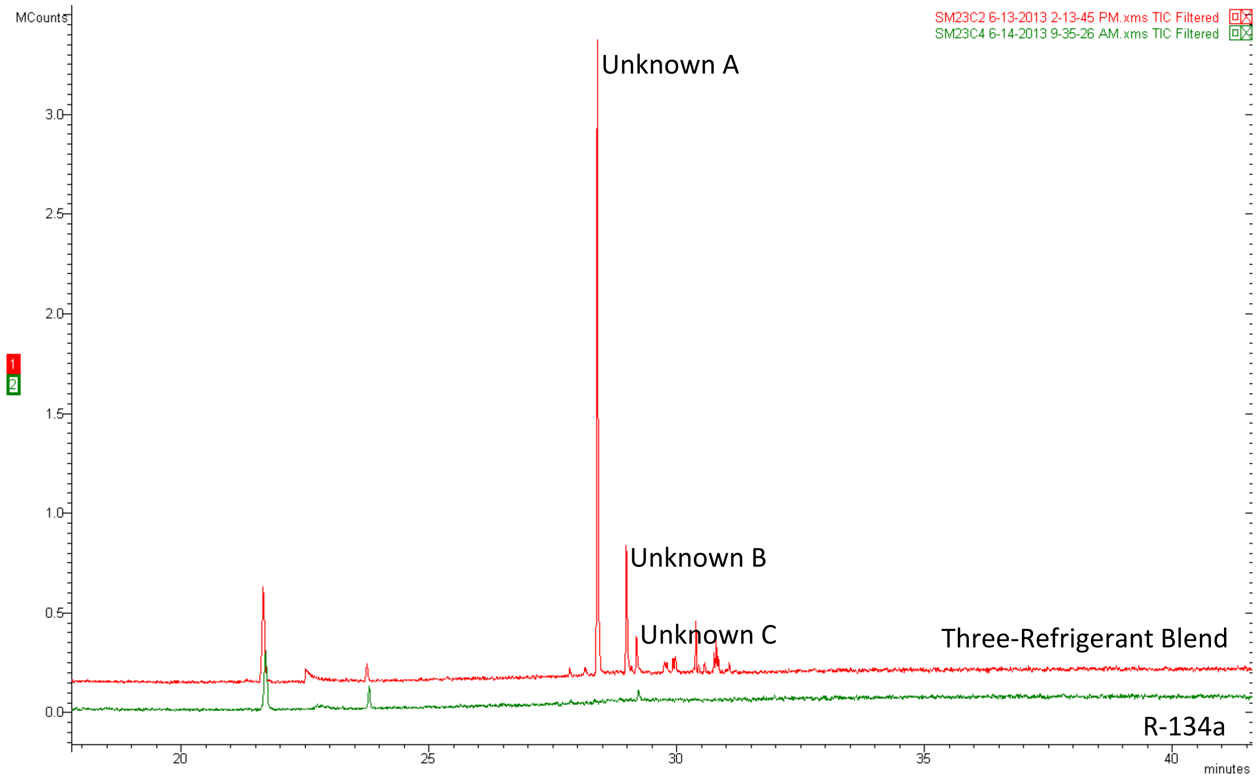


Figure 9. Chromatogram comparison of a three-refrigerant blend sample that was exposed with PVE, and R-134a that was exposed with PVE.

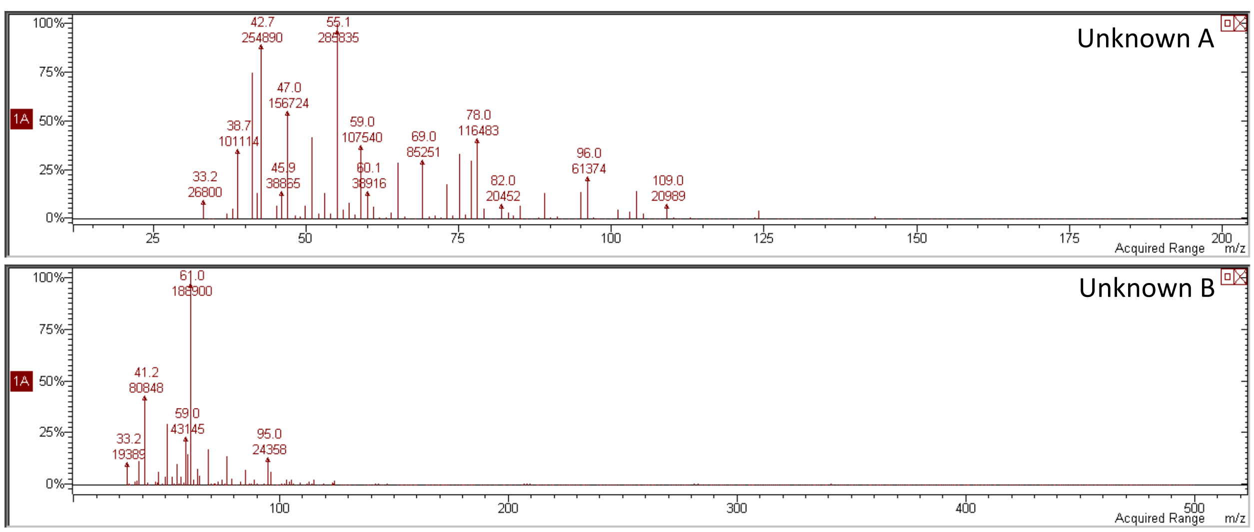


Figure 10. Example mass spectra of two of the unknown compounds from Figure 9.

To prevent degradation of the capillary column stationary phase, refrigerant GC-MS analyses were not conducted on samples from some of the exposed tubes prepared with elastomers. Samples that exhibited very significant appearance changes (neoprenes 1 and 2, nitrile-based NBR, EPDM, epichlorohydrin, and butyl rubber) were not analyzed by GC-MS.

The only material that resulted in >0.5% volatile impurities in the refrigerant analyses was the Guardian™ water-borne varnish. Samples from all four exposure conditions exhibited the presence of a component identified as methyl chloride which is proposed to be from the sample material itself. This contaminant was present in the range of 0.6 - 1.5% (peak area %) and was higher in R-134a samples than the corresponding three-refrigerant blend samples. See Figures 11 and 12 for an example chromatogram and the mass spectrum of the compound identified as methyl chloride (R-40). It should be noted that the varnish puck samples that were exposed to the fluids in the sealed glass tubes were thicker than the typical varnish application thickness on motor construction materials. It's possible that the varnish may have undergone additional curing during the exposures at elevated temperatures that would not be representative of actual system applications.

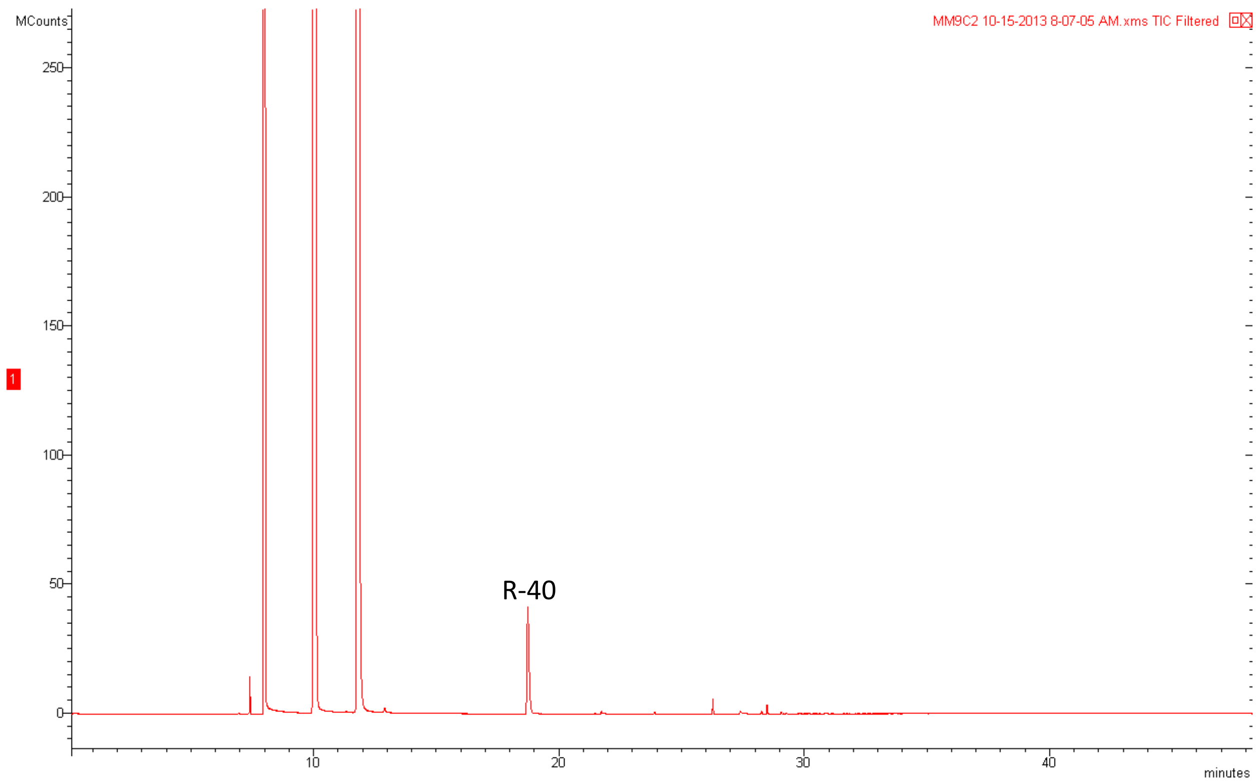


Figure 11. Example chromatogram of the three-refrigerant blend sample exposed with PVE lubricant and Guardian™ water-borne varnish.

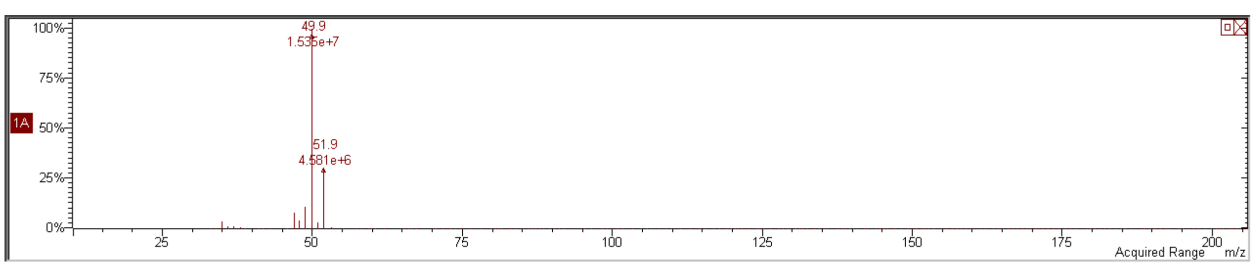


Figure 12. Mass Spectrum of R-40.

2.4.3 RESULTS OF LUBRICANT MOISTURE AND ACIDITY TESTS

The majority of the materials were used as received (not dried or further processed) to simulate how materials may be applied in systems. It was acknowledged that moisture concentrations would vary between different types of materials (and this was confirmed through moisture analyses of materials), but for the following reasons, no additional processing was conducted to attempt to remove moisture from the materials:

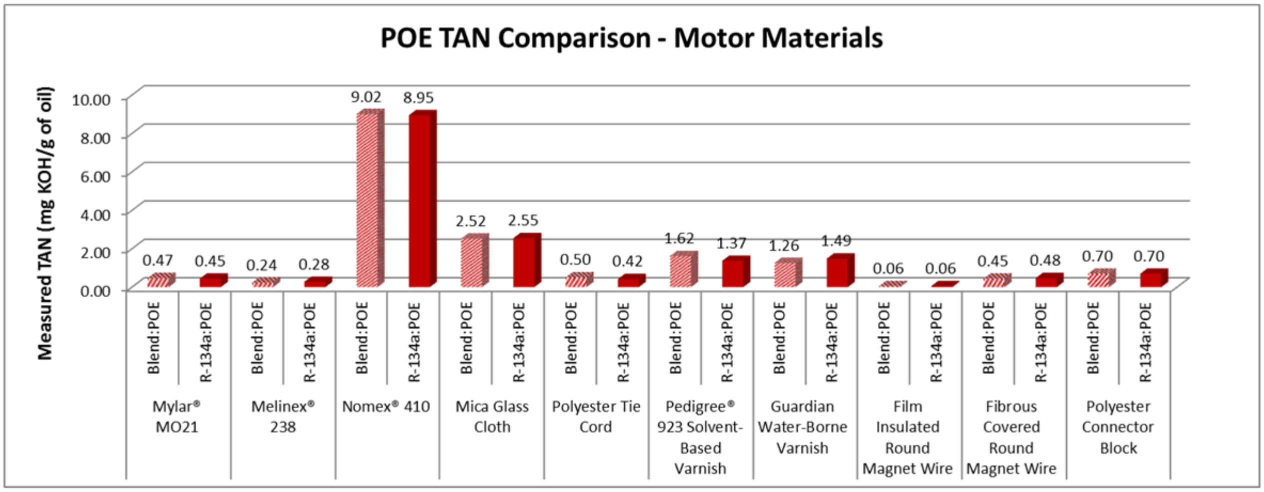
1) Different processing parameters would be necessary to accommodate the different types and configurations of materials, and additional testing would be required to verify the efficacy of moisture removal efforts.
2) Processing to remove moisture had the potential to result in the material properties no longer being representative of materials in use in actual system applications.
3) R-134a control samples were being evaluated for direct comparison to the results with the three-refrigerant blend. Thus, even if reactivity was observed as a result of moisture from the materials, the extent of the differences between the controls and test samples could be used as the basis upon which to draw conclusions.

Lubricant samples were evaluated to determine post-exposure moisture and acidity concentrations. Results in Appendix I, Tables 26-31, demonstrate that in general, the post-exposure POE lubricant samples exhibited lower moisture concentrations and higher acidity relative to the corresponding PVE lubricant samples.

High moisture concentrations in the PVE lubricant samples are a result of moisture from the materials being absorbed by the lubricant. POE lubricants also absorb moisture from the materials, but the absorbed water is subsequently consumed in hydrolysis reactions that occur during the exposures at elevated temperatures. In addition to consumption of water, these hydrolysis reactions result in the formation and accumulation of organic acids in the POE lubricant test samples which contribute to the increases observed in the POE lubricant acidity results. Thus, as expected, organic acid concentrations were elevated in lubricant samples from exposures with materials that had high moisture concentrations (see Table 6), such as Nomex 410, nylon 6,6, PAI, and all three of the gasket materials.

Besides organic acids from lubricant degradation, other acids - such as those formed from refrigerant degradation or those extracted from materials - may also contribute to increases in the total acid number values. To differentiate the acidity increase resulting from POE lubricant degradation from the acidity increase contributed by other sources, testing was conducted by GC-FID to quantify the organic acids resulting from POE hydrolysis. As summarized in Appendix I, Tables 33-38, valeric, heptanoic, and branched nonanoic acids were quantified in many of the samples. Only lubricants from one of the sample exposures, the motor material Nomex® 410, also had detectable concentrations of linear nonanoic acid present. Isobutyric, isovaleric, and hexanoic acids were not detected in any of the samples.

Graphical comparisons of lubricant moisture and TAN results from the three-refrigerant blend and R-134a are shown in Figures 13 and 14. Lubricant analysis results from motor material exposures were selected as an example, but similar trends were found when evaluating the results for the other materials evaluated in this study. Overall, for most of the materials, moisture and acidity results from the POE and PVE lubricants exposed with the three-refrigerant blend were comparable to results from the lubricants exposed with R-134a. In comparison to exposures with R-134a, higher lubricant acidity values were measured by TAN (a difference greater than 0.5 mg KOH/g of oil) and/or organic acid analyses, from exposures of the three-refrigerant blend with nitriles, EPDM, epichlorohydrin, and silicone.



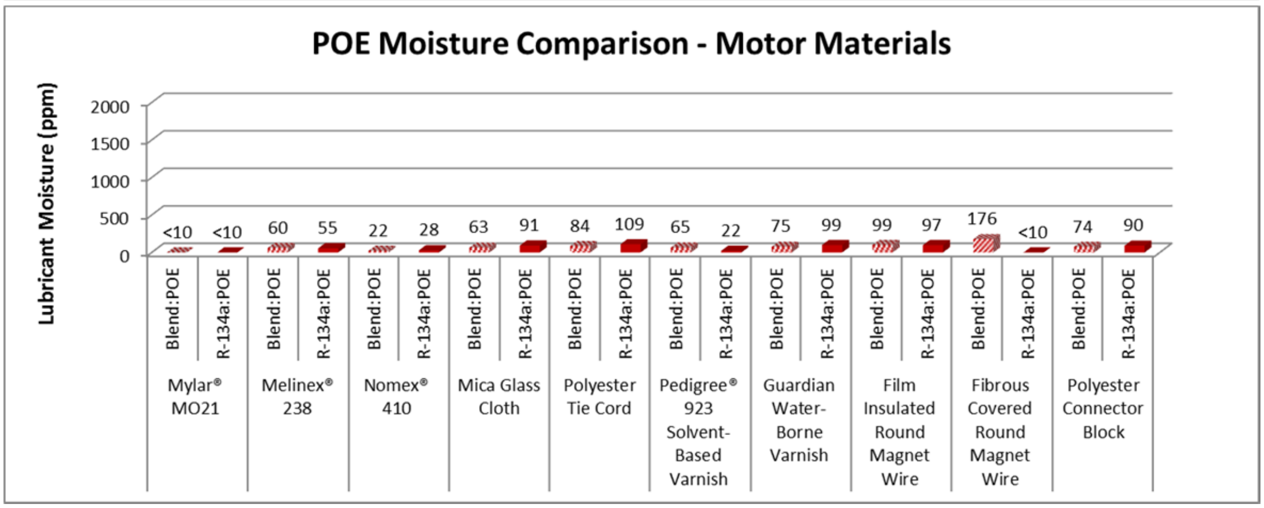


Figure 13. Post-exposure POE TAN (above) and moisture (below) results comparison.

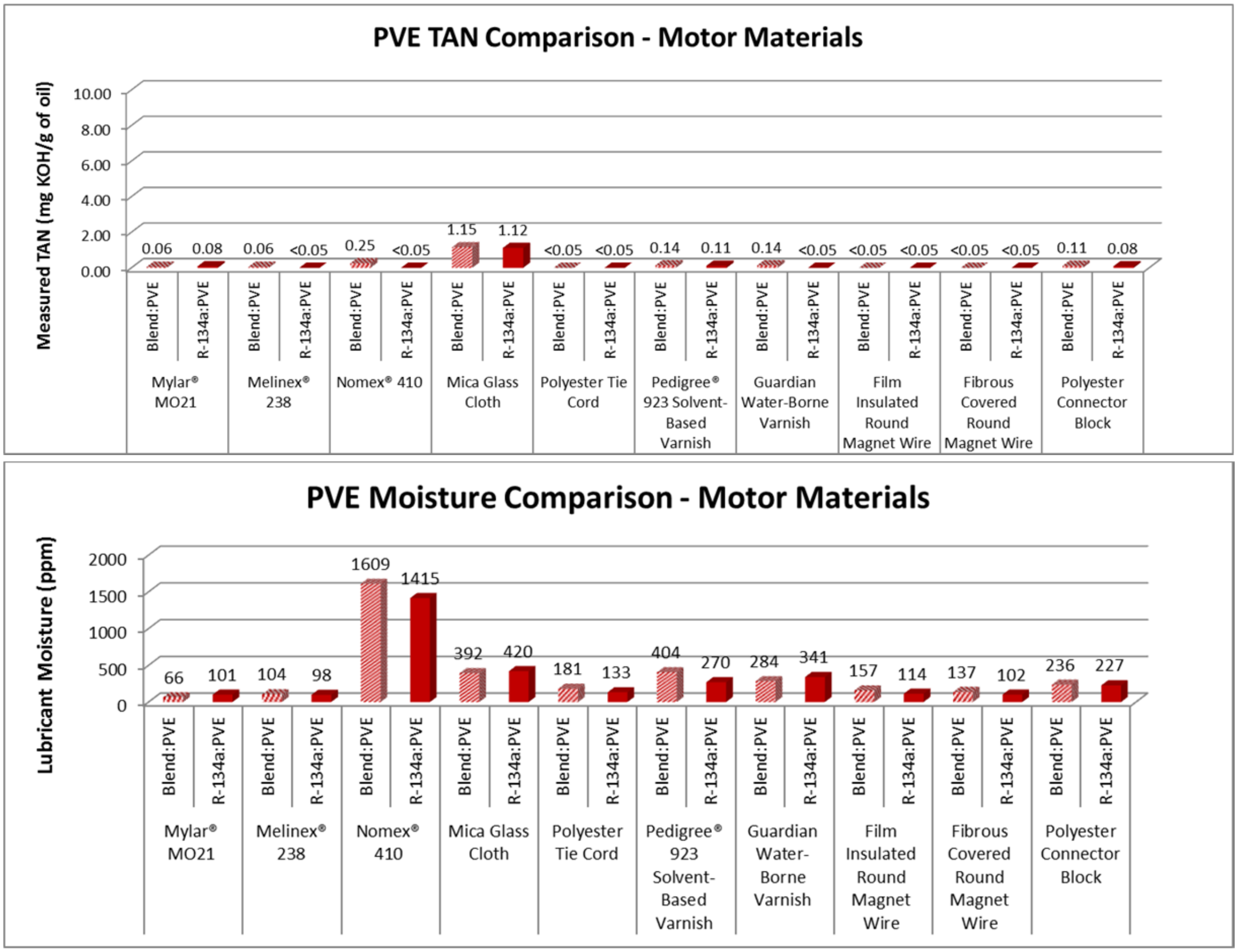


Figure 14. Post-exposure PVE TAN (above) and moisture (below) results comparison.

2.4.4 RESULTS OF DISSOLVED ELEMENTS IN LUBRICANTS BY INDUCTIVELY COUPLED PLASMA-OPTICAL EMISSION SPECTROSCOPY (ICP-OES)

Results of dissolved element concentrations in the lubricants are summarized in Appendix I, Table 32. As noted earlier, an internal standard is used in this test method to account for sample matrix interferences. When an internal standard recovery of 85-115% is able to be achieved, sample matrix interferences are minimal. However, in many of the lubricant samples that were analyzed in this study, the internal standard recovery was lower than 85%, and in some cases was significantly lower. In these same samples, it was noted that the lubricants were extremely difficult to push through the syringe filter. These observations indicate that an insoluble material associated with these samples, such as a component that was extracted from the materials or that was formed in solution from fluid interaction with the materials, may have contributed to the removal of the internal standard. Dissolved element concentrations in the lubricants were still accurately quantified; however, it’s possible that some dissolved elements may have been reduced in concentration or removed during the sample preparation process (as was observed with the internal standard). The identities and concentrations of specific elements in the lubricant samples were similar between samples prepared with the three-refrigerant blend and samples prepared with R-134a.

2.4.5 APPEARANCE CHANGE RESULTS

Sample images are provided in Appendix I, Table 41, and appearance rankings are summarized in Appendix I, Tables 39-40. Although some minor variations were noted in specific samples, overall appearance changes for samples prepared and exposed with R-134a were similar to the appearance changes observed for samples prepared and exposed with the three-refrigerant blend.

2.4.6 CHEMICAL COMPATIBILITY RESULT SUMMARY

In assessing the overall chemical compatibility results, the following criteria were applied to distinguish the reactivity as either notable or negligible. If all of the following criteria were met, the material was classified as having negligible reactivity with the three-refrigerant blend and lubricant under the conditions of study:

- <250 ppm fluoride,
- TAN increase <0.20 mg KOH/g of oil compared to tubes prepared with R-134a and the same lubricant and material catalyst,
- <20 ppm increase in dissolved elements in lubricants compared to lubricants from tubes prepared with R-134a and the same material catalyst,
- <0.10% reduction in purity by GC-MS compared to tubes prepared with R-134a and the same lubricant and material catalyst, and
- Minimal appearance changes in comparison to tubes prepared with R-134a (minimal is defined as a ranking within 1 unit of the assigned value for the appearance rankings in the tubes prepared with R-134a).

If all of the above criteria were not met, the specific reactivity concerns were noted, and are included in the summary in Table 9.

Table 9: Chemical Compatibility Result Summary

Material	Refrigerant	Lubricant	Reactivity compared to R-134a
Mylar® MO21	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Melinex® 238	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Nomex® 410	Three-Refrigerant Blend	POE	**Fluoride >250ppm**
		PVE	**Fluoride >250ppm** **TAN increase >0.20 mg KOH/g oil**
Mica Glass Cloth	Three-Refrigerant Blend	POE	**Fluoride >250ppm**
		PVE	Negligible
Polyester Tie Cord	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Pedigree® 923 Solvent-Based Varnish	Three-Refrigerant Blend	POE	**TAN increase >0.20 mg KOH/g oil**
		PVE	Negligible

Table 9 (continued): Chemical Compatibility Result Summary

Guardian™ Water-Borne Varnish	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Film Insulated Round Magnet Wire	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Fibrous Covered Round Magnet Wire	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Polyester Connector Block	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Neoprene 1 Elastomer	Three-Refrigerant Blend	POE	**Increase >20 ppm for Mg, Na, & Zn**
		PVE	**Fluoride >250ppm**
Neoprene 2 Elastomer	Three-Refrigerant Blend	POE	**Increase >20 ppm for Mg, Na, & Zn**
		PVE	**TAN increase >0.20 mg KOH/g oil**
Nitrile-Based HNBR Elastomer	Three-Refrigerant Blend	POE	**TAN increase >0.20 mg KOH/g oil Increase >20 ppm for Zn**
		PVE	Negligible
Nitrile-Based NBR Elastomer	Three-Refrigerant Blend	POE	**Fluoride >250ppm TAN increase >0.20 mg KOH/g oil Liquid phase color change**
		PVE	**Fluoride>250ppm TAN increase >0.20 mg KOH/g oil**
Fluorocarbon Elastomer	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
EDPM Elastomer	Three-Refrigerant Blend	POE	**TAN increase >0.20 mg KOH/g oil Increase >20 ppm for Zn**
		PVE	Negligible
Epichlorohydrin Elastomer	Three-Refrigerant Blend	POE	**Fluoride >250ppm TAN increase >0.20 mg KOH/g oil Increase >20 ppm for Mg**
		PVE	Negligible
Butyl Rubber Elastomer	Three-Refrigerant Blend	POE	Negligible
		PVE	**Fluoride >250ppm**
Silicone Elastomer	Three-Refrigerant Blend	POE	**TAN increase >0.20 mg KOH/g oil Increase >20 ppm for Si**
		PVE	Negligible
Garlock® 3300 Gasket	Three-Refrigerant Blend	POE	**Fluoride >250ppm TAN increase >0.20 mg KOH/g oil Increase >20 ppm for Zn**
		PVE	Negligible
Armstrong N-8092 Gasket	Three-Refrigerant Blend	POE	**TAN increase >0.20 mg KOH/g oil Increase >20 ppm for Al**
		PVE	Negligible
Klingersil® C-4401 Gasket	Three-Refrigerant Blend	POE	**TAN increase >0.20 mg KOH/g oil**
		PVE	Negligible

Table 9 (continued): Chemical Compatibility Result Summary

Nylon 6,6 (unfilled) Polymer	Three-Refrigerant Blend	POE	**Fluoride >250ppm**
		PVE	**Fluoride >250ppm, TAN increase >0.20 mg KOH/g oil Increase >20 ppm for Si**
PEEK (unfilled) Polymer	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
PPS (filled) Polymer	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
PAI (unfilled) Polymer	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
PTFE (unfilled) Polymer	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
3A molecular sieve 1	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
3A molecular sieve 2	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
3A molecular sieve 3	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
4A molecular sieve	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Activated Alumina	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Free cutting brass	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Cartridge brass	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Phosphor bronze	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Manganese phosphate	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Lead-free polymer bearing	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Leaded polymer bearing	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Powder metal alloy	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Loctite 620	Three-Refrigerant Blend	POE	Negligible
		PVE	Negligible
Loctite 640	Three-Refrigerant Blend	POE	**Fluoride >250ppm TAN increase >0.20 mg KOH/g oil**
		PVE	**Fluoride >250ppm**

Additional details on the chemical compatibility testing results are summarized in Appendix I.

3. MATERIAL COMPATIBILITY

The material compatibility portion of this study was divided into two separate sections to accommodate the distinct sample testing requirements for the different classes of materials: 1) seal and polymer compatibility, and 2) motor material compatibility.

3.1 MATERIAL COMPATIBILITY – SEALS AND POLYMERS

Compatibility of seals and polymers was evaluated by exposing material samples in Parr pressure vessels (Parr bombs) with refrigerants, lubricants, and mixtures thereof under accelerated thermal aging conditions. After the aging period, the properties of exposed materials were compared to the properties of unexposed baseline materials, to determine the extent of specific changes resulting from the exposures. The material samples detailed in Table 3 were evaluated in this portion of the study.

3.1.1 SEALS AND POLYMERS SAMPLE PREPARATION

Sample preparation information is provided in Table 10.

Table 10: Seal and Polymer Materials Sample Preparation Details

Material Type	Materials Included	Sample Configurations
Elastomers	Neoprene 1	1 inch sections of O-rings
	Neoprene 2	
	Nitrile-Based HNBR	
	Nitrile-Based NBR	
	Fluorocarbon	
	EDPM	
	Epichlorohydrin	
	Butyl Rubber	
	Silicone	
Gaskets	Garlock® 3300	1 square inch sections of the flat gaskets
	Armstrong N-8092	
	Klingersil® C-4401	
Polymers	Polyester (unfilled)	Molded ASTM Type 1 tensile bars were received from suppliers. Sections of 1 square inch size were cut from the ends of the tensile bars for weight/volume change determinations. The remaining portions of the tensile bars were exposed for tensile property testing.
	Nylon 6,6 (unfilled)	
	PEEK (unfilled)	
	PPS (filled)	
	PAI (unfilled)	
	PTFE (unfilled)	1 square inch sections

3.1.2 SEALS AND POLYMERS SAMPLE EXPOSURES

Material compatibility evaluations of seal and polymer materials were conducted with three refrigerants at 100%, and combinations of each of these refrigerants with two different lubricants. The twelve exposure conditions (including controls) are summarized in Table 11. Because the critical temperature of the three-refrigerant blend is below 90°C, the exposure temperature was lowered to 85°C for this fluid mixture, and the exposure time was extended to 28 days instead of 21 days.

