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MEASUREMENT OF VISCOSITY, DENSITY, AND GAS SOLUBILITY OF REFRIGERANT BLENDS IN SELECTED SYNTHETIC LUBRICANTS

Final Report

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ABSTRACT

The lubricants tested in this project were chosen based on the results of liquid/liquid miscibility tests. EMKARATE RL32S and Emery 2968A were selected. The Vapor Liquid Equilibrium (VLE) viscosity reduction and gas fractionation of each was measured with three different refrigerant blends: 1) R-404A; 2) R-507; and 3) R-407C. In addition, the four single refrigerants that make up the blends, HFC-32, HFC-125, HFC-134a, and HFC-143a, were also measured.

Lubricants found to have the lowest liquid/liquid miscibilities had nearly equal viscosity reduction profiles, as did the more miscible lubricants. Analytical methodology consisted of maintaining equally both the composition of the head space vapor above the lubricant/refrigerant mixture, and the composition of the liquid blend refrigerant. Blends with large temperature glides were re-evaluated in order to test the concept of head space quality and a vented piston hydraulic cylinder assembly was developed to perform this task. Fluid property data, above critical temperature and pressure conditions, is presented for the two lubricants with HFC-32, HFC-125, HFC-143a refrigerants.

This research shows that the lubricant EMKARATE RL32S, which had the lowest (poorest) liquid/liquid miscibilities with the selected refrigerants, also had nearly equal viscosity reduction profiles to the more miscible Emery 2968A lubricant. The analytical methodology consisted of maintaining the composition of the refrigerant gas above the lubricant to be equal in composition to that of the pure liquid refrigerant blend being introduced into the lubricant. Refrigerant blends with large temperature glides were re-evaluated in order to validate the concept of the importance of the composition of the gas over the lubricant. To do perform this task, a special vented piston hydraulic cylinder assembly was developed. Fluid property data is also presented for HFC-32, HFC-125, and HFC-143a above the critical temperature and pressure of each.

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SCOPE

This report will present information regarding the measurements of the viscosity, solubility, and density of solutions of two lubricants with single HFC refrigerants. Also measured were the viscosity, solubility, density, and solution compositions of these two lubricants with HFC blends. The two lubricants selected include: 1) Emery 2968A, a 32 ISO VG branched acid polyolester (Lubricant B); and 2) EMKARATE RL32S, a 32 ISO VG mixed acid polyolester (Lubricant C). These lubricants were selected based on the data of the miscibility evaluations of five lubricants and six different refrigerant blends (see Appendix A). The refrigerants selected include: 1) HFC-32; 2) HFC-125; 3) HFC-134a; and 4) HFC-143a. The refrigerant blends include: 1) R-404A; 2) R-507; and 3) R-407C.

In order to provide a basis for comparing viscosity, density, and gas solubility, evaluations of R-502 and HCFC-22 with a 32 ISO VG mineral oil are included; the results of these tests are presented in appendices B and C.

Statement and Chemical Properties of Lubricants

The viscosity and liquid/liquid miscibility of lubricants with refrigerants are dependent on the composition of the lubricants. Because the pentaerythritol polyolesters used in this study are proprietary formulations, information about the specific structural properties of each polyolester, including alcohol type and the stoichiometry of the carboxylic acids used in synthesis, remains with the manufacturers. Therefore, only the miscibility and viscosity differences between the polyolesters are reported.

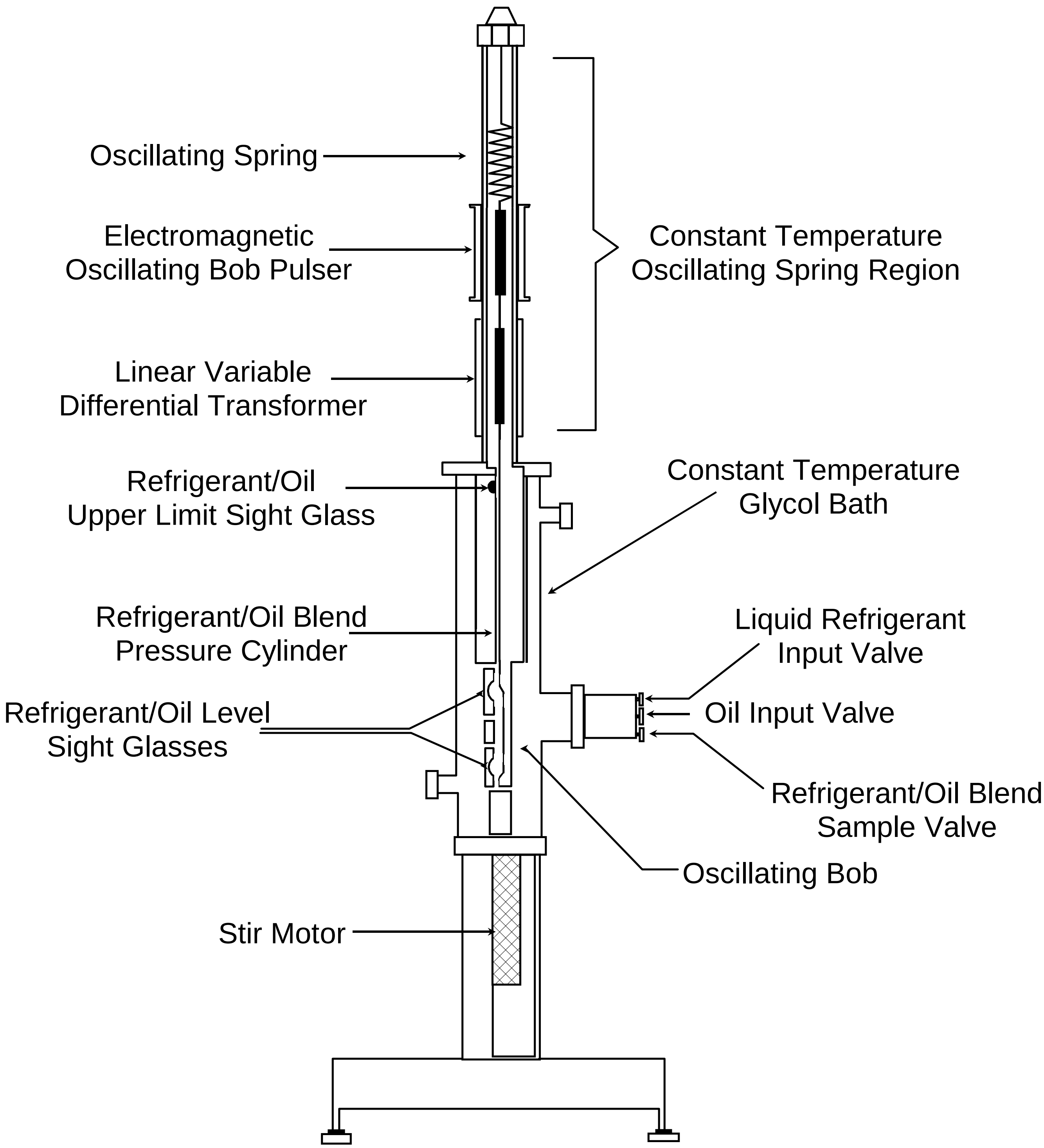
METHODS

Viscosity Determinations

The viscosity reduction method used in this study is similar to that described by Albright (1956-59), Little (1956), and Parmelee (1964). These authors use the saturation of liquid with vapor, or *the gas equilibrium concept*, to study the viscosity reduction of hydrocarbon refrigeration oils in refrigerant gases. In conjunction with the gas equilibrium approach, this study uses temperature and pressure limitations to determine refrigerant gas concentrations.

Viscosity and density are determined accurately by a fourth generation viscometer/densimeter, seen in Figure 1, which was designed and built based on information taken from Solomons and White (1965; 1969), and Nissen (1980; 1983). This viscometer system consists of an oscillating body device

Figure 1
Oscillating Body Viscometer



enclosed in a low volume pressure tube. The system is contained within a stainless steel pipe. A highly polished, solid, stainless steel oscillating cylinder is connected to a precisely thermostatted spring. An external electromagnet reacts with an internal steel and nickel alloy core that is mechanically connected to the cylindrical bob causing the bob to oscillate until it gradually slows and stops. The sinusoidal decay of its motion is called the *decrement*. Position and movement of the bob is determined by a Linear Variable Differential Transformer (LVDT) and an internal steel and nickel alloy core. Rapid decay indicates high viscosity; slow decay indicates low viscosity. The viscosity of the solution can then be determined from the decrement and density measurements.

This viscometer allows a wide range (0.10 to 800 cP) of viscosity determinations to be made with a single oscillating bob. In addition, the bob can also be used to determine density. By accurately observing the position changes of the bob, density can be determined to within 0.0005 g/ml. By measuring, a determination of density changes at constant temperature and pressure is a very accurate method of measuring fluid consistency. Any change in density indicates that the fluid gas system is not at equilibrium. Accurate density measurements allow the calculation of kinematic viscosity (centistokes; cSt) from dynamic viscosity (centipoise; cP). The density range of the instrument is calibrated with known, readily available pure fluids that are dried over molecular sieve prior to use. This provides a straight calibration line for density at specified temperatures. The precision of this determination is ± 0.3%.

The viscosity of Emery 2968A, the 32 ISO VG branched acid polyolester, and EMKARATE RL32S, the 32 ISO VG mixed acid polyolester, as well as Suniso 3GS, the 32 ISO VG mineral oil were measured by Cannon Laboratories, an independent research facility. The standards used were water and certified standard test fluids that are NIST traceable. These standards are calibrated from -25°C to 125°C (-13°F to 257°F) and are reported in both cP and cSt values. This information, as well as the densities of each lubricant, is presented in the raw data tables under the heading "Neat Viscosity Check". See Tables B.1, C.1, D.1, E.1, F.1, G.1, H.1, I.1, J.1, K.1, L.1, M.1, N.1, O.1, P.1, and Q.1 for the mineral oil, branched acid polyolesters, and mixed acid polyolesters.

The readability of the viscometer is 0.06 cP. Viscosity results in a significant overlap that serves as an internal standard and self check. The difference between standards for low (68 to 0.4 cSt) viscosity solutions is ±0.5%; this increases to ±1.5% for high (500 cSt) viscosity solutions.

Viscosity, density, and gas solubility measurements are taken when the lubricant refrigerant gas system has reached equilibrium. To do this, lubricant refrigerant mixture is pumped from the bottom of the viscometer and sprayed into the refrigerant vapor space at specific pressures and temperatures. Consequently, density is monitored for equilibrium conditions, the decrement is measured, and the viscosity is calculated. Before the fluid is sampled, it is visually examined several times in order to determine that true solution conditions are present. There are generally four to six separate density and viscosity decrement determinations made for each data set before a liquid sample is taken. The fluid sample is then drawn through a very low volume capillary line (380µl) into a deeply evacuated, lightweight glass sampling bulb where a total charge of a refrigerant/lubricant sample is retained. The ratio of gas to liquid oil (percentage by weight) is then measured. The concentration measurement is reproducible within ±0.5% by weight at a given isothermal pressure test point.

The gas solubility ranges of refrigerant/lubricant combinations can be inconsistent. According to the principles of gas equilibrium, forced saturation with liquefied gas is required to produce immiscible layers. Lubricant may be kept saturated with gas at a specific pressure and temperature by accurately monitoring the gas pressure and maintaining it below the saturation pressure of the refrigerant. For lubricants that are miscible to low temperatures (see Appendix A), liquid refrigerant can be added to the viscometer under pressure. Fluid properties can then be measured for viscosity, density, pressure, and refrigerant concentration.

If there is any void space in a pressurized viscometer cell, the refrigerant-oil pair combinations will change with temperature. When refrigerant blends are used, the composition of the gas in the vapor space of the viscometer is maintained by purging the gaseous blend through the lubricant to be nearly equal (±2%) of the pure liquid refrigerant blend. The fractionation of the mixed gases in solution in the lubricant is measured by gas chromatography at every temperature and pressure test point. This is done by sampling the lubricant/refrigerant mixture and determining the percent refrigerant by weight in the fluid. The ratio of gases is determined by gas chromatography, as stated in REFRIGERANT BLEND SAMPLING.

This viscometer is equipped with three glass sight windows, one at the top and two at the bottom. In the fluid measurement portion of the viscometer, there are two sight glasses directly adjacent to the suspended stainless steel solid cylindrical bob, as seen in Figure 1. The two bottom sight glasses are used to continually monitor the solution for the formation of any immiscible layers of lubricant and refrigerant. The observer can visually insure that the viscometer is charged with enough fluid to completely cover the bob. The second sight glass is lower on the column and is adjacent to the gas introduction port and to the oil sampling port. The third sight glass is located at the top of the vapor space directly adjacent to the pump exit. This allows for observation of the foaming qualities of the lubricant. This also enables observation of the liquid contents inside the viscometer, which can then ensure that the contents are below the top level of the constant temperature circulating fluid.

