International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

1994

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CRITICAL SOLUTION TEMPERATURES FOR TEN DIFFERENT NON-CFC REFRIGERANTS WITH FOURTEEN DIFFERENT LUBRICANTS

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ABSTRACT

Miscibility data are needed to determine the suitability of refrigerant/lubricant combinations for use in refrigeration systems. A new method for obtaining refrigerant/lubricant miscibility data has been developed, and miscibility data have been obtained for a variety of non-CFC refrigerants and their potential lubricants. The refrigerants include R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, and R-152a. The lubricants consist of mineral oils, alkylbenzenes, polyglycols, and polyol esters with varying viscosities. The miscibility tests were performed in a test facility consisting of a series of miniature test cells submerged in a constant temperature bath. The bath temperature can be precisely controlled over a temperature range of -50°C to 90°C (-58°F to 194°F). The test cells are constructed to allow for complete visibility of refrigerant/lubricant mixtures under all test conditions. Critical solution temperatures obtained from the miscibility data are presented for each refrigerant/lubricant combination. Each of the refrigerants tested is miscible over the entire test temperature range with at least one of the lubricants, with the exception of R-143a which exhibits immiscibility over the entire test temperature range with each of the lubricants.

INTRODUCTION

The development of acceptable alternative refrigerants requires the identification of compatible lubricants so that refrigeration systems will operate properly. The first requirement of a compatible lubricant is that it be miscible with the refrigerant over the operating temperatures of the system. Refrigeration systems require a miscible refrigerant/lubricant mixture for compressor lubrication, for maximum heat transfer performance in the evaporator, and for proper lubricant return to the compressor. Therefore, miscibility data for a wide variety of refrigerant/lubricant mixtures were taken in this study.

To obtain miscibility data, one must visually observe and record the physical conditions of a refrigerant/lubricant mixture at a specific temperature. The procedure is repeated for desired ranges of temperatures and refrigerant concentrations. Visual inspection of the mixture allows for determination of whether the mixture showed signs of cloudiness, floc or precipitate formation, and the formation of a second liquid phase.

Scope

Miscibility tests were performed on refrigerant/lubricant mixtures for refrigerant concentrations of 10, 20, 35, 50, 65, 80, 90, and 95% by weight. These tests were performed by keeping the refrigerant/lubricant mixture visible at all times, by controlling temperatures to ±1°C (±1.8°F), and by providing agitation of the test cells.

Each refrigerant/lubricant combination was tested for miscibility in 10°C (18°F) increments over the test temperature ranges. The test temperature range for R-22, R-32, R-123, R-125, R-134, and R-143a was -50 to +60°C (-58 to +140°F). The test temperature range for R-124, R-134a, R-142b and R-152a was -50 to +90°C (-58 to +194°F). Each of the above refrigerants was tested for miscibility with the lubricants listed in Table 1.

REFRIGERANT/LUBRICANT TEST FACILITY

The test facility includes test cells capable of withstanding the high pressures and the extreme temperatures encountered in the study of refrigerant/lubricant mixtures. The facility was designed for the purpose of determining the miscibility characteristics of refrigerant/lubricant mixtures over the temperature range of -50°C to 90°C (-58°F to 194°F) and for pressures up to 3.5 MPa (500 psia). The test cells have glass viewports and are submerged in one of two constant temperature baths so that the miscibility characteristics of the mixture can be observed and recorded. The test facility is described in detail in a previous publication (Zoz, 1994).

The precise temperature of each bath fluid was measured by a platinum RTD that is connected to a signal conditioner/current transmitter. The RTD's have an accuracy of ±0.1°C (±0.18°F). Since the miscibility characteristics of each cell were noted at 10°C (18°F) intervals in this study, the uncertainty in the actual temperature where a change in the miscibility characteristics occurred is ±5°C (±9°F). Due to the magnitude of this latter uncertainty, the uncertainty in the temperature measurements is insignificant.

Miscibility Characteristics

When a refrigerant/lubricant mixture is miscible, it appears as one homogeneous transparent solution. However, when a refrigerant/lubricant mixture is immiscible, there is either cloudiness, evidence of particles dispersed throughout the mixture, or there are two liquid phases present in the cell. Throughout all testing, visual inspections were made for these signs of immiscibility. The presence of two liquid phases was the most common form of immiscibility encountered in this study, while cloudiness was the next most commonly observed immiscibility. Particles were seldom seen in this study.

