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MATERIALS COMPATIBILITY AND LUBRICANTS RESEARCH ON CFC-REFRIGERANT SUBSTITUTES

Quarterly MCLR Program Technical Progress Report

1 July 1992 - 30 September 1992

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MATERIALS COMPATIBILITY AND LUBRICANT RESEARCH ON CFC-REFRIGERANT SUBSTITUTES

ABSTRACT

The Materials Compatibility and Lubricants Research (MCLR) program supports critical research to accelerate the introduction of CFC-refrigerant substitutes. The MCLR program addresses refrigerant and lubricant properties and materials compatibility. The primary elements of the work include data collection and dissemination, materials compatibility testing, and methods development. The work is guided by an Advisory Committee consisting of technical experts from the refrigeration and air-conditioning industry and government agencies. Under the current MCLR program the Air-Conditioning and Refrigeration Technology Institute, Inc., (ARTI) is contracting and managing several research projects and a data collection and dissemination effort. Preliminary results from these projects are reported in technical progress reports prepared by each researcher.

SCOPE

The Materials Compatibility and Lubricant Research (MCLR) program is a 36 month research grant administered by the Air-Conditioning and Refrigeration Technology Institute (ARTI), a not-for-profit organization for scientific research in the public interest. The program was implemented on 30 September 1991 and will run through 30 September 1994. The MCLR program currently consists of a number of research projects grouped in phases. Phase I encompasses seven research projects and a data collection and dissemination project. Phase I projects began in January 1992 and will run through March 1993. Phase II currently consists of eight research projects and a data collection and dissemination project. Phase II projects began in October 1992 and will run through September 1994. This report summarizes the research conducted during the 3rd quarter of calendar year 1992.

SIGNIFICANT RESULTS

THERMOPHYSICAL PROPERTIES

Objective:

To provide highly accurate, selected thermophysical properties data for refrigerants HFC-32, HCFC-123, HCFC-124, and HFC-125, and to fit these data to simple, theoretically-based equations of state, as well as complex equations of state and detailed transport property models. The new data will fill the gaps in existing data sets and resolve the problems and uncertainties that exist in and between the data sets. Thermodynamic properties measurements and determinations will include vapor pressure-volume-temperature behavior, liquid pressure-volume-temperature behavior, saturation and critical points, vapor sound speed and ideal gas heat capacity, isochoric heat capacity, Carnahan-Starling-DeSantis (CSD) and the modified Benedict-Webb-Rubin (MBWR) equations of state. Transport properties measurements and correlations will include thermal conductivity and viscosity measurements.

Results:

The Thermophysics Division of the National Institute of Standards and Technology (NIST) is performing this research under contract with ARTI. A detailed report of their progress is contained in DOE report number DOE/CE/23810-4A, *Thermophysical Properties*, Quarterly Report 1 July 1992 - 30 September 1992, by Dr. Richard F. Kayser. Key results are summarized below:

HFC-32: NIST has obtained sufficient pressure-volume-temperature (PVT) data to develop a preliminary wide-range equation of state of the modified Benedict-Webb-Rubin (MBWR) type. The Burnett apparatus was used in the isochoric mode to derive vapor phase PVT data and a vibrating tube densimeter was used to determine the PVT relation for the liquid phase. The data were extrapolated to the vapor pressure to determine the density of the liquid at the saturated vapor pressure. A preliminary MBWR equation of state was fitted to the Burnett and vibrating tube data. Additional measurements of the vapor pressure and coexisting densities of HFC-32 have been completed at temperatures from 300 K (80°F) to near its critical point. A manuscript prepared by V. G. Niesen, et al., entitled *Coexisting Densities, Vapor Pressures, and Critical Densities of R-32 and R-152a at 300 to 385 K*, is included in the NIST quarterly technical report as an appendix.

NIST used an adiabatic calorimeter to measure the molar heat capacity at constant volume (C_v) for HFC-32. The NIST report presents data ranging from 138 K to 345 K (-211 to 161°F) with pressures to 35 MPa (5000 psi).

The transient hot-wire study of the thermal conductivity of HFC-32 has been extended from 300 to 340K (80 to 160°F) at pressures to 70 MPa (10,000 psi). Preliminary results from the analysis of the 926 transient hot-wire measurements were presented in the NIST quarterly report.