Table 11: Exposure Conditions for Material Compatibility of Seals and Polymers

Description	Exposure Conditions
100% R-1234yf	90°C for 21 days
100% R-1234ze(E)	90°C for 21 days
100% three-refrigerant blend (33 ⅓% of each by weight: R-1234yf, R-1234ze(E), and R-32)	85°C for 28 days
100% nitrogen	90°C for 21 days
50% R-1234yf:50% POE Lubricant	90°C for 21 days
50% R-1234ze(E):50% POE Lubricant	90°C for 21 days
50% three-refrigerant blend:50% POE Lubricant	85°C for 28 days
100% POE Lubricant (no refrigerant)	90°C for 21 days
50% R-1234yf:50% PVE Lubricant	90°C for 21 days
50% R-1234ze(E):50% PVE Lubricant	90°C for 21 days
50% three-refrigerant blend:50% PVE Lubricant	85°C for 28 days
100% PVE Lubricant (no refrigerant)	90°C for 21 days

Each type of material was exposed in an individual Parr bomb except for the neoprenes, nitriles, and polymers. Neoprene 1 and neoprene 2 material samples were combined, the nitrile-based HNBR and nitrile-based NBR samples were grouped together, and all of the polymer materials except PTFE were exposed together in the same Parr bomb.

Refrigerant samples were assessed for purity by gas chromatography and moisture by Karl Fischer coulometry prior to charging the vessel.

The lubricant was assessed for moisture by Karl Fischer coulometry and Total Acid Number (TAN) by titration prior to addition to the Parr bomb. Lubricant moisture concentration requirements were ≤50 ppm and TAN requirements were ≤0.05 mg KOH/gram of oil. The TAN requirements were met in all instances throughout the duration of the project. When the lubricant moisture concentration exceeded the requirement, the lubricant was dried and degassed before adding it to the test vessel.

Materials of interest were added to the Parr bomb first. For the 100% refrigerant exposure conditions, the Parr bomb was filled to <80% volume with liquid refrigerant. For the exposures with lubricant, the lubricant was added to the Parr bomb containing the materials of interest, a vacuum was applied to remove air, and liquid refrigerant was added to reach a 50% lubricant:50% refrigerant (by weight) ratio.

Weight checks were conducted after 24 hours and after one week of exposure to ensure that the vessels had maintained at least 95% of the original refrigerant mass.

3.1.3 SEALS AND POLYMERS SAMPLE ANALYSES

Post-aging tests were conducted on the samples according to the details in Table 12. All of the tests were conducted using sample replicates of three, with the exception of the polymer tensile tests which were performed using sample replicates of five.

Table 12: Seal and Polymer Materials Post-Exposure Test Summary

Material Type	Materials Included	Evaluations Conducted
Elastomers	Neoprene 1 Neoprene 2 Nitrile-Based HNBR Nitrile-Based NBR Fluorocarbon EDPM Epichlorohydrin Butyl Rubber Silicone	Weight Change Volume Change Extractable Determination Appearance Change Sample Imaging Shore A Durometer Hardness Change Post-Bakeout Appearance Change Post-Bakeout Weight Change
Gaskets	Garlock® 3300 Armstrong N-8092 Klingersil® C-4401	Weight Change Volume Change Extractable Determination Appearance Change Sample Imaging Post-Bakeout Appearance Change Post-Bakeout Weight Change
Polymers	Polyester (unfilled) Nylon 6,6 (unfilled) PEEK (unfilled) PPS (filled) PAI (unfilled) PTFE (unfilled)[1]	Weight Change Volume Change Extractable Determination Appearance Change Sample Imaging Tensile Property Changes[1] Post-Bakeout Appearance Change Post-Bakeout Weight Change

[1]Tensile testing was not performed on the PTFE material due to the configuration that the samples were received in (strips instead of tensile bars).

Weight Change and Volume Change

Weight change and volume change measurements were conducted immediately after removing the samples from the Parr bombs. Measurements were performed using a process based on ASTM D471 (Standard Test Method for Rubber Property—Effect of Liquids). All of the volume measurements were carried out with methanol except for the Garlock® 3300 gasket material. Due to the highly absorptive nature of this material, measurements were made using distilled water instead of methanol.

Appearance Change

Documentation and imaging of sample appearance changes were completed after the weight and volume change measurements had been conducted. Samples were evaluated for the presence of the following characteristics: discoloration, cracking/crazing, blistering, and noticeable or severe swelling.

Material samples from the 100% refrigerant exposure conditions were evaluated to determine if any extractable material was present on the sample surfaces, or if extractable material was present inside of the test vessel. When observed, extractable material was characterized by FTIR spectroscopy.

Shore A Durometer Hardness

Shore A durometer hardness measurements were conducted on the elastomer samples using a procedure based on ASTM D2240 (Standard Test Method for Rubber Property—Durometer Hardness).

Quality controls were run using two standard test blocks to confirm that the Shore A durometer hardness values were within 2.0 units of the certified standard values.

After the tests described above had been completed, samples were exposed to an air bakeout period to remove absorbed refrigerant and to assess the appearance changes and overall weight changes of the materials after the refrigerant had been removed. The air bakeout process was conducted for 24 hours at the temperature at which the samples were initially exposed.

Tensile Testing

Tensile properties of polymer samples were measured according to procedures based on ASTM D638 (Standard Test Method for Tensile Properties of Plastics).

3.1.4 SEALS AND POLYMERS RESULTS AND DISCUSSION

Appearance change results are summarized in Appendix II, Table 44. In the 100% refrigerant exposures, the fluorocarbon and silicone elastomers exhibited significant swelling as a consequence of exposure to the three different refrigerants. As displayed in Figures 15 and 16, the volume and weight change measurement results are consistent with the visual observations of swelling. In addition - as expected with materials that significantly absorb refrigerant - hardness measurements (Figure 17) confirmed softening of the fluorocarbon and silicone materials.

The neoprene 2 material exhibited the presence of extractable material on the sample surfaces after the R-1234yf and three-refrigerant blend exposures, and in the bottom of the test vessel after the R-1234ze(E) exposure (Appendix II, Table 45). Post-exposure hardness measurements also revealed an increase in hardness for the neoprene 2 material (Figure 17).

Trends observed in the results for the fluorocarbon, silicone, and neoprene 2 materials from the 50% refrigerant:50% lubricant exposures were similar to those observed for the samples from the 100% refrigerant exposures.

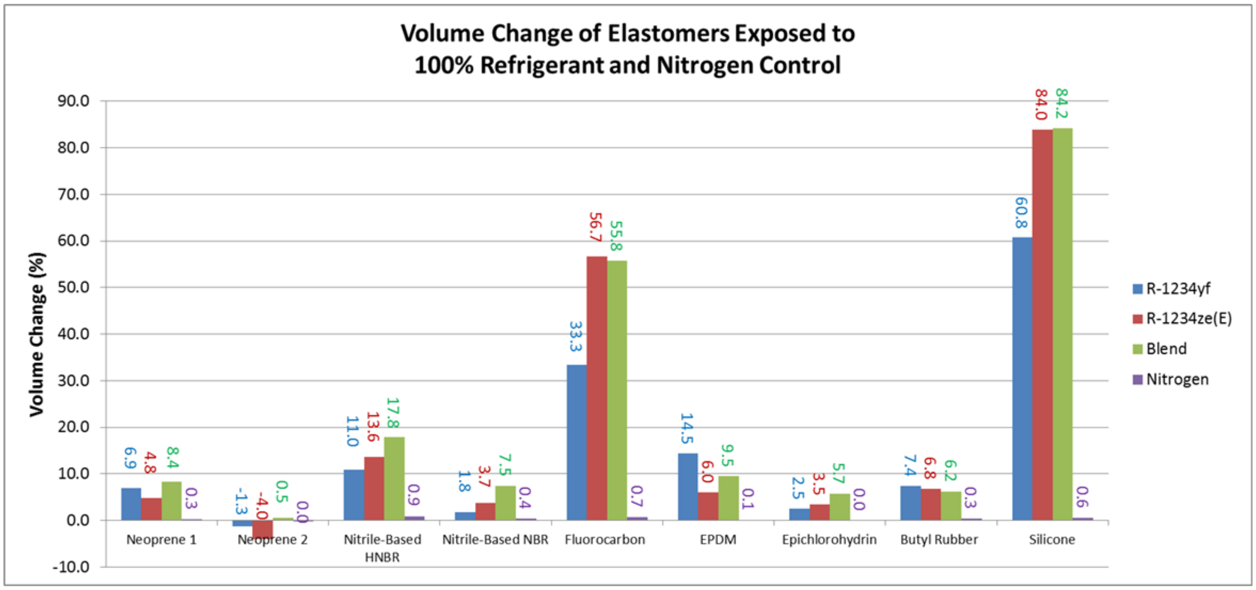


Figure 15. Volume change summary for elastomers exposed to refrigerants.

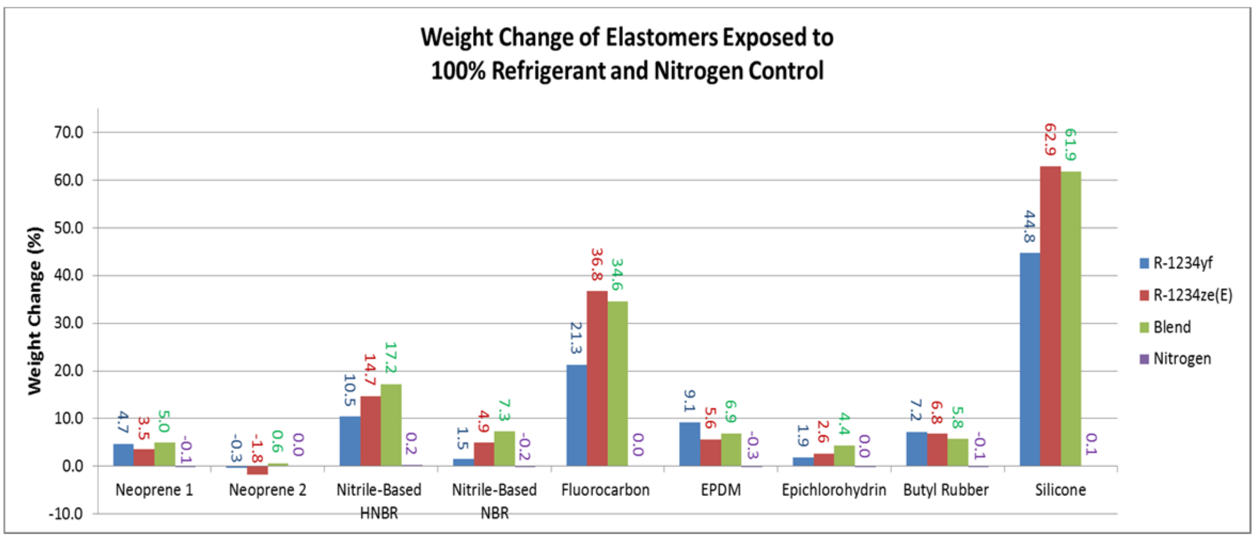


Figure 16. Weight change summary for elastomers exposed to refrigerants.

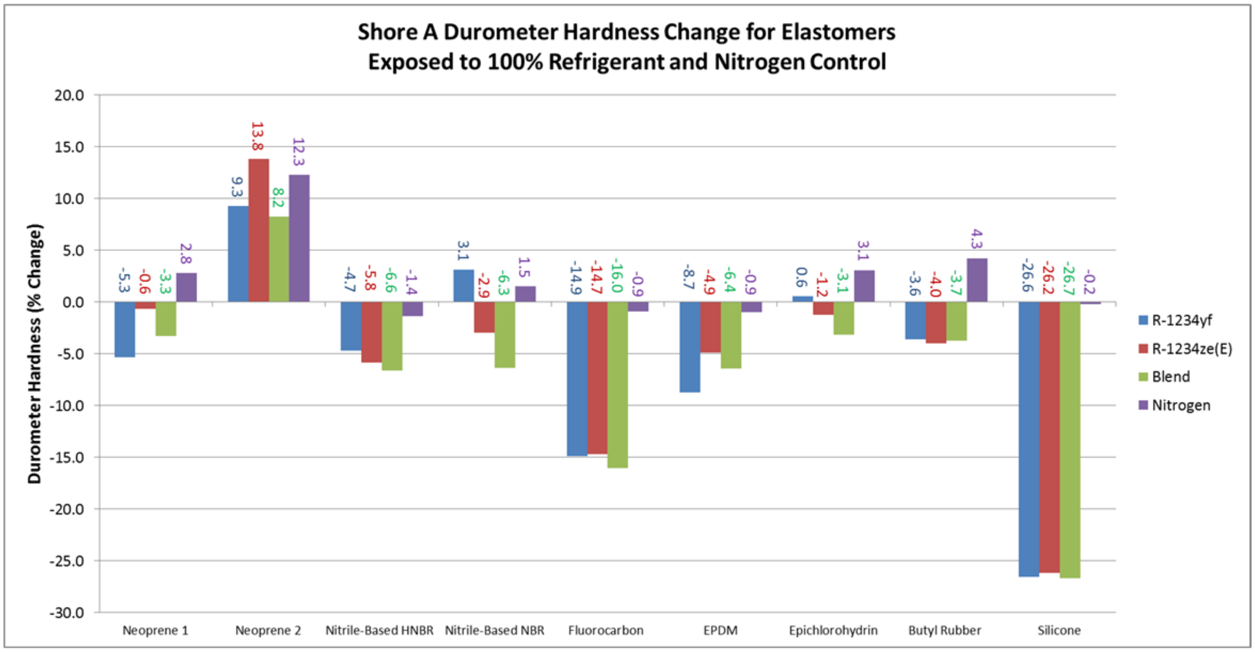
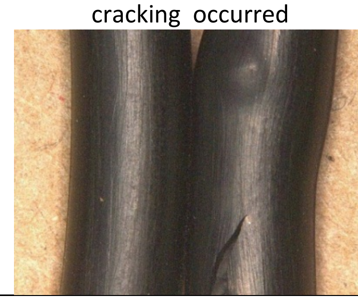
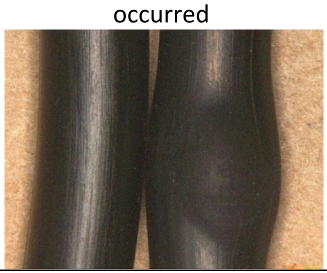


Figure 17. Shore A durometer hardness summary for elastomers exposed to refrigerants.

Extractable materials were observed either on the sample surfaces or in the bottom of the test vessels after many of the sample exposures (Appendix II, Table 45). FTIR spectra of the extractable materials, and reference spectra of the unexposed materials, are shown in Appendix II, Figures 23-27. Extractable materials on the sample surfaces are also evident in some of the images summarized in Appendix II, Tables 61-69.

After the bakeout process, the fluorocarbon, butyl rubber, and silicone samples exhibited notable changes (Appendix II, Table 47). Example images of the blistering and cracking observed on the butyl rubber and silicone materials are presented in Table 13.

Table 13: Elastomer Post-Bakeout Appearance Change Summary (only the materials that exhibited changes in at least one exposure condition are summarized)

Results from 100% Refrigerant and Nitrogen Control Exposures			
Material	**Post-Bakeout Appearance Change**		
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**
Fluorocarbon	No change	Noticeable reduction in swelling	Noticeable reduction in swelling
Silicone	Noticeable reduction in swelling; appearance of cracks and white marks	Noticeable reduction in swelling; appearance of cracks and white marks	Noticeable reduction in swelling; appearance of cracks and white marks 
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures			
Material	**Post-Bakeout Appearance Change**		
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**
Fluorocarbon	Lubricant present on material surface	Lubricant present on material surface	Lubricant present on material surface
Butyl Rubber	Blistering occurred	No change	Significant blistering and cracking occurred 
Silicone	Noticeable reduction in swelling; lubricant present on material surface	Noticeable reduction in swelling; lubricant present on material surface	Noticeable reduction in swelling; lubricant present on material surface
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures			
Material	**Post-Bakeout Appearance Change**		
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**
Butyl Rubber	Significant blistering occurred 	No change	Blistering occurred

There was little notable visual impact to the gasket materials under any of the exposure conditions (Appendix II, Tables 49 and 70-72). The Armstrong N-8092 material exhibited significant weight and volume increases in all of the exposures with lubricants, relative to the corresponding exposures in 100% refrigerant. The Garlock® 3300 and Klingersil® C-4401 materials demonstrated similar trends but less dramatic differences, in comparison to the Armstrong N-8092 material.

Polymer sample testing results revealed impacts to the material properties when the polyester material was exposed to R-1234ze(E) and the three-refrigerant blend. As shown in Figures 18 and 19, the volume and weight change increases were minimal (≤3.0%) after the three 100% refrigerant exposures, but refrigerant absorption roughly doubled for R-1234ze(E) and three-refrigerant blend compared to R-1234yf. In addition, the polyester tensile property test results confirm a correlation between increased refrigerant absorption and impact to the material tensile properties (Figure 20). Trends observed for the 50% refrigerant:50% lubricant polyester material exposures were similar to those observed for the 100% refrigerant exposures.

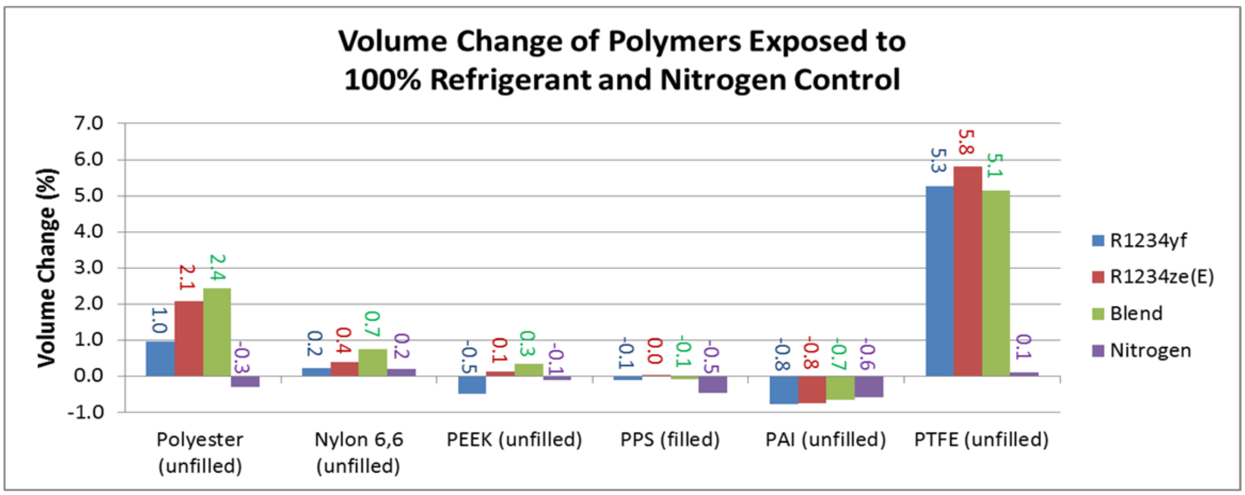


Figure 18. Volume change summary for polymers exposed to refrigerants.

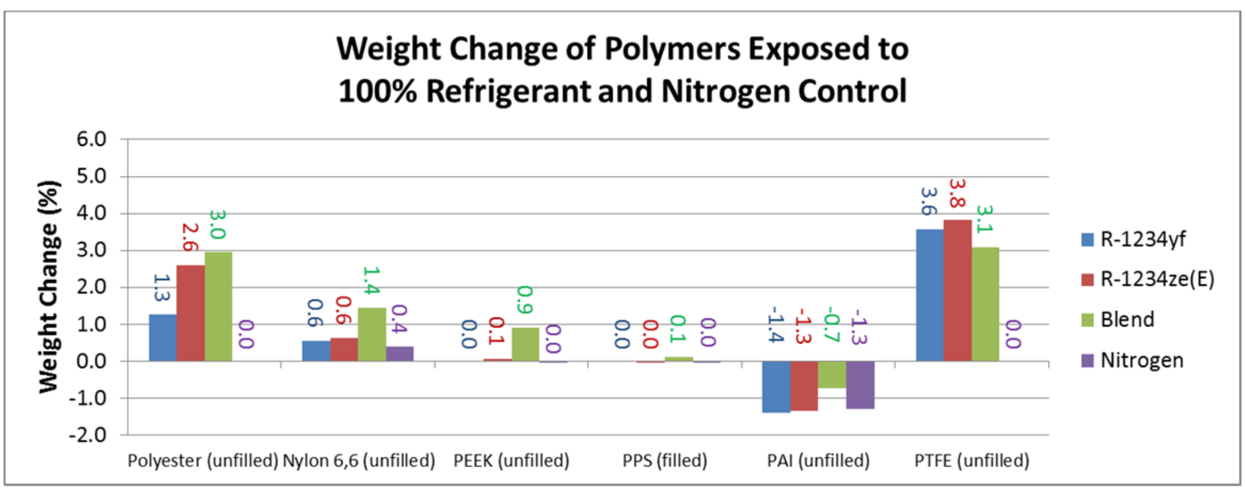


Figure 19. Weight change summary for polymers exposed to refrigerants.

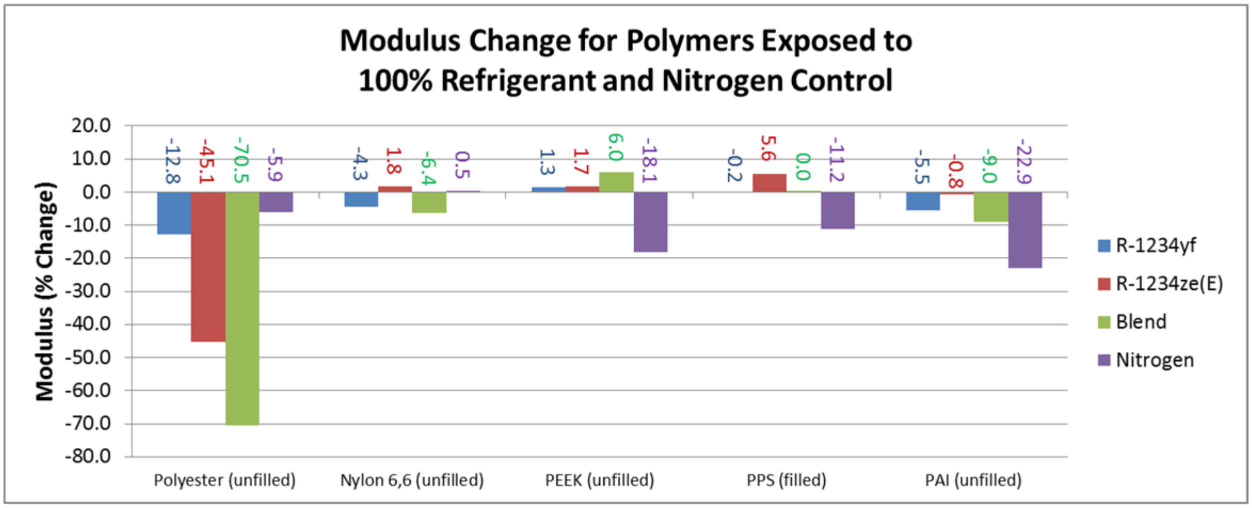


Figure 20. Tensile property change example for polymers exposed to refrigerants.

3.2 MATERIAL COMPATIBILITY – MOTOR MATERIALS

Material samples detailed in Table 2 were evaluated in the motor material compatibility portion of the study. Similarly to the seal and polymer material compatibility study, the compatibility of motor materials was evaluated by exposing material samples in Parr bombs with refrigerants, lubricants, and mixtures thereof under accelerated thermal aging conditions. After the aging process, the properties of exposed materials were compared to the properties of unexposed baseline materials. In contrast to the seal and polymer study, much more extensive sample preparation processes and different post-exposure test methods were required for assessing the compatibility of motor materials.

3.2.1 MOTOR MATERIALS SAMPLE PREPARATION

An overview of the sample categories and configurations is provided in Table 14. Detailed descriptions of the sample preparation processes for varnish compatibility test samples are described in the text below.

Table 14: Motor Material Tests and Sample Configurations

Material Type	Materials Included	Evaluations Conducted	Number of Replicates	Sample Configuration
Unvarnished Materials	Mylar® MO21, Melinex® 238, Nomex® 410, & Mica Glass Cloth	Appearance Change Weight Change Dielectric Strength	5	Strips of 1.5 x 3 inches
		Tensile Strength % Elongation	5	Strips of 0.5 x 6 inches
	Polyester Tie Cord	Appearance Change Weight Change	5	6-inch lengths
		Break Load Strength % Elongation	5	6-inch lengths
Varnish Pucks	Pedigree® 923 Solvent-Based Varnish	Appearance Change Weight Change Volume Change Post-Bakeout Weight Change Post-Bakeout Appearance Change	5	Circular pucks approximately 1 inch in diameter and 0.125 inches thick
	Guardian™ Water-Borne Varnish		5	
Varnished Magnet Wires	Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	<u>Single Strands:</u> Appearance Change 1X Mandrel Bending <u>Twisted Pairs:</u> Dielectric Strength Burnout Strength <u>Helical Coils:</u> Bond Strength	5	<u>Single Strands:</u> 8-inch lengths <u>Twisted Pairs:</u> 9-inch lengths encompassing 8 twists <u>Helical Coils:</u> Coil sections of approximately 0.35 x 4 inches
	Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish			
	Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish			
	Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish			

To assess varnish compatibility, varnish pucks were prepared to examine effects on pure varnish cast in the form of thin disks. Magnet wire test specimens were also prepared to assess impacts to the varnish adherence, flexibility, bond strength, dielectric strength, and burnout strength using samples that more accurately simulate varnish application on actual motors.

Varnish pucks were prepared and cured based on recommendations from the manufacturer. Samples of varnish were weighed into aluminum dishes and cured according to the steps listed in Table 15. Weight changes were recorded for each puck to evaluate the consistency in preparation and mass loss during the curing process.

Table 15: Varnish Curing Processes

Material	Step Curing Process
Pedigree® 923 Solvent-Based Varnish	1) 24 hours at 100°C 2) 1 hour at 140°C 3) 6 hours at 165°C
Guardian™ Water-Borne Varnish	1) 24 hours at 90°C 2) 2 hours at 165°C

Because the varnish thickness on magnet wire in actual motors is much less than the thickness of the prepared varnish pucks (approximately 1/8 inch or 0.3 cm), the effects of refrigerants and lubricants on the varnish pucks are only indicators of potential problems that may occur in actual motors. To better simulate varnish application on actual motors, magnet wire test specimens were prepared from each of two different types of wire, with two different types of varnish, to evaluate impacts to the physical and electrical insulation strength of the varnish.

Single strand, twisted pair, and helical coil wire test specimens were prepared from spools of magnet wire, and varnishes were applied as described in Tables 16-17. Magnet wire samples were prepared with the solvent-based varnish (Pedigree® 923, 35% solids) using the procedure outlined in Table 16, and with the water-borne varnish (Guardian™ Water-Borne Varnish, 50% solids) using the procedure in Table 17.

Table 16: Magnet Wire Varnish Application Process for the Solvent-Based Varnish

Description	Procedure
First Dip	1) Magnet wire samples were placed into an oven preheated to 100°C. 2) The oven temperature was increased to 175°C and was maintained at this setting for 2 hours. 3) The oven temperature was decreased to 90°C, where it was maintained for 30 minutes. 4) Sets of hot wires were dipped at a rate of 4 inches/minute and were kept fully submerged for 2-3 minutes. 5) The wires were removed from the varnish at a rate of 4 inches/minute and the excess varnish was allowed to drip off at room temperature for several minutes. 6) The wires were placed in an oven at 100°C for 2 hours. 7) The oven temperature was then increased to 165°C for 2 additional hours.
Second Dip	1) The wires were inverted and placed into an oven preheated to 100°C. 2) The oven temperature was increased to 165°C and was maintained at this setting for 15 minutes. 3) The oven temperature was decreased to 90°C, where it was maintained for 30 minutes. 4) Sets of hot wires were dipped at a rate of 4 inches/minute and were kept fully submerged for 2-3 minutes. 5) The wires were removed from the varnish at a rate of 4 inches/minute and the excess varnish was allowed to drip off at room temperature for several minutes. 6) The wires were placed in an oven at 100°C for 2 hours. 7) The oven temperature was then increased to 165°C for 6 hours.

Table 17: Magnet Wire Varnish Application Process for the Water-Borne Varnish

Description	Procedure
First Dip	1) The same procedures used in steps 1) – 5) of the first dip process for the solvent-based varnish were applied. 2) The wires were placed in an oven at 90°C for 2 hours. 3) The oven temperature was increased to 150°C for 2 hours.
Second Dip	1) The wires were inverted and placed into an oven preheated to 100°C. 2) The oven temperature was increased to 150°C, where it was held for 15 minutes. 3) The oven temperature was decreased to 90°C, where it was maintained for 30 minutes. 4) Sets of hot wires were dipped at a rate of 4 inches/minute and were kept fully submerged for 2-3 minutes. 5) The wires were removed from the varnish at a rate of 4 inches/minute and the excess varnish was allowed to drip off at room temperature for several minutes. 6) The wires were placed in an oven at 90°C for 2 hours. 7) The oven temperature was increased to 150°C for 4 hours.

3.2.2 MOTOR MATERIALS SAMPLE EXPOSURES

Material compatibility evaluations of motor materials were conducted with three refrigerants at 100%, and combinations of each of these three refrigerants with two different lubricants. The twelve exposure conditions (including controls) are summarized in Table 18. In contrast to the seal and polymer compatibility study, all exposures with lubricants were conducted at 127°C for consistency with prior motor material compatibility studies (Doerr and Kujak, 1993).