Refrigerant Concentration

The refrigerant concentration of each test cell was calculated from the total masses of refrigerant and lubricant charged into the cell. The uncertainty in the concentration measurements depends upon the concentration that is being considered, but the maximum uncertainty in concentration is ±0.001 (0.1%). The uncertainty was calculated by using a propagation-of-error method discussed by Beckwith, Buck, and Marangoni (1982).

It is important to note that the concentration in the test cell changed as the temperature of the cell was varied. This occurred because a vapor space was required above the liquid mixture so that the thermal expansion of the liquid mixture did not cause cell failure due to extremely high pressures internal to the cell. Due to the large uncertainty in the temperature at which a change in the miscibility characteristics occurred (i.e. ±5°C), small changes in the refrigerant concentration with temperature can be disregarded.

Critical Solution Temperatures

The critical solution temperature, as defined in the ASHRAE Refrigeration Handbook (1990), is the temperature above which a refrigerant/lubricant combination is miscible for all refrigerant concentrations. Since some of the new refrigerant/lubricant combinations have regions of immiscibility that occur with increasing temperature, an additional definition must be used. The lower critical solution temperatures presented herein are based on the ASHRAE definition, while the upper critical solution temperature is defined as the temperature below which a refrigerant/lubricant combination is miscible for all refrigerant concentrations.

Some refrigerant/lubricant combinations were found to be immiscible over the entire test temperature range for certain concentrations. Other refrigerant/lubricant combinations never became immiscible (i.e. they were always miscible) regardless of the test temperature and concentration. For these cases, a critical solution temperature is not defined. Therefore, when presenting critical solution temperatures, these cases will be identified as immiscible (I) and miscible (M), respectively.

REFRIGERANT AND LUBRICANT SOLUTION RESULTS

This section presents results of miscibility measurements for each of four HCFC and six HFC refrigerants with fourteen lubricants. The data is presented in tables showing critical solution temperatures. A complete list of the raw experimental data is tabulated in a final report (Zoz and Pate, 1993). Each lubricant is commercially available and their trade names are also given in the final report. Additionally, properties of the fourteen lubricants are provided herein.

Results of the measurements of four HCFCs (R-22, R-123, R-124, and R-142b) and six HFCs (R-32, R-125, R-134, R-134a, R-143a and R-152a) in each lubricant are presented below. For every refrigerant/lubricant combination investigated, the data set consists of the concentration, temperature, and visual characteristics of the contents of the cell. Temperature-concentration plots showing regions of immiscibility were constructed from these data, and critical solution temperatures were then identified from the plots. Table 2 provides a summary of the critical solution temperatures for each lubricant and HCFC refrigerant pair. Table 3 provides a summary of the critical solution temperatures for each lubricant and HFC refrigerant pair.

Lubricant Characteristics

Each lubricant is designated by its chemical type (base fluid) and viscosity. The viscosity presented is a nominal value as designated by ASTM standard D2422-86 (ASTM 1988). Table 1 provides densities and actual viscosities at various temperatures along with the flash points and pour points for each of the fourteen lubricants. The moisture, iron, and copper content of each lubricant along with the acid number are provided in the final report (Zoz and Pate, 1993). As mentioned previously, the results presented below are summarized in Tables 2 and 3.

R-22 Miscibility Data

The ISO 32 naphthenic mineral oil, the ISO 68 naphthenic mineral oil, and the ISO 32 modified polyglycol, have lower critical solution temperatures of -10°C, 10°C, and -20°C, respectively. R-22 was found to be completely miscible over the temperature range -50°C to 60°C (-58°F to 140°F) with the alkylbenzene (ISO 32), polypropylene glycol butyl monoether (ISO 32), polypropylene glycol diol (ISO 32), pentaerythritol ester mixed-acid (ISO 22), pentaerythritol ester mixed-acid (ISO 32), pentaerythritol ester branched-acid (ISO 32), alkylbenzene (ISO 68), polypropylene glycol butyl monoether (ISO 58), polypropylene glycol diol (ISO 100), pentaerythritol ester mixed-acid (ISO 100), and pentaerythritol ester branched-acid (ISO 100) lubricants.