A torsional quartz crystal viscometer was used to measure the shear viscosity of HFC-32. Measurements on the compressed liquid were initiated. However, excessive electrical conductance of the fluid have hampered NIST's measurements; resulting in errors as large as 15 percent in the apparent viscosity. This effect has been noticed by NIST in other refrigerants (HFC-134a), but never with a typical non-polar fluid. NIST described two procedures to reduce the electrical conductance of refrigerants in the apparatus: (1) storing the refrigerant in contact with activated molecular sieves and (2) cleaning the apparatus with a polar solvent such as acetone (toluene has not been beneficial). Researchers at NIST are now continuing their measurements. They are also using a new capillary flow viscometer to measure the viscosity of saturated liquid HFC-32 over a limited temperature range as an independent check.

HCFC-123: During the last quarter NIST researchers have expanded their measurements of the thermal conductivity of liquid and vapor HCFC-123 using the low- and high-temperature transient hot-wire thermal conductivity instruments. Data for both the liquid and vapor were extended from 440 to 480 K (332 to 405°F) and a significant thermal conductivity critical enhancement was found in the saturated liquid, saturated vapor, and supercritical gas. The results of a preliminary analysis of 1618 transient hot-wire measurements are presented in the NIST quarterly report.

HCFC-124: NIST has made additional measurements of the vapor pressure and coexisting densities of HCFC-124 at temperatures ranging from 300 K (80°F) to near its critical temperature at 395 K (251°F). Two manuscripts, one by V. G. Niesen, et al., entitled *Coexisting Densities and Vapor Pressures of Refrigerants R-22, R-134a, and R-124 at 300 to 395 K* and another by L. J. Van Poolen, et al., entitled *Critical Densities from Coexisting Density Data: Application to Refrigerants R-22, R-134a, and R-124* were included in the NIST quarterly report as appendices.

Also reported in the NIST quarterly report is the analysis of the cylindrical acoustic resonator measurements

of the speed of sound in HCFC-124 along isotherms between 250 and 400 K (-9 and 261°F) at pressures between 20 and 900 kPa (3 and 130 psi).

NIST has performed extensive research on the transport properties of HCFC-124 under separate sponsorship from the Department of Energy. Results of this research span the range of temperatures from 180 to 383 K (-135 to 230°F) at pressures up to 70 MPa (10,000 psi). Similarly, measurements of the viscosity of HCFC-124 have been completed for temperatures between 120 and 420 K (-243 and 297°F) at pressures up to 50 MPa (7,300 psi). Because differences as large as 65% were found between the NIST data and previously published data, measurements of the viscosity of saturated liquid HCFC-124 were conducted with a new high-pressure capillary flow viscometer. Good agreement was obtained with the earlier NIST measurements. A paper prepared by D. E. Diller and S. M. Peterson entitled, *Measurements of the Viscosities of Saturated and Compressed fluid 1-Chloro-1,2,2,2-Tetrafluoroethane (R-124) and Pentafluoroethane (R-125) at Temperatures Between 120 and 400 K*, was included in the NIST quarterly report as an appendix.

HFC-125: NIST used an adiabatic calorimeter to measure molar heat capacity at constant volume (C_v) for HFC-125. A total of 120 C_v values were measured in the liquid state and 100 values in the vapor + liquid two-phase region. The temperatures ranged from 176 to 342 K (-143 to 156°F) with pressures to 35 MPa (5000 psi). These measurements are present in the NIST quarterly report.

As in the case of HCFC-124, NIST has performed extensive research on transport properties of HFC-125 under the sponsorship of the Department of Energy. Measurements of thermal conductivity of HFC-125 have been completed for temperatures from 190 to 390 K (-112 to 245°F) at pressures up to 70 MPa (10,000 psi). Viscosity measurements of HFC-125 have also been completed for temperatures between 120 and 420 K (-243 and 297°F) at pressures to 70 MPa (7300 psi). Differences as large as 80% were found between the NIST data obtained with two torsional crystal viscometers and previous published values. NIST conducted measurements of viscosity of saturated liquid HFC-125 using a new high-pressure capillary flow viscometer to investigate these differences. Good agreement was obtained between the two NIST methods.