Density, viscosity, and vapor pressure are measured under isothermal conditions. The viscometer temperature is maintained by a circulating, constant temperature glycol bath controlled by a Platinum Resistance Temperature Device (RTD, ±0.1°C/±0.2°F) microprocessor. The RTD probe is mounted at the surface of the viscometer tube inside the liquid bath. The other temperature zones are controlled by electric heaters, using a microprocessor controller (±0.1°C/±0.2°F) with type "J" thermocouples.

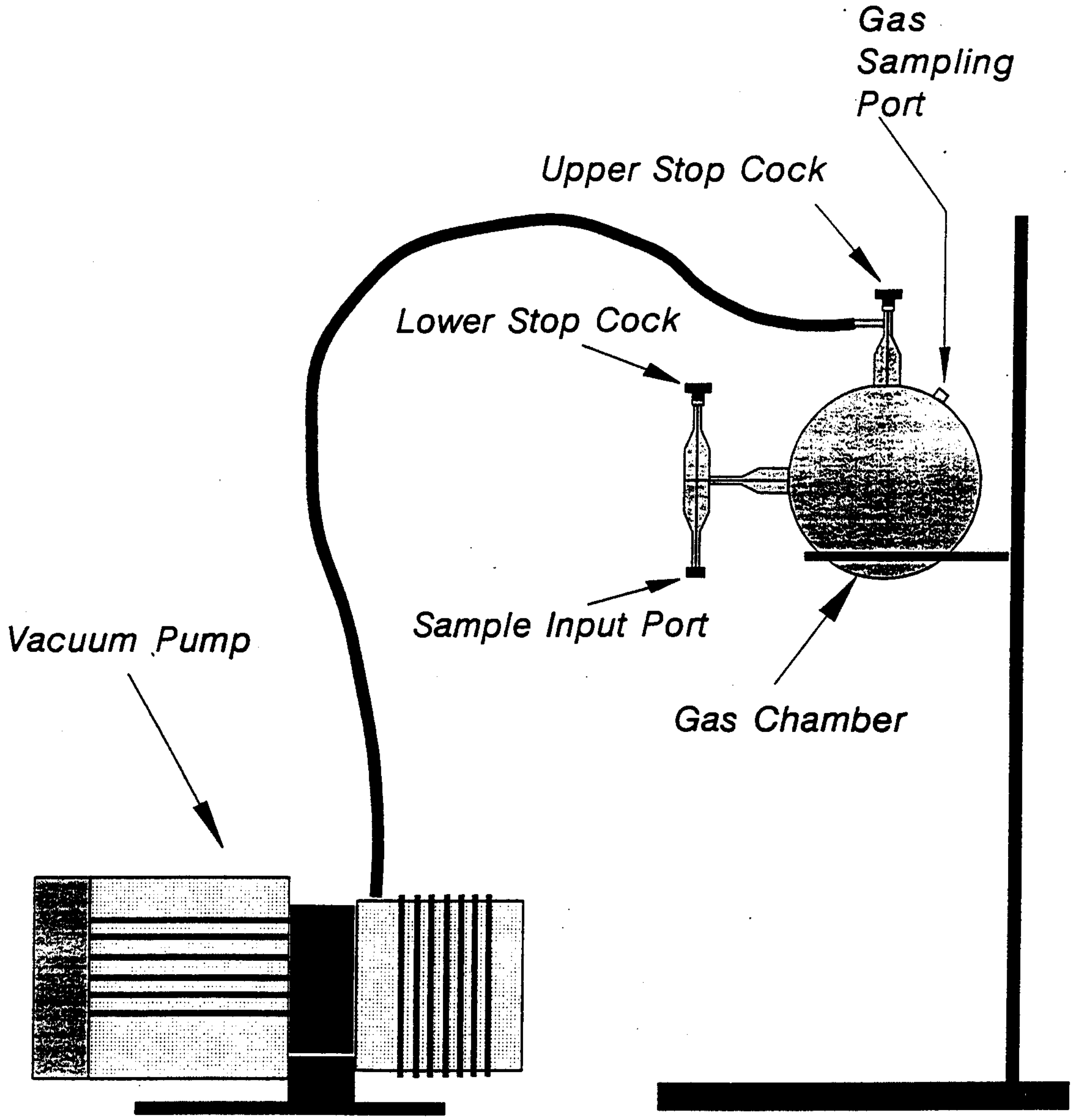
Equilibrium refrigerant vapor pressure is measured using a Heise, double helix Bourdon tube gauge, model #CMM-110733. This temperature-compensated gauge is calibrated with both gas and liquid, is accurate to ±0.0013 MPa (±0.2 psia), and is traceable to NIST standards. Because the gas content of the fluid is measured, the amount of gas contained in the Bourdon tube is irrelevant.

The lubricant/refrigerant mixture is pumped throughout the viscometer by a magnetically coupled impeller located in the base of the instrument and comprising the pump body. To drive towards equilibrium, the lubricant/refrigerant mixture is then sprayed into a soluble gas vapor space at the top of the viscometer. For equilibrium and thermodynamic reasons, we emphasize the importance that viscosity and concentration measurements are taken when the gas is at equilibrium at isothermal and isobaric conditions. Therefore, the pressure and temperature in the instrument is varied to simulate the lubricant/refrigerant pair conditions that exist in operating compressor systems. Prior to use, test fluids are degassed at 60°C (140°F) to 20 millitorr for 24 hours and are dried to at least 50 ppm water. Similarly, the viscometer is then evacuated to 20 millitorr for several hours, purged with the refrigerant gas several times, and then evacuated. The test oil is then drawn through the oil charging valve and re-evacuated to 20 millitorr. The lubricant/refrigerant mixture is purged with refrigerant gas and again evacuated. Non-condensable gas content is not allowed to exceed 10 ppm. This standard has been established and is used by this laboratory.

Refrigerant Blend Sampling

After refrigerant/lubricant samples are obtained from the viscometer, the glass sampling container and its glass stopcock are weighed. The glass sampling bulb is placed on the sample input port of the apparatus (Figure 2) with the lower stopcock closed. The upper stopcock is opened and attached to the vacuum pump. The upper stopcock remains open until a sufficient vacuum (30-50 millitorr) has been pulled on the gas chamber. When the upper stopcock is closed, the lower stopcock is opened. The low pressure in the gas chamber pulls out the refrigerant contained in the glass sampling bulb. To separate the refrigerant from the lubricant, the glass sampling bulb is carefully heated with a propane torch to between 60°C and 82°C (140°F and 180°F). The lower stopcock is closed within 30 seconds after heating and within one to two minutes, equilibrium is established inside of the gas chamber.

Figure 2. Refrigerant Blend Sampling Apparatus



The composition of the solubilized gases in the lubricant is determined by a gas sample drawn out of the gas chamber. A second gas sample is obtained in order to determine if equilibrium has been established and whether the ratio of gases has changed. Gas chromatography is used to analyze the composition of the refrigerant samples. (Separate measurement studies have indicated that more than 80% of the refrigerant contained in the liquid sampling bulb has been removed.) Finally, all remaining traces of refrigerant are removed by heating the bulb to constant weight under vacuum conditions. The final weight of the sampling bulb is then used for the final measurements of the net percentage of the refrigerant mixture by weight. The composition of the gas mixture is determined using known gas chromatography calibrated response curves established for each individual refrigerant in a particular mixture.

Viscosity Reduction Procedure

The viscosity reduction procedure developed at IRI injects liquid refrigerant (blend or single) and then purges the refrigerant gas through the lubricant at a constant gas back pressure at isothermal conditions. The viscometer is shown in Figure 1 with an indication of the point of refrigerant introduction.

The objective of purging the blend through the lubricant is to saturate the lubricant with the composite gas blend at specific conditions of temperature and pressure. Gas is purged through the liquid until the gas in the head space above the liquid is within ±2% of the composition of the liquid gas blend that is being injected into the lubricant.

For analytical purposes, our purging protocol was developed to mimic the conditions seen in systems and compressors. The assumption has been made that the refrigerant blend is always in excess to the lubricant. Therefore, because we produce gas equilibrium viscosity data, it is necessary to keep the gas in the head space over the lubricant at known composition. The composition of HFC blends is maintained to within ±2% of the composition of the liquid blend.

Purged and Unpurged Viscosity Measurement Conditions

Lubricants are purged when it is necessary to know the viscosity reduction of an HFC blend with any lubricant at specific conditions of pressure and temperature. However, there is an unpurged method developed by this laboratory that is used when it is necessary to visualize the change of HFC components in the lubricant when approaching the gas equilibrium point of the blend at specific conditions.

With the unpurged method, refrigerant liquid is bubbled through the lubricant to a specified pressure at isothermal conditions. For a few minutes after recirculation of the lubricant refrigerant mixture and the gas pressure has reached equilibrium, the viscosity, density, and solubility of the refrigerant(s) in the lubricant are determined. The composition of the gases in the head space is closely monitored and recorded. Past and ongoing evaluations of HFC blends and lubricants indicate a unique change in solubilized gas content and when conditions of gas composition equilibrium are reached. Comparative unpurged data is presented for all of the blends containing the Emery 2968A, whereas, R-407C is also evaluated with the EMKARATE RL32S. With R-407C and polyolesters, there is a unique change in head space gas properties and composition. It appears that when dissolved in the lubricant, blends that have a very narrow temperature glide reveal small changes in composition. However, with binary and ternary blends that have large temperature glides, larger compositional changes were observed.

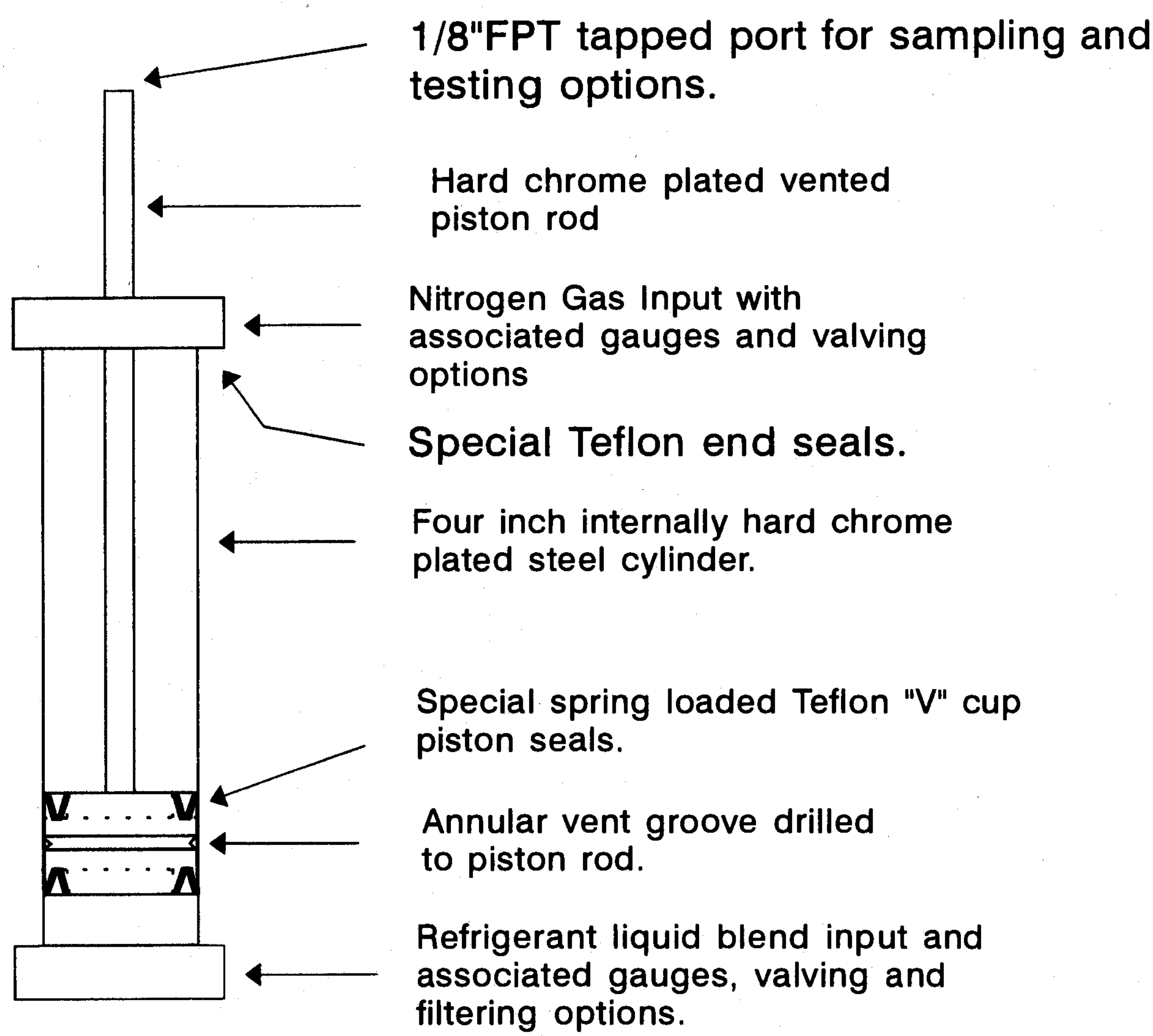
HFC Liquid Blend Injection

Upon completion of this study, we were concerned that some of the data produced was faulty because some liquid HFC blends can have a large temperature glide. Because of successive samplings, it is therefore possible for a 20 pound supply tank of R-407C to experience a significant change in the liquid composition. When the supply tank is sampled at room temperature, each successive liquid sample creates a larger head space within the tank causing the composition of the liquid to change. The basis of this study is to measure the viscosity change and blend fractionation that occurs in solution with the lubricant. To achieve this, an analytical goal is to maintain the head space to within ±2% of the injected liquid. Therefore, if we are to monitor compositional changes in the lubricant due to temperature and pressure changes, it is logical to maintain the composition of the injected liquid at consistent conditions.