R-123 Miscibility Data

The naphthenic mineral oil (ISO 68) has a lower critical solution temperature of -40°C, and the polypropylene glycol butyl monoether (ISO 58) has an upper critical solution temperature of 20°C. R-123 was found to be completely miscible over the temperature range -50°C to 60°C (-58°F to 140°F) with the naphthenic mineral oil (ISO 32), alkylbenzene (ISO 32), polypropylene glycol butyl monoether (ISO 32), polypropylene glycol diol (ISO 32), modified polyglycol (ISO 32), pentaerythritol ester mixed-acid (ISO 22), pentaerythritol ester mixed-acid (ISO 32), pentaerythritol ester branched-acid (ISO 32), alkylbenzene (ISO 68), polypropylene glycol diol (ISO 100), pentaerythritol ester mixed-acid (ISO 100), and pentaerythritol ester branched-acid (ISO 100) lubricants.

R-124 Miscibility Data

The lower critical solution temperatures for the naphthenic mineral oils (ISO 32 and 68) and the modified polyglycol (ISO 32) are 20°C, 50°C, and -10°C, respectively. R-124 was found to be completely miscible over the temperature range -50°C to 90°C (-58°F to 194°F) with the alkylbenzene (ISO 32), polypropylene glycol butyl monoether (ISO 32), polypropylene glycol diol (ISO 32), pentaerythritol ester mixed-acid (ISO 22), pentaerythritol ester mixed-acid (ISO 32), pentaerythritol ester branched-acid (ISO 32), alkylbenzene (ISO 68), polypropylene glycol butyl monoether (ISO 58), polypropylene glycol diol (ISO 100), pentaerythritol ester mixed-acid (ISO 100), and pentaerythritol ester branched-acid (ISO 100) lubricants.

R-142b Miscibility Data

The lower critical solution temperatures for the naphthenic mineral oils (ISO 32 and 68) and the modified polyglycol (ISO 32) are -40°C, -40°C, and -30°C, respectively. R-142b was found to be completely miscible over the temperature range -50°C to 90°C (-58°F to 194°F) with the alkylbenzene (ISO 32), polypropylene glycol butyl monoether (ISO 32), polypropylene glycol diol (ISO 32), pentaerythritol ester mixed-acid (ISO 22), pentaerythritol ester mixed-acid (ISO 32), pentaerythritol ester branched-acid (ISO 32), alkylbenzene (ISO 68), polypropylene glycol butyl monoether (ISO 58), polypropylene glycol diol (ISO 100), pentaerythritol ester mixed-acid (ISO 100), and pentaerythritol ester branched-acid (ISO 100) lubricants.

R-32 Miscibility Data

The modified polyglycol (ISO 32) has a lower critical solution temperature of 10°C and an upper critical solution temperature of 60°C. The pentaerythritol ester mixed acid (ISO 22) has a lower critical solution temperature of 0°C and an upper critical solution temperature of 50°C. The pentaerythritol ester mixed acid (ISO 32) and the pentaerythritol ester branched acid (ISO 32) each have a lower critical solution temperature of -20°C. R-32 was found to be completely miscible over the temperature range -50°C to 60°C (-58°F to 140°F) with the polypropylene glycol diol (ISO 32) lubricant.

R-125 Miscibility Data

The modified polyglycol (ISO 32) has a lower critical solution temperature of 0°C and an upper critical solution temperature of 30°C. The polypropylene glycol butyl monoether (ISO 32), the polypropylene glycol butyl monoether (ISO 58), the polypropylene glycol diol (ISO 100), the pentaerythritol ester mixed acid (ISO 100), and the pentaerythritol ester branch acid (ISO 100) have upper critical solution temperatures of 50°C, 40°C, 40°C, 60°C, and 50°C, respectively. R-125 was found to be completely miscible over the temperature range -50°C to 60°C with the polypropylene glycol diol (ISO 32), pentaerythritol ester mixed-acid (ISO 22), pentaerythritol ester mixed-acid (ISO 32), and pentaerythritol ester branched-acid (ISO 32) lubricants.