THEORETICAL EVALUATIONS OF R-22 ALTERNATIVE FLUIDS:

Objective:

To provide information regarding the Coefficients of Performance (COP), capacities, compressor discharge temperatures, compressor discharge pressures, and compressor discharge pressure ratios of the following nine alternative fluids, relative to HCFC-22:

Alternative Refrigerants/Blends (% Weight)

HFC-32/HFC-123 (60/40)	HFC-32/HFC-134a (30/70)
HFC-125/HFC-134a (45/55)	HFC-32/HFC-125/HFC-134a (10/70/20)
HFC-32/HFC-125/HFC-134a (30/10/60)	HFC-134a
HFC-32/HFC-125/HFC-134a/R-290 (20/55/20/5)	R-290 (Propane)
HFC-125/HFC-143a/HFC-134a (40/45/15)	

The Building Environment Division of the National Institute of Standards and Technology (NIST) is performing this research under contract with ARTI. Detailed results of this study are reported in DOE report number DOE/CE/23810-7, *Theoretical Evaluations of R-22 Alternative Fluids*, Final Report, by Dr. David Didion.

CHEMICAL AND THERMAL STABILITY OF REFRIGERANT-LUBRICANT MIXTURES WITH METALS

Objectives:

- To provide information on the stability of potential substitutes for CFC refrigerants and appropriate lubricants.

Results:

Spausch Associates, Inc., has completed this research under contract with ARTI. A detailed report of their results is contained in DOE report number DOE/CE/23810-5, *Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures with Metals*, Final Report, by Dr. Dietrich F. Huttenlocher. Key results are summarized below:

Alternative Refrigerant-Lubricant Combinations

CFC-11 (baseline) with:	HFC-134 with:
naphthenic mineral oil ISO 32	pentaerythritol ester, branched acid
naphthenic mineral oil ISO 46	HFC-134a with:
CFC-12 (baseline) with:	pentaerythritol ester, mixed acid
naphthenic mineral oil ISO 32	pentaerythritol ester, branched acid
alkylbenzene	pentaerythritol ester, 100 cSt
HCFC-22 with:	polypropylene glycol butyl monoether
naphthenic mineral oil ISO 32	polypropylene glycol diol
HFC-32 with:	modified polyglycol
pentaerythritol ester, branched acid	HCFC-142b with:
polypropylene glycol butyl monoether	alkylbenzene
HCFC-123 with:	HFC-143a with:
naphthenic mineral oil ISO 32	pentaerythritol ester, branched acid
naphthenic mineral oil ISO 46	HFC-152a with:
HCFC-124 with:	alkylbenzene
alkylbenzene	HFC-125 with:
	pentaerythritol ester, branched acid
	polypropylene glycol butyl monoether
	modified polyglycol

Based on the results of his research, Dr. Huttenlocher made the following conclusions:

- All HFCs tested, along with HCFC-22, were very stable and did not undergo any measurable chemical reactions or thermal decompositions at temperatures up to 200°C (392°F).
- HCFC-124 and HCFC-142b were less stable than the HFCs tested but more stable than CFC-12 - a long time industry standard.
- While HCFC-123 was the least stable of the "new" refrigerants tested, it was still ten fold more stable than CFC-11 - the refrigerant it is intended to replace in low pressure chiller applications.
- The pentaerythritol esters included in the project exhibited acid number increases after aging at 200°C (392°F). The high viscosity (100 cSt) pentaerythritol ester exhibited additional evidence of molecular changes during aging at 200°C. The formation of CO₂ indicated decarboxylation of the high viscosity pentaerythritol ester lubrication at that temperature.
- All of the polyalkylene glycol lubricants indicated signs of molecular change after aging.

MISCIBILITY OF LUBRICANTS WITH REFRIGERANTS

Objectives:

- To provide information on the miscibility of both current and new lubricants with potential substitutes for CFC refrigerants.

Results:

Iowa State University of Science and Technology is performing this research under contract with ARTI. Part 1 of the project, preliminary miscibility screening, has been completed. A detailed report on the results of this research is contained in DOE report number DOE/CE/23810-6, *Miscibility of Lubricants with Refrigerants*, Final Report (Part 1), by Dr. Michael B. Pate, Mr. Steven C. Zoz, and Mr. Lyle J. Berkenbosch. Key results are summarized in Table 1.