To minimize the change in liquid composition, IRI has developed a liquid injection technique whereby there is no head space above the liquid R-407C. This technique operates as follows: 1) the liquid blend is refrigerated to a temperature of -20°C (-4°F); 2) the refrigerated liquid blend is then drawn into a specially designed hydraulic cylinder at the same temperature; and 3) To use the contents of the hydraulic cylinder, the piston is pressurized on the opposite side of the refrigerant to 500 psia (3.45 mPa).

Our hydraulic cylinder design is seen in Figure 3. A steel, chrome plated cylinder is used with a vented piston. It is very important to have a vented piston because without it, there is a possibility of nitrogen gas mixing with the refrigerant. The mechanically connected piston is vented to the atmosphere through the piston rod and between two specially designed spring loaded Teflon™ "V" cup seals. This design guarantees no gas cross-mixing, which would result in false, pressures in the viscometer and inaccurate viscosity, pressure, and solubility data.

Figure 3. Hydraulic Cylinder Design



RESULTS OF MEASUREMENTS WITH SINGLE REFRIGERANTS

Viscosity of EMKARATE RL32S with HFC-134a

Appendix D, Table D.1, presents the isothermal viscosity, density, and solubility of gaseous HFC-134a with EMKARATE RL32S with good miscibility characteristics. Some isothermal curves illustrate reasonably straight viscosity reduction with increasing refrigerant dilution, while some show a characteristic solubility knee. Several viscosity data points were taken; the lowest temperature at which viscosity was measured was -30°C (-22°F). Figure 4 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 5 presents a modified "Daniel plot" which exhibits viscosity and pressure at constant concentrations as a function of temperature. Figure 6 shows density as a function of temperature at constant concentrations.

Viscosity of Emery 2968A with HFC-134a

Appendix E, Table E.1, presents the isothermal viscosity, density, and solubility of gaseous HFC-134a with Emery 2968A with good miscibility characteristics. Figure 7 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 8 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 9 shows density as a function of temperature at constant concentrations.

Viscosity of Emery 2968A with HFC-143a

Appendix F, Table F.1, presents the isothermal viscosity, density, and solubility of gaseous HFC-143a with Emery 2968A. Five viscosity data points were taken for each temperature. Figure 10 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 11 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. The 10% and 20% concentration lines flatten as the temperature increases. The characteristics of HFC-143a may cause this effect, which is confirmed by the isothermal test points. However, it is not seen with mixed-acid polyolester (see Figure 13). Figure 12 shows density as a function of temperature at constant concentrations. Figure 12 indicates predicted density lines for the 30% to 60% refrigerant concentrations.

Viscosity of EMKARATE RL32S with HFC-143a

Appendix G, Table G.1, presents the isothermal viscosity, density, and solubility of gaseous HFC-143a with EMKARATE RL32S with good miscibility characteristics. Five viscosity data points were taken for each temperature. Figure 13 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 14 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 15 shows density as a function of temperature at constant concentrations. Please note that the density lines for 30% to 60% refrigerant are predicted for the higher temperatures.

Viscosity of Emery 2968A with HFC-125

Appendix H, Table H.1, presents the isothermal viscosity, density, and solubility of gaseous HFC-125 with Emery 2968A with good miscibility characteristics. Five viscosity data points were taken for each temperature. Figure 16 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 17 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 18 shows density as a function of temperature at constant concentrations. Please note that the density lines for 30% to 60% refrigerant are predicted for the higher temperatures.

Viscosity of EMKARATE RL32S with HFC-125

Appendix I, Table I.1, presents the isothermal viscosity, density, and solubility of gaseous HFC-125 with EMKARATE RL32S with good miscibility characteristics. Five viscosity data points were taken for each temperature. Figure 19 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 20 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 21 shows density as a function of temperature at constant concentrations. Please note that the density lines for 30% to 60% refrigerant are predicted for the higher temperatures.

Viscosity of EMKARATE RL32S with HFC-32

Appendix J, Table J.1, presents the isothermal viscosity, density, and solubility of gaseous HFC-32 with EMKARATE RL32S with good miscibility characteristics. Five viscosity data points were taken for each temperature. Figure 22 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 23 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 24 shows density as a function of temperature at constant concentrations. Please note that the density lines for 30% to 60% refrigerant are predicted for the higher temperatures.

Viscosity of Emery 2968A with HFC-32

Appendix K, Table K.1, presents the isothermal viscosity, density, and solubility of gaseous HFC-32 with Emery 2968A with good miscibility characteristics. Five viscosity data points were taken for each temperature. Figure 25 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 26 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 27 shows density as a function of temperature at constant concentrations. Please note that the density lines for 30% to 60% refrigerant are predicted for the higher temperatures.

RESULTS OF MEASUREMENTS WITH REFRIGERANT BLENDS

Viscosity of Emery 2968A with R-404A

Appendix L, Table L.1, presents the isothermal viscosity, density, and solubility of the gaseous R-404A with Emery 2968A. Viscosity reduction was accomplished by purging the liquid blend through the lubricant at constant temperature and pressure. The refrigerant composition at each viscosity data point was determined by gas chromatography. Six viscosity data points were taken for each temperature. Figure 28 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 29 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 30 shows density as a function of temperature at constant concentrations. The density points are predicted for some of the 30% to 60% concentrations at the high temperature end.

R-404A was also subsequently added to this polyolester in an unpurged manner in order to check the sensitivity of the R-404A fraction when the composition of the gas in the head space is not at equilibrium. This data is shown in Appendix L, Figure L.9, raw data Table L.2. The isothermal point at 60°C (140°F) indicates that the lubricant was not at equilibrium with complete fractionation as seen in Figure L.3.

Viscosity of EMKARATE RL32S with R-404A

Appendix M, Table M.1, presents the isothermal viscosity, density, and solubility of the gaseous R-404A with EMKARATE RL32S. Viscosity reduction was accomplished by purging liquid blend through the lubricant at constant temperature and pressure. The refrigerant composition at each viscosity data point was determined by gas chromatography. Six viscosity data points were taken for each temperature. Figure 31 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 32 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 33 shows density as a function of temperature at constant concentrations.

Viscosity of EMKARATE RL32S with R-507

Appendix N, Table N.1, presents the isothermal viscosity, density, and solubility of the gaseous R-507 with EMKARATE RL32S. Viscosity reduction was accomplished by purging liquid R-507 through the lubricant at constant temperature and pressure. The refrigerant composition at each viscosity data point was determined by gas chromatography. Six viscosity data points were taken for each temperature. Figure 34 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 35 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 36 shows density as a function of temperature at constant concentrations. Concentration lines of 50% to 60% at the high temperature end are predicted.

Viscosity of Emery 2968A with R-507

Appendix O, Table O.1, presents the isothermal viscosity, density, and solubility of the gaseous R-507 with Emery 2968A. Viscosity reduction was accomplished by purging liquid R-507 through the lubricant at constant temperature and pressure. The refrigerant composition at each viscosity data point was determined by gas chromatography. Six viscosity data points were taken for each temperature. Figure 37 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 38 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 39 shows density as a function of temperature at constant concentrations.

Unpurged viscosity reductions are included with this R-507 lubricant combination in order to check the susceptibility of gas fractionation when the composition of the gas in the head space is not at equilibrium. This data is shown in Appendix O, Figure O.9 and the raw data as Table O.2. R-507 is reported to be an azeotrope. In the unpurged addition, a variance in the head space is visible. However, in the purged method, the composition of the gas soluble in lubricant favors HFC-143a, which is apparently the more soluble component. This is even further favored as the pressure increases.

Viscosity of Emery 2968A with R-407C

Appendix P, Table P.1, presents the isothermal viscosity, density, and solubility of the gaseous R-407C with Emery 2968A. Viscosity reduction was accomplished by purging liquid R-407C through the lubricant at constant temperature and pressure. The refrigerant composition at each viscosity data point was determined by gas chromatography. Six viscosity data points were taken for each temperature. Figure 40 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 41 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 42 shows density as a function of temperature at constant concentrations.

Because this refrigerant has the largest temperature glide of the three blends evaluated, we re-evaluated the PVT measurements using two different refrigerant injection methods. The initial unpurged raw data is seen in Table P.2 and in Figure P.9. When 60°C (140°F) was chosen for the unpurged work, we discovered a discrepancy of compositional shift and vastly different viscosities when compared to the normal trend. It was this point of data re-examination that suggested a compositional shift existed. Therefore, the zero head space injection cylinder was designed. In raw data Table P.1, we have demonstrated the isothermal data in a comparative format, indicating the small differences as well as the reliability of both measurements. The first, purged 60°C (140°F) isothermal data collection has been determined by us to be inconsistent due to a lack of data correlation. Therefore, this set of data has been eliminated from the calculations of the modified Daniel plots.

Viscosity of EMKARATE RL32S with R-407C

Appendix Q, Table Q.1, presents the isothermal viscosity, density, and solubility of the gaseous R-407C with EMKARATE RL32S. Viscosity reduction was accomplished by purging liquid R-407C through the lubricant at constant temperature and pressure. The refrigerant composition at each viscosity data point was determined by gas chromatography. Six viscosity data points were taken for each temperature. Figure 43 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 44 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 45 shows density as a function of temperature at constant concentrations.

The unpurged raw data is seen in Table Q.2 and the 60°C (140°F) isothermal is seen in Figure Q.9. Without purging, the composition of the gases in the head space does not match the composition of the refrigerant mixture entering the viscometer. This lubricant was the last completed in this series using R-407C. There is concern that there may have been R-407C changes when removing successive aliquots of refrigerant blend. Therefore, the composition in the lubricant may vary more than ±2% to 4% due to R-407C changes.

FITTING EMPIRICAL EQUATIONS TO EXPERIMENTAL DATA

All of the measured experimental data is presented as raw data tables in appendices B through Q. This information has been provided so that the data can be evaluated against any estimations and/or smoothing equations. All of our experimental data has been compiled in an automated manner as is acquired into a working matrix. This matrix uses an equation that was designed by IRI for this fluid property study. The individual parameters are not separately acquired or reported.

Therefore and for presentation purposes, all of the compiled graphical data illustrated uses a smoothing equation determined by the method of least squares. However, the design of the equation (see Appendix R) takes into consideration the saturation pressure of each refrigerant, the mole fraction of both refrigerant and lubricant, and all of the averaged data points from all of the isothermal viscosity, density, and solubility data. All isothermal viscosity and density points are averages of at least six separate determinations and the concentration values are from at least two separate equilibrium points. Some isothermal data indicates a solubility curve that has a rapid change in pressure and is referred to by IRI as a solubility knee.

DIFFERENTIAL SOLUBILITY OF REFRIGERANT BLEND COMPONENTS

The vapor phase is maintained to be constant and equal to that of the liquid refrigerant. Depending on the temperature glide and azeotropic properties of a refrigerant blend, there are differing degrees of gas solubility, which have been found to be temperature and pressure selective. Therefore, in tabular format and in graphical format, the differential solubility is presented for each isothermal lubricant and/or blend plot (see Appendices L through Q). A decision was made to keep this differential solubility data in tabular format due to presentation complications in Figures 28 through 45.

DISCUSSION

Producing fluid property profiles for the viscosity reduction of single refrigerants is relatively simple; however, performing the same tasks with blends is difficult. The most troublesome blends are those with large temperature glides. Refrigerant R-404A and azeotrope R-507 were the least difficult with which to work. R-407C had the larger glide. Although viscosity reduction by R-407C was re-examined and then compared to a more rigorous handling procedure (i.e.: the use of the vented hydraulic cylinder), both sets of data for the last blend were adequately comparable.