Table 1 Test Lubricant Properties

Lubricant	Viscosity cSt	Density g/mL	Pour Point	Flash Point
pentaerythritol ester mixed-acid (ISO 22)	19.9@40°C 4.3@100°C	0.9983@ 15°C	-52°C	195°C
polypropylene glycol diol (ISO 32)	29.7@40°C 4.49@100°C	1.007@ 25°C	-45°C	166°C
pentaerythritol ester mixed-acid (ISO 32)	32.0@40°C 5.7@100°C	0.98@ 20°C	-54°C	245°C
polypropylene glycol butyl monoether (ISO 32)	Not Available	Not Available	Not Available	Not Available
naphthenic mineral oil (ISO 32)	33.0@37.8°C 4.45@98.9°C	0.910@ 20°C	-40°C	168°C
alkylbenzene (ISO 32)	28.0@40°C 6.0@100°C	0.872@ 15.6°C	-42.8°C	155°C
modified polyglycol (ISO 32)	32.0@40°C 4.1@100°C	Not Available	-60°C	Not Available
pentaerythritol ester branched-acid (ISO 32)	30.0@40°C 5.3@100°C	0.995@ 15.6°C	-48°C	234°C
naphthenic mineral oil (ISO 68)	62.5@37.8°C 6.04@98.9°C	0.916@ 20°C	-34.4°C	179°C
alkylbenzene (ISO 68)	57.0@40°C 5.8@100°C	0.871@ 15.6°C	-40°C	155°C
polypropylene glycol butyl monoether (ISO 58)	58.0@40°C 11.0@100°C	0.993@ 15°C	-40°C	255°C
polypropylene glycol diol (ISO 100)	82.7@40°C 13.2@100°C	1.0007@ 25°C	-40°C	175°C
pentaerythritol ester mixed-acid (ISO 100)	100@40°C 11.4@100°C	0.98@ 20°C	-30°C	255°C
pentaerythritol ester branched-acid (ISO 100)	100@40°C 13@100°C	1.057@ 15.6°C	-40°C	258°C

Table 2 Critical Solution Temperatures For Fourteen Lubricants With Four HCFC Refrigerants

CRITICAL SOLUTION TEMPERATURES (LOWER/UPPER)				
Refrigerant	R-22	R-123	R-124	R-142b
Lubricant	-50°C to 60°C	-50°C to 60°C	-50°C to 90°C	-50°C to 90°C
naphthenic mineral oil (ISO 32)	-10°C/None	M	20°C/None	-40°C/None
alkylbenzene (ISO 32)	M	M	M	M
polypropylene glycol butyl monoether (ISO32)	M	M	M	M
polypropylene glycol diol (ISO 32)	M	M	M	M
modified polyglycol (ISO 32)	-20°C/None	M	-10°C/None	-40°C/None
pentaerythritol ester mixed-acid (ISO 22)	M	M	M	M
pentaerythritol ester mixed-acid (ISO 32)	M	M	M	M
pentaerythritol ester branched-acid (ISO 32)	M	M	M	M
naphthenic mineral oil (ISO 68)	10°C/None	-40°C/None	50°C/None	-30°C/None
alkylbenzene (ISO 68)	M	M	M	M
polypropylene glycol butyl monoether (ISO58)	M	None/20°C	M	M
polypropylene glycol diol (ISO 100)	M	M	M	M
pentaerythritol ester mixed-acid (ISO 100)	M	M	M	M
pentaerythritol ester branched-acid (ISO 100)	M	M	M	M

Table 3 Critical Solution Temperatures For Fourteen Lubricants With Six HFC Refrigerants

CRITICAL SOLUTION TEMPERATURES (LOWER/UPPER)						
Refrigerant	**R-32**	**R-125**	**R-134**	**R-134a**	**R-143a**	**R-152a**
Lubricant	-50°C to 60°C	-50°C to 60°C	-50°C to 60°C	-50°C to 90°C	-50°C to 60°C	-50°C to 90°C
naphthenic mineral oil (ISO 32)	I	I	I	I	I	I
alkylbenzene (ISO 32)	I	I	I	I	I	50°C/None
polypropylene glycol butyl monoether (ISO32)	I	None/50°C	-20°C/None	None/60°C	I	M
polypropylene glycol diol (ISO 32)	M	M	M	M	I	M
modified polyglycol (ISO 32)	10°C/60°C	0°C/30°C	0°C/None	0°C/None	I	M
pentaerythritol ester mixed-acid (ISO 22)	0°C/50°C	M	M	-50°C/None	I	M
pentaerythritol ester mixed-acid (ISO 32)	-20°C/None	M	M	M	I	M
pentaerythritol ester branched-acid (ISO 32)	-20°C/None	M	M	M	I	M
naphthenic mineral oil (ISO 68)	I	I	I	I	I	I
alkylbenzene (ISO 68)	I	I	I	I	I	50°C/None
polypropylene glycol butyl monoether (ISO58)	I	None/40°C	M	None/50°C	I	None/80°C
polypropylene glycol diol (ISO 100)	I	None/40°C	M	None/60°C	I	None/70°C
pentaerythritol ester mixed-acid (ISO 100)	I	None/60°C	M	-10°C/None	I	M
pentaerythritol ester branched-acid (ISO 100)	I	None/50°C	M	None/60°C	I	None/90°C