COMPATIBILITY OF REFRIGERANTS AND LUBRICANTS WITH MOTOR MATERIALS

Objective:

To provide information on the compatibility of motor materials with potential substitutes for CFC refrigerants and with suitable lubricants.

Results:

The Trane Company is performing this research under contract with ARTI. A detailed report of their progress is contained in DOE report number DOE/CE/23810-4B, *Compatibility of Refrigerants and Lubricants with Motor Materials*, Quarterly Report 1 July 1992 - 30 September 1992, by Dr. Robert Doerr and Mr. Stephen Kujak.

This project investigates the compatibility of 24 samples of commercially available motor materials with ten pure refrigerants and 17 refrigerant-lubricant mixtures. At the end of the reporting period, Trane had completed all of the compatibility tests with pure refrigerants except for the dielectric strength, burnout resistance and bond strength of samples exposed to HFC-134. They have also completed compatibility tests with six refrigerant/lubricant combinations. Discussion of these refrigerant-lubricant mixtures will be presented after all of the refrigerant/lubricant mixture tests have been completed.

The sample motor materials were exposed to refrigerant or refrigerant-lubricant mixtures for 500 hours at temperatures specified for each refrigerant. The effect of heat alone was determined by exposing the samples in nitrogen gas at the same temperatures as the refrigerants exposures.

<u>HCFC Refrigerants</u>		<u>HFC Refrigerants</u>		<u>Baseline Exposures</u>
HCFC-22	@ 90°C*	HFC-152a	@ 90°C	Nitrogen @ 60°C
HCFC-123	@ 90°C	HFC-134a	@ 90°C	Nitrogen @ 90°C
HCFC-124	@ 90°C	HFC-134	@ 90°C	
HCFC-142b	@ 90°C	HFC-125	@ 60°C**	*90°C = 194°F
		HFC-32	@ 60°C	**60°C = 140°F
		HFC-143a	@ 60°C	

The various evaluations listed below were made on the motor materials immediately after the 500 hour exposure, and also after the 500 hour exposure with an additional 24 hour air bake at 150°C (302°F) to out-gas the absorbed refrigerant. The test samples included six different varnishes, three different magnet wires, six different sheet insulation materials, one tie cord, three different spiral wrapped sleeving insulating materials, and three different tapes. For the magnet wire/varnish samples, the three types of magnet wire were overcoated with one of each of the six varnishes, producing eighteen different magnet wire/varnish combinations.

Motor Materials Evaluations

<u>Varnish</u>	<u>Magnet Wire/Varnish</u>	<u>Sheet Insulation</u>
weight change	bond strength	weight change
	burnout resistance	tensile strength
<u>Lead Wire</u>	dielectric strength	elongation
weight change		dielectric strength
dielectric strength	<u>Spiral Wrapped Sleeving</u>	
	weight change	<u>Tapes</u>
<u>Tie Cord</u>	break load strength	weight change
weight change		
break load strength		

Results of the project indicated that the motor materials absorbed HCFC-123 more readily than any of the other test refrigerants. However, the absorption of HCFC-22, HFC-32, HFC-134a and HFC-152a, followed by their desorption at higher temperatures, resulted in greater damage to the insulating material than that from HCFC-123. This suggests that the effects from the rate of desorption were greater than those for absorption. The rapid desorption of a refrigerant from the insulating materials caused blisters, cracking, internal bubbles and delamination. The resulting measured effects on the physical properties of the materials were a decrease of the bond strength, dielectric strength, and physical integrity of the material. Burnout tests on magnet wire/varnish samples indicated that magnet wire with Dacron-glass serving was more resistant to burnout than the other magnet wires, and was influenced less by refrigerant absorption. The sheet insulation, lead wires and tapes appeared to be less affected by the refrigerant than the varnished magnet wires. However, the Permacel assembly tape exhibited a high extraction of material after exposure to refrigerants.

Of the ten refrigerants tested to date, HCFC-22 appeared to have the most deleterious effects on the motor material test samples. However, since HCFC-22 has an excellent reliability history with many motor materials, the other test refrigerants should pose no serious incompatibility problems with most of the motor materials tested in actual system applications.