Table 18: Exposure Conditions for the Motor Materials Compatibility Assessment

Description	Exposure Conditions
100% R-1234yf	90°C for 21 days
100% R-1234ze(E)	90°C for 21 days
100% three-refrigerant blend (33 ⅓% of each by weight: R-1234yf, R-1234ze(E), and R-32)	85°C for 28 days
100% nitrogen	90°C for 21 days
50% R-1234yf:50% POE Lubricant	127°C for 21 days
50% R-1234ze(E):50% POE Lubricant	127°C for 21 days
50% three-refrigerant blend:50% POE Lubricant	127°C for 21 days
100% POE Lubricant (no refrigerant)	127°C for 21 days
50% R-1234yf:50% PVE Lubricant	127°C for 21 days
50% R-1234ze(E):50% PVE Lubricant	127°C for 21 days
50% three-refrigerant blend:50% PVE Lubricant	127°C for 21 days
100% PVE Lubricant (no refrigerant)	127°C for 21 days

Samples were grouped for exposures as detailed in Table 19.

Table 19: Motor Material Sample Grouping

Material Grouping in Parr Bombs
Mylar® MO21, Melinex® 238, Nomex® 410, & Mica Glass Cloth
Polyester Tie Cord
Pedigree® 923 Solvent-Based Varnish Pucks
Guardian™ Water-Borne Varnish Pucks
Film Insulated & Fibrous Covered Round Magnet Wires with Pedigree® 923 Solvent-Based Varnish
Film Insulated & Fibrous Covered Round Magnet Wires with Guardian™ Water-Borne Varnish

The materials of interest were added to the Parr bomb first. Refrigerants and lubricants were quality checked, handled, and added to the Parr bombs as described earlier in the seal and polymer material compatibility portion of this study.

Weight checks were conducted after 24 hours and after one week of exposure to ensure that the vessels had maintained at least 95% of the original refrigerant mass.

3.2.3 MOTOR MATERIALS SAMPLE ANALYSES

Weight Change and Volume Change

Weight change and volume change measurements were conducted immediately after removing the samples from the Parr bombs.

Appearance Change

Sample appearances after an exposure were compared to unexposed samples of the same type to evaluate the extent of visual changes. Samples were evaluated for the presence of the following characteristics: discoloration, cracking/crazing, blistering, and noticeable or severe swelling. Representative sample images were acquired.

Dielectric Strength

Dielectric strength measurements of the unvarnished motor material sample films were conducted using a procedure based on ASTM D149 (Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies).

Dielectric strength measurements of the twisted pairs were conducted according to a procedure based on ASTM D1676 (Standard Test Methods for Film-Insulated Magnet Wire), sections 70-76.

A dielectric tester from A/Z Tech, Inc., model MW-2, was used for the analyses. Voltage was applied at a rate of 500 Volts/second for the magnet wire samples.

Burnout Strength

Burnout strength measurements of the twisted pairs were conducted according to a procedure based on ASTM D1676 (Standard Test Methods for Film-Insulated Magnet Wire), sections 13-21. A TCA wire burnout tester, model WBT-3, was used for the analyses. A controlled current is induced through both strands of the twisted pair, and thermal degradation of the varnish film occurs from the resistance heating of the specimen. When the level of degradation is sufficient for a 50 mA current to pass through the film, the burnout time in seconds is noted.

Tensile Testing

Tensile tests of the polyester tie cord material and the other unvarnished motor materials were conducted using procedures based on ASTM D882 (Tensile Testing of Thin Plastic Sheeting).

Bond Strength

Varnish bond strength was assessed using test procedures consistent with ASTM D2519 (Standard Test Method for Bond Strength of Electrical Insulating Varnishes by the Helical Coil Test).

Mandrel Bend Testing

Mandrel bend testing was conducted to assess the film adherence & flexibility of the varnish. For the film-insulated round magnet wires, the testing was conducted using a 0.2-inch diameter mandrel and following the steps outlined in ASTM D1676, sections 141-148.

For the fibrous-covered round magnet wire samples, testing was conducted with a 0.5-inch diameter mandrel and using the general procedures in ASTM D3353 (Standard Test Methods for Fibrous-Insulated Magnet Wire).

3.2.4 MOTOR MATERIALS RESULTS AND DISCUSSION

When evaluating the appearance change of the unvarnished motor materials, particulates were observed on the surface of the Mylar® MO21 material that had been exposed to R-1234ze(E) with lubricants, and the three-refrigerant blend with lubricants. Because the unvarnished motor materials were grouped together for the exposures, it was of initial concern that the particulates were a consequence of concurrent exposure with other materials in the vessels. To investigate whether the particulates were due to refrigerant and lubricant extraction, and not from the concurrently exposed materials, the 50% R-1234ze(E):50% PVE, and 50% three-refrigerant blend:50% PVE exposures with Mylar® MO21 were repeated. No other materials were included in these exposures. Results indicated that particulates were still present on the materials, in particular those exposed to the three-refrigerant blend and PVE (Figure 21). The particulates were characterized by FTIR spectroscopy (Figure 22) and appear to be a material extracted from the polyester.

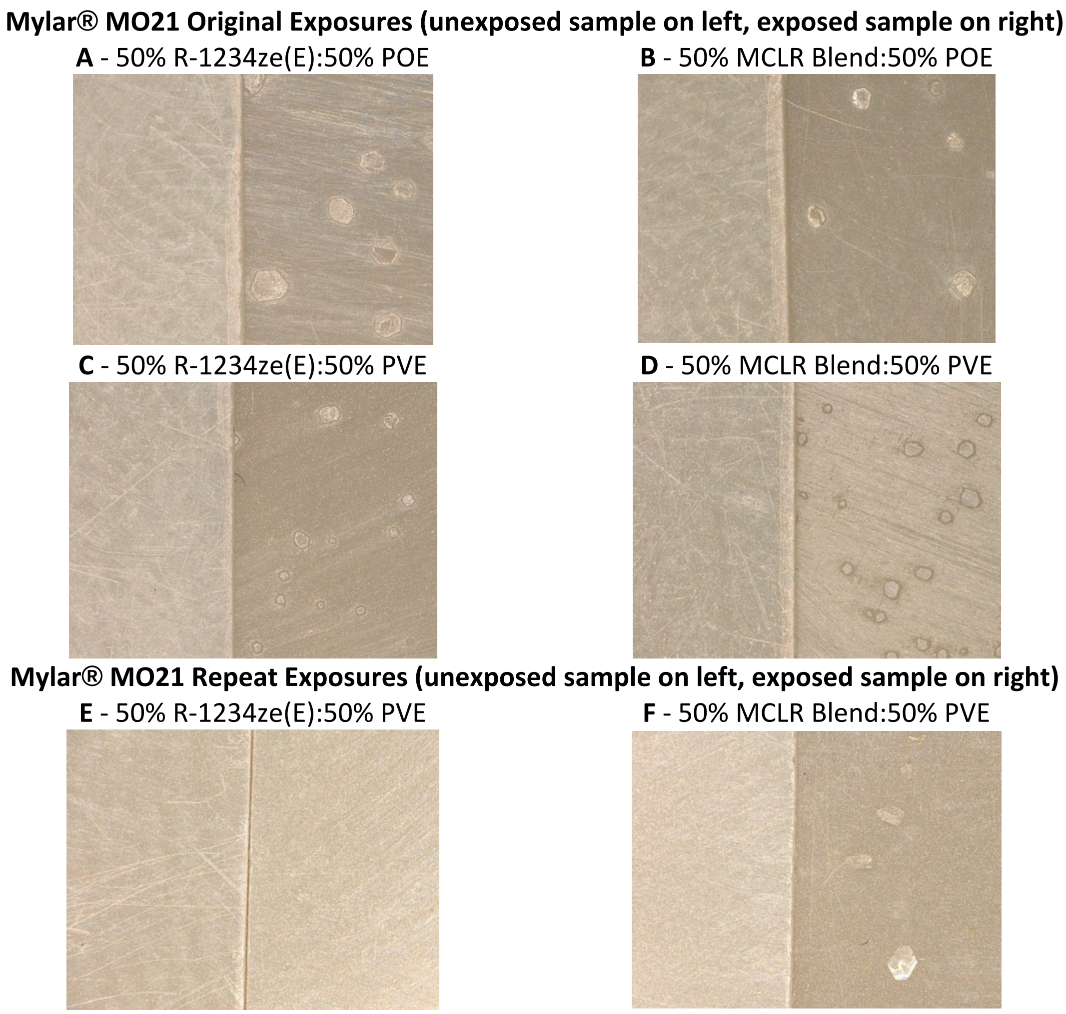


Figure 21. Images of Mylar® MO21 samples after exposures to R-1234ze(E) with lubricants (A, C, and E), and after exposures to the three-refrigerant blend with lubricants (B, D, and F).

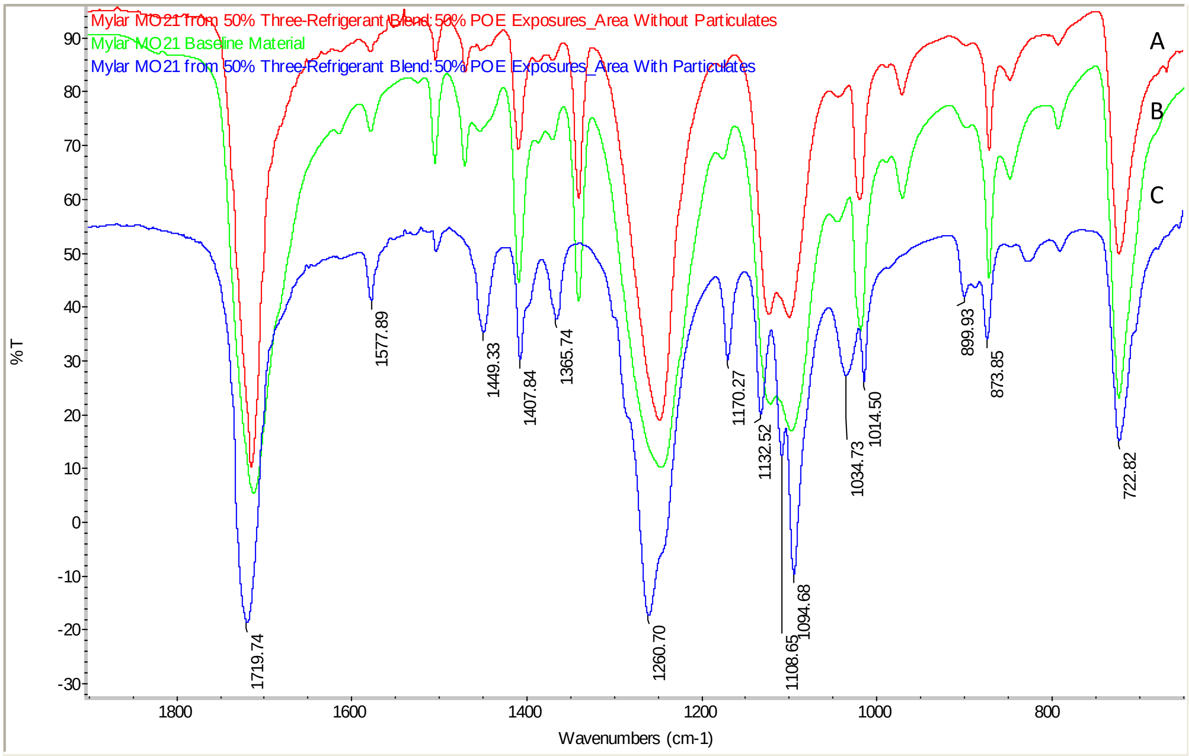


Figure 22. FTIR spectral comparison of a particulate area on Mylar MO21 that was exposed to 50% three-refrigerant blend:50% POE (C), from an area without particulates (A), and a reference Mylar® MO21 baseline material spectrum (B).

Results from the varnish testing of samples are detailed in Appendix III, Tables 93-103. There were no catastrophic changes in dielectric strength, burnout strength, or bond strength in any of the exposed samples (Appendix III, Tables 93-103). The varnish pucks exhibited darkening in some exposure conditions (Appendix III, Tables 94, 98, and 99), and some extractable material was present in the test vessels after exposures of the solvent-based varnish to refrigerants (Appendix III, Table 95 and Figure 29).

Additional results from the motor material testing are detailed in Appendix III.

REFERENCES

Doerr, R.G., and Kujak, S.A. 1993. *Compatibility of Refrigerants and Lubricants with Motor Materials*. Report DOE/CE/23810-13. Air-Conditioning and Refrigeration Technology Institute, Arlington, VA, USA.

Field, J.E. 1995. *Sealed Tube Comparisons of the Compatibility of Desiccants with Refrigerants and Lubricants*. Report DOE/CE/23810-54. Air-Conditioning and Refrigeration Technology Institute, Arlington, VA, USA.

Fujitaka, A., Shimizu, T., Sato, S., and Kawabe, Y. 2010. *Application of Low Global Warming Potential Refrigerants for Room Air Conditioner.* Paper presented at the 2010 International Symposium on Next-generation Air Conditioning and Refrigeration Technology, 17 – 19 February 2010, Tokyo, Japan.

Rohatgi, N.D., Clark, R.W., and Hurst, D.R. 2012. *Material Compatibility & Lubricants Research for Low GWP Refrigerants – Phase I: Thermal and Chemical Stability of Low GWP Refrigerants with Lubricants*. AHRTI Report No. 09004-01. Air Conditioning, Heating, and Refrigeration Technology Institute, Inc., Arlington, VA, USA.

Rohatgi, N.D. 1998. *Effects of Temperature on Desiccant Catalysis of Refrigerant Lubricant Decomposition.* Report DOE/CE/23810-95. Air-Conditioning and Refrigeration Technology Institute, Arlington, VA, USA.

APPENDIX I – SUPPLEMENTAL CHEMICAL COMPATIBILITY INFORMATION

Table 20: Sample Preparation and Exposure Details for Chemical Compatibility of Motor Materials

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
Mylar® MO21	6 strips (each 2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 0.70 ± 0.03 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Melinex® 238	6 strips (each 2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 0.66 ± 0.03 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Nomex® 410	6 strips (each 2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 0.67 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Mica Glass Cloth	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 1.00 ± 0.06 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Polyester Tie Cord	8 lengths (each 2 ½ inches (6.4 cm) long) 0.25 ± 0.01 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Pedigree® 923 Solvent-Based Varnish	Cured Material 0.65 ± 0.04 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Guardian™ Water-Borne Varnish	Cured Material 0.69 ± 0.05 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 20 (continued): Sample Preparation and Exposure Details for Chemical Compatibility of Motor Materials

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
Film Insulated Round Magnet Wire	6 lengths (each 2 ½ inches (6.4 cm) long) 2.90 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Fibrous Covered Round Magnet Wire	6 lengths (each 2 ½ inches long) 3.04 ± 0.06 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Polyester Connector Block	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 0.87 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 21: Sample Preparation and Exposure Details for Chemical Compatibility of Elastomers

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
Neoprene 1 Elastomer	2 ½ x 3/16 inch (6.4 x 0.5 cm) length of O-ring 2.14 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Neoprene 2 Elastomer	2 ½ x 3/16 inch (6.4 x 0.5 cm) length of O-ring 2.03 ± 0.01 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Nitrile-Based HNBR Elastomer	2 ½ x 3/16 inch (6.4 x 0.5 cm) length of O-ring 1.68 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 21 (continued): Sample Preparation and Exposure Details for Chemical Compatibility of Elastomers

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
Nitrile-Based NBR Elastomer	2 ½ x 3/16 inch (6.4 x 0.5 cm) length of O-ring 1.78 ± 0.01 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Fluorocarbon Elastomer	2 ½ x 3/16 inch (6.4 x 0.5 cm) length of O-ring 2.60 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
EDPM Elastomer	2 ½ x 3/16 inch (6.4 x 0.5 cm) length of O-ring 1.86 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Epichlorohydrin Elastomer	2 ½ x 3/16 inch (6.4 x 0.5 cm) length of O-ring 2.29 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Butyl Rubber Elastomer	2 ½ x 3/16 inch (6.4 x 0.5 cm) length of O-ring 1.63 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Silicone Elastomer	2 ½ x 3/16 inch (6.4 x 0.5 cm) length of O-ring 2.20 ± 0.4grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 22: Sample Preparation and Exposure Details for Chemical Compatibility of Gaskets

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
Garlock® 3300 Gasket	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 1.11 ± 0.03 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Armstrong N-8092 Gasket	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 0.97 ± 0.01 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Klingersil® C-4401 Gasket	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 0.90 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 23: Sample Preparation and Exposure Details for Chemical Compatibility of Polymers

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
Nylon 6,6 (unfilled) Polymer	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 0.83 ± 0.03 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
PEEK (unfilled) Polymer	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 1.15 ± 0.08 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
PPS (filled) Polymer	2 strips (each 2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 1.65 ± 0.06 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 23 (continued): Sample Preparation and Exposure Details for Chemical Compatibility of Polymers

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
PAI (unfilled) Polymer	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 0.93 ± 0.08 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
PTFE (unfilled) Polymer	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 1.0 ± 0.1 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 24: Sample Preparation and Exposure Details for Chemical Compatibility of Desiccants

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
3A molecular sieve 1	0.50 ± 0.01 grams	Three-Refrigerant Blend	POE	2	100°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
3A molecular sieve 2	0.50 ± 0.01 grams	Three-Refrigerant Blend	POE	2	100°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
3A molecular sieve 3	0.50 ± 0.01 grams	Three-Refrigerant Blend	POE	2	100°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
4A molecular sieve	0.50 ± 0.01 grams	Three-Refrigerant Blend	POE	2	100°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 24 (continued): Sample Preparation and Exposure Details for Chemical Compatibility of Desiccants

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
Activated Alumina	0.50 ± 0.01 grams	Three-Refrigerant Blend	POE	2	100°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 25: Sample Preparation and Exposure Details for Chemical Compatibility of Miscellaneous HVACR Materials

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
Free cutting brass	1 length (2 ½ inches (6.4 cm)) 9.5 ± 0.2 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Cartridge brass	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 5.2 ± 0.4 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Phosphor bronze	3 pieces (each ¾ x 3/16 inch (1.9 x 0.5 cm)) 4.5 ± 0.1 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Manganese phosphate	1 strip (2 ½ x 1/8 inch, or 6.4 x 0.3 cm) 4.87 ± 0.02 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Lead-free polymer bearing	3 pieces (each ¾ x 3/16 inch (1.9 x 0.5 cm)) 3.63 ± 0.08 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 25 (continued): Sample Preparation and Exposure Details for Chemical Compatibility of Miscellaneous HVACR Materials

Material	Sample Configuration	Refrigerant (0.5 grams)	Lubricant (9.5 grams)	Number of Tubes	Exposure Temperature	Exposure Time
Leaded polymer bearing	3 pieces (each ¾ x 3/16 inch (1.9 x 0.5 cm)) 4.39 ± 0.07 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Powder metal alloy	2 pieces, 1 ¾ inches long (4.4 cm) rough cut 7.52 ± 0.35 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Loctite 620	0.10 ± 0.01 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		
Loctite 640	0.10 ± 0.01 grams	Three-Refrigerant Blend	POE	2	150°C	28 days
		Three-Refrigerant Blend	PVE	2		
		R-134a	POE	1		
		R-134a	PVE	1		

Table 26: Chemical Stability Results for Refrigerant Purity, Lubricant Moisture, Lubricant Total Acid Number, and Inorganic Anion Concentrations for Fluids Exposed to Motor Materials

Material	Exposure	Refrigerant Purity by GC-MS (area %)	Lubricant Moisture (ppm)	Total Acid Number, TAN (mg KOH/g of oil)	Inorganic Anions (ppm in Refrigerant)		
					Fluoride	Chloride	Bromide
Mylar® MO21	Blend:POE	99.98%	<10	0.47	<20	<20	<20
	Blend:PVE	99.96%	66	0.06	<20	<20	<20
	R-134a:POE	99.96%	<10	0.45	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.96%	101	0.08	Not Tested[A]	Not Tested[A]	Not Tested[A]
Melinex® 238	Blend:POE	99.98%	60	0.24	<20	<20	<20
	Blend:PVE	99.97%	104	0.06	<20	<20	<20
	R-134a:POE	99.94%	55	0.28	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.94%	98	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Nomex® 410	Blend:POE	99.96%	22	9.02	2850	<20	<20
	Blend:PVE	99.95%	1609	0.25	3680	<20	<20
	R-134a:POE	99.88%	28	8.95	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.94%	1415	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Mica Glass Cloth	Blend:POE	99.97%	63	2.52	610	<20	<20
	Blend:PVE	99.96%	392	1.15	90	<20	<20
	R-134a:POE	99.88%	91	2.55	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.89%	420	1.12	Not Tested[A]	Not Tested[A]	Not Tested[A]
Polyester Tie Cord	Blend:POE	99.96%	84	0.50	<20	<20	<20
	Blend:PVE	99.94%	181	<0.05	240	20	<20
	R-134a:POE	99.92%	109	0.42	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.88%	133	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Pedigree® 923 Solvent-Based Varnish	Blend:POE	99.98%	65	1.62	30	<20	<20
	Blend:PVE	99.96%	404	0.14	40	<20	180
	R-134a:POE	99.90%	22	1.37	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.92%	270	0.11	Not Tested[A]	Not Tested[A]	Not Tested[A]
Guardian™ Water-Borne Varnish	Blend:POE	99.22%	75	1.26	240	70	<20
	Blend:PVE	99.22%	284	0.14	250	70	<20
	R-134a:POE	98.43%	99	1.49	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	98.75%	341	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Film-Insulated Round Magnet Wire	Blend:POE	99.97%	99	0.06	<20	<20	<20
	Blend:PVE	99.90%	157	<0.05	60	<20	<20
	R-134a:POE	99.94%	97	0.06	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.89%	114	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Fibrous Covered Round Magnet Wire	Blend:POE	99.98%	176	0.45	<20	<20	<20
	Blend:PVE	99.94%	137	<0.05	60	<20	<20
	R-134a:POE	99.93%	<10	0.48	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.90%	102	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Polyester Connector Block	Blend:POE	99.95%	74	0.70	40	<20	<20
	Blend:PVE	99.88%	236	0.11	100	<20	<20
	R-134a:POE	99.85%	90	0.70	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.87%	227	0.08	Not Tested[A]	Not Tested[A]	Not Tested[A]

[A]Separate tubes were not prepared for anion analyses with R-134a.

Table 27: Chemical Stability Results for Refrigerant Purity, Lubricant Moisture, Lubricant Total Acid Number, and Inorganic Anion Concentrations for Fluids Exposed to Elastomers

Material	Exposure	Refrigerant Purity by GC-MS (area %)	Lubricant Moisture (ppm)	Total Acid Number, TAN (mg KOH/g of oil)	Inorganic Anions (ppm in Refrigerant)		
					Fluoride	Chloride	Bromide
Neoprene 1	Blend:POE	Not Tested[A]	116	8.67	240	1610	<20
	Blend:PVE	Not Tested[A]	963	0.84	280	1850	<20
	R-134a:POE	Not Tested[A]	80	10.88	Not Tested[B]	Not Tested[B]	Not Tested[B]
	R-134a:PVE	Not Tested[A]	544	0.67	Not Tested[B]	Not Tested[B]	Not Tested[B]
Neoprene 2	Blend:POE	Not Tested[A]	41	4.27	200	1600	<20
	Blend:PVE	Not Tested[A]	126	0.56	190	560	<20
	R-134a:POE	Not Tested[A]	54	4.54	Not Tested[B]	Not Tested[B]	Not Tested[B]
	R-134a:PVE	Not Tested[A]	117	0.31	Not Tested[B]	Not Tested[B]	Not Tested[B]
Nitrile-Based HNBR	Blend:POE	99.95%	97	0.95	<20	<20	<20
	Blend:PVE	99.92%	257	0.14	<20	<20	<20
	R-134a:POE	99.90%	46	0.14	Not Tested[B]	Not Tested[B]	Not Tested[B]
	R-134a:PVE	99.91%	232	0.06	Not Tested[B]	Not Tested[B]	Not Tested[B]
Nitrile-Based NBR	Blend:POE	Not Tested[A]	52	2.13	510	<20	<20
	Blend:PVE	Not Tested[A]	382	1.40	600	<20	<20
	R-134a:POE	Not Tested[A]	41	1.23	Not Tested[B]	Not Tested[B]	Not Tested[B]
	R-134a:PVE	Not Tested[A]	265	0.31	Not Tested[B]	Not Tested[B]	Not Tested[B]
Fluoro-carbon	Blend:POE	99.97%	151	0.25	<20	<20	<20
	Blend:PVE	99.96%	284	<0.05	<20	<20	<20
	R-134a:POE	99.93%	133	0.20	Not Tested[B]	Not Tested[B]	Not Tested[B]
	R-134a:PVE	99.92%	176	<0.05	Not Tested[B]	Not Tested[B]	Not Tested[B]
EDPM	Blend:POE	Not Tested[A]	21	2.02	30	40	<20
	Blend:PVE	Not Tested[A]	648	0.36	20	<20	<20
	R-134a:POE	Not Tested[A]	17	1.60	Not Tested[B]	Not Tested[B]	Not Tested[B]
	R-134a:PVE	Not Tested[A]	631	0.31	Not Tested[B]	Not Tested[B]	Not Tested[B]
Epichloro-hydrin	Blend:POE	Not Tested[A]	64	8.29	1030	40	<20
	Blend:PVE	Not Tested[A]	914	0.39	<20	<20	<20
	R-134a:POE	Not Tested[A]	36	7.49	Not Tested[B]	Not Tested[B]	Not Tested[B]
	R-134a:PVE	Not Tested[A]	581	0.53	Not Tested[B]	Not Tested[B]	Not Tested[B]
Butyl Rubber	Blend:POE	Not Tested[A]	208	2.43	80	1110	<20
	Blend:PVE	Not Tested[A]	605	1.04	780	5000	<20
	R-134a:POE	Not Tested[A]	188	2.69	Not Tested[B]	Not Tested[B]	Not Tested[B]
	R-134a:PVE	Not Tested[A]	644	0.98	Not Tested[B]	Not Tested[B]	Not Tested[B]
Silicone	Blend:POE	99.97%	81	1.21	<20	<20	<20
	Blend:PVE	99.93%	321	<0.05	<20	<20	<20
	R-134a:POE	99.93%	192	0.59	Not Tested[B]	Not Tested[B]	Not Tested[B]
	R-134a:PVE	99.87%	316	<0.05	Not Tested[B]	Not Tested[B]	Not Tested[B]

[A]Several of the samples from the elastomer exposure conditions were not tested by GC-MS due to the sample appearances indicating a potential GC column degradation concern.

[B]Separate tubes were not prepared for anion analyses with R-134a.

Table 28: Chemical Stability Results for Refrigerant Purity, Lubricant Moisture, Lubricant Total Acid Number, and Inorganic Anion Concentrations for Fluids Exposed to Gaskets

Material	Exposure	Refrigerant Purity by GC-MS (area %)	Lubricant Moisture (ppm)	Total Acid Number, TAN (mg KOH/g of oil)	Inorganic Anions (ppm in Refrigerant)		
					Fluoride	Chloride	Bromide
Garlock® 3300	Blend:POE	99.94%	47	2.85	770	510	<20
	Blend:PVE	99.83%	631	0.10	<20	60	<20
	R-134a:POE	99.90%	20	2.55	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.53%	559	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Armstrong N-8092	Blend:POE	99.96%	91	6.28	170	<20	<20
	Blend:PVE	99.96%	1929	0.11	<20	<20	<20
	R-134a:POE	99.92%	56	5.47	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.95%	1270	0.14	Not Tested[A]	Not Tested[A]	Not Tested[A]
Klingersil® C-4401	Blend:POE	99.91%	99	2.45	<20	<20	<20
	Blend:PVE	99.92%	534	0.20	20	<20	<20
	R-134a:POE	99.80%	55	1.92	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.88%	485	0.11	Not Tested[A]	Not Tested[A]	Not Tested[A]

[A]Separate tubes were not prepared for anion analyses with R-134a.

Table 29: Chemical Stability Results for Refrigerant Purity, Lubricant Moisture, Lubricant Total Acid Number, and Inorganic Anion Concentrations for Fluids Exposed to Polymers

Material	Exposure	Refrigerant Purity by GC-MS (area %)	Lubricant Moisture (ppm)	Total Acid Number, TAN (mg KOH/g of oil)	Inorganic Anions (ppm in Refrigerant)		
					Fluoride	Chloride	Bromide
Nylon 6,6 (unfilled)	Blend:POE	99.97%	25	3.23	3210	<20	<20
	Blend:PVE	99.96%	694	0.39	1240	<20	<20
	R-134a:POE	99.94%	20	3.23	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.94%	780	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
PEEK (unfilled)	Blend:POE	99.92%	148	0.53	<20	<20	<20
	Blend:PVE	99.95%	241	<0.05	<20	<20	<20
	R-134a:POE	99.94%	178	0.34	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.91%	290	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
PPS (filled)	Blend:POE	99.96%	184	0.08	<20	<20	<20
	Blend:PVE	99.90%	238	<0.05	<20	<20	<20
	R-134a:POE	99.94%	120	0.08	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.92%	213	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
PAI (unfilled)	Blend:POE	99.98%	70	7.32	<20	<20	<20
	Blend:PVE	99.93%	1328	<0.05	100	<20	<20
	R-134a:POE	99.94%	45	7.54	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.93%	1174	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
PTFE (unfilled)	Blend:POE	99.98%	152	<0.05	<20	<20	<20
	Blend:PVE	99.89%	98	<0.05	<20	<20	<20
	R-134a:POE	99.93%	59	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.88%	56	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]

[A]Separate tubes were not prepared for anion analyses with R-134a.

Table 30: Chemical Stability Results for Refrigerant Purity, Lubricant Moisture, Lubricant Total Acid Number, and Inorganic Anion Concentrations for Fluids Exposed to Desiccants

Material	Exposure	Refrigerant Purity by GC-MS (area %)	Lubricant Moisture (ppm)	Total Acid Number, TAN (mg KOH/g of oil)	Inorganic Anions (ppm in Refrigerant)		
					Fluoride	Chloride	Bromide
3A molecular sieve 1	Blend:POE	99.97%	24	<0.05	<20	<20	<20
	Blend:PVE	99.98%	48	<0.05	<20	<20	<20
	R-134a:POE	99.94%	16	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.93%	22	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
3A molecular sieve 2	Blend:POE	99.97%	40	<0.05	<20	<20	<20
	Blend:PVE	99.98%	95	<0.05	<20	<20	<20
	R-134a:POE	99.92%	10	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.92%	21	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
3A molecular sieve 3	Blend:POE	99.93%	16	0.17	<20	<20	<20
	Blend:PVE	99.95%	25	<0.05	<20	<20	<20
	R-134a:POE	99.98%	<10	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.95%	11	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
4A molecular sieve	Blend:POE	99.97%	17	<0.05	<20	<20	<20
	Blend:PVE	99.97%	20	<0.05	<20	<20	<20
	R-134a:POE	99.90%	<10	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.92%	16	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Activated alumina	Blend:POE	99.96%	28	0.28	<20	<20	<20
	Blend:PVE	99.97%	74	<0.05	<20	<20	<20
	R-134a:POE	99.91%	30	0.22	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.89%	22	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]

[A]Separate tubes were not prepared for anion analyses with R-134a.