R-134 Miscibility Data

The polypropylene glycol butyl monoether (ISO 32) and the modified polyglycol (ISO 32) have a lower critical solution temperatures of -20°C and 0°C, respectively. R-134 was found to be completely miscible over the temperature range -50°C to 60°C (-58°F to 140°F) with the polypropylene glycol diol (ISO 32), pentaerythritol ester mixed-acid (ISO 22), pentaerythritol ester mixed-acid (ISO 32), pentaerythritol ester branched-acid (ISO 32), polypropylene glycol butyl monoether (ISO 58), polypropylene glycol diol (ISO 100), pentaerythritol ester mixed-acid (ISO 100), and pentaerythritol ester branched-acid (ISO 100) lubricants.

R-134a Miscibility Data

The polypropylene glycol butyl monoether (ISO 32), polypropylene glycol butyl monoether (ISO 58), polypropylene glycol diol (ISO 100), pentaerythritol ester branched acid (ISO 100) lubricants have upper critical solution temperatures of 60°C, 50°C, 60°C, and 60°C, respectively. The modified polyglycol (ISO 32), pentaerythritol ester mixed acid (ISO 22), and pentaerythritol ester mixed acid (ISO 100) lubricants have lower critical solution temperatures of 0°C, -50°C, and -10°C, respectively. R-134a was found to be completely miscible over the temperature range -50°C to 90°C (-58°F to 194°F) with the polypropylene glycol diol (ISO 32), pentaerythritol ester mixed-acid (ISO 32), and pentaerythritol ester branched-acid (ISO 32) lubricants.

R-143a Miscibility Data

R-143a was found to be partially miscible over the temperature range -50°C to 60°C (-58°F to 140°F) with all of the lubricants. For each lubricant and R-143a pair, at least one concentration remained immiscible over the entire test temperature range. Therefore, in this case, critical solution temperatures are not presented.

R-152a Miscibility Data

The alkylbenzene lubricants (ISO 32 and 68) each have a lower critical solution temperature of 50°C. The polypropylene glycol butyl monoether (ISO 58), polypropylene glycol diol (ISO 100), and pentaerythritol ester branched acid (ISO 100) lubricants have upper critical solution temperatures of 80°C, 70°C, and 90°C, respectively. R-152a was found to be completely miscible over the temperature range -50°C to 90°C (-58°F to 194°F) with the polypropylene glycol butyl monoether (ISO 32), polypropylene glycol diol (ISO 32), modified polyglycol (ISO 32), pentaerythritol ester mixed-acid (ISO 22), pentaerythritol ester mixed-acid (ISO 32), pentaerythritol ester branched-acid (ISO 32), and pentaerythritol ester mixed-acid (ISO 100) lubricants.

CONCLUSIONS

Critically needed miscibility data have been obtained for a variety of refrigerants and lubricants. The test facility incorporates test cells with sight windows that, when valves are screwed into opposing ports, serve as pressure vessels. The cells were charged with variable amounts of refrigerant and lubricant to facilitate refrigerant compositions from 0 to 100%. Operating temperatures and pressure ranges for the facility are -50°C to 90°C (-58°F to 194°F), and 0 to 3.5 MPa (0 to 500 psia), respectively. The facility has been successfully employed to obtain experimental results for R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, and R-152a. Each refrigerant was tested with each of fourteen lubricants.

Data for the HCFC refrigerants (R-22, R-123, R-124, and R-142b) and the HFC refrigerants (R-32, R-125, R-134, R-134a, R-143b, and R-152a) in each of the test lubricants have been collected for refrigerant concentrations of 10, 20, 35, 50, 65, 80, 90, and 95%. The results are summarized and presented as critical solution temperatures.

Each of the refrigerants tested was found to be completely miscible over the entire test temperature range with at least one of the lubricants except R-143a. It is left to the system designer to determine the suitability of a particular refrigerant/lubricant mixture for use in a system. The presentation of critical solution temperatures provides the designer with limits on the applicability of a refrigerant/lubricant mixture for use in a system.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support provided by the Air-Conditioning and Refrigeration Technology Institute, Inc., under a Materials Compatibility and Lubricant Research (MCLR) grant from the U.S. Department of Energy.

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