COMPATIBILITY OF REFRIGERANTS AND LUBRICANTS WITH ELASTOMERS

Objectives:

- To provide compatibility information for elastomers with potential substitutes for CFC refrigerants and with suitable lubricants.
- To obtain data on changes in the physical and mechanical properties of selected elastomers after thermal aging in refrigerant-lubricant mixtures.

Results:

The University of Akron is performing this research under contract with ARTI. A detailed report of their progress is contained in DOE report number DOE/CE/23810-4C, *Compatibility of Refrigerants and Lubricants with Elastomers*, Quarterly Report 1 July 1992 - 30 September 1992, by Dr. Gary R. Hamed and Mr. Robert H. Seiple.

This research project examines the compatibility of ten refrigerant and seven lubricants with 95 elastomeric materials.

Refrigerants

HCFC-22
 HCFC-123
 HFC-134a
 HCFC-142b
 HFC-152a
 HFC-32
 HCFC-124
 HFC-125
 HFC-143a
 HFC-134

Lubricants

naphthenic mineral oil
 alkylbenzene
 polypropylene glycol butyl monoether
 polypropylene glycol diol
 modified polyglycol
 pentaerythritol ester, mixed-acid
 pentaerythritol ester, branched-acid

Elastomer Families

SBR-High/Low Styrene Content
 Polyisoprene
 Butyls-Chlorinated/Brominated
 CI/Rubbers
 Nitriles-Low/Medium/High ACN
 Nitriles-Hydrogenated
 Fluorinated Elastomers
 Silicones
 Epichlorohydrin Based Rubbers
 Fluorosilicones
 EPDM/Polypropylene TPEs

Copolyester TPEs
 Nitrile/Polypropylene TPEs
 Polysulfide Rubbers
 Polyurethanes
 EPR
 Chlorosulfonated Polyethylene
 Chlorinated PE
 Ethylene/Acrylic Elastomers
 EPDM Rubbers
 Fluorinated/Chlorinated Rubbers

Swell behavior of elastomer samples were determined by comparing pre-exposure sample measurements for weight, thickness and diameter with their measurements after exposure.

For lubricant exposures, elastomer samples were completely immersed in the test lubricant, sealed in a glass vessel and then heated at 60°C for 14 days. Sample diameters were remeasured after 24 hours of exposure. The elastomer samples were also measured for weight, thickness and diameter immediately after the 14 day exposure and then again 24 hours after removal. For refrigerant exposures, samples were measured for weight and diameter, then loaded into pressure vessels and charged with refrigerants. In situ diameter changes are determined using a traveling microscope after 24 hour, 72 hour and 14 day exposures. Following the 14 day exposures the samples were weighed. Finally the samples were remeasured 2 hours and 24 hours after they were removed from the pressure vessels.

Lubricant Exposure Tests

Lubricants:	Good Swell Characteristics:	Bad Swell Characteristics:
Modified Polyglycol	Fluoroelastomers Fluorosilicones	Ethylene/Acrylic Elastomers
Mineral Oil	Fluoroelastomers Fluorosilicones High ACN Nitriles	Butyl Low ACN Nitriles SBR CI/Rubbers EPDM
Polypropylene Glycol Butyl Monoether	Butyl High ACN Nitriles Fluorosilicones Fluoroelastomers EPDM EPR	CI/Rubbers Polyisoprene Low ACN Nitriles
Alkylbenzene	High ACN Nitriles Fluoroelastomers Fluorosilicones	Most others
Polypropylene Glycol Diol	Most Materials	Low ACN Nitriles CI/Rubbers
Pentaerythritol Ester Mixed & Branched	Fluoroelastomers EPDM EPR Silicones	CI/Rubbers Polyisoprene SBR Low ACN Nitriles

Refrigerant Exposure Tests

- HCFC-123 exposed samples had the largest swell.
- HCFC-22, HCFC-124, HCFC-142b exposed samples had moderate swell.
- HFC-134a, HFC-125, HFC-152a, and HFC-143a exposed samples had the least swell.
- Fluorosilicones, fluoroelastomers, silicones, nitriles had large swell in HCFC's, and moderate swell in HFCs.
- SBR, Polyisoprene, Butyl, CI/Rubbers, EPR, EPDM had small swell in HFC's
- TPE has good swell resistance. However, extraction occurs in softer TPE's.