Table 31: Chemical Stability Results for Refrigerant Purity, Lubricant Moisture, Lubricant Total Acid Number, and Inorganic Anion Concentrations for Fluids Exposed to Other HVACR Materials

Material	Exposure	Refrigerant Purity by GC-MS (area %)	Lubricant Moisture (ppm)	Total Acid Number, TAN (mg KOH/g of oil)	Inorganic Anions (ppm in Refrigerant)		
					Fluoride	Chloride	Bromide
Free cutting brass	Blend:POE	99.97%	38	0.20	<20	<20	<20
	Blend:PVE	99.94%	44	<0.05	<20	<20	<20
	R-134a:POE	99.92%	<10	0.20	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.93%	63	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Cartridge brass	Blend:POE	99.98%	48	0.14	<20	<20	<20
	Blend:PVE	99.97%	178	<0.05	<20	<20	<20
	R-134a:POE	99.90%	15	0.17	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.93%	133	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Phosphor bronze	Blend:POE	99.93%	64	0.28	<20	<20	<20
	Blend:PVE	99.93%	133	0.06	60	20	<20
	R-134a:POE	99.92%	31	0.39	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.88%	147	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Manganese phosphate	Blend:POE	99.96%	81	0.07	<20	<20	<20
	Blend:PVE	99.91%	152	<0.05	30	<20	<20
	R-134a:POE	99.88%	93	0.14	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.81%	176	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Lead-free polymer bearing	Blend:POE	99.98%	72	0.11	180	<20	<20
	Blend:PVE	99.94%	95	<0.05	100	<20	<20
	R-134a:POE	99.90%	35	0.17	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.89%	86	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Leaded polymer bearing	Blend:POE	99.98%	27	0.73	70	<20	<20
	Blend:PVE	99.98%	108	<0.05	<20	<20	<20
	R-134a:POE	99.94%	40	0.73	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.96%	98	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Powder metal alloy	Blend:POE	99.98%	115	0.11	<20	<20	<20
	Blend:PVE	99.96%	173	<0.05	<20	<20	<20
	R-134a:POE	99.90%	40	0.28	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.93%	135	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Loctite 620	Blend:POE	99.97%	75	0.14	40	<20	<20
	Blend:PVE	99.94%	103	<0.05	80	<20	<20
	R-134a:POE	99.94%	57	0.11	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.91%	97	<0.05	Not Tested[A]	Not Tested[A]	Not Tested[A]
Loctite 640	Blend:POE	99.95%	44	1.12	450	<20	<20
	Blend:PVE	99.96%	362	0.17	1550	100	<20
	R-134a:POE	99.93%	136	0.50	Not Tested[A]	Not Tested[A]	Not Tested[A]
	R-134a:PVE	99.93%	254	0.08	Not Tested[A]	Not Tested[A]	Not Tested[A]

[A]Separate tubes were not prepared for anion analyses with R-134a.

Table 32: Results of Lubricant ICP-OES Analyses for Dissolved Elements

Material	Lubricant Dissolved Element Concentrations			
	Exposure Condition			
	Blend:POE	**Blend:PVE**	**R-134a:POE**	**R-134a:PVE**
Motor Materials				
Mylar® MO21	All <5 ppm*	All <5 ppm*	All <5 ppm*	All <5 ppm*
Melinex® 238	All <5 ppm*	All <5 ppm*	All <5 ppm*	All <5 ppm*
Nomex® 410	**19 ppm Si***	**19 ppm Si***	All <5 ppm	All <5 ppm
Mica Glass Cloth	All <5 ppm*	All <5 ppm*	All <5 ppm*	All <5 ppm*
Polyester Tie Cord	All <5 ppm*	All <5 ppm*	All <5 ppm*	All <5 ppm
Pedigree® 923 Solvent-Based Varnish	**14 ppm P**	**18 ppm P***	**13 ppm P***	**13 ppm P**
Guardian™ Water-Borne Varnish	**11 ppm B** **5 ppm Si**	<5 ppm B* **8 ppm Si***	**13 ppm B** <5 ppm Si	<5 ppm B <5 ppm Si
Film-Insulated Round Magnet Wire	All <5 ppm*	All <5 ppm*	All <5 ppm*	All <5 ppm*
Fibrous Covered Round Magnet Wire	All <5 ppm	All <5 ppm*	All <5 ppm	All <5 ppm*
Polyester Connector Block	All <5 ppm*	All <5 ppm*	All <5 ppm*	All <5 ppm*
Elastomers				
Neoprene 1	**6 ppm B** **5 ppm Ca** **8 ppm K** **875 ppm Mg** **55 ppm Na** **10 ppm Si** **1405 ppm Zn**	<5 ppm B* <5 ppm Ca* <5 ppm K* <5 ppm Mg* <5 ppm Na* <5 ppm Si* **37 ppm Zn***	<5 ppm B <5 ppm Ca **5 ppm K** **567 ppm Mg** **13 ppm Na** **6 ppm Si** **1087 ppm Zn**	<5 ppm B <5 ppm Ca <5 ppm K **36 ppm Mg** <5 ppm Na <5 ppm Si **68 ppm Zn**
Neoprene 2	**41 ppm Ca** **892 ppm Mg** **33 ppm Na** **265 ppm P** **9 ppm Si** **1160 ppm Zn**	<5 ppm Ca* <5 ppm Mg* <5 ppm Na* **37 ppm P*** **10 ppm Si*** **38 ppm Zn***	**36 ppm Ca** **803 ppm Mg** **15 ppm Na** **257 ppm P** **12 ppm Si** **1099 ppm Zn**	<5 ppm Ca <5 ppm Mg <5 ppm Na **28 ppm P** <5 ppm Si **21 ppm Zn**
Nitrile-Based HNBR	<5 ppm Mg **95 ppm Zn**	<5 ppm Mg <5 ppm Zn	**11 ppm Mg** <5 ppm Zn	<5 ppm Mg <5 ppm Zn
Nitrile-Based NBR	<5 ppm Mg* **293 ppm Si***	<5 ppm Mg* **23 ppm Si***	<5 ppm Mg* **1185 ppm Si*** **14 ppm Zn***	**11 ppm Mg** **11 ppm Si** **13 ppm Zn**
Fluorocarbon	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
EDPM	**5 ppm Al** **406 ppm Si** **72 ppm Zn**	<5 ppm Al **495 ppm Si** **13 ppm Zn**	**5 ppm Al** **427 pm Si** **40 ppm Zn**	<5 ppm Al **484 ppm Si** <5 ppm Zn
Epichlorohydrin	<5 ppm Ca **423 ppm Mg** <5 ppm P **5 ppm Si** **19 ppm Zn**	<5 ppm Ca <5 ppm Mg <5 ppm P <5 ppm Si <5 ppm Zn	**8 ppm Ca*** **141 ppm Mg*** **7 ppm P*** <5 ppm Si* **8 ppm Zn***	<5 ppm Ca <5 ppm Mg <5 ppm P <5 ppm Si <5 ppm Zn
Butyl Rubber	<5 ppm Na **32 ppm Si** **2207 ppm Zn**	<5 ppm Na* **17 ppm Si*** **217 ppm Zn***	**5 ppm Na** **15 ppm Si** **2540 ppm Zn**	<5 ppm Na* **15 ppm Si*** **233 ppm Zn***
Silicone	**720 ppm Si**	**537 ppm Si**	**685 ppm Si**	**567 ppm Si**

'*' indicates the samples had low internal standard recovery and were difficult to filter.

Table 32 (continued): Results of Lubricant ICP-OES Analyses for Dissolved Elements

Material	Lubricant Dissolved Element Concentrations			
	Exposure Condition			
	Blend:POE	Blend:PVE	R-134a:POE	R-134a:PVE
Gaskets				
Garlock® 3300	<5 ppm Al **69 ppm Mg** **189 ppm Zn**	<5 ppm Al <5 ppm Mg <5 ppm Zn	**7 ppm Al** **54 ppm Mg** **166 ppm Zn**	<5 ppm Al <5 ppm Mg <5 ppm Zn
Armstrong N-8092	**168 ppm Al**	<5 ppm Al*	**93 ppm Al**	<5 ppm Al*
Klingersil® C-4401	<5 ppm Mg <5 ppm Zn	<5 ppm Mg <5 ppm Zn	**19 ppm Mg** **55 ppm Zn**	<5 ppm Mg <5 ppm Zn
Polymers				
Nylon 6,6 (unfilled)	<5 ppm Si*	**21 ppm Si***	<5 ppm Si	<5 ppm Si
PEEK (unfilled)	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
PPS (filled)	All <5 ppm	All <5 ppm*	All <5 ppm	All <5 ppm
PAI (unfilled)	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
PTFE (unfilled)	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
Desiccants				
3A Molecular Sieve 1	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
3A Molecular Sieve 2	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
3A Molecular Sieve 3	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
4A Molecular Sieve	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
Activated Alumina	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
Other HVACR Materials				
Free cutting brass	**5 ppm Cu** **21 ppm Pb** **28 ppm Zn**	<5 ppm Cu <5 ppm Pb <5 ppm Zn	**5 ppm Cu** **22 ppm Pb** **24 ppm Zn**	<5 ppm Cu <5 ppm Pb <5 ppm Zn
Cartridge brass	<5 ppm Cu **7 ppm Zn**	<5 ppm Cu <5 ppm Zn	**8 ppm Cu** **29 ppm Zn**	<5 ppm Cu <5 ppm Zn
Phosphor bronze	**5 ppm Cu**	<5 ppm Cu	**13 ppm Cu**	<5 ppm Cu
Manganese phosphate	All <5 ppm	All <5 ppm*	All <5 ppm	All <5 ppm
Lead-free polymer bearing	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
Leaded polymer bearing	**88 ppm Fe** **99 ppm Pb** **19 ppm Sn**	<5 ppm Fe <5 ppm Pb <5 ppm Sn	**144 ppm Fe** **186 ppm Pb** **43 ppm Sn**	<5 ppm Fe <5 ppm Pb <5 ppm Sn
Powder metal alloy	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
Loctite 620	All <5 ppm	All <5 ppm	All <5 ppm	All <5 ppm
Loctite 640	All <5 ppm	All <5 ppm*	All <5 ppm	All <5 ppm*

'*' indicates the samples had low internal standard recovery and were difficult to filter.

Table 33: Organic Acid Concentrations in POE Lubricants Exposed to Motor Materials

Material	Exposure	Measured TAN (mg KOH/g oil)	Lubricant Organic Acid Concentrations (ppm)			
			Valeric	Heptanoic	Branched Nonanoic	Nonanoic
Mylar® MO21	Blend:POE	**0.47**	**300**	**340**	**<500** (~160[A])	**<300** (ND)
	R-134a:POE	**0.45**	**310**	**340**	**<500** (~170[A])	**<300** (ND)
Melinex® 238	Blend:POE	**0.24**	**<300** (~190[A])	**<300** (~210[A])	**<500** (~110[A])	**<300** (ND)
	R-134a:POE	**0.28**	**<300** (~210[A])	**<300** (~240[A])	**<500** (~120[A])	**<300** (ND)
Nomex® 410	Blend:POE	**9.02**	**7060**	**8870**	**3350**	**<300** (~80[A])
	R-134a:POE	**8.95**	**7110**	**8730**	**3190**	**<300** (~80[A])
Mica Glass Cloth	Blend:POE	**2.52**	**1780**	**2120**	**560**	**<300** (ND)
	R-134a:POE	**2.55**	**1740**	**2100**	**540**	**<300** (ND)
Polyester Tie Cord	Blend:POE	**0.50**	**360**	**460**	**<500** (~150[A])	**<300** (ND)
	R-134a:POE	**0.42**	**330**	**440**	**<500** (~160[A])	**<300** (ND)
Pedigree® 923 Solvent-Based Varnish	Blend:POE	**1.62**	**1330**	**1600**	**610**	**<300** (ND)
	R-134a:POE	**1.37**	**1120**	**1340**	**510**	**<300** (ND)
Guardian™ Water-Borne Varnish	Blend:POE	**1.26**	**1020**	**1220**	**<500** (~330[A])	**<300** (ND)
	R-134a:POE	**1.49**	**1220**	**1450**	**<500** (~410[A])	**<300** (ND)
Film-Insulated Magnet Wire	Blend:POE	**0.06**	**<300** (~150[A])	**<300** (~60[A])	**<500** (ND)	**<300** (ND)
	R-134a:POE	**0.06**	**<300** (~140[A])	**<300** (ND)	**<500** (ND)	**<300** (ND)
Fibrous Covered Magnet Wire	Blend:POE	**0.45**	**430**	**430**	**<500** (~130[A])	**<300** (ND)
	R-134a:POE	**0.48**	**430**	**420**	**<500** (~120[A])	**<300** (ND)
Polyester Connector Block	Blend:POE	**0.70**	**630**	**660**	**<500** (~170[A])	**<300** (ND)
	R-134a:POE	**0.70**	**610**	**660**	**<500** (~170[A])	**<300** (ND)

[A]Organic acids were detected at concentrations lower than the verified quantitation limit. Results are reported for informational purposes.

'ND' indicates Not Detected.

Table 34: Organic Acid Concentrations in POE Lubricants Exposed to Elastomers

Material	Exposure	Measured TAN (mg KOH/g oil)	Lubricant Organic Acid Concentrations (ppm)			
			Valeric	Heptanoic	Branched Nonanoic	Nonanoic
Neoprene 1	Blend:POE	**8.67**	Not Tested[B]			
	R-134a:POE	**10.88**	Not Tested[B]			
Neoprene 2	Blend:POE	**4.27**	Not Tested[B]			
	R-134a:POE	**4.54**	Not Tested[B]			
Nitrile-Based HNBR	Blend:POE	**0.95**	**570**	**740**	**<500** (~230[A])	**<300** (ND)
	R-134a:POE	**0.14**	**<300** (~150[A])	**<300** (~200[A])	**<500** (~90[A])	**<300** (ND)
Nitrile-Based NBR	Blend:POE	**2.13**	Not Tested[B]			
	R-134a:POE	**1.23**	Not Tested[B]			
Fluorocarbon	Blend:POE	**0.25**	**<300** (~140[A])	**<300** (~200[A])	**<500** (~100[A])	**<300** (ND)
	R-134a:POE	**0.20**	**<300** (~160[A])	**<300** (~220[A])	**<500** (~110[A])	**<300** (ND)
EDPM	Blend:POE	**2.02**	Not Tested[B]			
	R-134a:POE	**1.60**	Not Tested[B]			
Epichlorohydrin	Blend:POE	**8.29**	Not Tested[B]			
	R-134a:POE	**7.49**	Not Tested[B]			
Butyl Rubber	Blend:POE	**2.43**	Not Tested[B]			
	R-134a:POE	**2.69**	Not Tested[B]			
Silicone	Blend:POE	**1.21**	**810**	**1160**	**<500** (~380)	**<300** (ND)
	R-134a:POE	**0.59**	**380**	**540**	**<500** (~210[A])	**<300** (ND)

[A]Organic acids were detected at concentrations lower than the verified quantitation limit. Results are reported for informational purposes.

[B]Several of the lubricants from the elastomer exposure conditions were not tested due to very high TAN values and/or sample appearances indicating a potential GC column degradation concern.

'ND' indicates Not Detected.

Table 35: Organic Acid Concentrations in POE Lubricants Exposed to Gaskets

Material	Exposure	Measured TAN (mg KOH/g oil)	Lubricant Organic Acid Concentrations (ppm)			
			Valeric	Heptanoic	Branched Nonanoic	Nonanoic
Garlock® 3300	Blend:POE	**2.85**	**2190**	**2700**	**950**	**<300** (ND)
	R-134a:POE	**2.55**	**1760**	**2200**	**650**	**<300** (ND)
Armstrong N-8092	Blend:POE	**6.28**	**4930**	**6510**	**2170**	**<300** (ND)
	R-134a:POE	**5.47**	**4170**	**5520**	**1820**	**<300** (ND)
Klingersil® C-4401	Blend:POE	**2.45**	**1950**	**2530**	**790**	**<300** (ND)
	R-134a:POE	**1.92**	**1450**	**2050**	**580**	**<300** (ND)

'ND' indicates Not Detected.

APPENDIX I – SUPPLEMENTAL CHEMICAL COMPATIBILITY INFORMATION

Table 36: Organic Acid Concentrations in POE Lubricants Exposed to Polymers

Material	Exposure	Measured TAN (mg KOH/g oil)	Lubricant Organic Acid Concentrations (ppm)			
			Valeric	Heptanoic	Branched Nonanoic	Nonanoic
Nylon 6,6 (unfilled)	Blend:POE	**3.23**	**2520**	**3120**	**830**	**<300** (ND)
	R-134a:POE	**3.23**	**2640**	**3350**	**900**	**<300** (ND)
PEEK (unfilled)	Blend:POE	**0.53**	**460**	**510**	**<500** (~150[A])	**<300** (ND)
	R-134a:POE	**0.34**	**320**	**320**	**<500** (~90[A])	**<300** (ND)
PPS (filled)	Blend:POE	**0.08**	**<300** (~90[A])	**<300** (~70[A])	**<500** (ND)	**<300** (ND)
	R-134a:POE	**0.08**	**<300** (~120[A])	**<300** (~80[A])	**<500** (ND)	**<300** (ND)
PAI (unfilled)	Blend:POE	**7.32**	**6200**	**7670**	**2520**	**<300** (ND)
	R-134a:POE	**7.54**	**6350**	**7830**	**2590**	**<300** (ND)
PTFE (unfilled)	Blend:POE	**<0.05**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)
	R-134a:POE	**<0.05**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)

Table 37: Organic Acid Concentrations in POE Lubricants Exposed to Desiccants

Material	Exposure	Measured TAN (mg KOH/g oil)	Lubricant Organic Acid Concentrations (ppm)			
			Valeric	Heptanoic	Branched Nonanoic	Nonanoic
3A molecular sieve 1	Blend:POE	**<0.05**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)
	R-134a:POE	**<0.05**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)
3A molecular sieve 2	Blend:POE	**<0.05**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)
	R-134a:POE	**<0.05**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)
3A molecular sieve 3	Blend:POE	**0.17**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)
	R-134a:POE	**<0.05**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)
4A molecular sieve	Blend:POE	**<0.05**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)
	R-134a:POE	**<0.05**	**<300** (ND)	**<300** (ND)	**<500** (ND)	**<300** (ND)
Activated alumina	Blend:POE	**0.28**	**<300** (~210[A])	**<300** (~280[A])	**<500** (~90[A])	**<300** (ND)
	R-134a:POE	**0.22**	**<300** (~180[A])	**<300** (~250[A])	**<500** (~90[A])	**<300** (ND)

[A]Organic acids were detected at concentrations lower than the verified quantitation limit. Results are reported for informational purposes.

'ND' indicates Not Detected.

Table 38: Organic Acid Concentrations in POE Lubricants Exposed to Other HVACR Materials

Material	Exposure	Measured TAN (mg KOH/g oil)	Lubricant Organic Acid Concentrations (ppm)			
			Valeric	Heptanoic	Branched Nonanoic	Nonanoic
Free cutting brass	Blend:POE	**0.20**	**<300** (~190[A])	**<300** (~200[A])	**<500** (ND)	**<300** (ND)
	R-134a:POE	**0.20**	**<300** (~170[A])	**<300** ~200[A])	**<500** (ND)	**<300** (ND)
Cartridge brass	Blend:POE	**0.14**	**<300** (~110[A])	**<300** (~140[A])	**<500** (~80[A])	**<300** (ND)
	R-134a:POE	**0.17**	**<300** (~110[A])	**<300** (~160[A])	**<500** (~80[A])	**<300** (ND)
Phosphor bronze	Blend:POE	**0.28**	**<300** (~210[A])	**<300** (~230[A])	**<500** (~120[A])	**<300** (ND)
	R-134a:POE	**0.39**	**320**	**340**	**<500** (~170[A])	**<300** (ND)
Manganese phosphate	Blend:POE	**0.07**	**<300** (~70[A])	**<300** (~130[A])	**<500** (ND)	**<300** (ND)
	R-134a:POE	**0.14**	**<300** (~110[A])	**<300** (~190[A])	**<500** (~60[A])	**<300** (ND)
Lead-free polymer bearing	Blend:POE	**0.11**	**<300** (~120[A])	**<300** (~90[A])	**<500** (ND)	**<300** (ND)
	R-134a:POE	**0.17**	**<300** (~120[A])	**<300** (~150[A])	**<500** (ND)	**<300** (ND)
Leaded polymer bearing	Blend:POE	**0.73**	**550**	**640**	**<500** (~330[A])	**<300** (ND)
	R-134a:POE	**0.73**	**560**	**640**	**<500** (~330[A])	**<300** (ND)
Powder metal alloy	Blend:POE	**0.11**	**<300** (~110[A])	**<300** (~100[A])	**<500** (~50[A])	**<300** (ND)
	R-134a:POE	**0.28**	**<300** (~130[A])	**<300** (~220[A])	**<500** (~80[A])	**<300** (ND)
Loctite 620	Blend:POE	**0.14**	**<300** (~90[A])	**<300** (~140[A])	**<500** (~70[A])	**<300** (ND)
	R-134a:POE	**0.11**	**<300** (~80[A])	**<300** (~140[A])	**<500** (~80[A])	**<300** (ND)
Loctite 640	Blend:POE	**1.12**	**800**	**970**	**<500** (~300[A])	**<300** (ND)
	R-134a:POE	**0.50**	**350**	**440**	**<500** (~160[A])	**<300** (ND)

[A]Organic acids were detected at concentrations lower than the verified quantitation limit. Results are reported for informational purposes.

'ND' indicates Not Detected.

Table 39: Appearance Change Rankings for the Sealed Glass Tubes Prepared with POE Lubricant

Exposure	Three-Refrigerant Blend:POE			R-134a:POE		
Material	**Material**	**Cloudiness**	**Liquid Phase Color**	**Material**	**Cloudiness**	**Liquid Phase Color**
Mylar® MO21	0	0-1	0	0	0-1	0
Melinex® 238	0	0-1	0	0	0-1	0
Nomex® 410	0-1	0	0	0	0	0
Mica Glass Cloth	0	0	0-1	0	0	0-1
Polyester Tie Cord	0	0	0-1	0	0	0-1
Pedigree® 923 Solvent-Based Varnish	1	0	0	1	0	0
Guardian™ Water-Borne Varnish	0-1	0-1	0-1	0	1	0
Film-Insulated Round Magnet Wire	0	0	0	0	0	0
Fibrous Covered Round Magnet Wire	0	0-1	0	0	0-1	0
Polyester Connector Block	0-1	1	0	0-1	0-1	0
Neoprene 1	0	3	2-3	1	3	2
Neoprene 2	0	1-2	1	0	2	1
Nitrile-Based HNBR	0	0-1	0	0	0-1	0
Nitrile-Based NBR	0	2-3	2-3	1	3	1
Fluorocarbon	0	0	0	0	0	0
EDPM	0-1	2	0	0-1	2	0
Epichlorohydrin	0	2-3	2-3	0	2	1-2
Butyl Rubber	0-1	1	2	0-1	0-1	2
Silicone	0	0	0	0	0	0
Garlock® 3300	0	0-1	0	0	0-1	0-1
Armstrong N-8092	0	0	0	0	0	0
Klingersil® C-4401	0	0	0-1	0	0	0-1

Material Change	Liquid Phase Cloudiness	Liquid Phase Color Change
0 = No Change	0 = No Change	0 = No Change
1 = Minor Change	1 = Slight Cloudiness	1 = Slight Darkening or Color Change
2 = Moderate Change	2 = Moderate Cloudiness	2 = Moderate Darkening or Color Change
3 = Severe Change	3 = Very Cloudy (cannot see through)	3 = Very Dark (cannot see through) or Very Significant Color Change

Table 39 (continued): Appearance Change Rankings for the Sealed Glass Tubes Prepared with POE Lubricant

Exposure	Three-Refrigerant Blend:POE			R-134a:POE		
Material	**Material**	**Cloudiness**	**Liquid Phase Color**	**Material**	**Cloudiness**	**Liquid Phase Color**
Nylon 6,6 (unfilled)	0	0	0	0	0	0
PEEK (unfilled)	0-1	0	0	0-1	0	0
PPS (filled)	0	0	0	0	0	0
PAI (unfilled)	0	0	0	0	0	0
PTFE (unfilled)	0	0	0	0	0	0
3A Molecular Sieve 1	0	0	0	0	0	0
3A Molecular Sieve 2	0-1	0	0	0-1	0	0
3A Molecular Sieve 3	0	0	0	0	0	0
4A Molecular Sieve	0	0	0	0	0	0
Activated Alumina	0	0	0	0	0	0
Free Cutting Brass	0-1	0	0	0-1	0	0
Cartridge Brass	0	0	0	0	0	0
Phosphor Bronze	0	0	0-1	0	0	0-1
Manganese Phosphate	0	0	0	0	0-1	0
Lead-Free Polymer Bearing	0	0	0	0	0	0
Leaded Polymer Bearing	1	1	1	1	1-2	1
Powder Metal Alloy	0	0	0	0	0	0
Loctite 620	1	0	0-1	1	0	0-1
Loctite 640	0	0	1	0	0	1

Material Change	**Liquid Phase Cloudiness**	**Liquid Phase Color Change**
0 = No Change	0 = No Change	0 = No Change
1 = Minor Change	1 = Slight Cloudiness	1 = Slight Darkening or Color Change
2 = Moderate Change	2 = Moderate Cloudiness	2 = Moderate Darkening or Color Change
3 = Severe Change	3 = Very Cloudy (cannot see through)	3 = Very Dark (cannot see through) or Very Significant Color Change

Table 40: Appearance Change Rankings for the Sealed Glass Tubes Prepared with PVE Lubricant

Exposure	Three-Refrigerant Blend:PVE			R-134a:PVE		
Material	**Material**	**Cloudiness**	**Liquid Phase Color**	**Material**	**Cloudiness**	**Liquid Phase Color**
Mylar® MO21	0	1	0	0	1	0
Melinex® 238	0	0-1	0	0	0-1	0
Nomex® 410	1	0	0	0	0	0
Mica Glass Cloth	0	0	0-1	0	0	0-1
Polyester Tie Cord	0	0	0	0	0	0
Pedigree® 923 Solvent-Based Varnish	1	0	0	1	0	0
Guardian™ Water-Borne Varnish	0	0	0-1	0	0-1	0
Film-Insulated Round Magnet Wire	0	0	0	0	0	0
Fibrous Covered Round Magnet Wire	0	0-1	0	0	0	0
Polyester Connector Block	0	0-1	0	0	0-1	0
Neoprene 1	1	2-3	0-1	0	2	0-1
Neoprene 2	0	2	0-1	0	2	0-1
Nitrile-Based HNBR	0	0	0	0	0	0
Nitrile-Based NBR	0-1	2	1-2	0-1	1	1
Fluorocarbon	0	0	0	0	0	0
EDPM	0-1	2	0	0-1	2	0
Epichlorohydrin	0	0-1	0-1	0	0-1	0-1
Butyl Rubber	0-1	0	1	0	0	1
Silicone	0	0	0	0	0	0
Garlock® 3300	0	0	0	0	0	0
Armstrong N-8092	0	0	0	0	0	0
Klingersil® C-4401	0	0	0	0	0	0

Material Change	Liquid Phase Cloudiness	Liquid Phase Color Change
0 = No Change	0 = No Change	0 = No Change
1 = Minor Change	1 = Slight Cloudiness	1 = Slight Darkening or Color Change
2 = Moderate Change	2 = Moderate Cloudiness	2 = Moderate Darkening or Color Change
3 = Severe Change	3 = Very Cloudy (cannot see through)	3 = Very Dark (cannot see through) or Very Significant Color Change

Table 40 (continued): Appearance Change Rankings for the Sealed Glass Tubes Prepared with PVE Lubricant

Exposure	**Three-Refrigerant Blend:PVE**			**R-134a:PVE**		
Material	**Material**	**Cloudiness**	**Liquid Phase Color**	**Material**	**Cloudiness**	**Liquid Phase Color**
Nylon 6,6 (unfilled)	0	1	0	0	1	0
PEEK (unfilled)	0	0	0	0	0	0
PPS (filled)	0	0	0	0	0	0
PAI (unfilled)	0	0	0	0	0	0
PTFE (unfilled)	0	0	0	0	0	0
3A Molecular Sieve 1	0	0	0	0	0	0
3A Molecular Sieve 2	0-1	0	0	0	0	0
3A Molecular Sieve 3	0-1	0	1	0	0	0
4A Molecular Sieve	0	0	0	0	0	0
Activated Alumina	2	0	1-2	2	0	1-2
Free Cutting Brass	0-1	0	0	0-1	0	0
Cartridge Brass	0	0	0	0	0	0
Phosphor Bronze	0	0	0-1	0	0	0-1
Manganese Phosphate	0	0	0	0	0-1	0
Lead-Free Polymer Bearing	0	0	0	0	0	0
Leaded Polymer Bearing	0	0	0	0	0	0
Powder Metal Alloy	0	0	0	0	0	0
Loctite 620	1	0-1	0	1	1	0
Loctite 640	0-1	0	0	0	0-1	0

Material Change	**Liquid Phase Cloudiness**	**Liquid Phase Color Change**
0 = No Change	0 = No Change	0 = No Change
1 = Minor Change	1 = Slight Cloudiness	1 = Slight Darkening or Color Change
2 = Moderate Change	2 = Moderate Cloudiness	2 = Moderate Darkening or Color Change
3 = Severe Change	3 = Very Cloudy (cannot see through)	3 = Very Dark (cannot see through) or Very Significant Color Change