Refrigerant blends with large temperature glides will need to be further studied using a liquid blend injection technique that does not allow for any head space fractionation to occur. The unpurged data illustrates that in order to guarantee reproducible viscosity reduction, the ideal method is to maintain a consistent head space gas composition so that there will be minimal changes of solubilized gases in the lubricant at specified conditions. Consequently, a good starting point exists if re-evaluation of any isothermal data becomes necessary in the future. Seen in Appendices P and Q are the differing viscosity, pressure points, and solubilized compositional changes of R-407C in the lubricant. Another analytical reason for measuring and maintaining a constant composition head space is to insure that the reported pressure is of the liquid blend composition, or at least a known gas composition, and not of some other mixture. Experimental observations indicate that if a gas is introduced into the lubricant without adjusting the equilibrium by purging with liquid refrigerant, the pressure swings toward the high end and then falls toward what the pressure should be for the given gas composition.

One salient result of this study is that when selecting a lubricant for good return properties, liquid/liquid miscibility data can be very misleading. When evaluated by a gas equilibrium solubility method, the viscosity reduction of both tested lubricants is relatively equal. This study guarantees that there are no liquid/liquid phases and that there are only liquid and refrigerant gas phases in the viscometer. Therefore, the physical fluid property of the mixture can be accurately evaluated. Therefore, for compressor reliability the key to understanding the physical properties of good lubricant return is viscosity reduction by gas solubility.

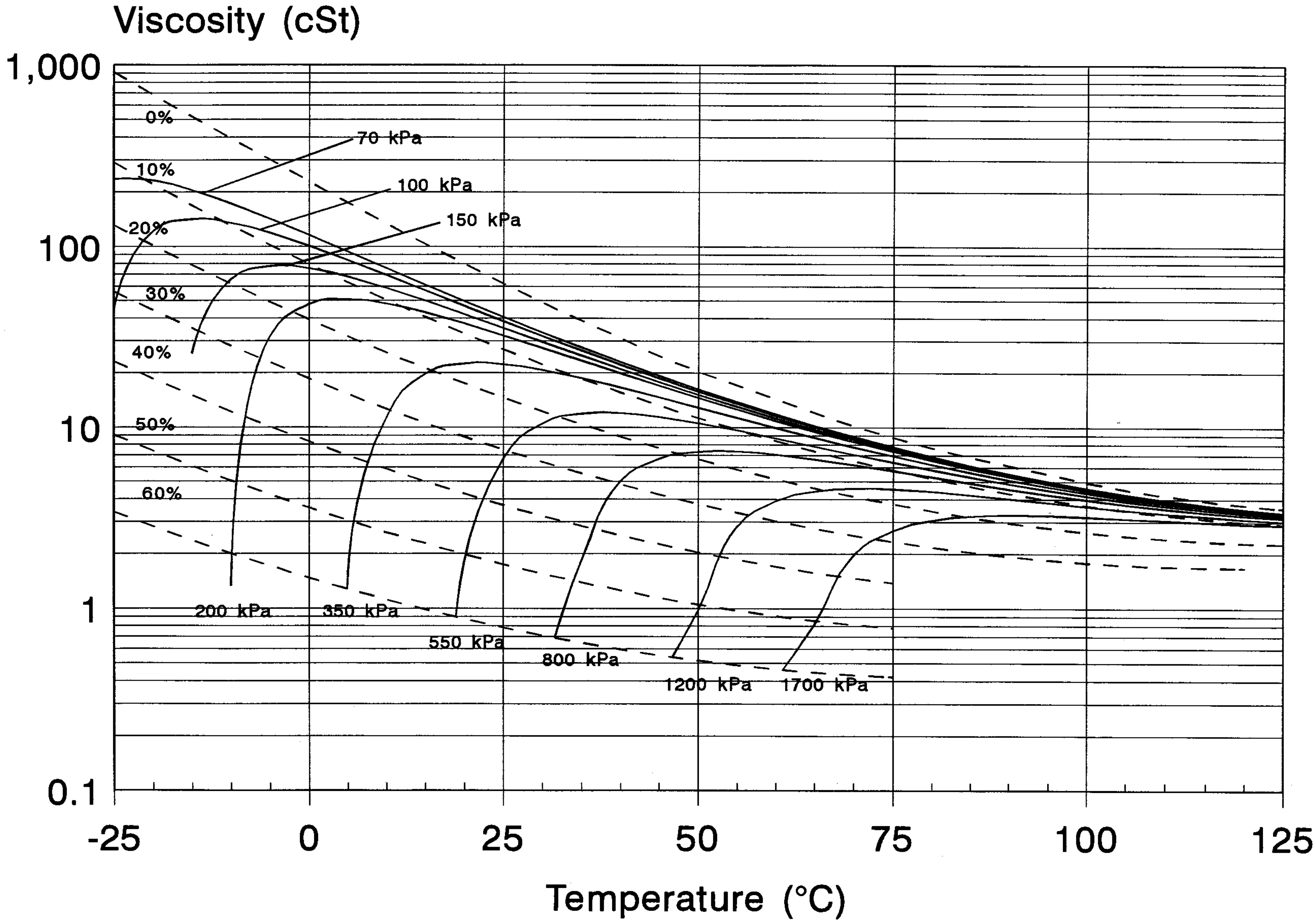
Presented in this report are viscosity reductions of lubricants with HFC-32, HFC-125, and HFC-143a above the critical temperatures and pressures. To the best of our knowledge, this is the first published information regarding viscosity reduction due to gas dissolved in lubricant above their critical pressure and temperature limits. Because compressors frequently surpass these limits of pressure and temperature, this information is important and illustrative of how compressors can be designed for increased performance and reliability.

Because of this study, a starting point now exists for system designers to consider how changes in fluid properties can improve system operations and heat transfer. Our research has also indicated that the viscosity reduction of fluids may affect foaming, bearing lubrication, and heat transfer. However, this data is not presented in this report.

A more significant viscosity reduction is evident with blends that contain lower molecular weight refrigerant such as HFC-32. Proportionately, viscosity reduction was more evident with R-407C at the same refrigerant concentration than with the other blends tested.

In closing, viscosity reduction with HFC-32 is more pronounced on a molecular basis than with the other refrigerants. Viscosity reduction is easier to determine for blends that have a small temperature glide and when the composition of the lubricant in solution is closer to the composition of the liquid blend. Refrigerant blends with increased temperature glides are analytically more difficult to handle and have a more pronounced viscosity reduction when HFC-32 is present. Further studies are needed to examine the effects of HFC-32 in other ternary refrigerant lubricant mixtures.

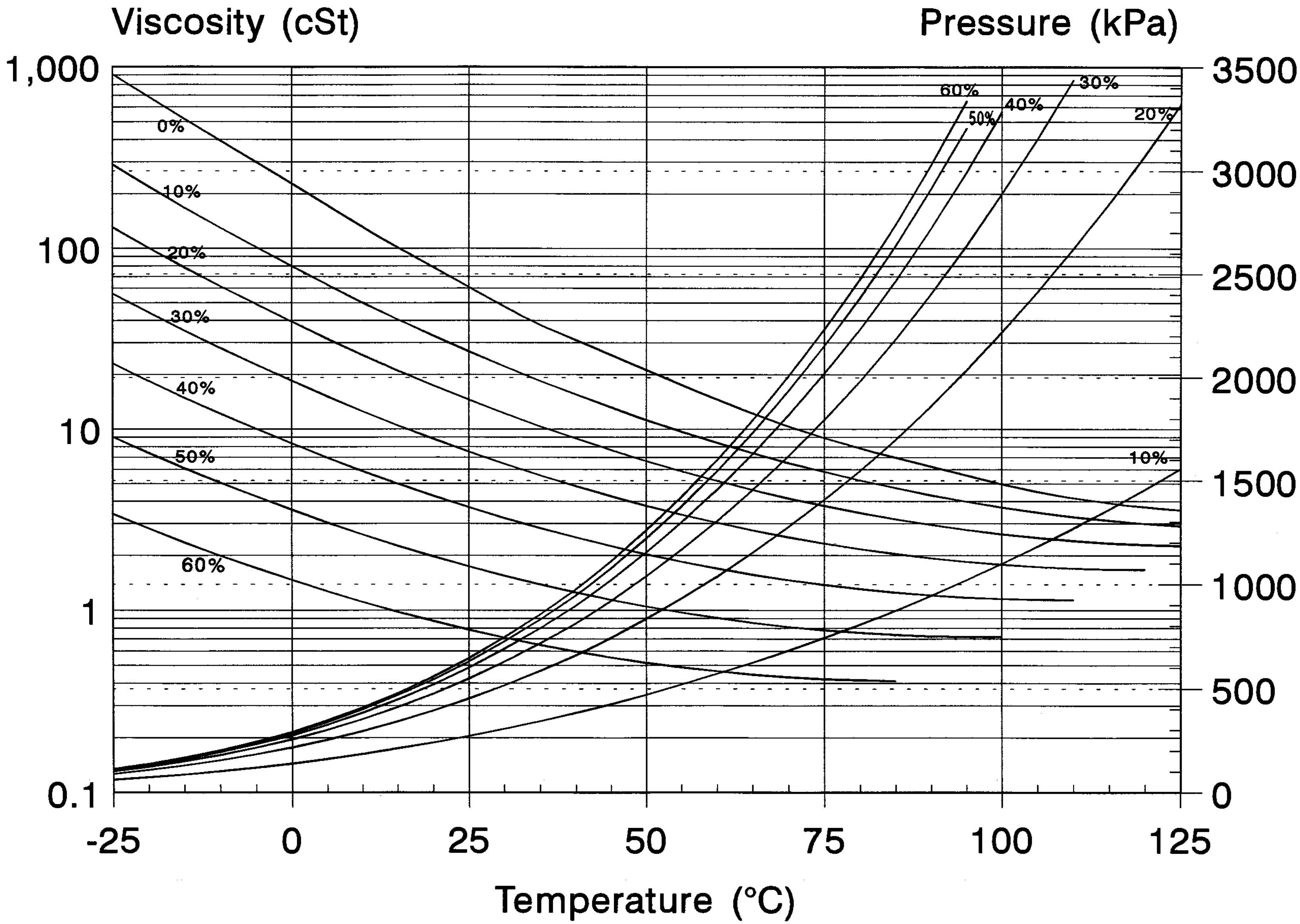
Viscosity vs. Temperature
HFC-134a with EMKARATE RL32S
Figure 4



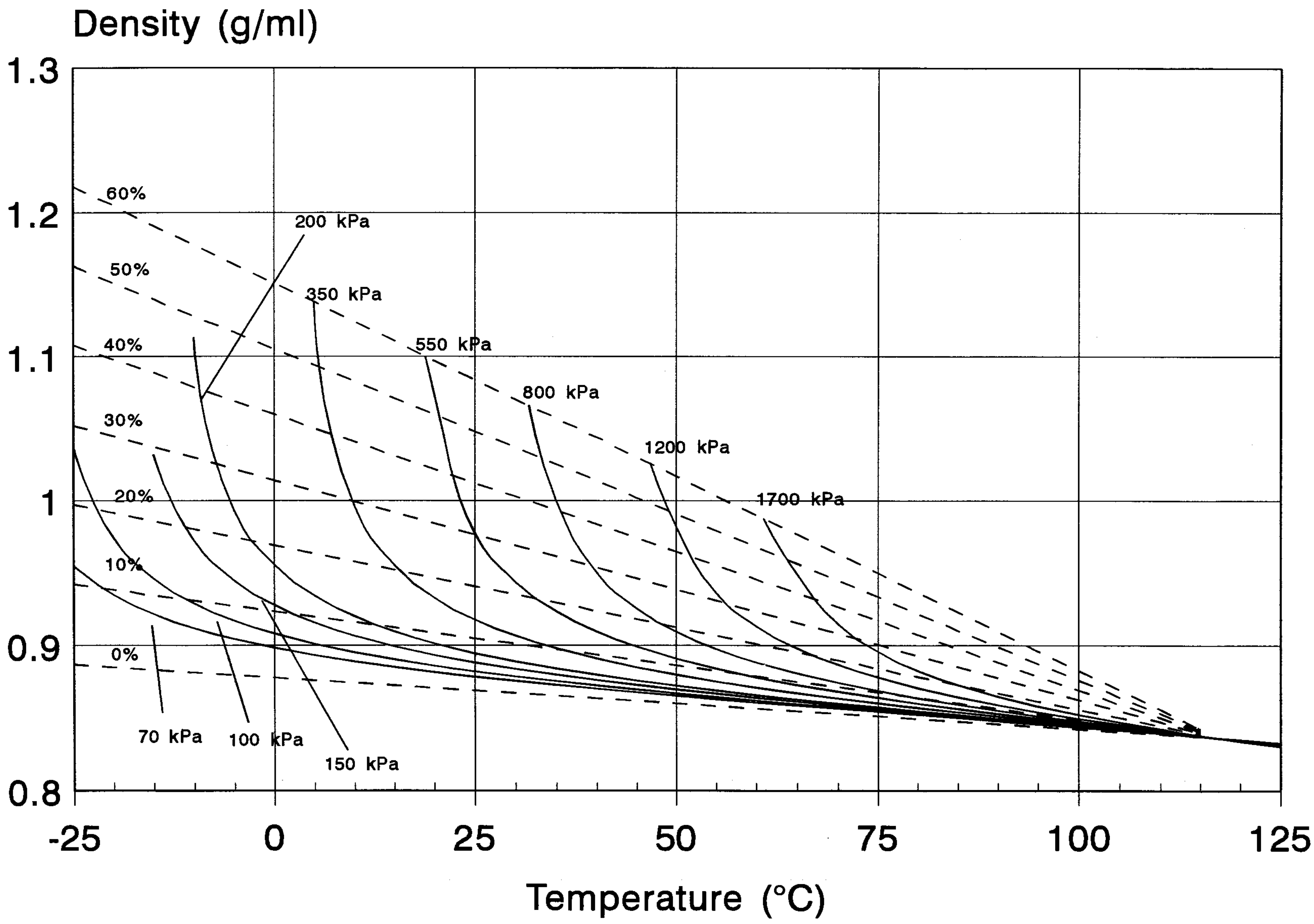
Viscosity and Pressure at Constant Concentrations

