Performance Evaluation of Pure and Mixed Refrigerants in Domestic Refrigerators: Drop-in Replacement of R12

D. S. Jung  
*University of Maryland*

R. Radermacher  
*University of Maryland*

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NEW METHODS OF DETERMINING VISCOSITY AND PRESSURE OF REFRIGERANT/LUBRICANT MIXTURES

H. O. Spaushus and D. R. Henderson
Spaushus Associates, Inc.
Atlanta Technology Center, Suite 410
1575 Northside Drive, NW
Atlanta, GA 30318

ABSTRACT
Properties of refrigerant/lubricant mixtures are important for design and reliable operation of vapor compression and absorption refrigeration equipment. Evaluation of substitute refrigerants and lubricants for CFCs and of new working fluids for absorption systems can be enhanced by the availability of rapid and accurate methods for determining fluid properties. This paper describes new methods for measuring viscosity and pressure of refrigerant/lubricant mixtures over compositions from zero to one hundred percent refrigerant and temperatures from -40 to +150 Celsius. The equipment and methods can also be applied to fluids for absorption systems. Automatic data acquisition, data reduction, and computer generated graphics are utilized. Typical viscosity-pressure-temperature-composition data are presented to illustrate engineering applicability.

INTRODUCTION
The primary reason for introducing an oil into positive displacement vapor compression systems is to lubricate the compressor bearings; secondary reasons, depending on compressor design, include sealing of clearances and to aid in heat removal from the compressor. In absorption systems, the compressor is replaced by a thermally activated generator. The low volatility fluid serves as solvent for the refrigerant and, in the evaporator and condenser of these absorption systems, it behaves in a similar manner as does the lubricant circulating through the condenser and evaporator of vapor compression systems. In both types of equipment, thermal performance is determined by properties of the refrigerant/lubricant working fluid and not by properties of the pure refrigerant. In addition, in the case of vapor compression systems, the lubricant for the compressor consists of a mixture of lubricant and refrigerant. Thus it is clear that knowledge of the properties of these refrigeration working fluids is required for system design and performance analysis.

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Properties of refrigerant/lubricant mixtures are important for design and reliable operation of vapor compression and absorption refrigeration equipment. Evaluation of substitute refrigerants and lubricants for CFCs and of new working fluids for absorption systems can be enhanced by the availability of rapid and accurate methods for determining fluid properties. This paper describes new methods for measuring viscosity and pressure of refrigerant/lubricant mixtures over compositions from zero to one hundred percent refrigerant and temperatures from -40 to +150 Celsius. The equipment and methods can also be applied to fluids for absorption systems. Automatic data acquisition, data reduction, and computer generated graphics are utilized. Typical viscosity-pressure-temperature-composition data are presented to illustrate engineering applicability.

HEAT TRANSFER AND PRESSURE DROP
The presence of oil in refrigeration systems has effects on heat exchanger thermal performance and pressure drop which are not negligible (for example Parmelee 1984, Schlager et al. 1990). The performance prediction of systems with these mixtures as working fluids is further complicated by the facts that two phase, multi-component flow exists and that the evaporation and condensation of the working fluid may be incomplete. These complexities render an analytical approach impractical and current practice is to develop correlations from empirical data which allow prediction of the convective heat transfer coefficient and friction factor. Development and use of these correlations generally require knowledge of the dynamic viscosity, density, thermal conductivity and specific heat of the mixture. It is the purpose here to examine the effect of viscosity on heat transfer and pressure drop and to present typical experimental data.

The concentration of oil in the working fluid varies quite widely from point to point in the refrigeration system from only a few percent in the heat exchangers to a large concentration in the compressor sump. The low oil-concentration condition is important from the viewpoint of heat exchanger design and pumping power, while the high oil concentration is important for proper compressor lubrication. The viscosity of the mixture varies considerably with respect to oil concentration and with respect to temperature (for example, ASHRAE Handbook Reference 1, Spaushus et al. 1987, Baustain et al. 1986). A number of attempts have been made to predict the viscosity of refrigerant/lubricant mixtures from viscosities of the pure fluids as a function of temperature (Hirschberg 1986, Kruse et al. 1984, Baustain et al. 1986 and Speaker et al. 1986). Predictions based on averages of mass and molar concentrations, as well as more complicated expressions, have been evaluated, but to date no universal expression, suitable for all mixtures over wide ranges
of temperature and concentration has been developed. Accurate mixture viscosity measurements for many refrigerant/lubricant combinations are required to advance basic understanding of heat transfer mechanisms for these fluids.

Measurement of the pressure at saturation of the mixtures over the temperature range of interest is also important due to pressure drop and pumping power considerations (Parmelee 1964). Experimental studies (Macken et al. 1979, Alois et al. 1990) have shown increases in pressure drop due to the presence of small amounts of oil at typical suction line conditions.

HYDRODYNAMIC LUBRICATION

The role of refrigeration oils is to lubricate compressors to assure efficient performance, high reliability and long life. Several modes of lubrication are important: boundary lubrication for start-up, hydrodynamic lubrication to produce a stable oil film between bearing elements during running and mixed lubrication in intermediate stages. Compressor bearings are designed to operate with the bearing elements separated by a refrigerant/lubricant fluid film that can carry a substantial load without significant friction loss and wear. To achieve this requirement, minimum film thickness must be maintained over the entire range of compressor operating conditions. Factors to consider include friction loss, heat removal, oil supply to the bearing, elastic and thermal distortion of the bearings and stability of the oil film.