Table 41: Sealed Glass Tube Image Summary

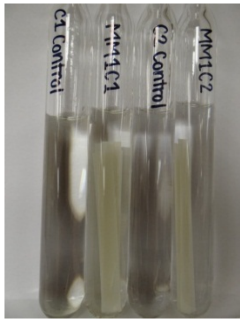
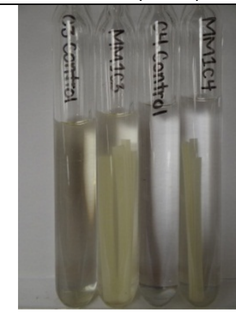
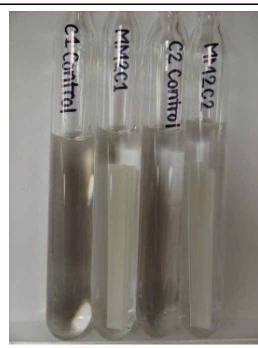
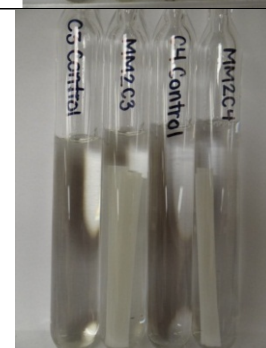
Sample Details	Blend:POE and Blend:PVE Pre-Exposure	Blend:POE and Blend:PVE Post-Exposure	R-134a:POE and R-134a:PVE Pre-Exposure	R-134a:POE and R-134a:PVE Post-Exposure
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
Mylar® MO21				
Melinex® 238				
Nomex® 410				

Table 41 (continued): Sealed Glass Tube Image Summary

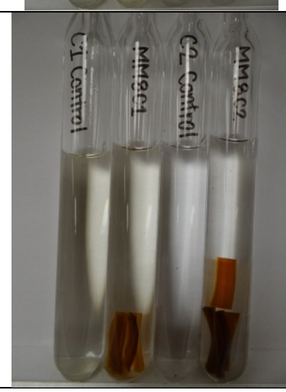
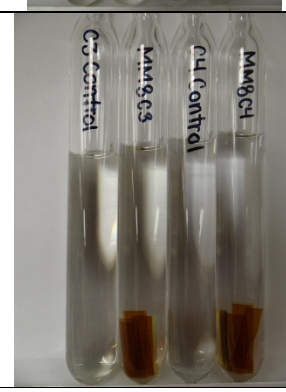
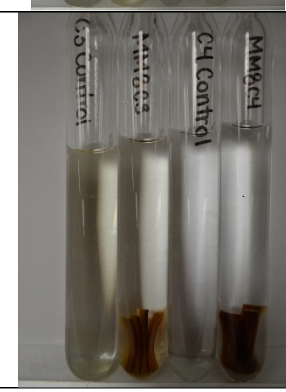
Sample Details	Blend:POE and Blend:PVE Pre-Exposure	Blend:POE and Blend:PVE Post-Exposure	R-134a:POE and R-134a:PVE Pre-Exposure	R-134a:POE and R-134a:PVE Post-Exposure
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
Mica Glass Cloth				
Polyester Tie Cord				
Pedigree® 923 Solvent-Based Varnish				

Table 41 (continued): Sealed Glass Tube Image Summary

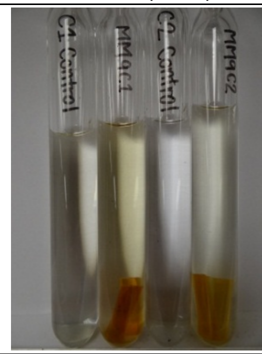
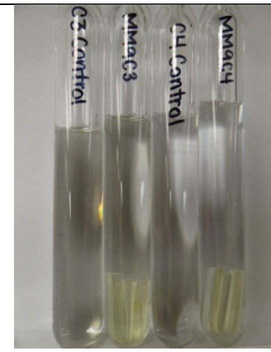
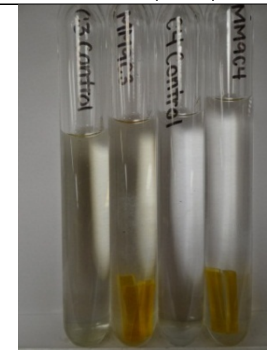
Sample Details	**Blend:POE and Blend:PVE Pre-Exposure**	**Blend:POE and Blend:PVE Post-Exposure**	**R-134a:POE and R-134a:PVE Pre-Exposure**	**R-134a:POE and R-134a:PVE Post-Exposure**
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
Guardian™ Water-Borne Varnish				
Film-Insulated Round Magnet Wire				
Fibrous Covered Round Magnet Wire				

Table 41 (continued): Sealed Glass Tube Image Summary

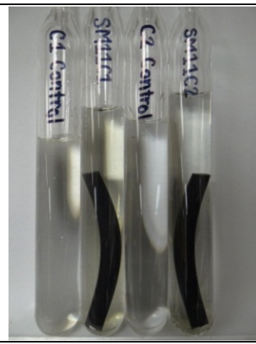
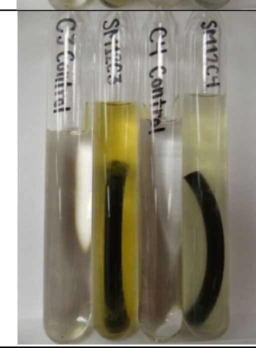
Sample Details	Blend:POE and Blend:PVE Pre-Exposure	Blend:POE and Blend:PVE Post-Exposure	R-134a:POE and R-134a:PVE Pre-Exposure	R-134a:POE and R-134a:PVE Post-Exposure
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
Polyester Connector Block				
Neoprene 1 Elastomer				
Neoprene 2 Elastomer				

Table 41 (continued): Sealed Glass Tube Image Summary

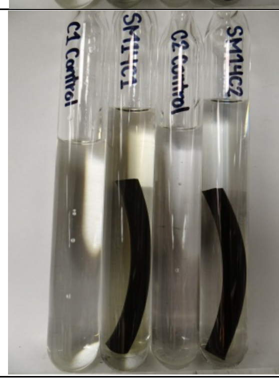
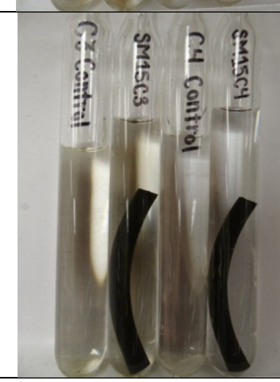
Sample Details	Blend:POE and Blend:PVE Pre-Exposure	Blend:POE and Blend:PVE Post-Exposure	R-134a:POE and R-134a:PVE Pre-Exposure	R-134a:POE and R-134a:PVE Post-Exposure
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
Nitrile-Based HNBR Elastomer				
Nitrile-Based NBR Elastomer				
Fluorocarbon Elastomer				

Table 41 (continued): Sealed Glass Tube Image Summary

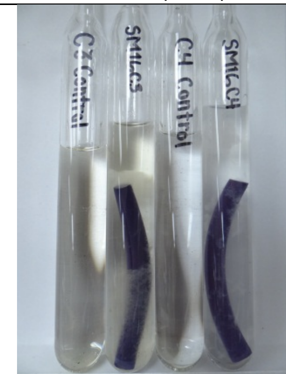
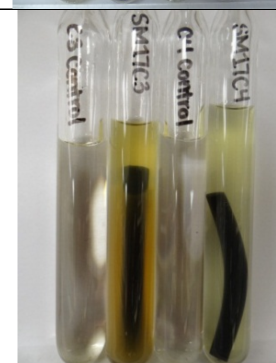
Sample Details	Blend:POE and Blend:PVE Pre-Exposure	Blend:POE and Blend:PVE Post-Exposure	R-134a:POE and R-134a:PVE Pre-Exposure	R-134a:POE and R-134a:PVE Post-Exposure
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
EDPM Elastomer				
Epichlorohydrin Elastomer				
Butyl Rubber Elastomer				

Table 41 (continued): Sealed Glass Tube Image Summary

Sample Details	Blend:POE and Blend:PVE Pre-Exposure	Blend:POE and Blend:PVE Post-Exposure	R-134a:POE and R-134a:PVE Pre-Exposure	R-134a:POE and R-134a:PVE Post-Exposure
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
Silicone Elastomer				
Garlock® 3300 Gasket				
Armstrong N-8092 Gasket				

Table 41 (continued): Sealed Glass Tube Image Summary

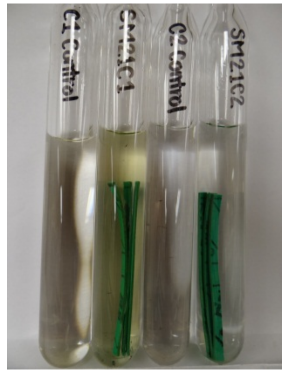
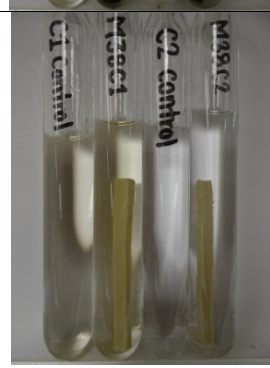
Sample Details	Blend:POE and Blend:PVE Pre-Exposure	Blend:POE and Blend:PVE Post-Exposure	R-134a:POE and R-134a:PVE Pre-Exposure	R-134a:POE and R-134a:PVE Post-Exposure
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
Klingersil® C-4401 Gasket				
Nylon 6,6 (Unfilled) Polymer				
PEEK (Unfilled) Polymer				

Table 41 (continued): Sealed Glass Tube Image Summary

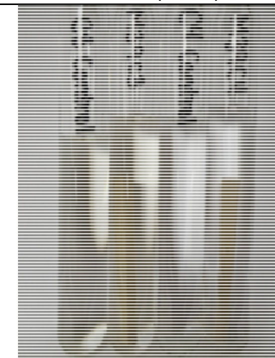
Sample Details	**Blend:POE and Blend:PVE Pre-Exposure**	**Blend:POE and Blend:PVE Post-Exposure**	**R-134a:POE and R-134a:PVE Pre-Exposure**	**R-134a:POE and R-134a:PVE Post-Exposure**
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
PPS (Filled) Polymer				
PAI (Unfilled) Polymer				
PTFE (Unfilled) Polymer				

Table 41 (continued): Sealed Glass Tube Image Summary

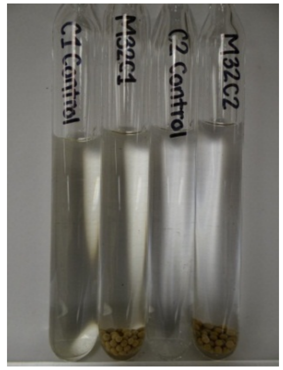
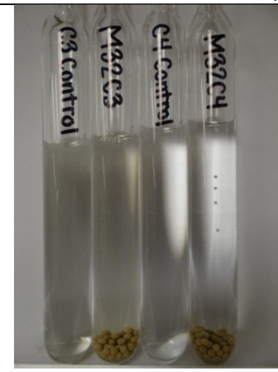
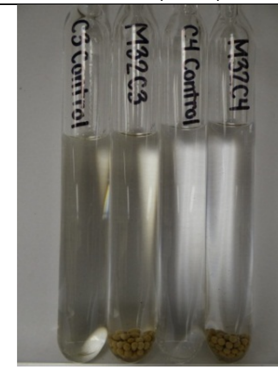
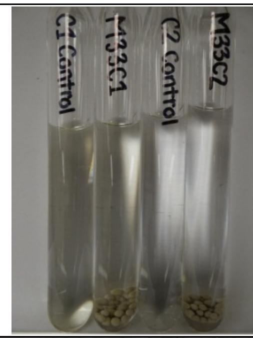
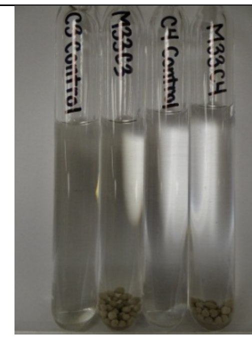
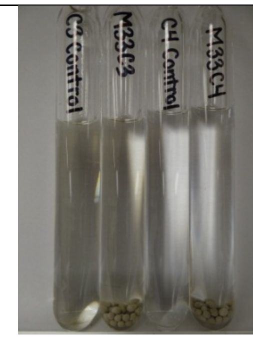
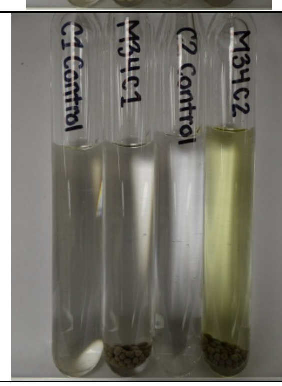
Sample Details	**Blend:POE and Blend:PVE Pre-Exposure**	**Blend:POE and Blend:PVE Post-Exposure**	**R-134a:POE and R-134a:PVE Pre-Exposure**	**R-134a:POE and R-134a:PVE Post-Exposure**
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
3A Molecular Sieve 1				
3A Molecular Sieve 2				
3A Molecular Sieve 3				

Table 41 (continued): Sealed Glass Tube Image Summary

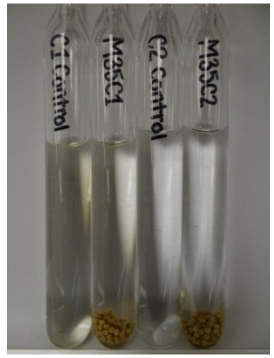
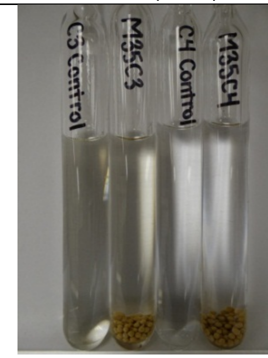
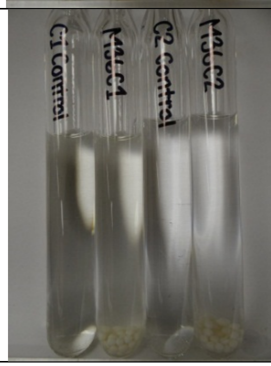
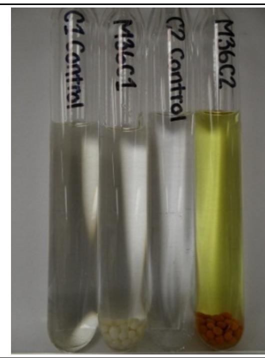
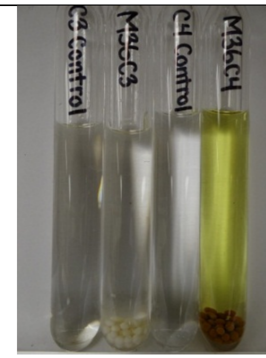
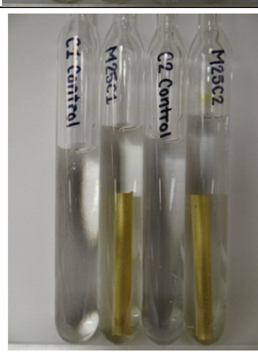
Sample Details	Blend:POE and Blend:PVE Pre-Exposure	Blend:POE and Blend:PVE Post-Exposure	R-134a:POE and R-134a:PVE Pre-Exposure	R-134a:POE and R-134a:PVE Post-Exposure
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
4A Molecular Sieve				
Activated Alumina				
Free Cutting Brass				

Table 41 (continued): Sealed Glass Tube Image Summary

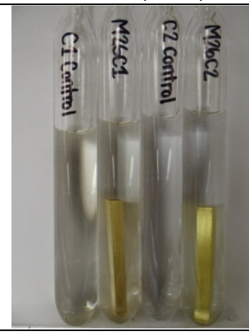
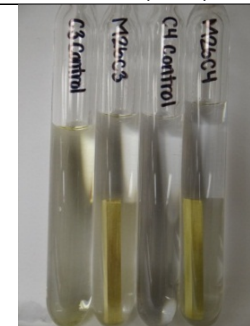
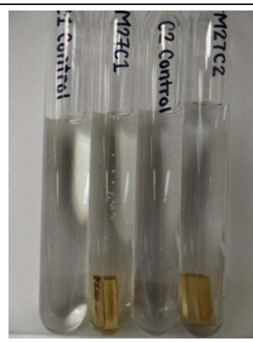
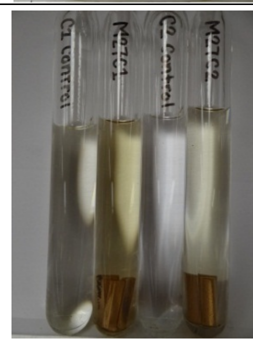
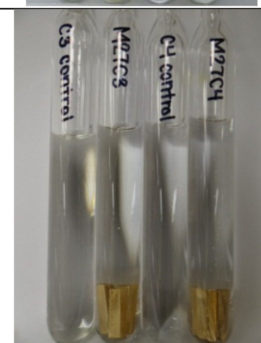
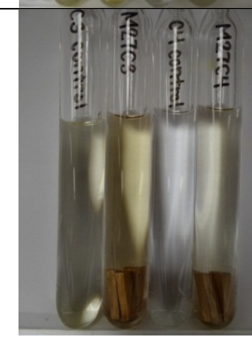
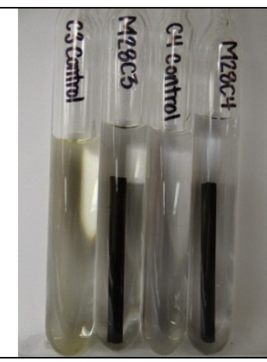
<table>
<tr><th rowspan="2">Sample Details</th><th>Blend:POE and Blend:PVE
Pre-Exposure</th><th>Blend:POE and Blend:PVE
Post-Exposure</th><th>R-134a:POE and R-134a:PVE
Pre-Exposure</th><th>R-134a:POE and R-134a:PVE
Post-Exposure</th></tr>
<tr><td colspan="2">C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)</td><td colspan="2">C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)</td></tr>
<tr><td>Cartridge Brass</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Phosphor Bronze</td><td></td><td></td><td>
</td><td></td></tr>
<tr><td>Manganese Phosphate</td><td></td><td>
</td><td></td><td>
</td></tr>
</table>

Table 41 (continued): Sealed Glass Tube Image Summary

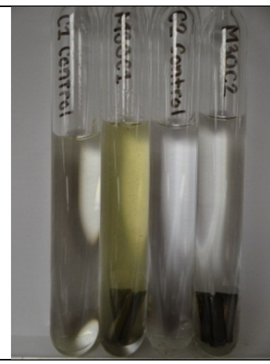
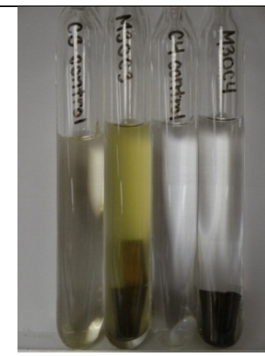
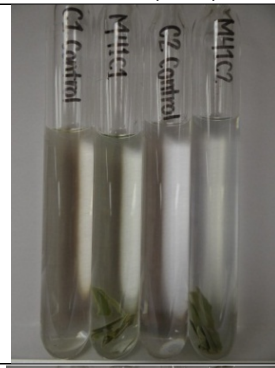
Sample Details	**Blend:POE and Blend:PVE Pre-Exposure**	**Blend:POE and Blend:PVE Post-Exposure**	**R-134a:POE and R-134a:PVE Pre-Exposure**	**R-134a:POE and R-134a:PVE Post-Exposure**
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
Lead-Free Polymer Bearing				
Leaded Polymer Bearing				
Powder Metal Alloy				

Table 41 (continued): Sealed Glass Tube Image Summary

Sample Details	**Blend:POE and Blend:PVE Pre-Exposure**	**Blend:POE and Blend:PVE Post-Exposure**	**R-134a:POE and R-134a:PVE Pre-Exposure**	**R-134a:POE and R-134a:PVE Post-Exposure**
	C1 = Blend/POE (5/95), C2 = Blend/PVE (5/95)		C3 = R-134a/POE (5/95), C4 = R-134a/PVE (5/95)	
Loctite 620				
Loctite 640				

APPENDIX II – SUPPLEMENTAL SEAL AND POLYMER MATERIAL COMPATIBILITY INFORMATION

Table 42: Elastomer Volume and Weight Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures								
Material	Average Volume and Weight Change (%), n=3							
	R-1234yf		R-1234ze(E)		Three-Refrigerant Blend		Nitrogen	
	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
Neoprene 1	6.9	4.7	4.8	3.5	8.4	5.0	0.3	-0.1
Neoprene 2	-1.3	-0.3	-4.0	-1.8	0.5	0.6	0.0	0.0
Nitrile-Based HNBR	11.0	10.5	13.6	14.7	17.8	17.2	0.9	0.2
Nitrile-Based NBR	1.8	1.5	3.7	4.9	7.5	7.3	0.4	-0.2
Fluorocarbon	33.3	21.3	56.7	36.8	55.8	34.6	0.7	0.0
EDPM	14.5	9.1	6.0	5.6	9.5	6.9	0.1	-0.3
Epichlorohydrin	2.5	1.9	3.5	2.6	5.7	4.4	0.0	0.0
Butyl Rubber	7.4	7.2	6.8	6.8	6.2	5.8	0.3	-0.1
Silicone	60.8	44.8	84.0	62.9	84.2	61.9	0.6	0.1
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures								
Material	Average Volume and Weight Change (%), n=3							
	R-1234yf:POE		R-1234ze(E):POE		Three-Refrigerant Blend:POE		100% POE	
	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
Neoprene 1	12.9	8.8	7.6	5.6	9.3	6.4	42.4	27.4
Neoprene 2	1.9	1.8	-1.3	-0.1	0.6	0.8	26.2	17.3
Nitrile-Based HNBR	21.5	18.8	21.3	20.1	27.0	25.1	18.8	15.4
Nitrile-Based NBR	12.6	9.8	12.4	11.2	18.3	16.2	16.8	12.5
Fluorocarbon	73.4	42.3	67.3	40.2	65.4	38.0	10.2	4.9
EDPM	14.4	11.7	11.9	9.9	10.7	9.0	12.3	8.9
Epichlorohydrin	11.8	7.7	9.3	6.6	12.9	9.0	30.6	18.9
Butyl Rubber	23.6	19.3	16.2	14.1	14.8	12.6	19.2	14.8
Silicone	50.8	35.1	40.5	29.4	32.9	23.1	5.4	2.7
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures								
Material	Average Volume and Weight Change (%), n=3							
	R-1234yf:PVE		R-1234ze(E):PVE		Three-Refrigerant Blend:PVE		100% PVE	
	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
Neoprene 1	5.9	3.7	4.2	3.0	5.9	3.5	18.6	10.8
Neoprene 2	-4.8	-3.2	-5.6	-3.3	-3.5	-2.4	5.4	2.7
Nitrile-Based HNBR	9.6	8.9	13.6	13.0	16.4	15.3	4.2	2.7
Nitrile-Based NBR	2.2	1.5	5.8	5.3	8.4	7.4	1.2	-0.7
Fluorocarbon	27.7	16.7	30.4	19.4	33.9	21.1	1.4	0.3
EDPM	14.5	11.2	15.6	12.1	12.9	10.2	25.0	17.1
Epichlorohydrin	3.0	1.5	3.5	2.5	5.4	3.8	2.0	0.7
Butyl Rubber	18.4	15.4	16.5	13.8	14.2	11.6	23.2	17.2
Silicone	31.2	22.5	32.8	24.1	36.4	25.5	2.4	0.6

Table 43: Elastomer Hardness Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	**Unexposed Material Results**	**Average Change in Shore A Durometer Hardness (%), n=3**			
		R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Neoprene 1	69.6	-5.3	-0.6	-3.3	2.8
Neoprene 2	65.1	9.3	13.8	8.2	12.3
Nitrile-Based HNBR	73.0	-4.7	-5.8	-6.6	-1.4
Nitrile-Based NBR	69.3	3.1	-2.9	-6.3	1.5
Fluorocarbon	77.8	-14.9	-14.7	-16.0	-0.9
EDPM	77.4	-8.7	-4.9	-6.4	-0.9
Epichlorohydrin	72.0	0.6	-1.2	-3.1	3.1
Butyl Rubber	65.8	-3.6	-4.0	-3.7	4.3
Silicone	73.2	-26.6	-26.2	-26.7	-0.2
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	**Unexposed Material Results**	**Average Change in Shore A Durometer Hardness (%), n=3**			
		R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Neoprene 1	69.6	-8.3	-4.1	-3.7	-17.2
Neoprene 2	65.1	5.9	8.9	6.4	-5.0
Nitrile-Based HNBR	73.0	-6.9	-7.5	-8.2	-6.4
Nitrile-Based NBR	69.3	-8.5	-7.7	-10.5	-8.9
Fluorocarbon	77.8	-16.5	-16.3	-16.5	-6.6
EDPM	77.4	-10.8	-8.0	-7.3	-10.6
Epichlorohydrin	72.0	-8.4	-5.7	-8.4	-13.8
Butyl Rubber	65.8	-12.5	-12.2	-11.3	-13.0
Silicone	73.2	-28.8	-23.8	-22.2	-7.5
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	**Unexposed Material Results**	**Average Change in Shore A Durometer Hardness (%), n=3**			
		R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Neoprene 1	69.6	-4.0	-0.8	-2.6	-9.6
Neoprene 2	65.1	12.6	13.0	13.1	7.2
Nitrile-Based HNBR	73.0	-4.2	-5.0	-7.0	-2.0
Nitrile-Based NBR	69.3	1.2	-3.0	-4.7	3.5
Fluorocarbon	77.8	-14.2	-13.9	-14.3	-0.6
EDPM	77.4	-10.8	-10.1	-8.5	-14.7
Epichlorohydrin	72.0	0.5	-1.5	-1.9	0.0
Butyl Rubber	65.8	-14.0	-13.7	-13.0	-13.9
Silicone	73.2	-20.2	-21.2	-19.6	-1.5

Table 44: Elastomer Appearance Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Appearance Change**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Neoprene 1	No Change	No Change	No Change	No Change
Neoprene 2	Extractable Material on Sample Surface	No Change	Extractable Material on Sample Surface	Extractable Material on Sample Surface
Nitrile-Based HNBR	No Change	No Change	No Change	No Change
Nitrile-Based NBR	No Change	No Change	No Change	No Change
Fluorocarbon	Noticeable Swelling	Severe Swelling	Severe Swelling	No Change
EDPM	White Extractable Material on Sample Surface	No Change	White Extractable Material on Sample Surface	No Change
Epichlorohydrin	No Change	No Change	No Change	No Change
Butyl Rubber	No Change	No Change	No Change	No Change
Silicone	Severe Swelling	Severe Swelling	Severe Swelling, Cracks and White Marks on Sample Surface	No Change
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Appearance Change**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Neoprene 1	No Change	No Change	No Change	Noticeable Swelling
Neoprene 2	No Change	No Change	No Change	No Change
Nitrile-Based HNBR	No Change	No Change	No Change	No Change
Nitrile-Based NBR	No Change	No Change	No Change	No Change
Fluorocarbon	Severe Swelling	Severe Swelling	Severe Swelling	No Change
EDPM	No Change	No Change	No Change	No Change
Epichlorohydrin	No Change	No Change	No Change	Noticeable Swelling
Butyl Rubber	Noticeable Swelling	No Change	No Change	Noticeable Swelling
Silicone	Severe Swelling	Severe Swelling	Noticeable Swelling	No Change
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Appearance Change**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Neoprene 1	No Change	No Change	No Change	No Change
Neoprene 2	No Change	No Change	No Change	No Change
Nitrile-Based HNBR	No Change	No Change	No Change	No Change
Nitrile-Based NBR	No Change	No Change	No Change	No Change
Fluorocarbon	Noticeable Swelling	Noticeable Swelling	Noticeable Swelling	No Change
EDPM	No Change	No Change	No Change	Noticeable Swelling
Epichlorohydrin	No Change	No Change	No Change	No Change
Butyl Rubber	Noticeable Swelling	No Change	No Change	Noticeable Swelling
Silicone	Noticeable Swelling	Noticeable Swelling	Noticeable Swelling	No Change

Table 45: Elastomer Extractable Material Observation Summary

Material	Presence and Location (if Observed) of Extractable Material			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Neoprene 1 **Neoprene 2**	Yes (on the surface of the Neoprene 2 material)	Yes (in the test vessel)	Yes (on the surface of the Neoprene 2 Material and in the test vessel)	Yes (on the surface of the Neoprene 2 material)
Nitrile-Based HNBR **Nitrile-Based NBR**	Yes (in the test vessel)	Yes (in the test vessel)	Yes (in the test vessel)	None Observed
Fluorocarbon	None Observed	None Observed	None Observed	None Observed
EDPM	Yes (on the surface of the EPDM material)	Yes (in the test vessel)	Yes (surface of the EPDM material)	None Observed
Epichlorohydrin	Yes (in the test vessel)	Yes (in the test vessel)	None Observed	None Observed
Butyl Rubber	None Observed	None Observed	None Observed	None Observed
Silicone	Yes (in the test vessel)	Yes (in the test vessel)	Yes (in the test vessel)	None Observed

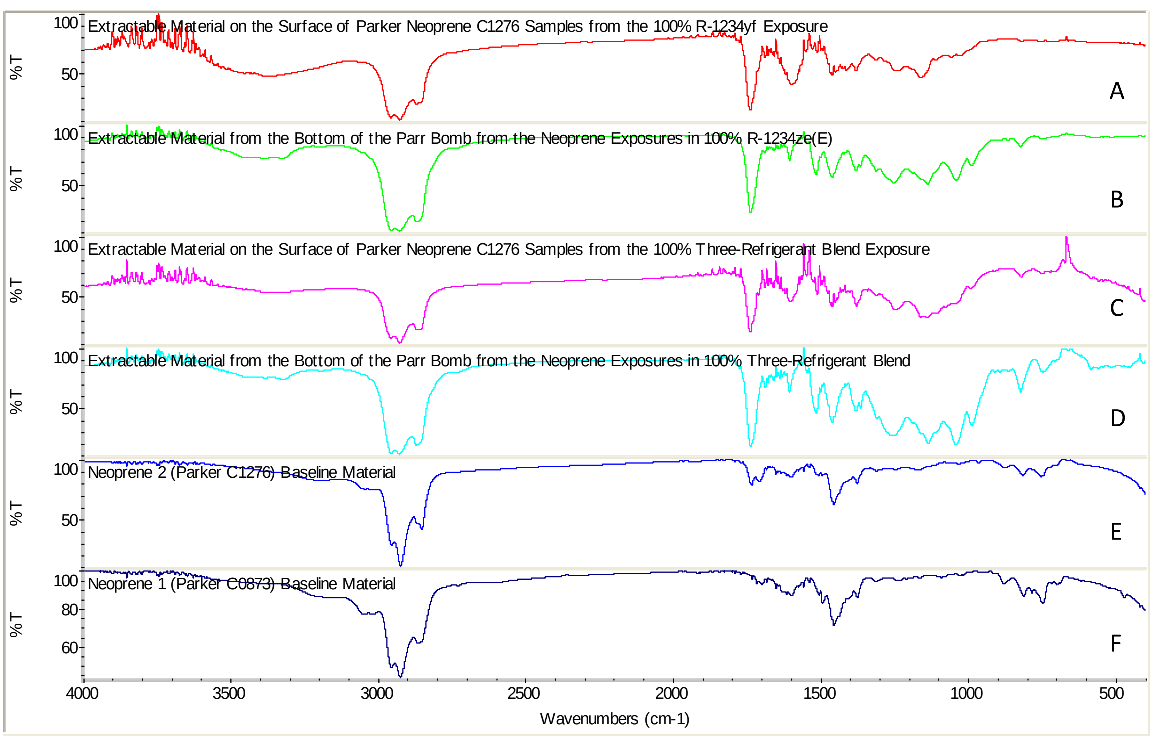


Figure 23. FTIR spectra of extractables from the exposures of the neoprene materials (A-D), and reference spectra of unexposed samples (E: neoprene 2 and F: neoprene 1).