HFC-134a with EMKARATE RL32S

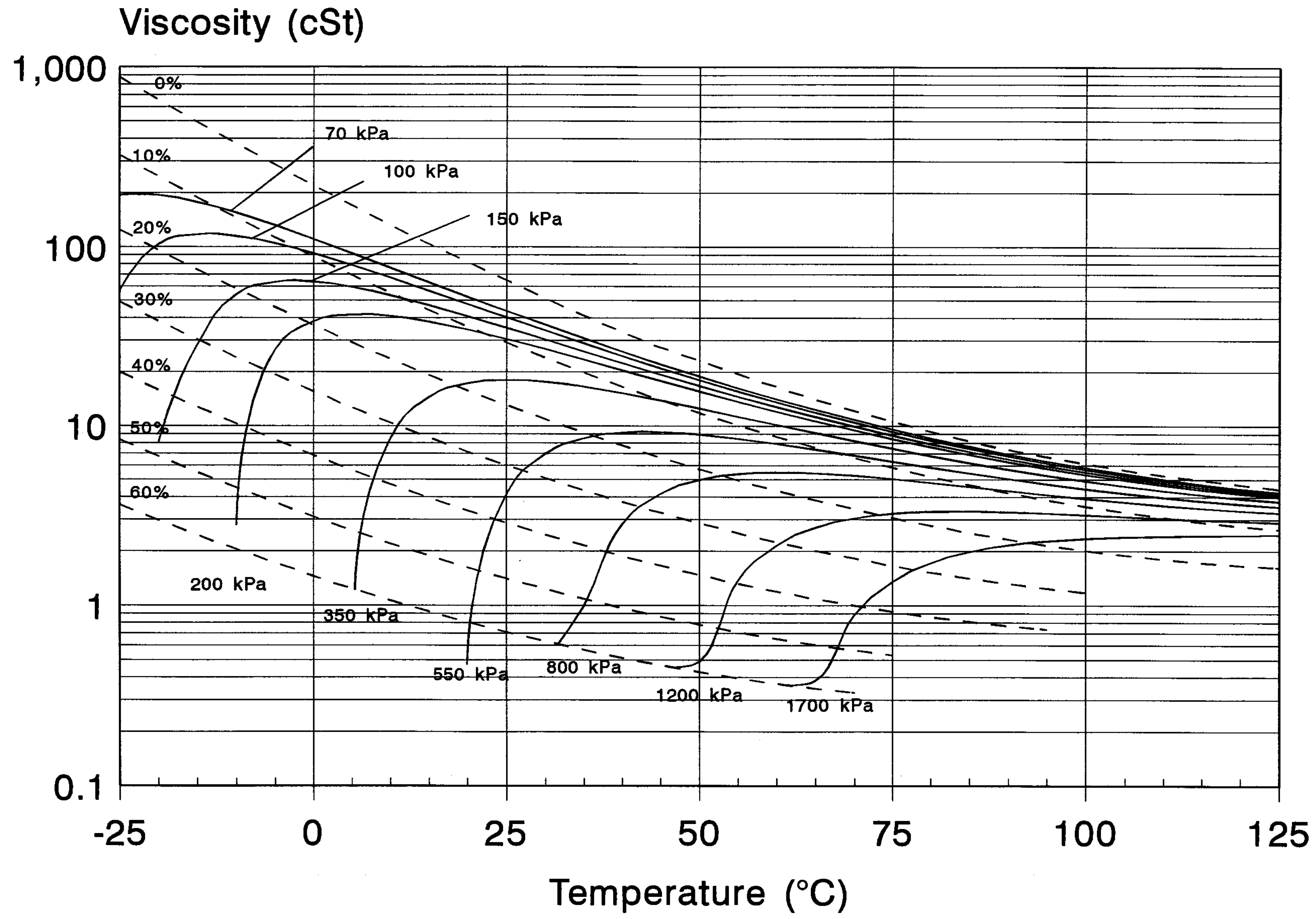
Figure 5



Density vs. Temperature
HFC-134a with EMKARATE RL32S
Figure 6



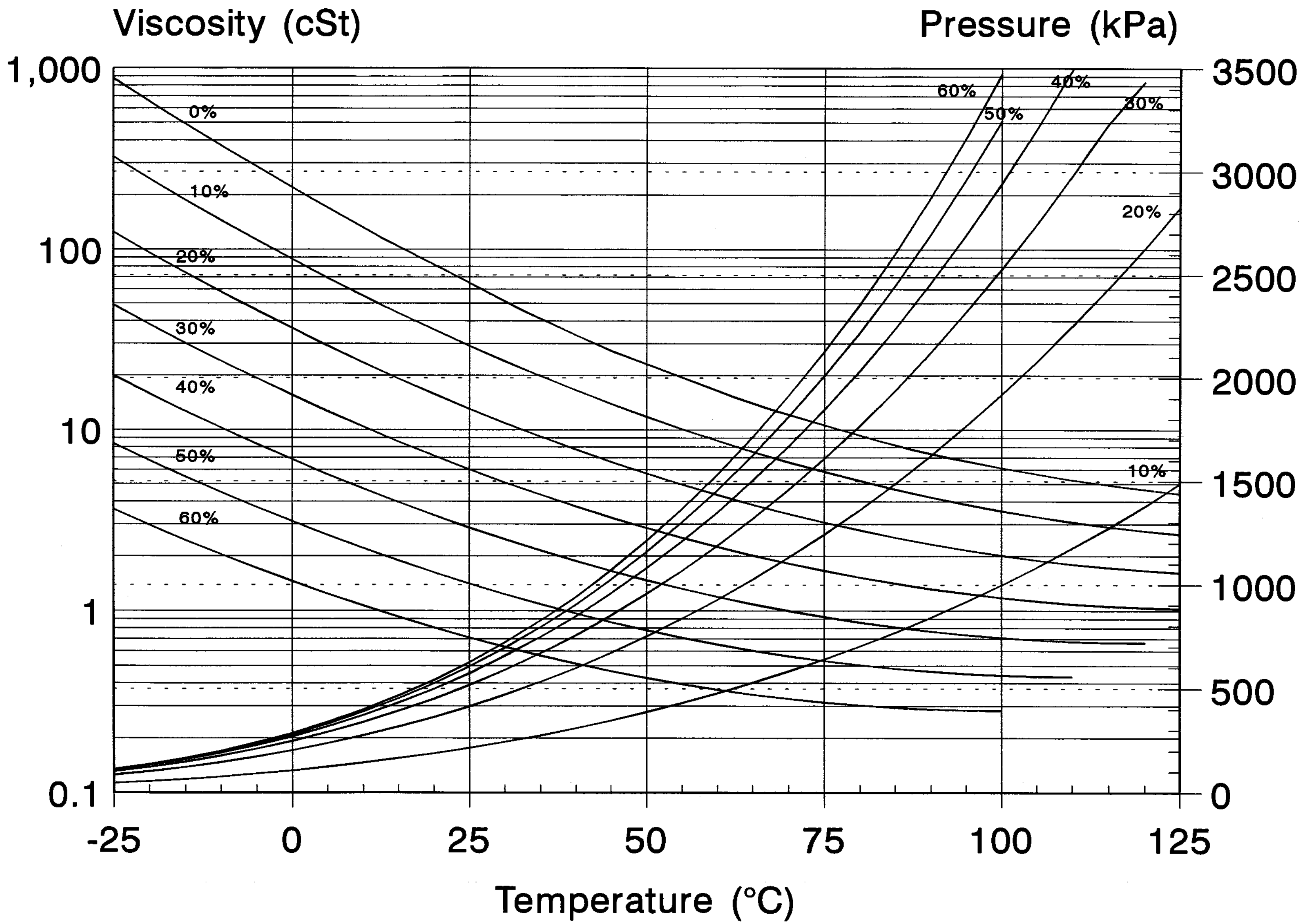
Viscosity vs. Temperature
HFC-134a with Emery 2968A
Figure 7



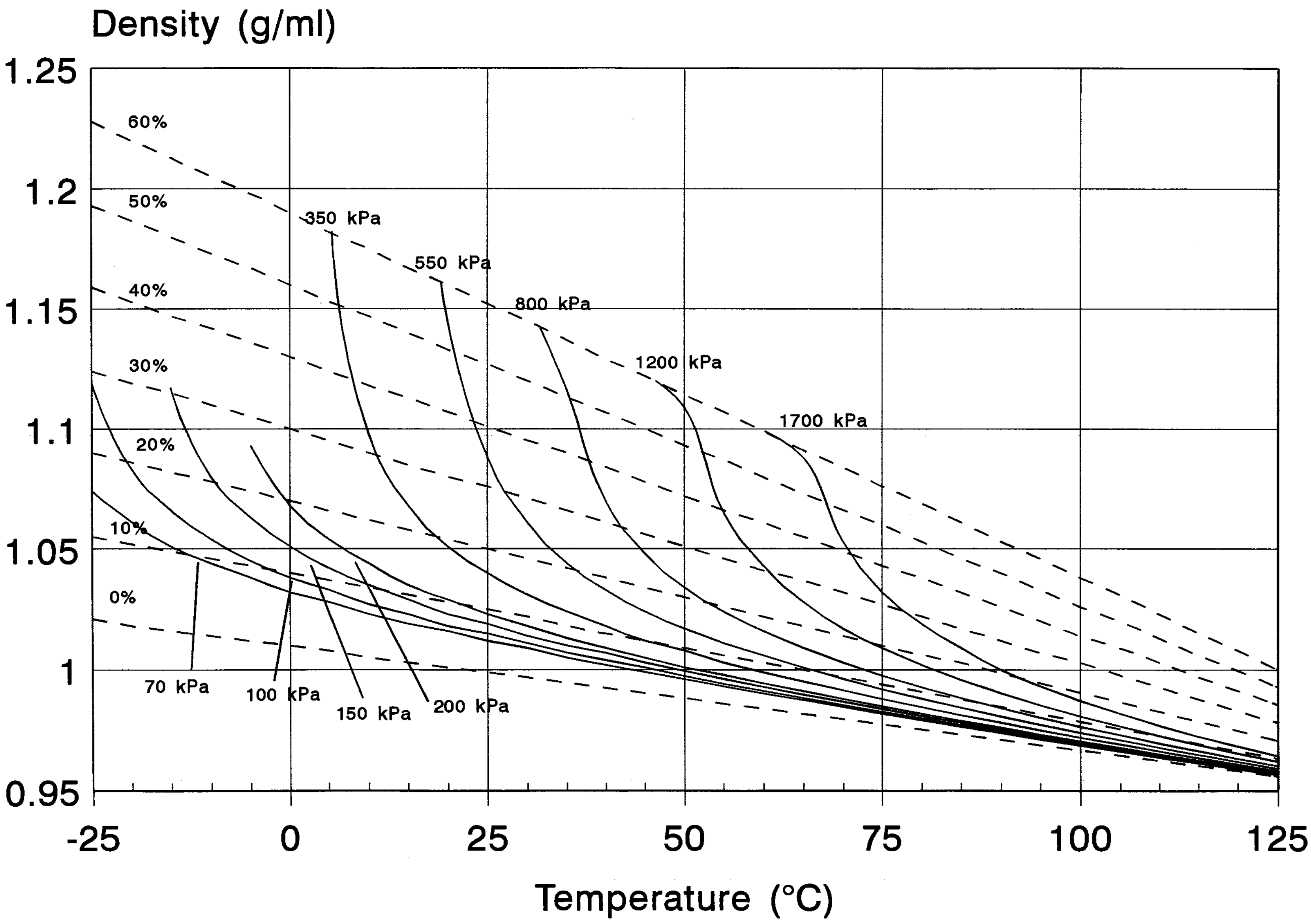
Viscosity and Pressure at Constant Concentrations