A major complexity in design of refrigeration compressors is the changing composition of the working fluid, and hence its viscosity, over a wide range of operating parameters. Viscosity data for refrigerant/oil mixtures are a basic requirement for compressor bearing design and lubricant specification; this viscosity is strongly influenced by temperature and composition. Increasing temperature and increasing refrigerant composition both result in reduced viscosity of the refrigerant/oil mixture and limit the bearing loads that the fluid film can support. These relationships are illustrated in Figure I for R-12/oil mixtures and in Figure II for R-22/oil mixtures. Figures I and II are from Chapter 8 of the 1985 ASHRAE Refrigeration Handbook with citation for references to Little 1952, Albright and Mandelbaum 1956 and Lotfier 1971, and are in each case for naphthenic mineral oils of ISO 32 viscosity.

Detailed analysis of these data and other viscosity studies previously reviewed by Speaker and Spaulkus lead to the following observations:

- Viscosity of HCFC-22 mixtures are significantly lower than those of CFC-12 with the same oil and at the same weight composition.
- Differences in viscosity increase with increasing refrigerant concentration and with decreasing temperature.
- For a 32 ISO mineral oil at temperatures of 100 °F and above, dissolution of 8 to 10 percent refrigerant in the mineral oil is about equivalent to a 40 °F (28 °C) increase in temperature.
- Little, if any, viscosity information is presently available for synthetic lubricants in combination with CFC alternative refrigerants.

EXPERIMENTAL EQUIPMENT AND MEASUREMENTS

A review of physical principles used for experimental determination of viscosity, which include capillary flow, angular deflection of coaxial cylinders, falling and rolling body and oscillatory motion, was presented by Speaker et al. 1987. These methods are generally not well suited for measurements of refrigerant/lubricant mixtures because of (a) the wide range of viscosities that are of interest, (b) high pressure at elevated temperatures and (c) difficulty of capturing output data electronically. The method reported in this paper utilizes a new type of viscometer developed by Cambridge Applied Systems, Inc. Operation of the instrument is based on electromagnetic forces and the time required for a metallic piston to traverse a known distance through the fluid. Two electric coils, one on each end, are installed on the outside of the passageway through which the piston moves. With the piston at one end, the coil at the other end is energized, creating a magnetic field which pulls the piston back to the starting point. The time required for this travel is
measured, which is related to the viscosity of the fluid. The passageway, coils and piston are enclosed in stainless steel which is threaded for connection to the high pressure cell which houses the fluid to be measured.

The instrument is calibrated by charging the cell with a fluid of known viscosity over the temperature range of interest. The cell is then charged, first with the lubricant and then with the refrigerant under controlled conditions to arrive at the desired composition. The fluid mixture is then heated or cooled at a predetermined slow rate with efficient magnetic stirring to assure equilibrium. Viscosity-temperature outputs are recorded electronically.

Temperature is measured by an RTD built into the viscosity head as near as possible to the piston. Temperature and viscosity readings may be viewed on a monitor during the run and the data are recorded on a computer disc for data analysis.

Pressure is measured in a separate cell equipped with thermocouples and a high accuracy electronic transducer with continuous output. The pressure transducer is first calibrated for zero pressure output and linearity by evacuating the cell and then charging with a fluid of known saturation pressure. The apparatus is then thermally cycled with concurrent recording of pressure and temperature. Care is taken to ensure adequate response time for the sensors and to avoid condensation in the pressure pick-up tube.

EXAMPLE MEASUREMENTS

Example measurements are shown in Figures III through V. Figure III shows data furnished by the manufacturer for the calibration fluid (for one piston) as the solid line, together with the data points as measured by our equipment. Excellent agreement is observed over the viscosity range of about 30 to 300 centipoise. Figure IV shows a comparison of our experimental data points for a 300 SUS mineral base lubricant with data provided by the oil supplier over the viscosity range of about 15 to 215 centipoise. Figure V shows a comparison of our experimental data with published data for HFC-134a. In all three examples, the agreement is seen to be excellent. It should be noted that the present method of measuring viscosity facilitates recording of many, often four to five hundred, data points which can then be reduced to equations by means of in-house multiple linear regression analysis.

Figures VI and VII illustrate viscosity and saturation pressure (or solubility) for a 60 percent mixture of a 300 SUS mineral base lubricant with HCFC-123. The experimental data points are recorded along with the curve that best fits the data in the least squares sense. The average error between measured and calculated values for viscosity is 0.276 centipoise and for pressure is 0.023 psia. The excellent agreement between measured data and those predicted by the equation is clearly evident.
CONCLUSIONS

- New methods for determining viscosity and vapor pressure of refrigerant/lubricant mixtures have been developed.

- The new methods are based on automatic data acquisition, with minimal requirement for attention once the cell is loaded with a mixture of the desired composition.

- Accuracy of the resultant data are excellent and can be extended by reducing the rate of thermal cycling and by further improving the quality of the sensors.

- The data acquisition and data reduction routines that have been developed will provide information on properties of refrigerant/lubricant mixtures required for heat transfer, pressure drop and hydrodynamic lubrication analyses.

REFERENCES