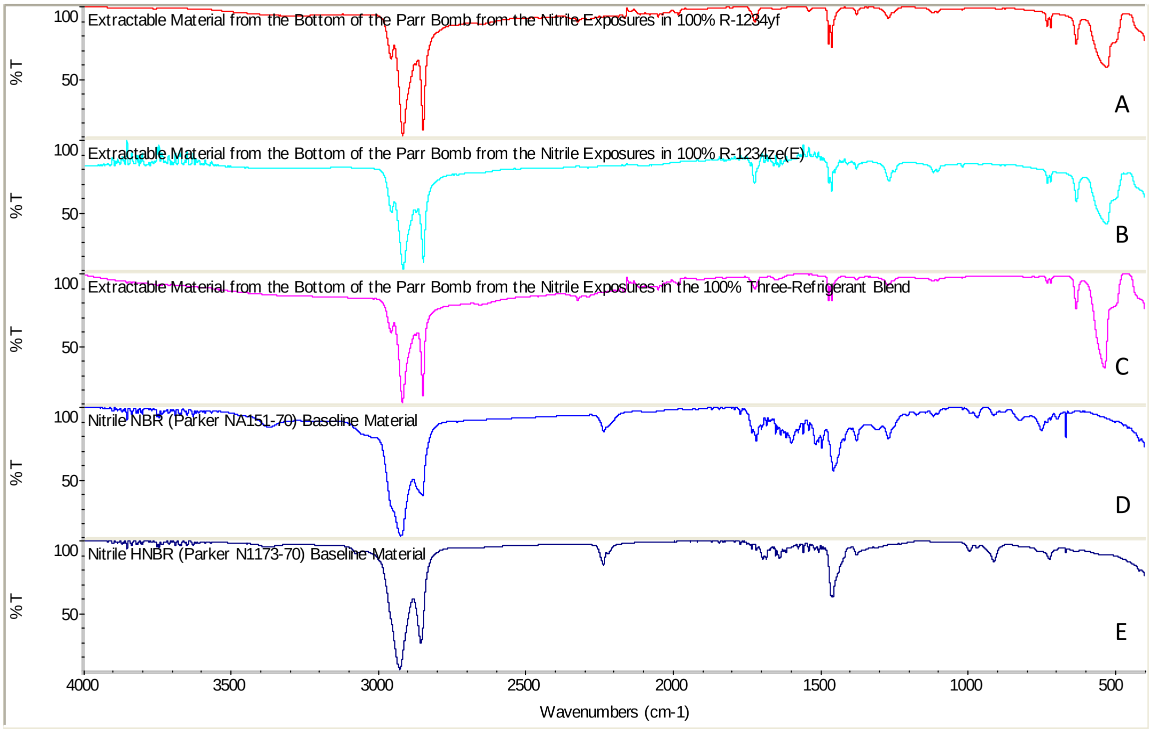


Figure 24. FTIR spectra of extractables from the exposures of the nitrile materials (A-C), and reference spectra of unexposed samples (D: nitrile-based NBR and E: nitrile-based HNBR).

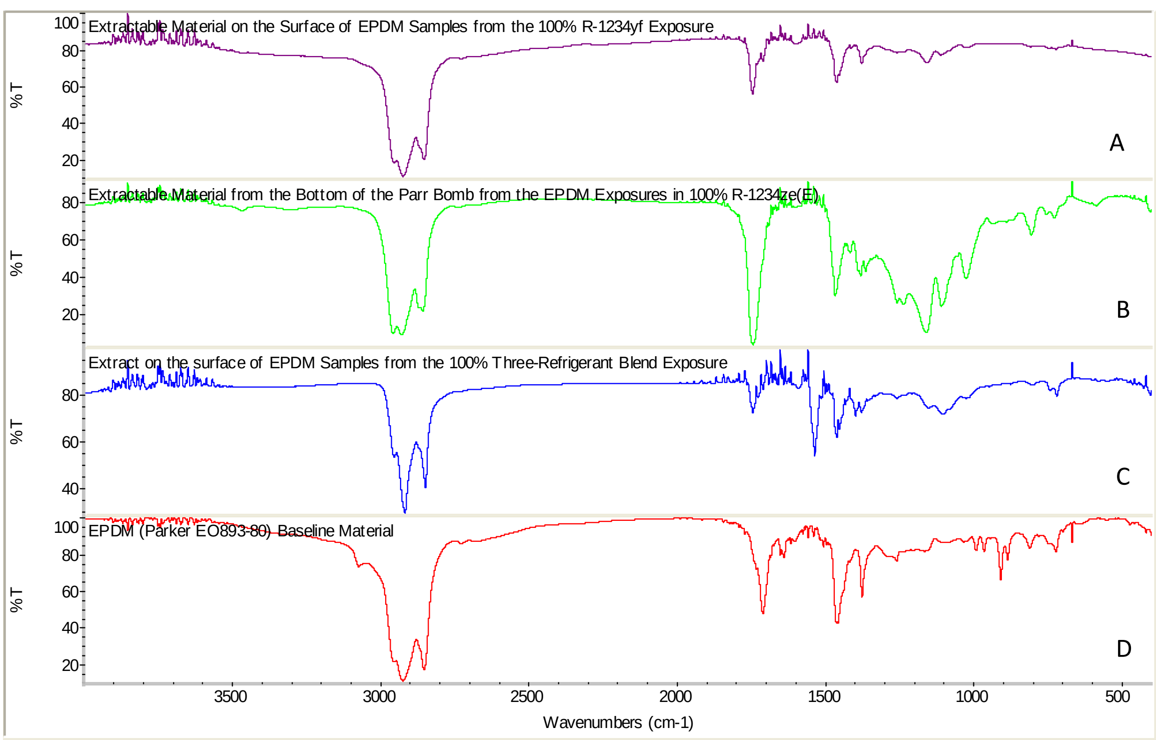


Figure 25. FTIR spectra of extractables from the exposures of the EPDM material (A-C), and reference spectrum of unexposed EPDM (D).

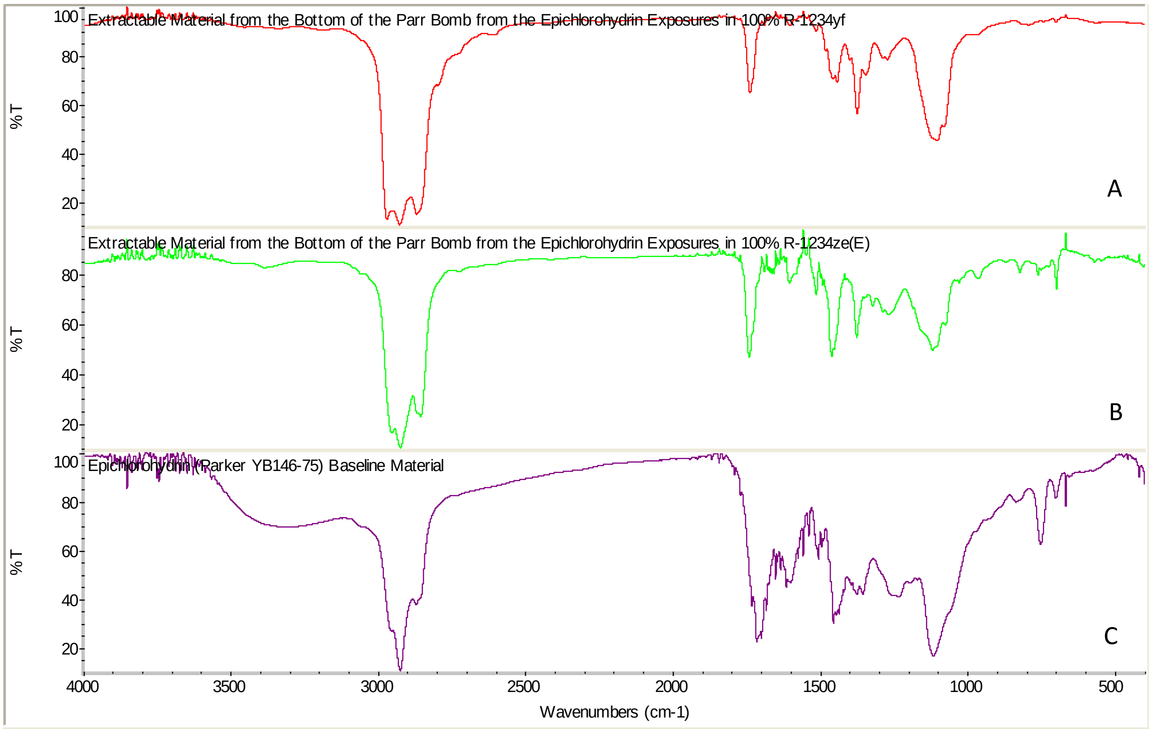


Figure 26. FTIR spectra of extractables from the exposures of the epichlorohydrin material (A-B), and reference spectrum of unexposed epichlorohydrin (C).

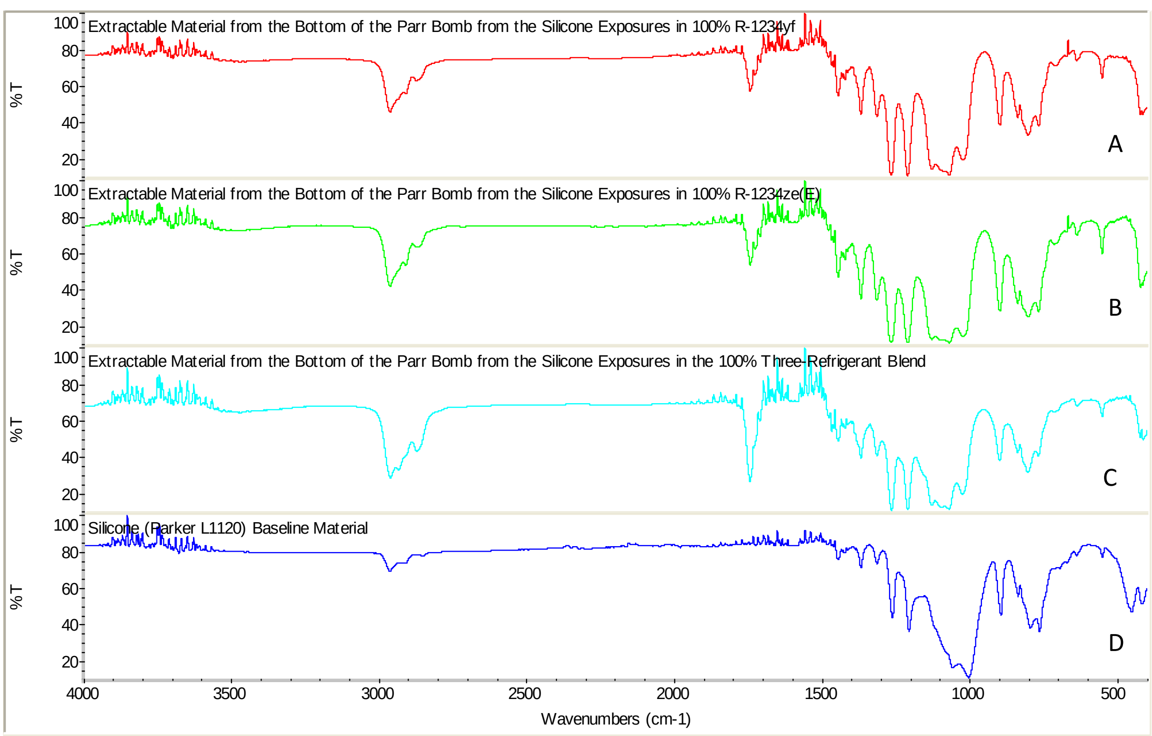


Figure 27. FTIR spectra of extractables from the exposures of the silicone material (A-C), and reference spectrum of unexposed silicone (D).

Table 46: Elastomer Post-Bakeout Weight Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Average Post-Bakeout Weight Change (%), n=3**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Neoprene 1	0.6	-1.1	0.3	-0.6
Neoprene 2	-4.3	-6.3	-4.7	-0.7
Nitrile-Based HNBR	2.2	0.5	1.4	-0.1
Nitrile-Based NBR	-4.5	-5.1	-4.3	-0.7
Fluorocarbon	0.2	-0.1	-0.1	0.0
EDPM	-0.9	-1.1	-0.7	-0.5
Epichlorohydrin	-1.2	-1.2	-1.0	-0.9
Butyl Rubber	0.9	-0.5	0.1	-0.3
Silicone	-2.0	-2.6	-2.3	-0.2
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Average Post-Bakeout Weight Change (%), n=3**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Neoprene 1	3.8	0.8	1.2	26.6
Neoprene 2	-2.9	-5.2	-4.8	16.1
Nitrile-Based HNBR	8.8	6.3	9.5	15.1
Nitrile-Based NBR	1.8	0.4	3.3	12.1
Fluorocarbon	12.2	9.8	9.7	4.9
EDPM	3.8	2.2	2.1	8.0
Epichlorohydrin	4.1	2.1	2.9	18.4
Butyl Rubber	7.9	3.8	3.6	13.4
Silicone	4.1	3.4	4.4	2.5
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Average Post-Bakeout Weight Change (%), n=3**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Neoprene 1	-0.6	-1.5	-1.1	9.0
Neoprene 2	-7.2	-7.9	-7.1	1.3
Nitrile-Based HNBR	1.2	1.3	2.3	2.1
Nitrile-Based NBR	-4.8	-3.9	-3.2	-1.7
Fluorocarbon	1.3	1.7	1.4	0.2
EDPM	2.4	2.9	2.8	13.6
Epichlorohydrin	-1.3	-1.1	-0.9	-0.1
Butyl Rubber	4.8	3.5	3.4	14.0
Silicone	0.8	0.6	1.6	-0.2

Table 47: Elastomer Post-Bakeout Appearance Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Neoprene 1	No change	No change	No change	No change
Neoprene 2	No change	No change	No change	No change
Nitrile-Based HNBR	No change	No change	No change	No change
Nitrile-Based NBR	No change	No change	No change	No change
Fluorocarbon	No change	Noticeable reduction in swelling	Noticeable reduction in swelling	No change
EDPM	No change	No change	No change	No change
Epichlorohydrin	No change	No change	No change	No change
Butyl Rubber	No change	No change	No change	No change
Silicone	Noticeable reduction in swelling; appearance of cracks and white marks	Noticeable reduction in swelling; appearance of cracks and white marks	Noticeable reduction in swelling; appearance of cracks and white marks	No change
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Neoprene 1	No change	No change	No change	No change
Neoprene 2	No change	No change	No change	No change
Nitrile-Based HNBR	No change	No change	No change	No change
Nitrile-Based NBR	No change	No change	No change	No change
Fluorocarbon	Lubricant present on material surface	Lubricant present on material surface	Lubricant present on material surface	No change
EDPM	No change	No change	No change	No change
Epichlorohydrin	No change	No change	No change	No change
Butyl Rubber	Blistering occurred	No change	Significant blistering and cracking occurred	No change
Silicone	Noticeable reduction in swelling; lubricant present on material surface	Noticeable reduction in swelling; lubricant present on material surface	Noticeable reduction in swelling; lubricant present on material surface	No change
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Neoprene 1	No change	No change	No change	No change
Neoprene 2	No change	No change	No change	No change
Nitrile-Based HNBR	No change	No change	No change	No change
Nitrile-Based NBR	No change	No change	No change	No change
Fluorocarbon	No change	No change	No change	No change
EDPM	No change	No change	No change	No change
Epichlorohydrin	No change	No change	No change	No change
Butyl Rubber	Significant blistering occurred	No change	Blistering occurred	No change
Silicone	No Change	No Change	No Change	No Change

Table 48: Gasket Volume and Weight Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures								
Material	Average Volume and Weight Change (%), n=3							
	R-1234yf		R-1234ze(E)		Three-Refrigerant Blend		Nitrogen	
	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
Garlock® 3300	-0.4	-0.2	0.0	0.0	-0.2	0.0	0.0	-0.6
Armstrong N-8092	-1.6	-1.6	-0.9	-1.2	-0.7	-1.1	-0.4	-1.1
Klingersil® C-4401	1.9	1.5	5.4	6.5	6.1	4.5	0.4	-0.7
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures								
Material	Average Volume and Weight Change (%), n=3							
	R-1234yf:POE		R-1234ze(E):POE		Three-Refrigerant Blend:POE		100% POE	
	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
Garlock® 3300	9.2	15.2	7.8	14.5	10.7	14.6	13.7	15.1
Armstrong N-8092	43.4	24.4	42.9	22.9	46.0	25.1	45.3	26.6
Klingersil® C-4401	7.7	11.1	7.9	11.5	8.4	11.6	7.3	10.9
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures								
Material	Average Volume and Weight Change (%), n=3							
	R-1234yf:PVE		R-1234ze(E):PVE		Three-Refrigerant Blend:PVE		100% PVE	
	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
Garlock® 3300	5.8	12.2	5.8	12.2	6.6	11.9	5.2	11.3
Armstrong N-8092	41.4	21.4	40.9	20.5	40.5	20.6	41.5	22.6
Klingersil® C-4401	5.9	9.0	5.9	9.8	6.5	9.4	4.0	7.4

Table 49: Gasket Appearance Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	Appearance Change			
	R-1234yf	R-1234ze(E)	Three-Refrigerant Blend	Nitrogen
Garlock® 3300	No change	No change	No change	No change
Armstrong N-8092	No change	No change	No change	No change
Klingersil® C-4401	No change	No change	No change	No change
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	Appearance Change			
	R-1234yf:POE	R-1234ze(E):POE	Three-Refrigerant Blend:POE	100% POE
Garlock® 3300	No change	No change	No change	No change
Armstrong N-8092	No change	No change	No change	No change
Klingersil® C-4401	No change	No change	No change	No change
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	Appearance Change			
	R-1234yf:PVE	R-1234ze(E):PVE	Three-Refrigerant Blend:PVE	100% PVE
Garlock® 3300	No change	No change	No change	No change
Armstrong N-8092	No change	No change	No change	No change
Klingersil® C-4401	No change	No change	No change	No change

Table 50: Gasket Extractable Material Observation Summary

Material	Presence and Location (if Observed) of Extractable Material			
	R-1234yf	R-1234ze(E)	Three-Refrigerant Blend	Nitrogen
Garlock® 3300	None Observed	None Observed	None Observed	None Observed
Armstrong N-8092	None Observed	None Observed	None Observed	None Observed
Klingersil® C-4401	None Observed	None Observed	None Observed	None Observed

Table 51: Gasket Post-Bakeout Weight Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	Average Post-Bakeout Weight Change (%), n=3			
	R-1234yf	R-1234ze(E)	Three-Refrigerant Blend	Nitrogen
Garlock® 3300	-0.6	-0.5	-0.4	-0.6
Armstrong N-8092	-1.7	-1.6	-1.8	-1.7
Klingersil® C-4401	-0.9	-0.9	-0.8	-1.1
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	Average Post-Bakeout Weight Change (%), n=3			
	R-1234yf:POE	R-1234ze(E):POE	Three-Refrigerant Blend:POE	100% POE
Garlock® 3300	12.4	10.3	11.6	14.5
Armstrong N-8092	19.4	15.6	19.1	23.3
Klingersil® C-4401	8.2	6.8	7.2	10.1
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	Average Post-Bakeout Weight Change (%), n=3			
	R-1234yf:PVE	R-1234ze(E):PVE	Three-Refrigerant Blend:PVE	100% PVE
Garlock® 3300	8.3	7.1	8.2	9.6
Armstrong N-8092	14.6	13.4	14.1	17.4
Klingersil® C-4401	5.8	4.6	4.5	5.7

Table 52: Gasket Post-Bakeout Appearance Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Garlock® 3300	No Change	No Change	No Change	No Change
Armstrong N-8092	No Change	No Change	No Change	No Change
Klingersil® C-4401	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Garlock® 3300	No Change	No Change	No Change	No Change
Armstrong N-8092	No Change	No Change	No Change	No Change
Klingersil® C-4401	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Garlock® 3300	No Change	No Change	No Change	No Change
Armstrong N-8092	No Change	No Change	No Change	No Change
Klingersil® C-4401	No Change	No Change	No Change	No Change

Table 53: Polymer Volume and Weight Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures								
Material	**Average Volume and Weight Change (%), n=3**							
	R-1234yf		**R-1234ze(E)**		**Three-Refrigerant Blend**		**Nitrogen**	
	Volume	**Weight**	**Volume**	**Weight**	**Volume**	**Weight**	**Volume**	**Weight**
Polyester (unfilled)	1.0	1.3	2.1	2.6	2.4	3.0	-0.3	0.0
Nylon 6,6 (unfilled)	0.2	0.6	0.4	0.6	0.7	1.4	0.2	0.4
PEEK (unfilled)	-0.5	0.0	0.1	0.1	0.3	0.9	-0.1	0.0
PPS (filled)	-0.1	0.0	0.0	0.0	-0.1	0.1	-0.5	0.0
PAI (unfilled)	-0.8	-1.4	-0.8	-1.3	-0.7	-0.7	-0.6	-1.3
PTFE (unfilled)	5.3	3.6	5.8	3.8	5.1	3.1	0.1	0.0
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures								
Material	**Average Volume and Weight Change (%), n=3**							
	R-1234yf:POE		**R-1234ze(E):POE**		**Three-Refrigerant Blend:POE**		**100% POE**	
	Volume	**Weight**	**Volume**	**Weight**	**Volume**	**Weight**	**Volume**	**Weight**
Polyester (unfilled)	0.3	0.6	1.1	1.5	0.9	1.7	-0.3	0.0
Nylon 6,6 (unfilled)	0.1	0.2	0.1	0.4	0.3	0.8	-0.2	0.0
PEEK (unfilled)	0.1	0.0	0.1	0.0	0.0	0.6	0.0	0.0
PPS (filled)	0.0	0.0	-0.9	0.0	-0.8	0.1	-0.5	0.0
PAI (unfilled)	-0.2	-1.2	-0.8	-1.5	-0.9	-1.0	-0.8	-1.5
PTFE (unfilled)	3.3	2.3	3.3	2.4	2.8	2.0	-0.1	0.0
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures								
Material	**Average Volume and Weight Change (%), n=3**							
	R-1234yf:PVE		**R-1234ze(E):PVE**		**Three-Refrigerant Blend:PVE**		**100% PVE**	
	Volume	**Weight**	**Volume**	**Weight**	**Volume**	**Weight**	**Volume**	**Weight**
Polyester (unfilled)	0.0	0.5	0.6	1.3	0.6	1.6	-0.2	0.0
Nylon 6,6 (unfilled)	0.0	0.2	-0.1	0.3	0.4	0.7	0.0	0.0
PEEK (unfilled)	0.0	0.0	-0.1	0.0	0.1	0.6	0.1	0.0
PPS (filled)	-0.5	0.0	-0.5	0.0	-0.2	0.1	-0.1	0.0
PAI (unfilled)	-0.8	-1.5	-0.9	-1.5	-0.6	-1.0	-0.7	-1.6
PTFE (unfilled)	3.1	2.2	3.3	2.4	3.3	2.1	0.0	0.0

Table 54: Polymer Appearance Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Appearance Change**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Polyester (unfilled)	No Change	No Change	No Change	No Change
Nylon 6,6 (unfilled)	No Change	No Change	No Change	No Change
PEEK (unfilled)	No Change	No Change	No Change	No Change
PPS (filled)	No Change	No Change	No Change	No Change
PAI (unfilled)	No Change	No Change	No Change	No Change
PTFE (unfilled)	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Appearance Change**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Polyester (unfilled)	No Change	No Change	No Change	No Change
Nylon 6,6 (unfilled)	No Change	No Change	No Change	No Change
PEEK (unfilled)	No Change	No Change	No Change	No Change
PPS (filled)	No Change	No Change	No Change	No Change
PAI (unfilled)	No Change	No Change	No Change	No Change
PTFE (unfilled)	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Appearance Change**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Polyester (unfilled)	No Change	No Change	No Change	No Change
Nylon 6,6 (unfilled)	No Change	No Change	No Change	No Change
PEEK (unfilled)	No Change	No Change	No Change	No Change
PPS (filled)	No Change	No Change	No Change	No Change
PAI (unfilled)	No Change	No Change	No Change	No Change
PTFE (unfilled)	No Change	No Change	No Change	No Change

Table 55: Polymer Extractable Material Observation Summary

Material	**Presence and Location (if Observed) of Extractable Material**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Polymers (Weight/Volume)	None Observed	None Observed	None Observed	None Observed
Polymers (Tensile Testing)	None Observed	None Observed	None Observed	None Observed
PTFE	None Observed	None Observed	None Observed	None Observed

Table 56: Polymer Tensile Stress Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	Unexposed Material Results (ksi)	Average Change in Tensile Stress at Break (%), n=5			
		R-1234yf	R-1234ze(E)	Three-Refrigerant Blend	Nitrogen
Polyester (unfilled)	7.5	-5.5	-18.2	-48.7	3.8
Nylon 6,6 (unfilled)	10.9	4.3	4.7	-25.8	-4.8
PEEK (unfilled)	11.5	-7.7	-5.5	-9.4	-19.8
PPS (filled)	18.5	9.7	4.2	4.9	-11.7
PAI (unfilled)	21.5	5.8	3.2	6.2	-14.8
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	Unexposed Material Results (ksi)	Average Change in Tensile Stress at Break (%), n=5			
		R-1234yf:POE	R-1234ze(E):POE	Three-Refrigerant Blend:POE	100% POE
Polyester (unfilled)	7.5	3.1	-14.6	-41.3	7.4
Nylon 6,6 (unfilled)	10.9	8.9	12.3	-14.8	3.7
PEEK (unfilled)	11.5	-4.4	-4.4	-10.5	-10.2
PPS (filled)	18.5	3.1	1.0	2.8	1.1
PAI (unfilled)	21.5	6.7	6.1	3.8	3.9
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	Unexposed Material Results (ksi)	Average Change in Tensile Stress at Break (%), n=5			
		R-1234yf:PVE	R-1234ze(E):PVE	Three-Refrigerant Blend:PVE	100% PVE
Polyester (unfilled)	7.5	9.2	-14.8	-47.1	7.8
Nylon 6,6 (unfilled)	10.9	20.6	7.7	-7.4	-6.8
PEEK (unfilled)	11.5	-5.4	-2.3	-10.2	-17.4
PPS (filled)	18.5	6.6	6.0	7.7	-8.1
PAI (unfilled)	21.5	8.9	9.1	8.3	1.6

Table 57: Polymer Modulus Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	Unexposed Material Results (ksi)	Average Change in Modulus (%), n=5			
		R-1234yf	R-1234ze(E)	Three-Refrigerant Blend	Nitrogen
Polyester (unfilled)	348.4	-12.8	-45.1	-70.5	-5.9
Nylon 6,6 (unfilled)	423.3	-4.3	1.8	-6.4	0.5
PEEK (unfilled)	496.4	1.3	1.7	6.0	-18.1
PPS (filled)	2902.1	-0.2	5.6	0.0	-11.2
PAI (unfilled)	621.3	-5.5	-0.8	-9.0	-22.9
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	Unexposed Material Results (ksi)	Average Change in Modulus (%), n=5			
		R-1234yf:POE	R-1234ze(E):POE	Three-Refrigerant Blend:POE	100% POE
Polyester (unfilled)	348.4	-11.8	-36.3	-66.4	-15.4
Nylon 6,6 (unfilled)	423.3	9.1	6.1	-0.8	3.1
PEEK (unfilled)	496.4	3.4	2.2	0.1	0.6
PPS (filled)	2902.1	7.5	8.8	-2.8	1.9
PAI (unfilled)	621.3	5.2	1.5	-6.9	-4.4
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	Unexposed Material Results (ksi)	Average Change in Modulus (%), n=5			
		R-1234yf:PVE	R-1234ze(E):PVE	Three-Refrigerant Blend:PVE	100% PVE
Polyester (unfilled)	348.4	-2.5	-36.9	-67.2	-8.6
Nylon 6,6 (unfilled)	423.3	14.4	6.8	0.6	-12.2
PEEK (unfilled)	496.4	2.2	4.6	4.3	-4.0
PPS (filled)	2902.1	9.4	5.8	2.4	-1.5
PAI (unfilled)	621.3	-0.5	2.0	-6.0	-2.2