HFC-134a with Emery 2968A

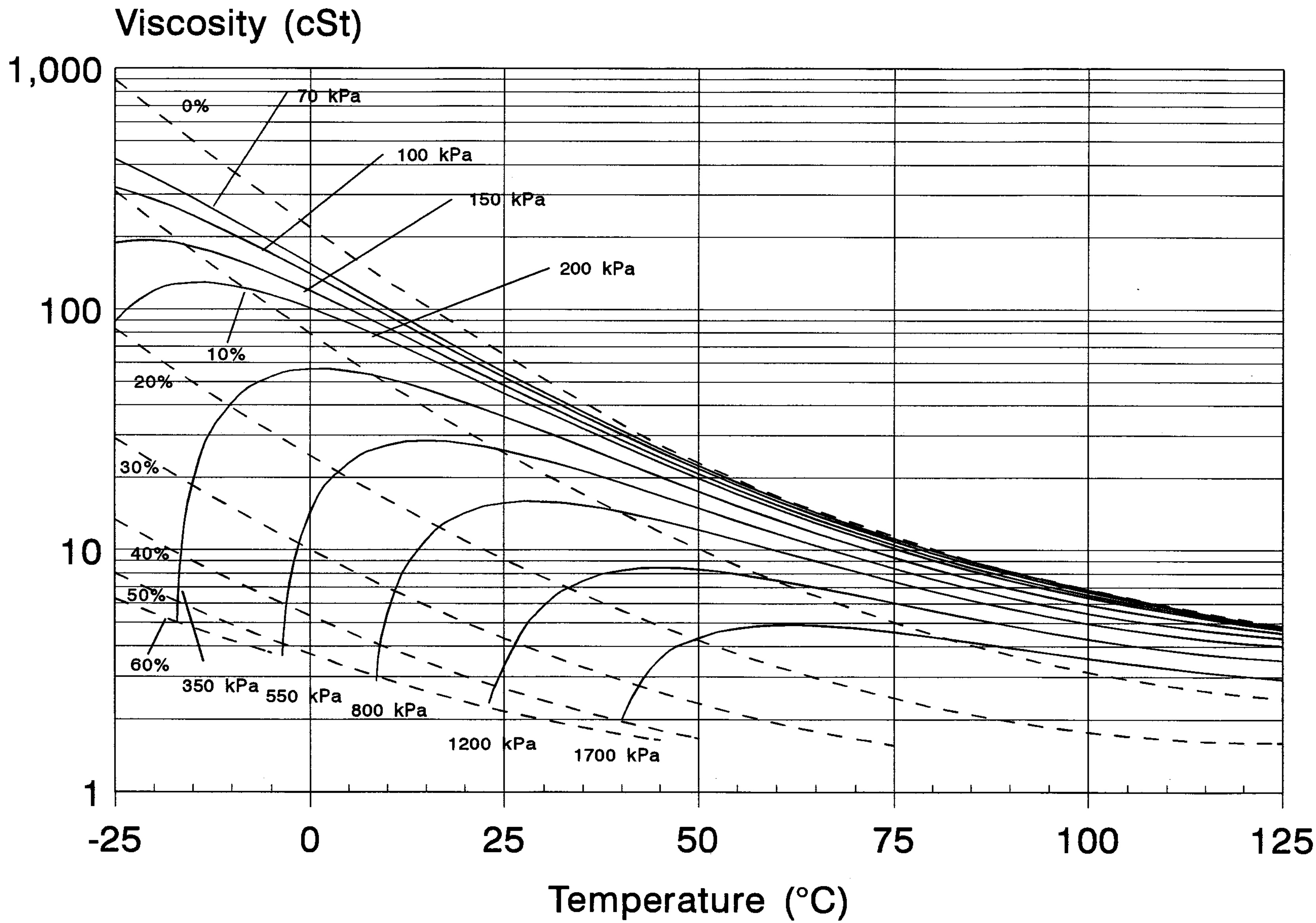
Figure 8



Density vs. Temperature
HFC-134a with Emery 2968A
Figure 9



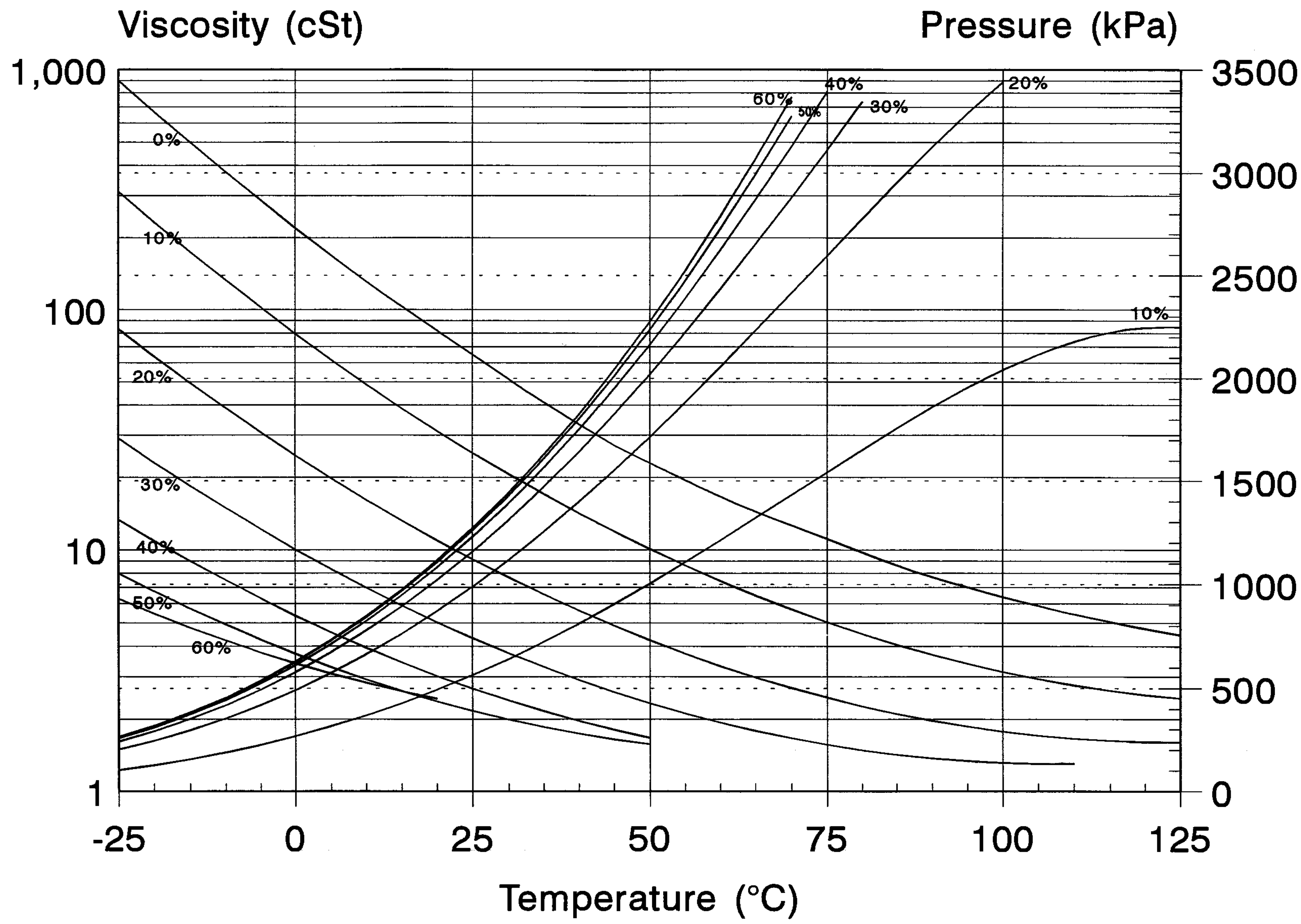
Viscosity vs. Temperature
HFC-143a with Emery 2968A
Figure 10



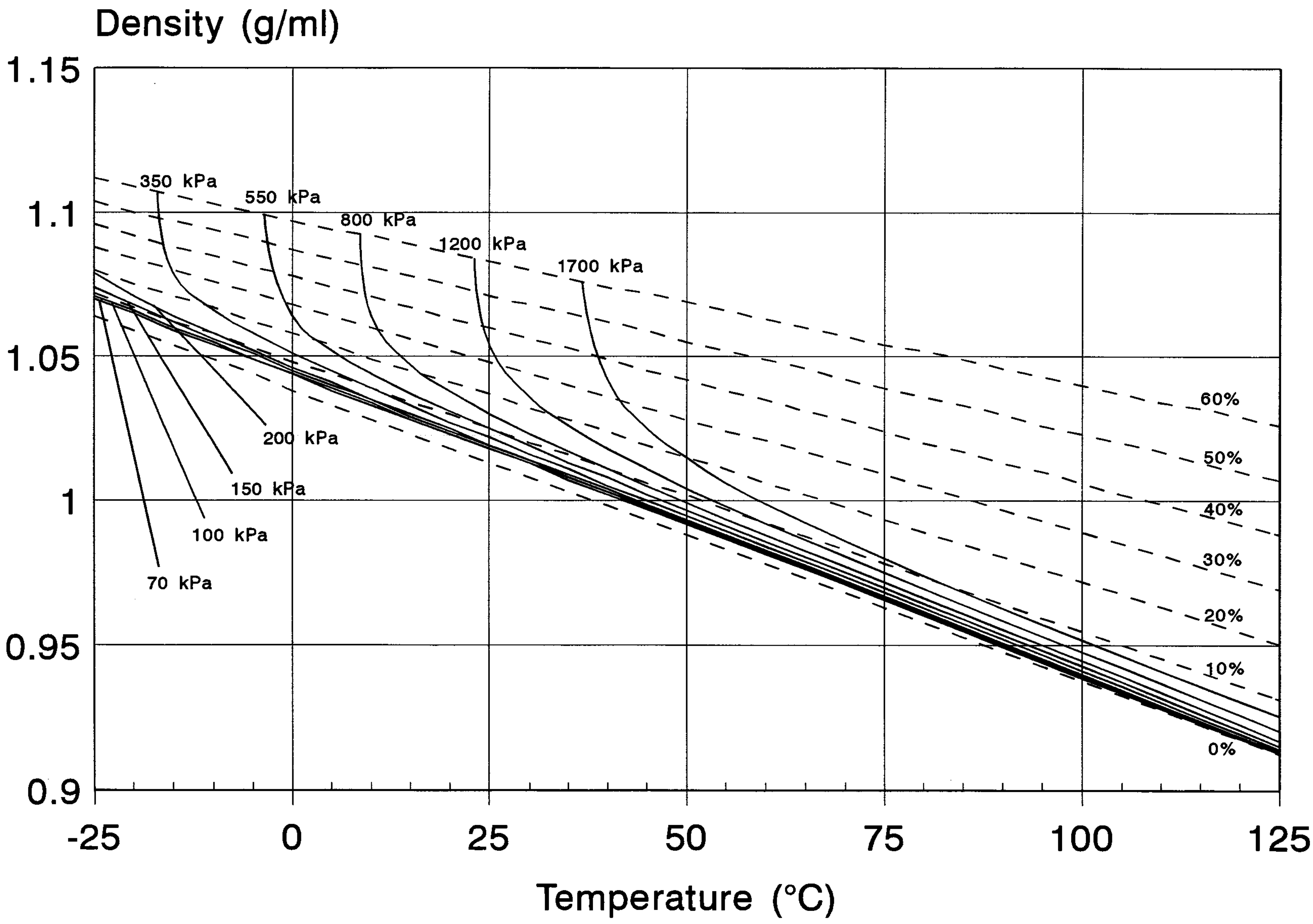
Viscosity and Pressure at Constant Concentrations