COMPATIBILITY OF REFRIGERANT AND LUBRICANTS WITH ENGINEERING PLASTICS:

Objectives:

- To provide compatibility information for engineering plastics with potential substitutes for CFC refrigerants and with suitable lubricants.
- To obtain data on changes in the mechanical properties of selected plastics after thermal aging in refrigerant-lubricant mixtures.

Results:

Imagination Resources, Inc., is performing this research under contract with ARTI. A detailed report of their progress is contained in DOE report number DOE/CE/23810-4D, *Compatibility of Refrigerants and Lubricants with Engineering Plastics*, Quarterly Report 1 July 1992 - 30 September 1992, by Dr. Richard C. Cavestri.

This research project examines the compatibility of ten refrigerants and seven lubricants with 23 engineering plastics.

Refrigerants

HCFC-22
HCFC-123
HFC-134a
HCFC-142b
HFC-152a
HFC-32
HCFC-124
HFC-125
HFC-143a
HFC-134

Lubricants

naphthenic mineral oil
alkylbenzene
polypropylene glycol butyl monoether
polypropylene glycol diol
modified polyglycol
pentaerythritol ester, mixed-acid
pentaerythritol ester, branched-acid

Engineering Plastics Tested

Polybutylene Terephthalate (PBT)	Polyethylene terephthalate (PET)	Nylon 6/6
Polyetherketone (PEK)	Polyetheretherketone (PEEK)	Polytetrafluoroethane (PTFE)
Liquid Crystal Polymer (LCP)	Polyetherimide	Polyamide-imide
Polyimide thermoset	ABS	Acetal
Phenolic	Polypropylene	Polyaryl sulfone
Polycarbonate	Polyphenylene sulfide (PPS)	
Polyphthalamide	Polyvinylidene Chloride	

Lubricant Immersion Studies: All plastic specimens were evaluated at 60°C and 100°C. All plastics were affected by the lubricants. The mineral oil and alkylbenzene lubricants caused the greatest effect on the plastics. The ABS specimen exhibited large swelling in the pentaerythritol branched-acid ester lubricant.

Refrigerant Immersion Studies: All plastics were evaluated at ambient and 60°C in pure refrigerant for 14 days at the saturation pressure of the refrigerant. All refrigerants had some effect on the plastics; generally,

weight increase and some softening of the plastics. HFCs seem to have the least effect. The ABS plastic failed in HCFC-22, HFC-32, HCFC-123, HCFC-124, and HFC-134. The polycarbonate and polyphenylene ether plastics failed in HCFC-123.

Stress Crack-Creep Rupture Tests: Nylon bars immersed in refrigerant and oil had measurable changes in the creep rate. Stress crack-creep information on the other plastics will be presented in future reports.

Refrigerant-Lubricant Thermal Aging Tests: Thermal aging tests of the plastic specimens in ten of the seventeen refrigerant-lubricant combinations were completed. These tests were performed at 150°C for 14 days at a 275-300 psia refrigerant pressure exposure. Physical changes were observed, dimensional changes measured, and tensile properties were compared to the original, unexposed specimens.

REFRIGERANT DATABASE

Objectives:

- To develop a database for materials compatibility and lubricant research (MCLR) information on substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants for air-conditioners, heat pumps, refrigeration equipment, and automotive and applied refrigeration cycles.
- To assemble physical properties, materials compatibility, lubricant, and related test data for these refrigerants, along with comparative data for currently-used refrigerants.
- To make the data readily accessible for rapid screening and identification of pertinent source documents based on user-defined search criteria.

Results:

The November update of the ARTI Refrigerant Database will contain over 500 paper citations.

COMPLIANCE WITH AGREEMENT

ARTI has complied with all terms of the grant agreement during the reported period.

PRINCIPAL INVESTIGATOR EFFORT

Mr. Mark Menzer is the ARTI principal investigator for the MCLR program. During the third quarter of calendar year 1992, Mr. Menzer devoted a total of two-hundred thirteen and one half labor hours (46% of his available work hours) on the MCLR program.