Table 58: Polymer Elongation Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	**Unexposed Material Results (%)**	**Average Change in Elongation (%), n=5**			
		R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Polyester (unfilled)	8.9	-96.4	-42.1	210.5	-90.2
Nylon 6,6 (unfilled)	1.7	269.8	15.1	1012.8	589.5
PEEK (unfilled)	29.1	8.6	21.8	34.8	5.2
PPS (filled)	0.9	-51.1	-29.8	-48.9	-70.2
PAI (unfilled)	2.2	-42.2	-21.1	-33.0	-36.7
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	**Unexposed Material Results (%)**	**Average Change in Elongation (%), n=5**			
		R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Polyester (unfilled)	8.9	-80.5	-65.3	16.1	-88.0
Nylon 6,6 (unfilled)	1.7	82.6	-16.3	408.1	35.2
PEEK (unfilled)	29.1	-12.1	17.0	34.0	-24.8
PPS (filled)	0.9	-89.4	-40.4	-42.6	-53.2
PAI (unfilled)	2.2	-61.5	-19.3	-33.9	-15.1
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	**Unexposed Material Results (%)**	**Average Change in Elongation (%), n=5**			
		R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Polyester (unfilled)	8.9	-89.5	-40.3	173.8	-95.7
Nylon 6,6 (unfilled)	1.7	-50.0	16.3	343.0	30.2
PEEK (unfilled)	29.1	-16.6	-12.9	103.2	8.0
PPS (filled)	0.9	-48.9	-87.2	-2.1	-100.0
PAI (unfilled)	2.2	-85.3	-38.5	11.9	-31.2

Table 59: Polymer Post-Bakeout Weight Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Average Post-Bakeout Weight Change (%), n=3**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Polyester (unfilled)	0.9	1.7	1.8	-0.1
Nylon 6,6 (unfilled)	0.1	0.2	0.9	0.0
PEEK (unfilled)	-0.1	0.0	0.7	-0.1
PPS (filled)	0.0	0.0	0.1	-0.1
PAI (unfilled)	-1.7	-1.6	-1.1	-1.7
PTFE (unfilled)	0.1	0.1	0.2	0.0
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Average Post-Bakeout Weight Change (%), n=3**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Polyester (unfilled)	0.4	1.0	1.0	-0.1
Nylon 6,6 (unfilled)	0.0	0.1	0.5	-0.2
PEEK (unfilled)	0.0	-0.1	0.5	-0.1
PPS (filled)	0.0	0.0	0.0	0.0
PAI (unfilled)	-1.7	-1.8	-1.3	-1.7
PTFE (unfilled)	0.1	0.1	0.2	0.0
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Average Post-Bakeout Weight Change (%), n=3**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Polyester (unfilled)	0.3	0.9	1.0	-0.1
Nylon 6,6 (unfilled)	-0.1	0.1	0.4	-0.1
PEEK (unfilled)	-0.1	0.0	0.5	-0.1
PPS (filled)	0.0	0.0	0.0	0.0
PAI (unfilled)	-1.7	-1.7	-1.2	-1.8
PTFE (unfilled)	0.2	0.1	0.2	0.0

Table 60: Polymer Post-Bakeout Appearance Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Polyester (unfilled)	No Change	No Change	No Change	No Change
Nylon 6,6 (unfilled)	No Change	No Change	No Change	No Change
PEEK (unfilled)	No Change	No Change	No Change	No Change
PPS (filled)	No Change	No Change	No Change	No Change
PAI (unfilled)	No Change	No Change	No Change	No Change
PTFE (unfilled)	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Polyester (unfilled)	No Change	No Change	No Change	No Change
Nylon 6,6 (unfilled)	No Change	No Change	No Change	No Change
PEEK (unfilled)	No Change	No Change	No Change	No Change
PPS (filled)	No Change	No Change	No Change	No Change
PAI (unfilled)	No Change	No Change	No Change	No Change
PTFE (unfilled)	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Polyester (unfilled)	No Change	No Change	No Change	No Change
Nylon 6,6 (unfilled)	No Change	No Change	No Change	No Change
PEEK (unfilled)	No Change	No Change	No Change	No Change
PPS (filled)	No Change	No Change	No Change	No Change
PAI (unfilled)	No Change	No Change	No Change	No Change
PTFE (unfilled)	No Change	No Change	No Change	No Change

Table 61: Image Compilation of Neoprene 1 Elastomer Material

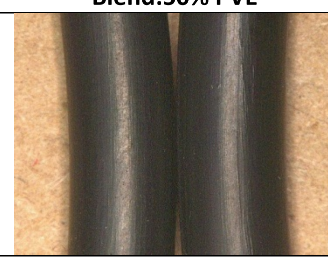
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 62: Image Compilation of Neoprene 2 Elastomer Material

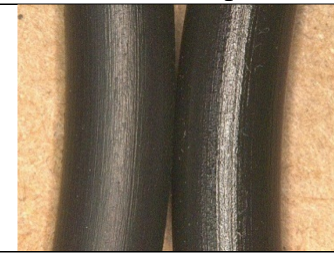
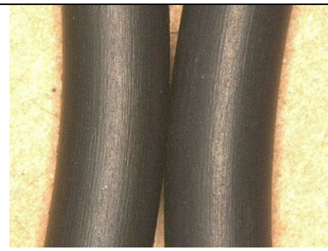
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 63: Image Compilation of Nitrile-Based HNBR Elastomer Material

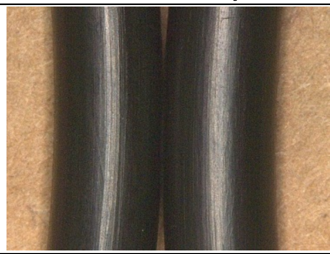
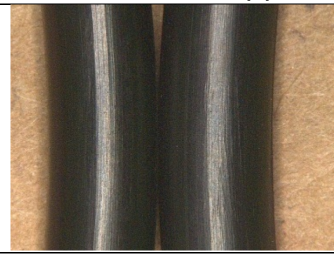
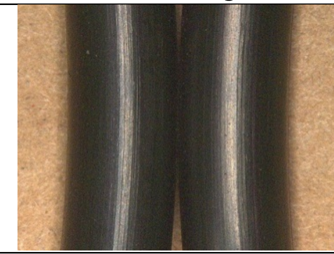
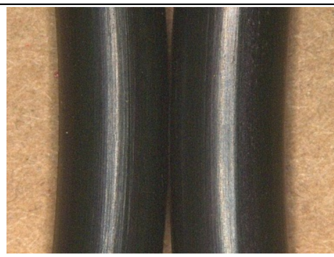
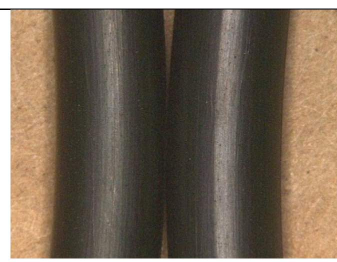
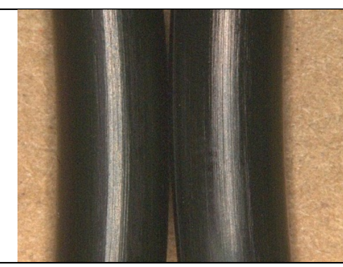
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 64: Image Compilation of Nitrile-Based NBR Elastomer Material

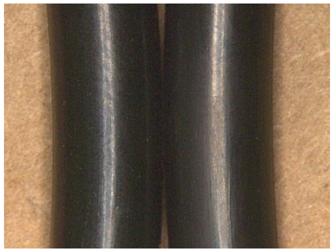
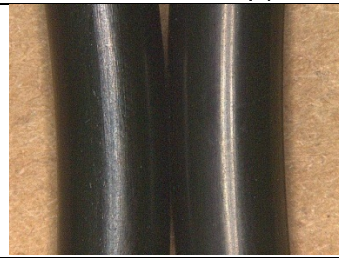
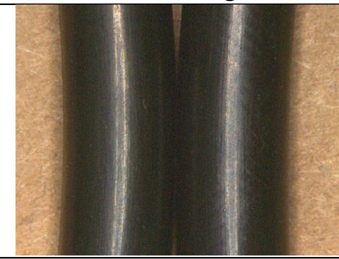
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 65: Image Compilation of Fluorocarbon Elastomer Material

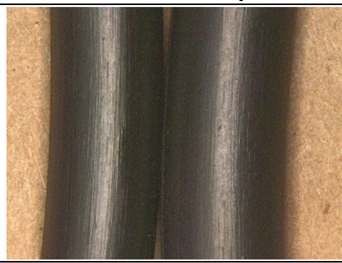
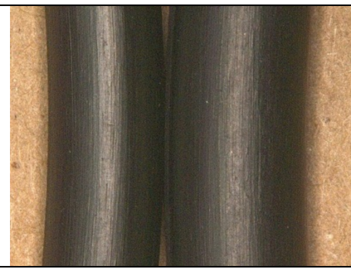
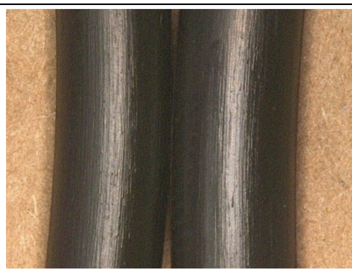
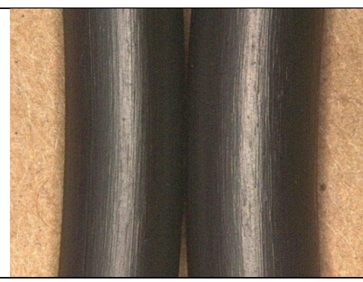
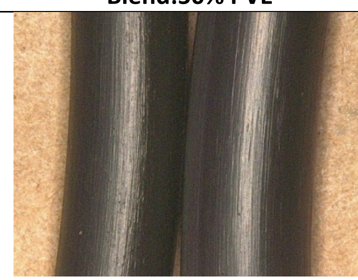
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 66: Image Compilation of EPDM Elastomer Material

Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 67: Image Compilation of Epichlorohydrin Elastomer Material

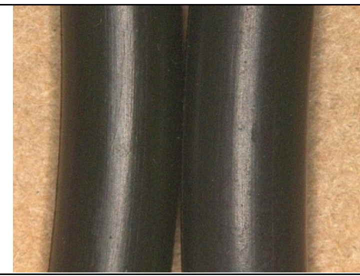
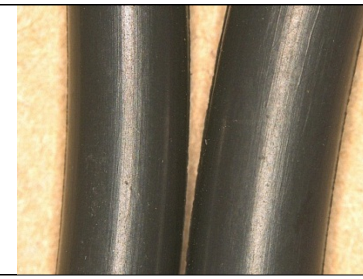
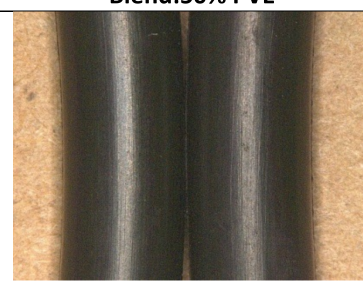
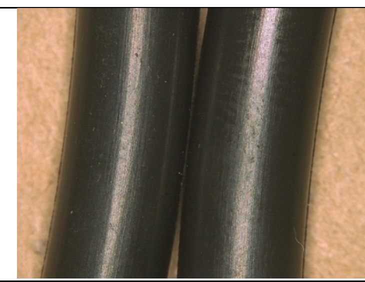
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 68: Image Compilation of Butyl Rubber Elastomer Material

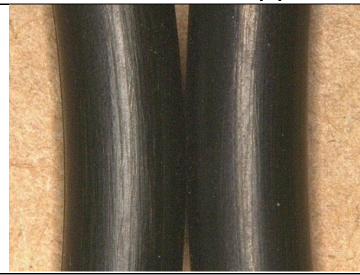
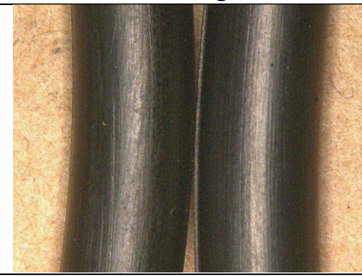
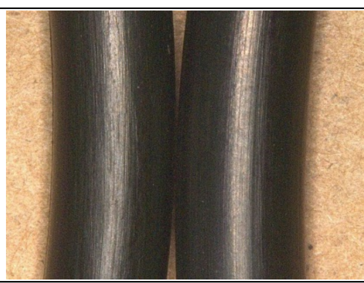
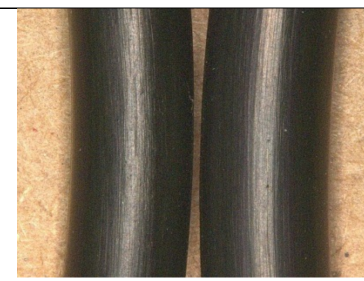
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 69: Image Compilation of Silicone Elastomer Material

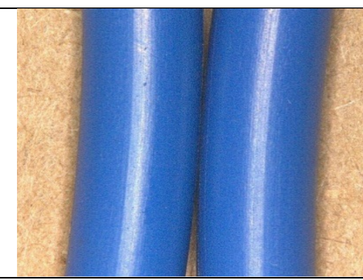
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 70: Image Compilation of Garlock® 3300 Gasket Material

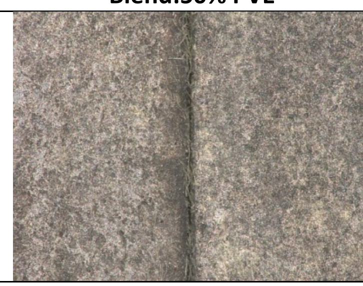
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 71: Image Compilation of Armstrong N-8902 Gasket Material

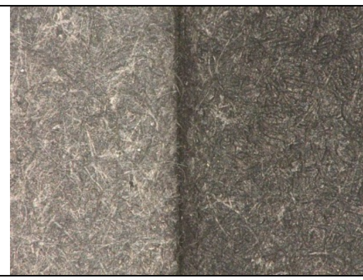
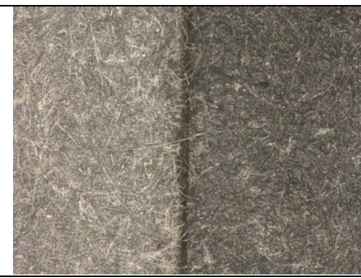
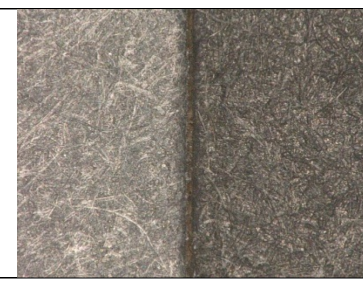
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 72: Image Compilation of Klingersil® C-4401 Gasket Material

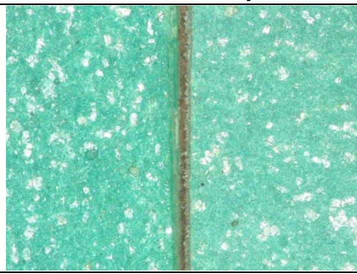
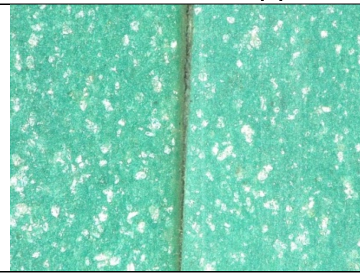
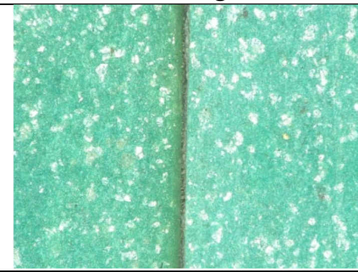
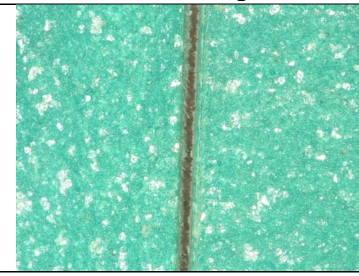
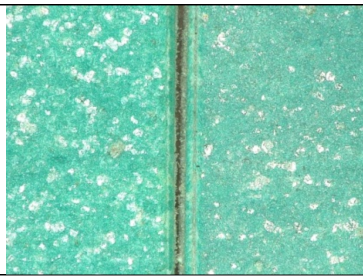
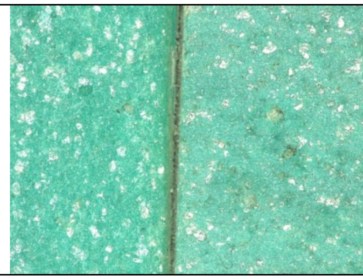
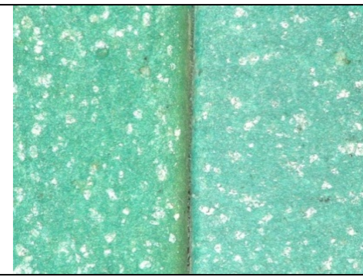
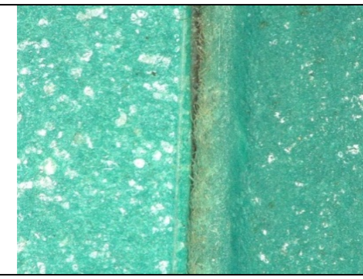
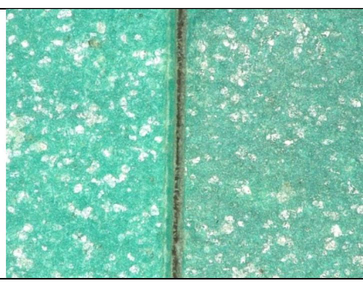
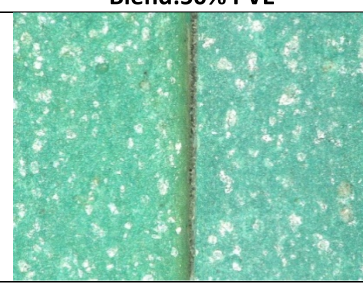
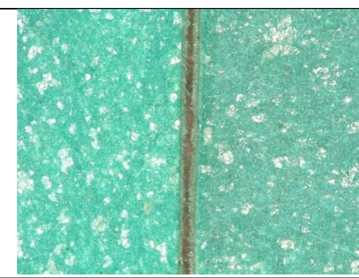
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 73: Image Compilation of Polyester (Unfilled) Polymer Material

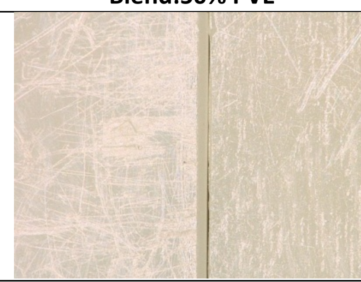
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 74: Image Compilation of Nylon 6,6 (Unfilled) Polymer Material

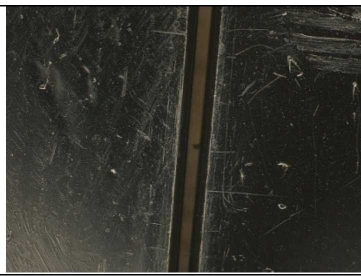
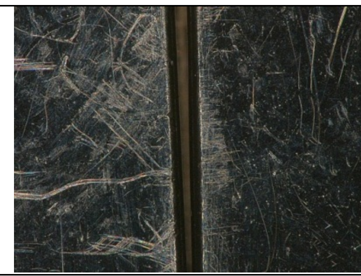
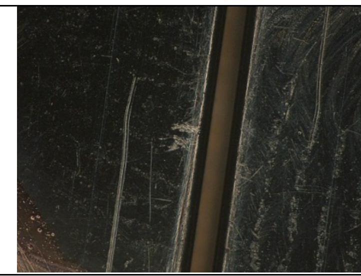
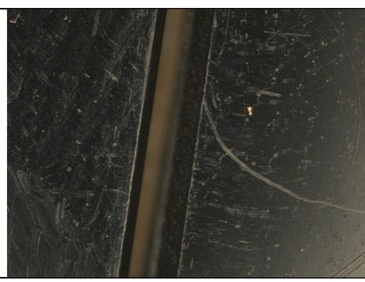
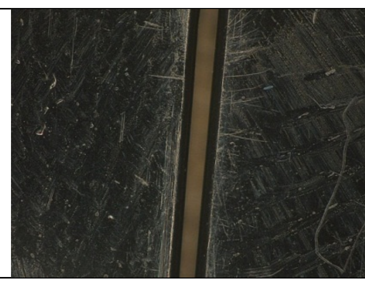
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 75: Image Compilation of PEEK (Unfilled) Polymer Material

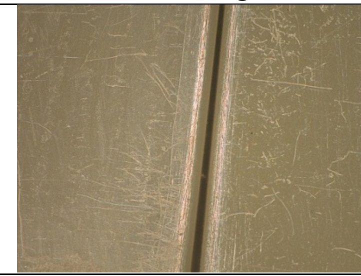
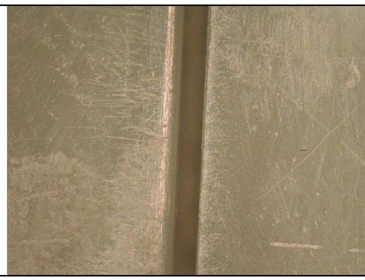
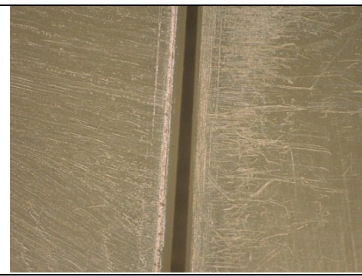
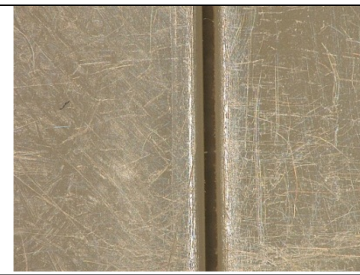
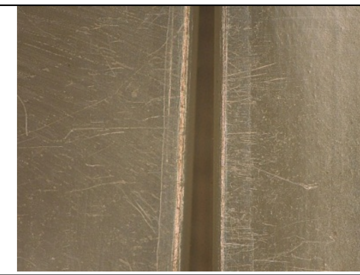
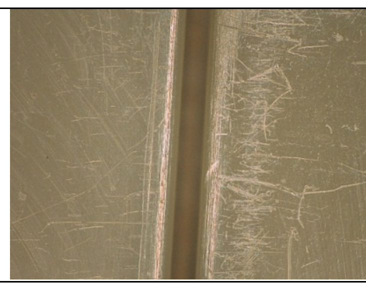
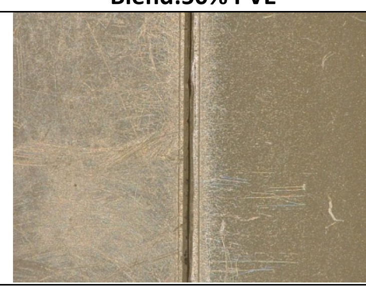
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 76: Image Compilation of PPS (Filled) Polymer Material

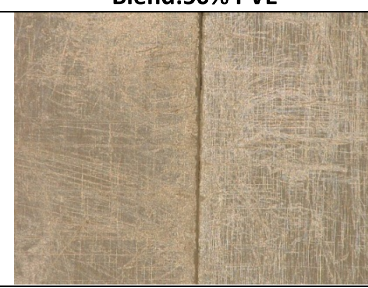
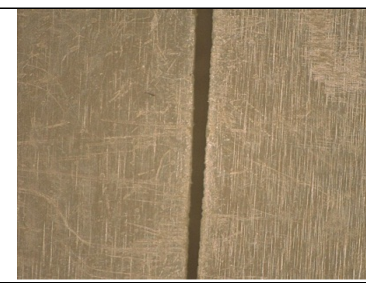
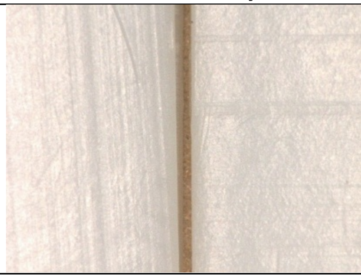
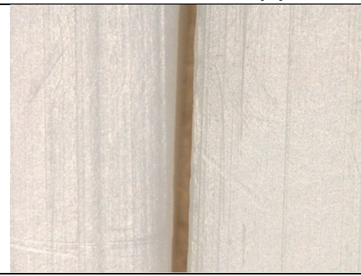
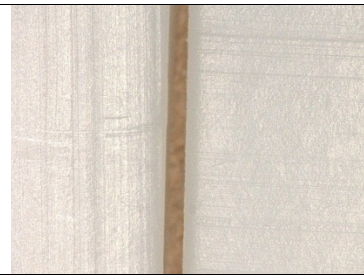
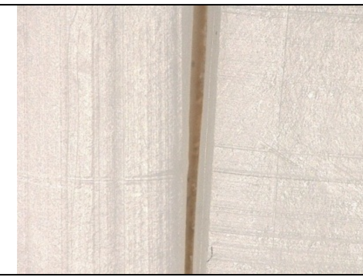
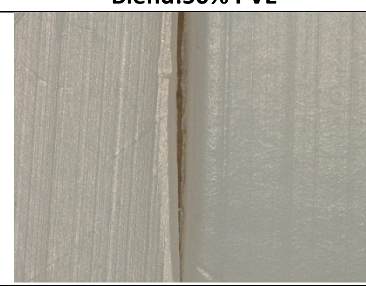
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 77: Image Compilation of PAI (Unfilled) Polymer Material

Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 78: Image Compilation of PTFE (Unfilled) Polymer Material

Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Post-Exposure Fluid Analyses from the Seal and Polymer Compatibility Study

Table 79: Post-Exposure Lubricant Moisture Changes (ppm) from the Seal and Polymer Compatibility Study

Material Exposures	R-1234yf		R-1234ze(E)		Three-Refrigerant Blend		100% POE	100% PVE
	POE	PVE	POE	PVE	POE	PVE		
Neoprenes 1 and 2	289	410	137	396	126	494	375	352
Nitriles (Nitrile-Based HNBR and NBR)	354	610	318	482	317	419	318	559
Fluorocarbon	336	154	258	383	552	197	344	362
EDPM	166	219	130	192	62	255	256	308
Epichlorohydrin	631	795	617	887	634	699	734	821
Butyl Rubber	183	391	113	340	302	509	103	335
Silicone	182	362	199	252	286	219	263	339
Garlock® 3300	552	815	423	734	580	768	615	680
Armstrong N-8092	961	1481	732	1135	932	1384	1008	1383
Klingersil® C-4401	589	1147	661	843	686	959	733	911
Polymers (Weight/Volume Change)	474	1052	464	937	659	873	634	789
Polymers (Tensile Testing)	597	736	516	503	668	911	657	633
PTFE (unfilled)	31	59	20	28	114	192	65	104

Table 80: Post-Exposure Lubricant Total Acid Number (TAN) Changes (mg KOH/g of oil) from the Seal and Polymer Compatibility Study

Material Exposures	R-1234yf		R-1234ze(E)		Three-Refrigerant Blend		100% POE	100% PVE
	POE	PVE	POE	PVE	POE	PVE		
Neoprenes 1 and 2	0.56	0.20	0.35	0.25	0.47	0.28	0.50	0.13
Nitriles (Nitrile-Based HNBR and NBR)	0.64	0.11	0.18	0.28	0.22	0.25	0.60	0.08
Fluorocarbon	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.05
EDPM	0.06	0.05	0.06	0.05	0.06	0.06	0.06	0.05
Epichlorohydrin	0.08	<0.05	0.06	0.06	0.08	0.05	0.05	<0.05
Butyl Rubber	2.47	0.30	0.97	0.30	1.19	0.28	0.84	0.26
Silicone	0.64	0.06	<0.05	<0.05	0.06	<0.05	<0.05	<0.05
Garlock® 3300	0.11	<0.05	0.11	<0.05	0.08	0.06	0.08	<0.05
Armstrong N-8092	0.27	<0.05	0.25	<0.05	0.26	<0.05	0.20	<0.05
Klingersil® C-4401	0.11	<0.05	0.20	0.08	0.13	0.06	0.11	<0.05
Polymers (Weight/Volume Change)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Polymers (Tensile Testing)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PTFE (unfilled)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

APPENDIX III - SUPPLEMENTAL MOTOR MATERIAL COMPATIBILITY INFORMATION

Table 81: Unvarnished Motor Materials Weight Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Average Weight Change (%), n=5**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Mylar® MO21	1.4	2.7	3.3	0.3
Melinex® 238	1.4	2.4	3.2	0.2
Nomex®410	1.5	7.1	4.5	0.4
Mica Glass Cloth	0.6	1.2	2.1	-0.1
Polyester Tie Cord	1.4	2.1	3.0	-0.2
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Average Weight Change (%), n=5**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Mylar® MO21	1.1	1.7	1.7	0.2
Melinex® 238	1.3	1.8	2.3	0.1
Nomex® 410	8.4	9.1	10.5	7.6
Mica Glass Cloth	0.4	-1.3	-0.6	14.2
Polyester Tie Cord	0.0	0.8	0.7	-0.7
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Average Weight Change (%), n=5**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Mylar® MO21	1.0	1.6	2.0	0.0
Melinex® 238	1.2	1.5	2.3	0.0
Nomex® 410	6.9	8.8	9.6	7.1
Mica Glass Cloth	-2.3	-3.1	-2.1	7.4
Polyester Tie Cord	0.1	0.8	1.1	-0.1

Table 82: Unvarnished Motor Materials Dielectric Strength Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	**Unexposed Material Baseline Value (kV)**	**Average Dielectric Strength Change (%), n=5**			
		R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Mylar® MO21	14.1	-2.7	9.2	-1.1	-2.8
Melinex® 238	14.1	0.1	4.4	3.2	-1.9
Nomex® 410	15.0	17.3	26.4	19.3	5.5
Mica Glass Cloth	15.5	5.6	1.8	14.2	-3.9

Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	**Unexposed Material Baseline Value (kV)**	**Average Dielectric Strength Change (%), n=5**			
		R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Mylar® MO21	14.1	0.3	1.5	2.9	-0.4
Melinex® 238	14.1	1.9	1.4	1.3	0.1
Nomex® 410	15.0	14.0	14.7	13.6	9.1
Mica Glass Cloth	15.5	11.0	5.8	20.2[1]	6.7

[1]Note that two of five replicates had dielectric strength measurements ≥ 20 kV, the maximum reading of the equipment.

Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	**Unexposed Material Baseline Value (kV)**	**Average Dielectric Strength Change (%), n=5**			
		R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Mylar® MO21	14.1	0.0	3.1	-0.1	1.1
Melinex® 238	14.1	-1.6	1.7	-0.9	0.4
Nomex® 410	15.0	12.3	14.4	16.6	5.9
Mica Glass Cloth	15.5	6.9	2.0	15.4	3.4

Table 83: Unvarnished Motor Materials Maximum Load Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	**Unexposed Material Baseline Value (lbs)**	**Average Maximum Load Change (%), n=5**			
		R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**100% Nitrogen**
Mylar® MO21	111.4	-3.4	-13.4	-14.1	-9.9
Melinex® 238	98.3	4.7	6.3	-0.2	2.2
Nomex® 410	113.8	-1.5	-5.2	-5.0	-7.8
Mica Glass Cloth	134.2	1.2	-2.2	-9.1	20.2
Polyester Tie Cord	34.5	-17.4	-10.0	-12.3	-8.9
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	**Unexposed Material Baseline Value (lbs)**	**Average Maximum Load Change (%), n=5**			
		R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Mylar® MO21	111.4	-22.2	-32.3	-29.0	-14.6
Melinex® 238	98.3	-12.7	-12.0	-15.4	-3.8
Nomex® 410	113.8	-5.3	-5.7	-12.6	-4.1
Mica Glass Cloth	134.2	-5.0	-8.5	-26.8	10.4
Polyester Tie Cord	34.5	-11.7	-14.8	-17.7	-17.5
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	**Unexposed Material Baseline Value (lbs)**	**Average Maximum Load Change (%), n=5**			
		R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Mylar® MO21	111.4	-25.3	-25.3	-32.1	-18.6
Melinex® 238	98.3	-13.8	-13.0	-16.3	-8.9
Nomex® 410	113.8	-2.7	-4.2	-7.0	-1.3
Mica Glass Cloth	134.2	1.7	-1.3	-8.1	27.1
Polyester Tie Cord	34.5	-22.5	-8.5	-12.3	-12.1

Table 84: Unvarnished Motor Materials Tensile Strength Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	Unexposed Material Baseline Value (ksi)	Average Tensile Strength Change (%), n=5			
		R-1234yf	R-1234ze(E)	Three-Refrigerant Blend	100% Nitrogen
Mylar® MO21	23.0	-7.3	-15.7	-16.4	-13.0
Melinex® 238	20.1	-1.3	3.4	-2.7	0.7
Nomex® 410	11.0	-3.4	-2.7	-3.5	-6.6
Mica Glass Cloth	14.5	-14.0	-13.3	-16.8	12.2
Polyester Tie Cord	NA	NA	NA	NA	NA
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	Unexposed Material Baseline Value (ksi)	Average Tensile Strength Change (%), n=5			
		R-1234yf:POE	R-1234ze(E):POE	Three-Refrigerant Blend:POE	100% POE
Mylar® MO21	23.0	-24.2	-34.8	-31.1	-15.3
Melinex® 238	20.1	-13.5	-14.0	-18.8	-3.6
Nomex® 410	11.0	-2.8	-4.2	-12.1	-3.9
Mica Glass Cloth	14.5	-17.0	-9.2	-35.3	2.8
Polyester Tie Cord	NA	NA	NA	NA	NA
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	Unexposed Material Baseline Value (ksi)	Average Tensile Strength Change (%), n=5			
		R-1234yf:PVE	R-1234ze(E):PVE	Three-Refrigerant Blend:PVE	100% PVE
Mylar® MO21	23.0	-26.3	-27.9	-31.8	-19.5
Melinex® 238	20.1	-15.0	-11.9	-10.7	-10.0
Nomex® 410	11.0	-2.7	-1.7	-3.3	2.5
Mica Glass Cloth	14.5	-9.9	-3.7	-26.5	15.2
Polyester Tie Cord	NA	NA	NA	NA	NA

Table 85: Unvarnished Motor Materials Percent Elongation Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	**Unexposed Material Baseline Value (%)**	**Average Percent Elongation Change (%), n=5**			
		R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**100% Nitrogen**
Mylar® MO21	118.1	0.8	24.0	-1.0	15.4
Melinex® 238	140.5	-20.7	-15.4	-23.9	-21.3
Nomex® 410	19.9	-24.2	-30.0	-18.5	-23.2
Mica Glass Cloth	3.7	8.6	11.9	0.8	5.7
Polyester Tie Cord	6.3	48.0	65.8	71.7	28.8
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	**Unexposed Material Baseline Value (%)**	**Average Percent Elongation Change (%), n=5**			
		R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Mylar® MO21	118.1	-52.2	-95.5	-77.6	-9.7
Melinex® 238	140.5	-51.7	-58.6	-63.4	-30.6
Nomex® 410	19.9	-50.5	-43.3	-49.2	-50.4
Mica Glass Cloth	3.7	5.8	17.9	-11.9	9.5
Polyester Tie Cord	6.3	111.9	118.7	124.1	90.1
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	**Unexposed Material Baseline Value (%)**	**Average Percent Elongation Change (%), n=5**			
		R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Mylar® MO21	118.1	-88.2	-73.3	-82.9	-49.7
Melinex® 238	140.5	-56.9	-60.3	-59.9	-41.9
Nomex® 410	19.9	-44.4	-42.3	-47.1	-48.2
Mica Glass Cloth	3.7	8.6	-2.2	12.6	9.8
Polyester Tie Cord	6.3	98.1	115.2	133.7	95.0

Table 86: Unvarnished Motor Materials Appearance Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Appearance Change**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Mylar® MO21	No Change	No Change	No Change	No Change
Melinex® 238	No Change	No Change	No Change	No Change
Nomex® 410	No Change	No Change	No Change	No Change
Mica Glass Cloth	Discoloration to dark golden color; Slight bubbling occurred between layers	Discoloration to dark golden color; Slight bubbling occurred between layers	Discoloration to dark golden color; Slight bubbling occurred between layers	Discoloration to dark golden color
Polyester Tie Cord	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Appearance Change**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Mylar® MO21	No Change	Pitting of Sample, Especially in Middle	Pitting of Sample, Especially in Middle	No Change
Melinex® 238	No Change	No Change	No Change	No Change
Nomex® 410	Discoloration to greyish color, darkest at edges	Discoloration to greyish color, darkest at edges	Discoloration to greyish color, darkest at edges	Slight Discoloration to greyish color, darkest at edges
Mica Glass Cloth	Discoloration to dark golden color; Slight bubbling occurred between layers	Discoloration to dark golden color; Slight bubbling occurred between layers	Discoloration to dark golden color; Slight bubbling occurred between layers	Discoloration to dark golden color; Oil observed moving around between layers
Polyester Tie Cord	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Appearance Change**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Mylar® MO21	No Change	Pitting of Sample, Especially in Middle	Pitting of Sample, Especially in Middle	No Change
Melinex® 238	No Change	No Change	No Change	No Change
Nomex® 410	Discoloration to greyish color, darkest at edges	Discoloration to greyish color, darkest at edges	Discoloration to greyish color, darkest at edges	Slight Discoloration to greyish color, darkest at edges
Mica Glass Cloth	Discoloration to dark golden color; Slight bubbling occurred between layers	Discoloration to dark golden color; Slight bubbling occurred between layers	Discoloration to dark golden color; Slight bubbling occurred between layers	Discoloration to dark golden color; Oil observed moving around between layers
Polyester Tie Cord	No Change	No Change	No Change	No Change

Table 87: Unvarnished Motor Materials Extractable Material Observation Summary

Material	Presence and Location (if Observed) of Extractable Material			
	R-1234yf	R-1234ze(E)	Three-Refrigerant Blend	Nitrogen
Mylar® MO21 Melinex® 238 Nomex® 410 Mica Glass Cloth	Oily extract observed on the bottom of the Parr bomb	Oily extract observed on the bottom of the Parr bomb	Oily extract observed on the bottom of the Parr bomb	None observed
Polyester Tie Cord	None observed	None observed	None observed	None observed

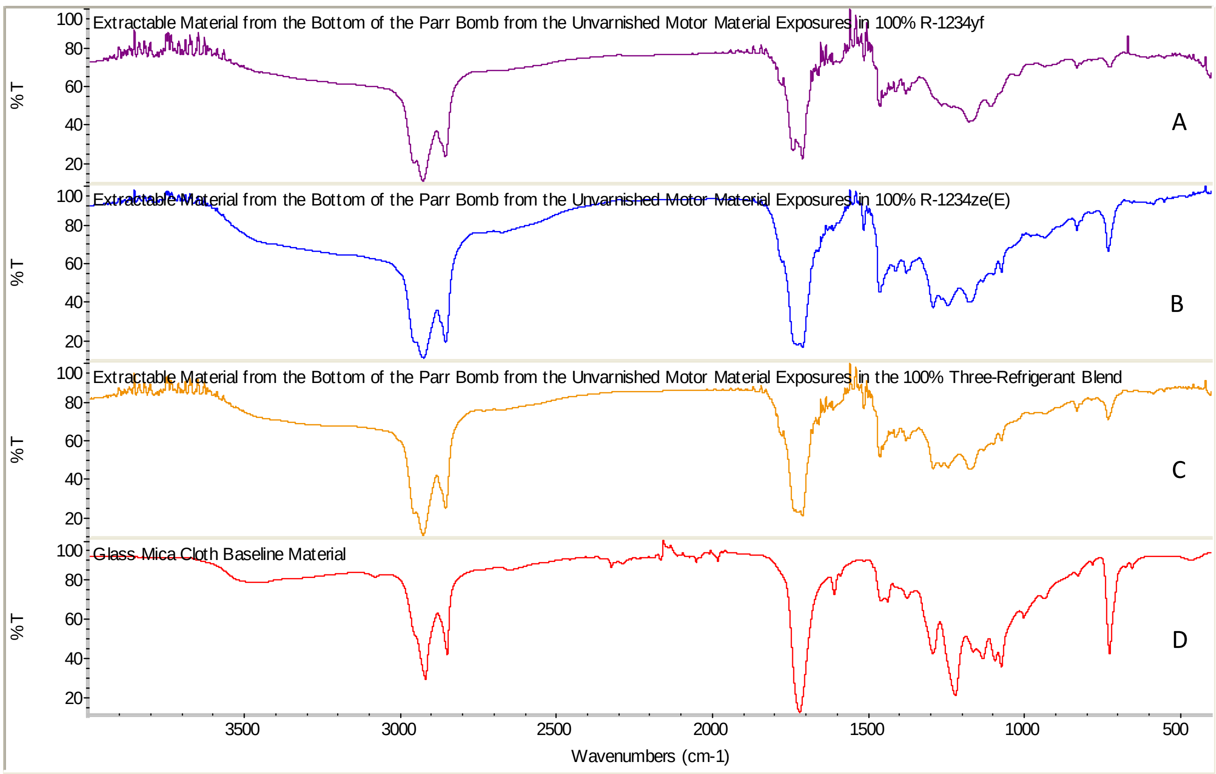


Figure 28. FTIR spectra of extractables from the exposures of the unvarnished motor materials (A-C), and reference spectrum of unexposed glass mica cloth (D).

Table 88: Image Compilation of Mylar® MO21 Polyester Material

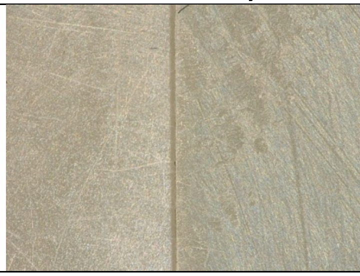
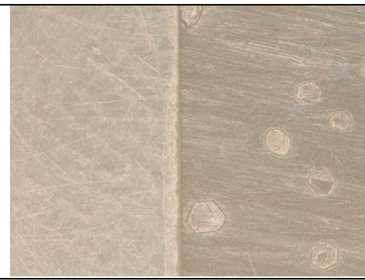
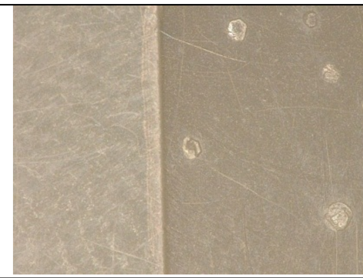
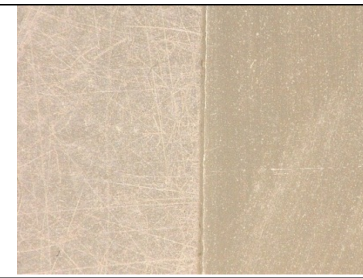
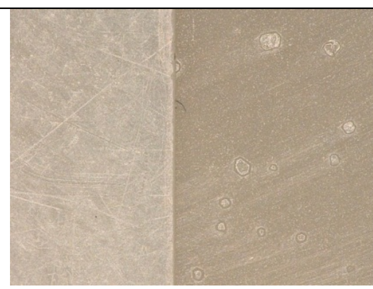
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 89: Image Compilation of Melinex® 238 Polyester Material

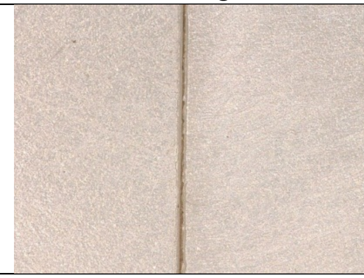
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 90: Image Compilation of Nomex® 410 Material

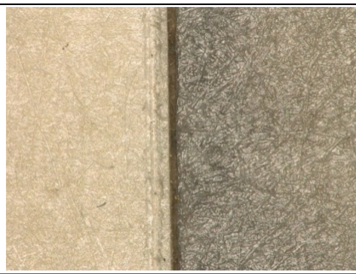
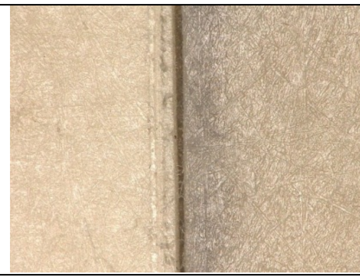
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 91: Image Compilation of Glass Mica Cloth Material

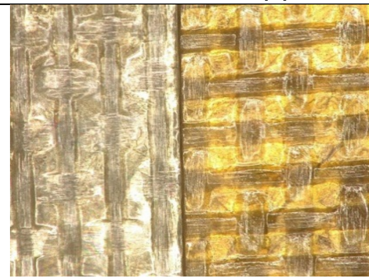
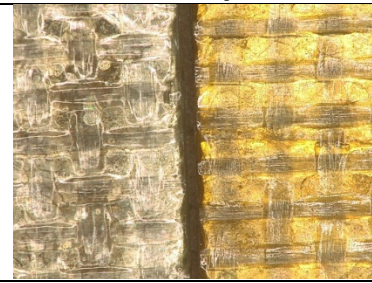
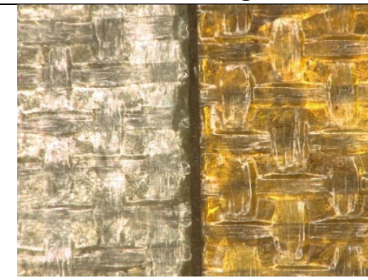
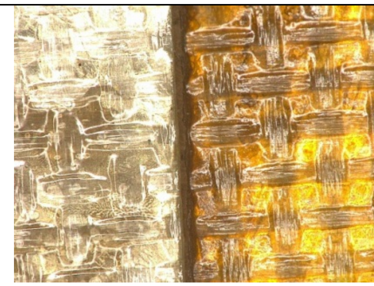
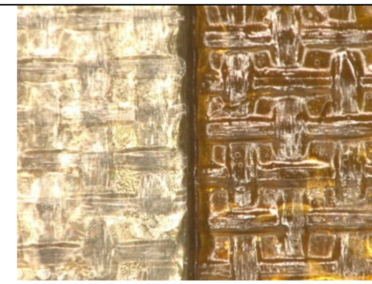
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 92: Image Compilation of the Polyester Tie Cord Material

Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 93: Varnish Pucks Volume and Weight Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures								
Material	Average Volume and Weight Change (%), n=5							
	R-1234yf		R-1234ze(E)		Three-Refrigerant Blend		Nitrogen	
	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
Pedigree® 923 Solvent-Based Varnish	1.4	0.7	2.0	1.8	1.8	2.2	-0.2	-0.8
Guardian™ Water-Borne Varnish	1.4	0.7	1.9	1.2	2.6	2.3	0.6	0.0
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures								
Material	Average Volume and Weight Change (%), n=5							
	R-1234yf:POE		R-1234ze(E):POE		Three-Refrigerant Blend:POE		100% POE	
	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
Pedigree® 923 Solvent-Based Varnish	-4.0	-4.2	-4.0	-4.5	-4.3	-3.8	-4.6	-4.7
Guardian™ Water-Borne Varnish	0.2	0.0	1.5	0.4	0.8	0.1	0.2	-0.1
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures								
Material	Average Volume and Weight Change (%), n=5							
	R-1234yf:PVE		R-1234ze(E):PVE		Three-Refrigerant Blend:PVE		100% PVE	
	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
Pedigree® 923 Solvent-Based Varnish	-4.6	-4.8	-3.9	-4.2	-4.5	-4.3	-4.5	-4.6
Guardian™ Water-Borne Varnish	0.7	0.0	1.4	0.3	0.9	0.4	0.3	-0.2

Table 94: Varnish Pucks Appearance Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Appearance Change**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Pedigree® 923 Solvent-Based Varnish	No Change	No Change	No Change	No Change
Guardian™ Water-Borne Varnish	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Appearance Change**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Pedigree® 923 Solvent-Based Varnish	No Change	No Change	Severely Darker in Color	No Change
Guardian™ Water-Borne Varnish	Samples Darkened to a Golden Amber Color	Samples Darkened to a Golden Amber Color	Samples Darkened to a Golden Amber Color	Samples Darkened to a Golden Amber Color
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Appearance Change**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Pedigree® 923 Solvent-Based Varnish	No Change	No Change	No Change	No Change
Guardian™ Water-Borne Varnish	Samples Darkened to a Golden Amber Color	Samples Darkened to a Golden Amber Color	Samples Darkened to a Golden Amber Color	Samples Darkened to a Golden Amber Color

Table 95: Varnish Pucks Extractable Material Observation Summary

Material	**Presence and Location (if Observed) of Extractable Material**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Pedigree® 923 Solvent-Based Varnish	Extract observed on the bottom of the vessel	Extract observed on the bottom of the vessel	Extract observed on the bottom of the vessel	None Observed
Guardian™ Water-Borne Varnish	None Observed	None Observed	None Observed	None Observed

Figure 29. Comparison of FTIR spectra of extractables from the exposures of the Pedigree® 923 solvent-based varnish (A-C), and reference spectrum of unexposed cured Pedigree® 923 (D).

Table 96: Varnish Pucks Post-Bakeout Weight Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Average Post-Bakeout Weight Change (%), n=5**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Pedigree® 923 Solvent-Based Varnish	0.0	0.8	0.5	-1.1
Guardian™ Water-Borne Varnish	-0.1	0.3	1.0	-0.4
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Average Post-Bakeout Weight Change (%), n=5**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Pedigree® 923 Solvent-Based Varnish	-4.5	-4.6	-4.3	-4.8
Guardian™ Water-Borne Varnish	-0.7	-0.4	-0.7	-1.1
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Average Post-Bakeout Weight Change (%), n=5**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Pedigree® 923 Solvent-Based Varnish	-5.0	-4.5	-5.0	-4.8
Guardian™ Water-Borne Varnish	-0.8	-0.6	-0.7	-1.2

Table 97: Varnish Pucks Post-Bakeout Appearance Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**Nitrogen**
Pedigree® 923 Solvent-Based Varnish	No Change	No Change	No Change	No Change
Guardian™ Water-Borne Varnish	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Pedigree® 923 Solvent-Based Varnish	Slightly Darker in Color	Slightly darker in color, but not as dark as the other conditions that darkened	No Change	Slightly Darker in Color
Guardian™ Water-Borne Varnish	No Change	No Change	No Change	No Change
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures				
Material	**Post-Bakeout Appearance Change**			
	R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Pedigree® 923 Solvent-Based Varnish	Slightly Darker in Color	Slightly Darker in Color	Slightly Darker in Color	Slightly Darker in Color
Guardian™ Water-Borne Varnish	No Change	No Change	No Change	No Change

Table 98: Image Compilation of Elantas Pedigree® 923 Solvent-Based Varnish Pucks

Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 99: Image Compilation of Elantas Guardian™ Water-Borne Varnish Pucks

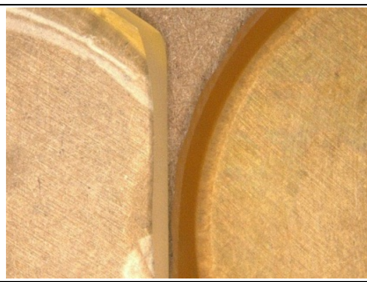
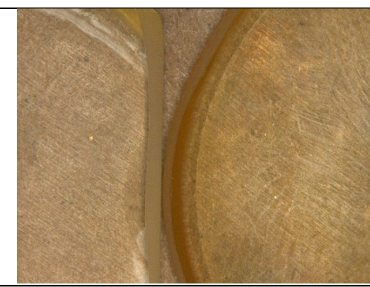
Post-Exposure Sample Comparison with Unexposed Control Sample (control sample on left, exposed sample on right)			
100% R-1234yf	**100% R-1234ze(E)**	**100% Three-Refrigerant Blend**	**100% Nitrogen**
			
50% R-1234yf:50% POE	**50% R-1234ze(E):50% POE**	**50% Three-Refrigerant Blend:50% POE**	**100% POE**
			
50% R-1234yf:50% PVE	**50% R-1234ze(E):50% PVE**	**50% Three-Refrigerant Blend:50% PVE**	**100% PVE**
			

Table 100: Single Strand Mandrel Bend Test Observation Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	**Unexposed Material Baseline Observations**	**Observations of Exposed Single Strand Samples after the Mandrel Bend Test**			
		R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**100% Nitrogen**
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	No Cracking	No Cracking	No Cracking	No Cracking	Severe Cracking
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	No Cracking	Minor Cracking	No Cracking	No Cracking	Minor Cracking
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	Minor Cracking	Minor Cracking	Minor Cracking	Minor Cracking	Significant Cracking
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	Minor Cracking	Minor Cracking	Minor Cracking	Minor Cracking	Minor Cracking
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	**Unexposed Material Baseline Observations**	**Observations of Exposed Samples**			
		R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	No Cracking	Severe Cracking	Severe Cracking	Minor Cracking	Severe Cracking
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	No Cracking	Minor Cracking	Minor Cracking	Minor Cracking	Minor Cracking
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	Minor Cracking	Significant Cracking	Significant Cracking	Minor Cracking	Significant Cracking
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	Minor Cracking	Minor Cracking	Significant Cracking	Minor Cracking	Minor Cracking

Table 100 (continued): Single Strand Mandrel Bend Test Observation Summary

Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	**Unexposed Material Baseline Observations**	**Observations of Exposed Samples**			
		R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	No Cracking	Severe Cracking	Severe Cracking	Minor Cracking	Severe Cracking
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	No Cracking	Minor Cracking	Minor Cracking	Minor Cracking	Minor Cracking
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	Minor Cracking	Significant Cracking	Significant Cracking	Minor Cracking	Significant Cracking
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	Minor Cracking	Significant Cracking	Significant Cracking	Minor Cracking	Significant Cracking

Table 101: Twisted Pairs Dielectric Strength Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	**Unexposed Material Baseline Value (kV)**	**Average Dielectric Strength Change (%), n=5**			
		R-1234yf	**R-1234ze(E)**	**Three-Refrigerant Blend**	**100% Nitrogen**
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	16.0	17.6	10.4	11.7	13.0
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	15.6	4.8	-13.6	1.8	-2.9
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	13.7	-10.0	-8.4	-9.1	-16.5
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	12.2	-7.9	-7.7	22.9	-6.3
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	**Unexposed Material Baseline Value (kV)**	**Average Dielectric Strength Change (%), n=5**			
		R-1234yf:POE	**R-1234ze(E):POE**	**Three-Refrigerant Blend:POE**	**100% POE**
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	16.0	17.8	18.0	9.6	-17.5
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	15.6	-7.9	2.9	-10.2	-7.7
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	13.7	11.9	-5.5	-12.7	-13.0
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	12.2	2.7	2.0	13.3	-4.9

Table 101 (continued): Twisted Pairs Dielectric Strength Change Summary

Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	Unexposed Material Baseline Value (kV)	Average Dielectric Strength Change (%), n=5			
		R-1234yf:PVE	R-1234ze(E):PVE	Three-Refrigerant Blend:PVE	100% PVE
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	16.0	-8.6	13.6	-3.6	18.0
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	15.6	-8.6	-1.5	-7.8	-2.3
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	13.7	-12.6	-2.3	-11.3	-12.6
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	12.2	-3.1	5.2	-0.3	-10.3

Table 102: Twisted Pairs Burnout Strength Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	Unexposed Material Baseline Value (seconds)	Average Burnout Strength Change (%), n=5			
		R-1234yf	R-1234ze(E)	Three-Refrigerant Blend	100% Nitrogen
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	774	0.6	-4.0	-2.0	1.9
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	636	-0.6	3.8	9.3	-1.6
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	915	-1.2	0.0	-4.4	0.1
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	899	-0.1	-0.4	-3.8	0.0

Table 102 (continued): Twisted Pairs Burnout Strength Change Summary

Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	Unexposed Material Baseline Value (seconds)	Average Burnout Strength Change (%), n=5			
		R-1234yf:POE	R-1234ze(E):POE	Three-Refrigerant Blend:POE	100% POE
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	774	-3.8	-4.8	-0.6	0.9
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	636	3.8	-0.7	0.4	0.7
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	915	0.6	-1.1	-0.1	-0.1
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	899	1.1	-2.5	-1.0	1.1
Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	Unexposed Material Baseline Value (seconds)	Average Burnout Strength Change (%), n=5			
		R-1234yf:PVE	R-1234ze(E):PVE	Three-Refrigerant Blend:PVE	100% PVE
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	774	-3.2	-2.2	0.1	0.3
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	636	4.2	-0.3	2.6	1.8
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	915	-0.2	-0.1	-0.3	0.4
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	899	-2.2	-3.2	-2.9	-1.1

Table 103: Helical Coils Bond Strength Change Summary

Results from 100% Refrigerant and Nitrogen Control Exposures					
Material	Unexposed Material Baseline Value (lbs)	Average Bond Strength Change (%), n=5			
		R-1234yf	R-1234ze(E)	Three-Refrigerant Blend	Nitrogen
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	44.5	25.0	-17.3	-4.1	-30.0
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	53.6	7.2	-1.9	0.7	18.4
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	28.2	0.2	-4.9	-25.8	-25.4
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	31.2	3.4	7.8	-2.8	-17.3
Results from 50% Refrigerant:50% Polyol Ester (POE) Lubricant and 100% POE Control Exposures					
Material	Unexposed Material Baseline Value (lbs)	Average Bond Strength Change (%), n=5			
		R-1234yf:POE	R-1234ze(E):POE	Three-Refrigerant Blend:POE	100% POE
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	44.5	-22.8	-37.9	-23.9	-21.3
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	53.6	-16.5	-31.9	17.7	11.5
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	28.2	-19.6	-31.2	-20.4	-25.0
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	31.2	-17.9	-22.4	-12.6	-8.6

Table 103 (continued): Helical Coils Bond Strength Change Summary

Results from 50% Refrigerant:50% Polyvinyl Ether (PVE) Lubricant and 100% PVE Control Exposures					
Material	**Unexposed Material Baseline Value (lbs)**	**Average Bond Strength Change (%), n=5**			
		R-1234yf:PVE	**R-1234ze(E):PVE**	**Three-Refrigerant Blend:PVE**	**100% PVE**
Film Insulated Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	44.5	-25.8	-26.5	-46.3	-41.9
Film Insulated Round Magnet Wire with Guardian™ Water-Borne Varnish	53.6	2.0	28.1	21.2	-1.7
Fibrous Covered Round Magnet Wire with Pedigree® 923 Solvent-Based Varnish	28.2	-25.8	-24.2	-20.7	-18.2
Fibrous Covered Round Magnet Wire with Guardian™ Water-Borne Varnish	31.2	-18.7	-4.8	-1.5	-13.3

Post-Exposure Fluid Analyses from the Motor Material Compatibility Study

Table 104: Post-Exposure Lubricant Moisture Changes (ppm) from the Motor Material Compatibility Study

Material Exposures	R-1234yf		R-1234ze(E)		Three-Refrigerant Blend		100% POE	100% PVE
	POE	PVE	POE	PVE	POE	PVE		
Mylar® MO21, Melinex® 238, Nomex® 410, & Mica Glass Cloth	284	777	345	727	565	963	290	637
Polyester Tie Cord	166	277	173	131	192	229	267	278
Pedigree® 923 Solvent-Based Varnish Pucks	518	1154	393	1119	528	1166	468	1087
Guardian™ Water-Borne Varnish Pucks	1913	3297	1803	3067	896	3474	1456	2325
Film Insulated & Fibrous Covered Round Magnet Wires with Pedigree® 923 Solvent-Based Varnish	123	184	88	163	116	207	100	127
Film Insulated & Fibrous Covered Round Magnet Wires with Guardian™ Water-Borne Varnish	172	257	147	229	168	264	153	147

Table 105: Post-Exposure Total Acid Number (TAN) Changes (mg KOH/g of oil) from the Motor Material Compatibility Study

Material Exposures	R-1234yf		R-1234ze(E)		Three-Refrigerant Blend		100% POE	100% PVE
	POE	PVE	POE	PVE	POE	PVE		
Mylar® MO21, Melinex® 238, Nomex® 410, & Mica Glass Cloth	2.44	0.45	1.91	0.39	1.95	0.39	1.26	0.20
Polyester Tie Cord	0.14	<0.05	0.58	<0.05	0.22	<0.05	0.13	<0.05
Pedigree® 923 Solvent-Based Varnish Pucks	2.88	0.11	0.88	0.11	6.21	0.11	2.65	<0.05
Guardian™ Water-Borne Varnish Pucks	2.26	0.06	3.41	0.08	0.24	0.06	1.96	<0.05
Film Insulated & Fibrous Covered Round Magnet Wires with Pedigree® 923 Solvent-Based Varnish	0.13	<0.05	0.11	<0.05	0.25	<0.05	0.06	<0.05
Film Insulated & Fibrous Covered Round Magnet Wires with Guardian™ Water-Borne Varnish	0.08	<0.05	0.11	<0.05	0.14	<0.05	0.06	<0.05