HFC-143a with Emery 2968A

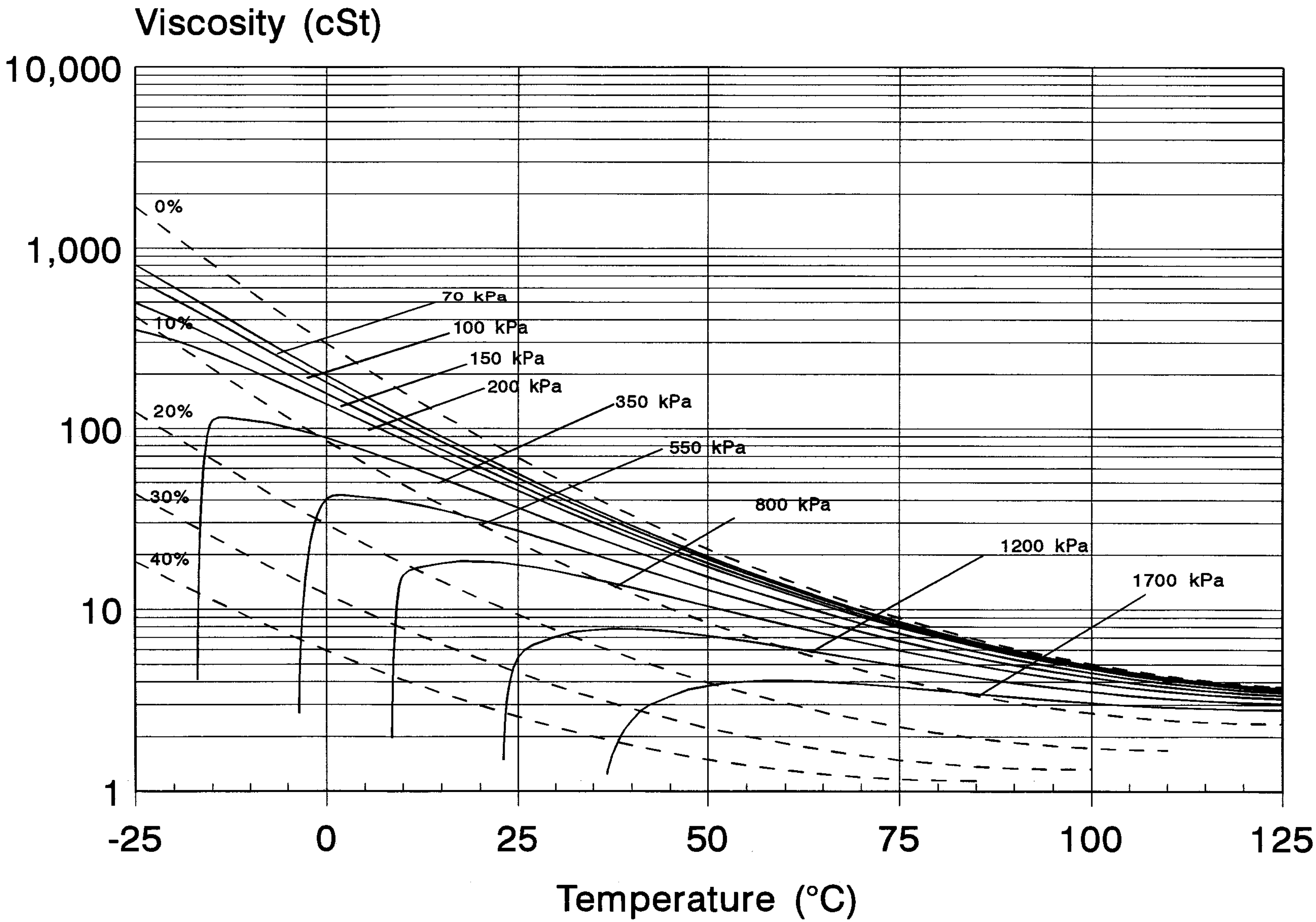
Figure 11



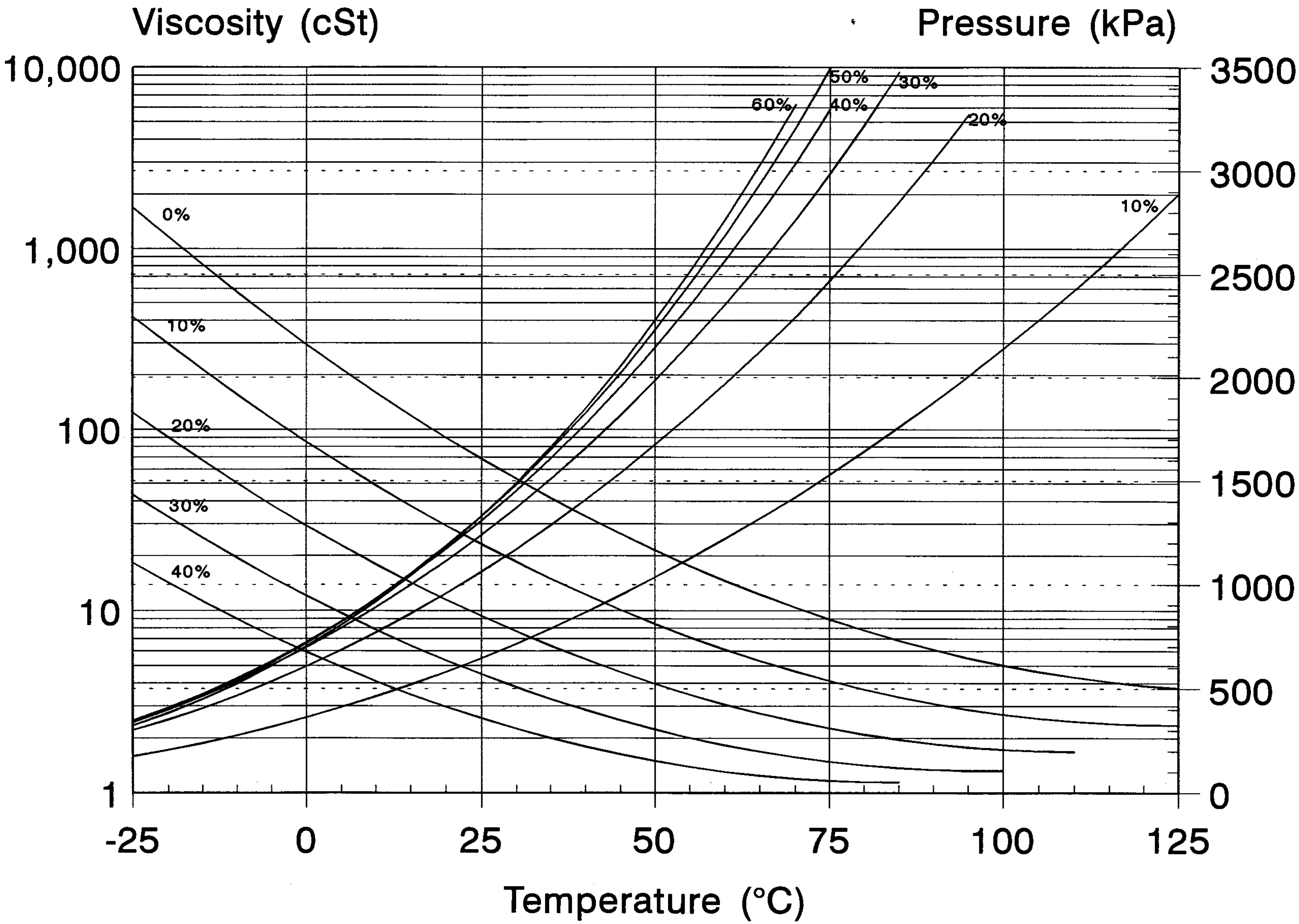
Density vs. Temperature
HFC-143a with Emery 2968A
Figure 12



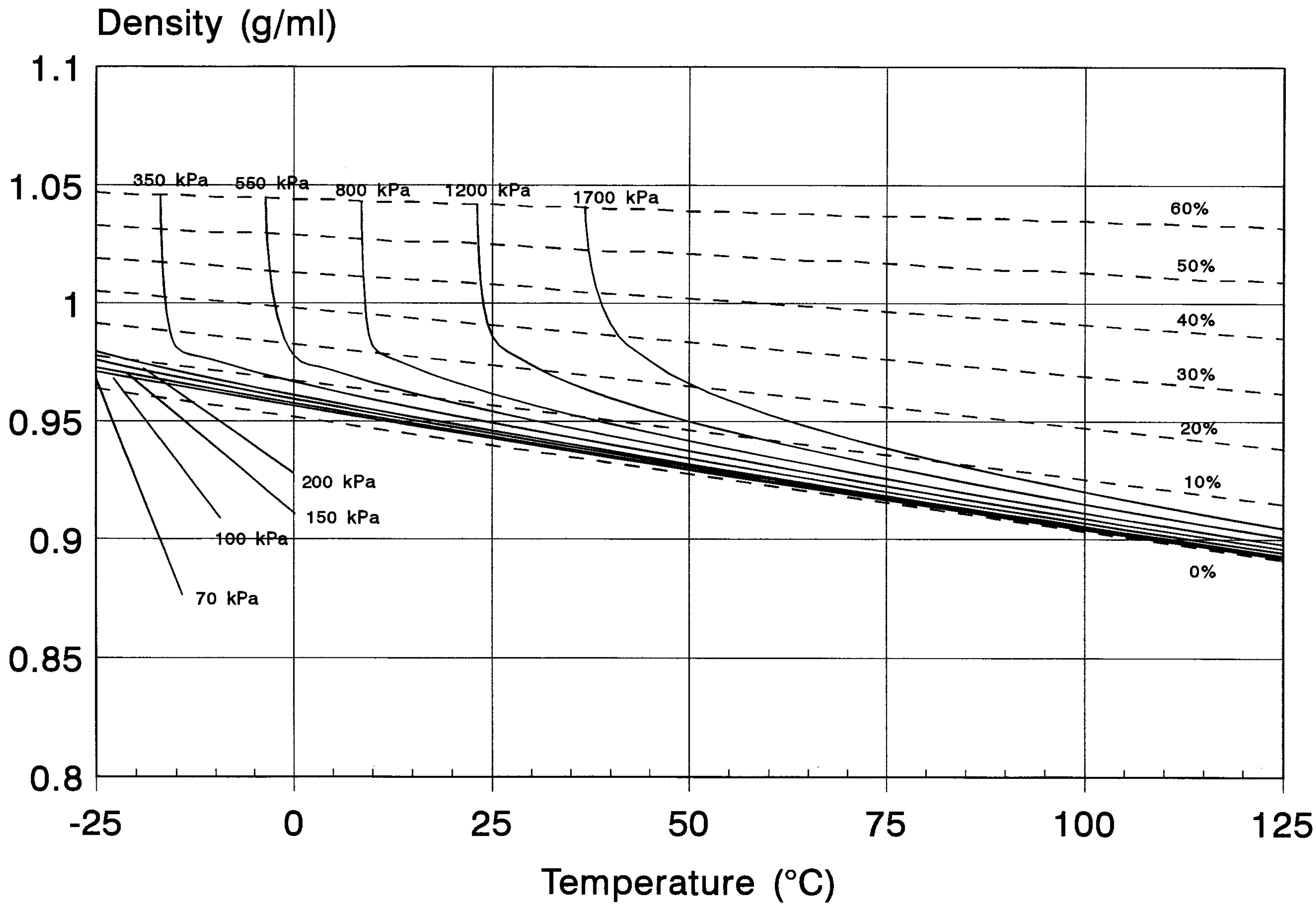
Viscosity vs. Temperature
HFC-143a EMKARATE RL32S
Figure 13



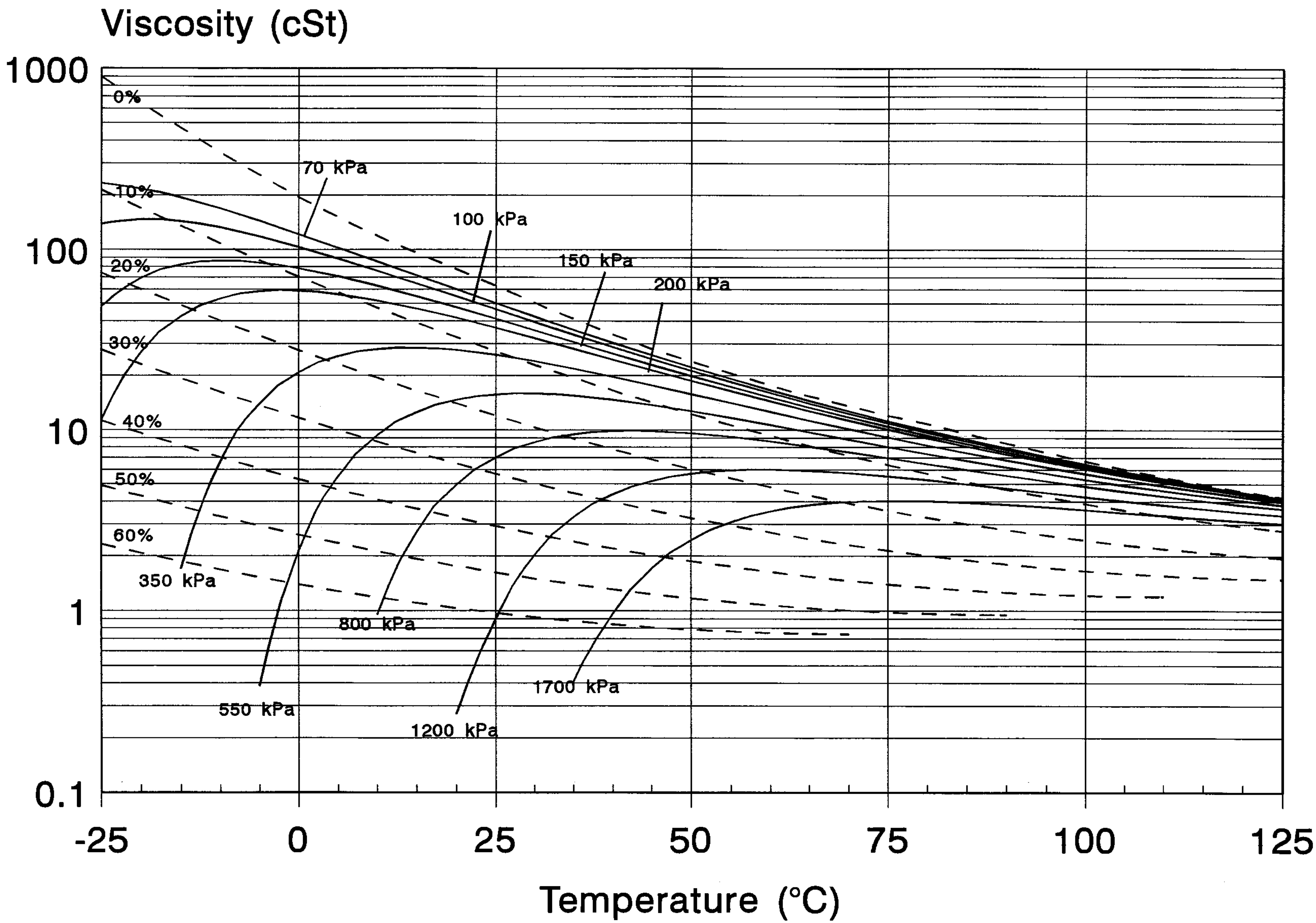
Viscosity and Pressure at Constant Concentrations
HFC-143a with EMKARATE RL32S
Figure 14