TABLE 1. Miscibility Results

HCFC-22				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	M	M	M	
modified polyglycol	I	M	M	
naphthenic mineral oil	M	< -20 deg C	< -30 deg C	
penta erythritol ester branched acid	M	M	M	
penta erythritol ester mixed acid	M	M	M	
polypropylene glycol butyl monoether	M	M	M	
polypropylene glycol diol	M	M	M	

HFC-32				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	< 20 deg C	I	I	
modified polyglycol	< -20 deg C	< 10 deg C	M	
naphthenic mineral oil	< 30 deg C	I	I	
penta erythritol ester branched acid	M	< -40 deg C	< -20 deg C	
penta erythritol ester mixed acid	M	< -20 deg C	< -30 deg C	
polypropylene glycol butyl monoether	M	> 60 deg C	> 40 deg C	
polypropylene glycol diol	M	M	M	

HCFC-123				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	M	M	M	
modified polyglycol	M	I	I	
naphthenic mineral oil	M	M	M	
penta erythritol ester branched acid	M	M	M	
penta erythritol ester mixed acid	M	M	M	
polypropylene glycol butyl monoether	M	M	M	
polypropylene glycol diol	M	M	M	

HFC-125				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	< 0 deg C	I	I	
modified polyglycol	M	< 0 deg C	> 40 deg C	
naphthenic mineral oil	< 30 deg C	I	I	
penta erythritol ester branched acid	M	M	< -30 deg C	
penta erythritol ester mixed acid	M	M	< 40 deg C	
polypropylene glycol butyl monoether	M	M	> 60 deg C	
polypropylene glycol diol	M	M	< -40 deg C	

HCFC-124				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	M	M	M	
modified polyglycol	M	M	M	
naphthenic mineral oil	M	< 0 deg C	< -30 deg C	
penta erythritol ester branched acid	M	M	M	
penta erythritol ester mixed acid	M	M	M	
polypropylene glycol butyl monoether	M	M	M	
polypropylene glycol diol	M	M	M	

HFC-143a				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	< 0 deg C	I	I	
modified polyglycol	< -40 deg C	> 20 deg C < -10 deg C	> 20 deg C < -40 deg C	
naphthenic mineral oil	< 40 deg C	I	I	
penta erythritol ester branched acid	M	I	I	
penta erythritol ester mixed acid	M	I	I	
polypropylene glycol butyl monoether	M	I	I	
polypropylene glycol diol	M	I	I	

HCFC-142b				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	M	M	M	
modified polyglycol	M	M	M	
naphthenic mineral oil	M	< -60 deg C	M	
penta erythritol ester branched acid	M	M	M	
penta erythritol ester mixed acid	M	M	M	
polypropylene glycol butyl monoether	M	M	M	
polypropylene glycol diol	M	M	M	

HFC-152a				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	< -40 deg C	< 40 deg C	< -10 deg C	
modified polyglycol	M	M	M	
naphthenic mineral oil	< 10 deg C	I	< 60 deg C	
penta erythritol ester branched acid	M	M	M	
penta erythritol ester mixed acid	M	M	M	
polypropylene glycol butyl monoether	M	M	M	
polypropylene glycol diol	M	M	M	

HFC-134				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	< -10 deg C	I	I	
modified polyglycol	M	< 0 deg C	M	
naphthenic mineral oil	I	I	I	
penta erythritol ester branched acid	M	M	M	
penta erythritol ester mixed acid	M	M	M	
polypropylene glycol butyl monoether	M	M	< -20 deg C	
polypropylene glycol diol	M	M	M	

HFC-134a				
Temperature Range: -60 to +60 degrees C				
Lubricant	Nominal 10% Refrigerant	Nominal 50% Refrigerant	Nominal 95% Refrigerant	
alkylbenzene	< 0 deg C	I	I	
modified polyglycol	M	< 0 deg C	< 0 deg C	
naphthenic mineral oil	< 20 deg C	I	I	
penta erythritol ester branched acid	M	< 10 deg C	M	
penta erythritol ester mixed acid	M	M	< -40 deg C	
polypropylene glycol butyl monoether	M	M	> 60 deg C	
polypropylene glycol diol	M	M	< -10 deg C	

M -- miscible over the complete test temperature range
 I -- immiscible over the complete test temperature range
 deg C -- the mixture became immiscible below or above this temperature, as indicated

END

DATE
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2/17/93