Density vs. Temperature
HFC-143a with EMKARATE RL32S
Figure 15



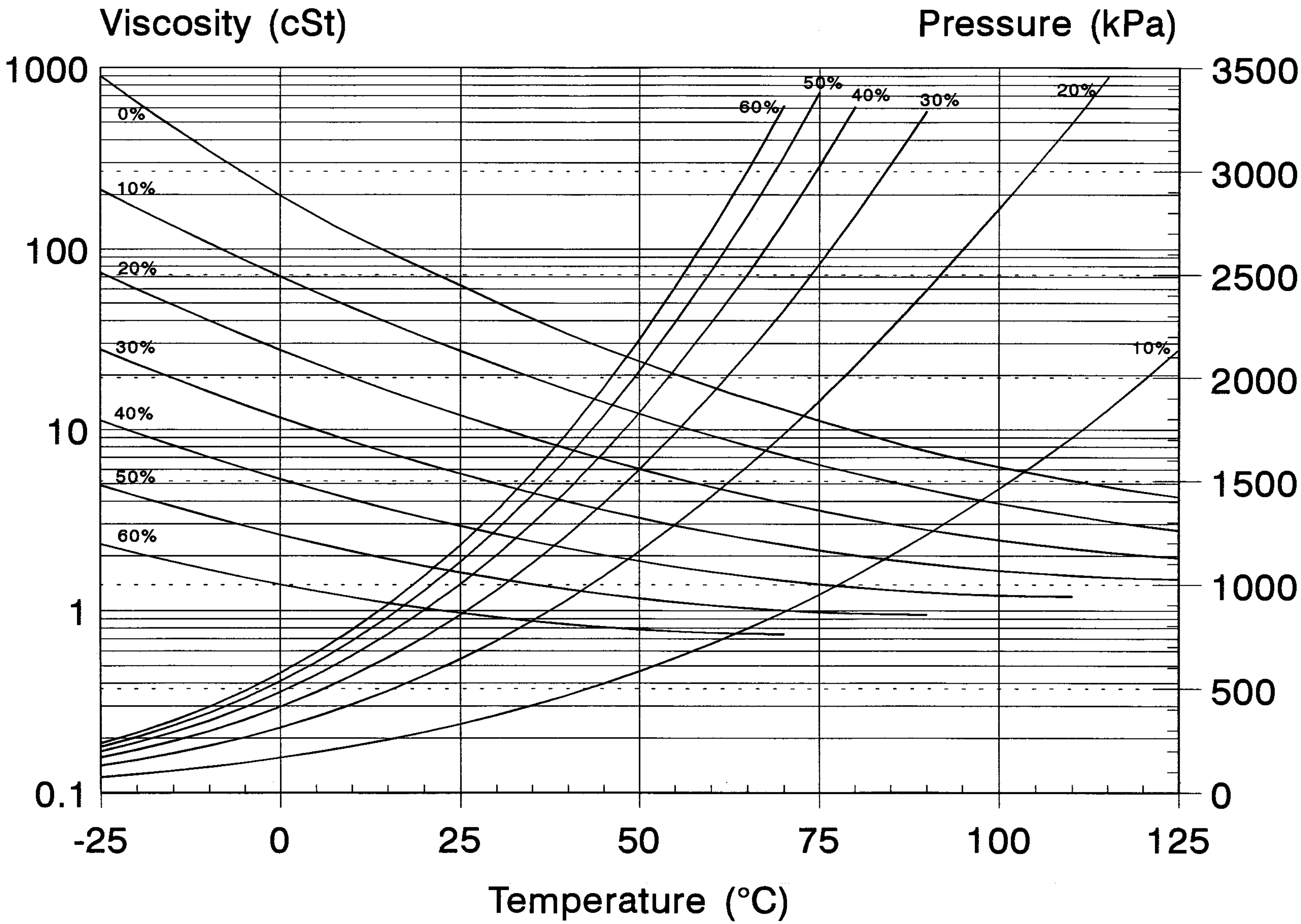
Viscosity vs. Temperature
HFC-125 with Emery 2968A
Figure 16



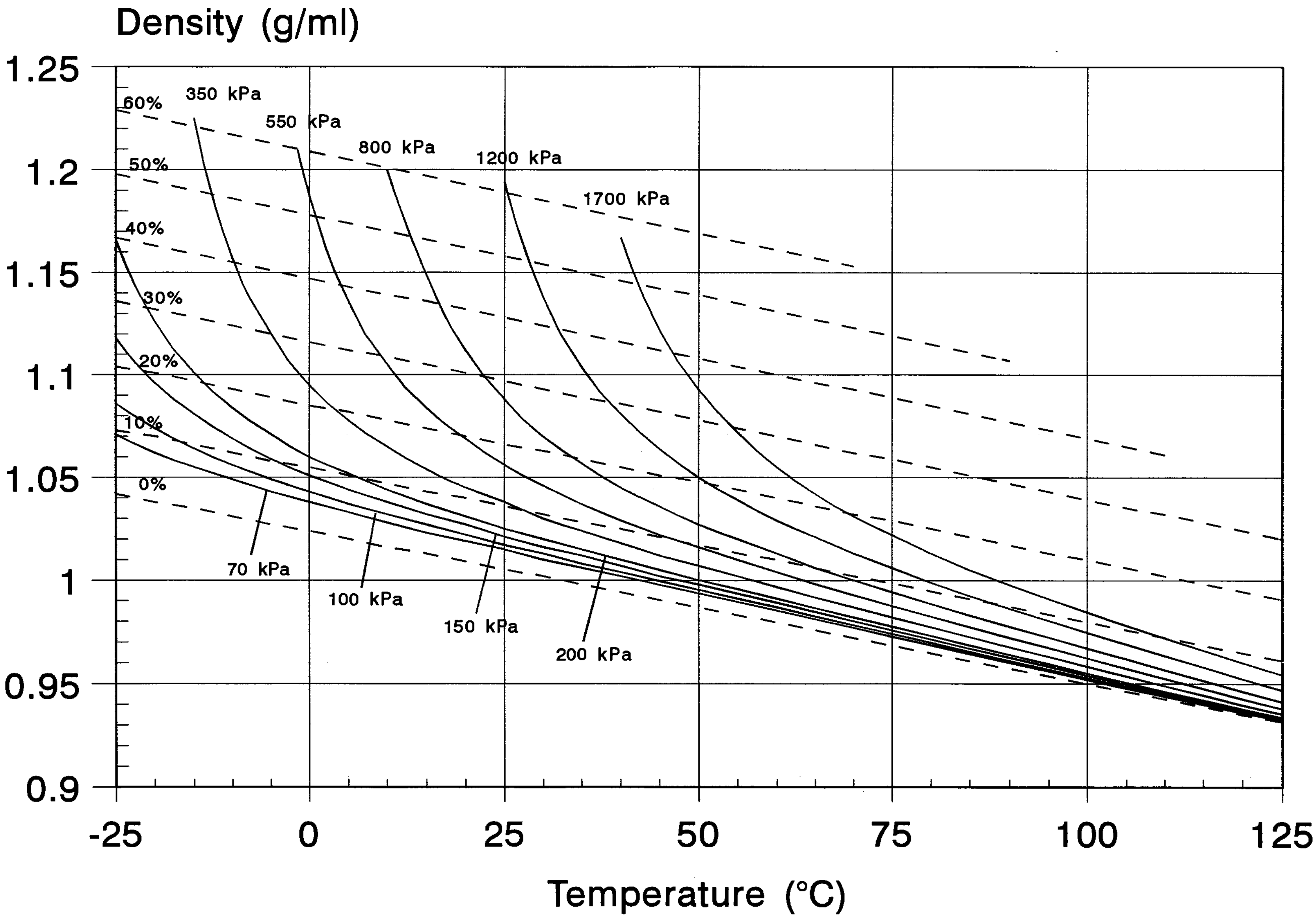
Viscosity and Pressure at Constant Concentrations

HFC-125 with Emery 2968A

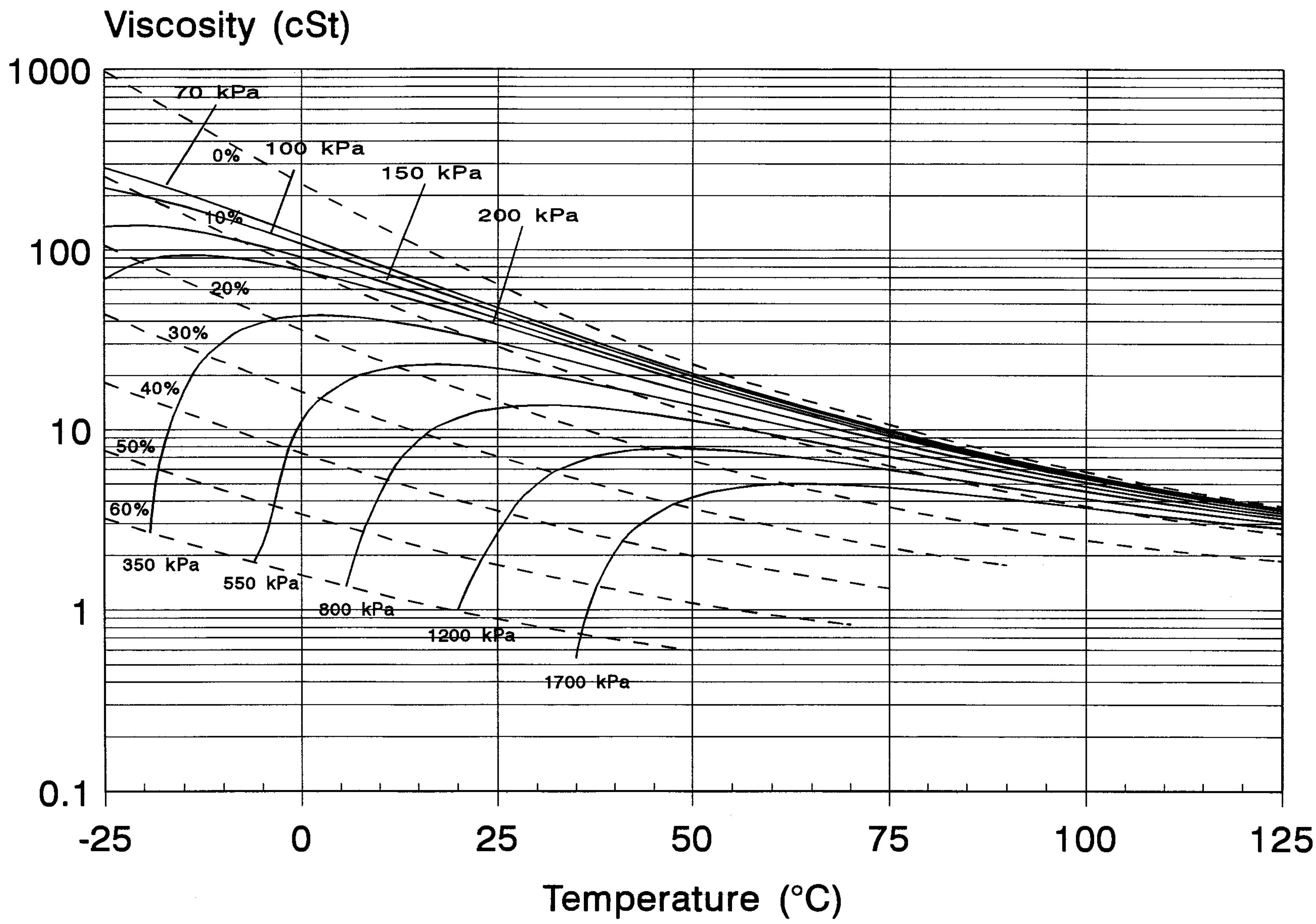
Figure 17



Density vs. Temperature
HFC-125 with Emery 2968A
Figure 18



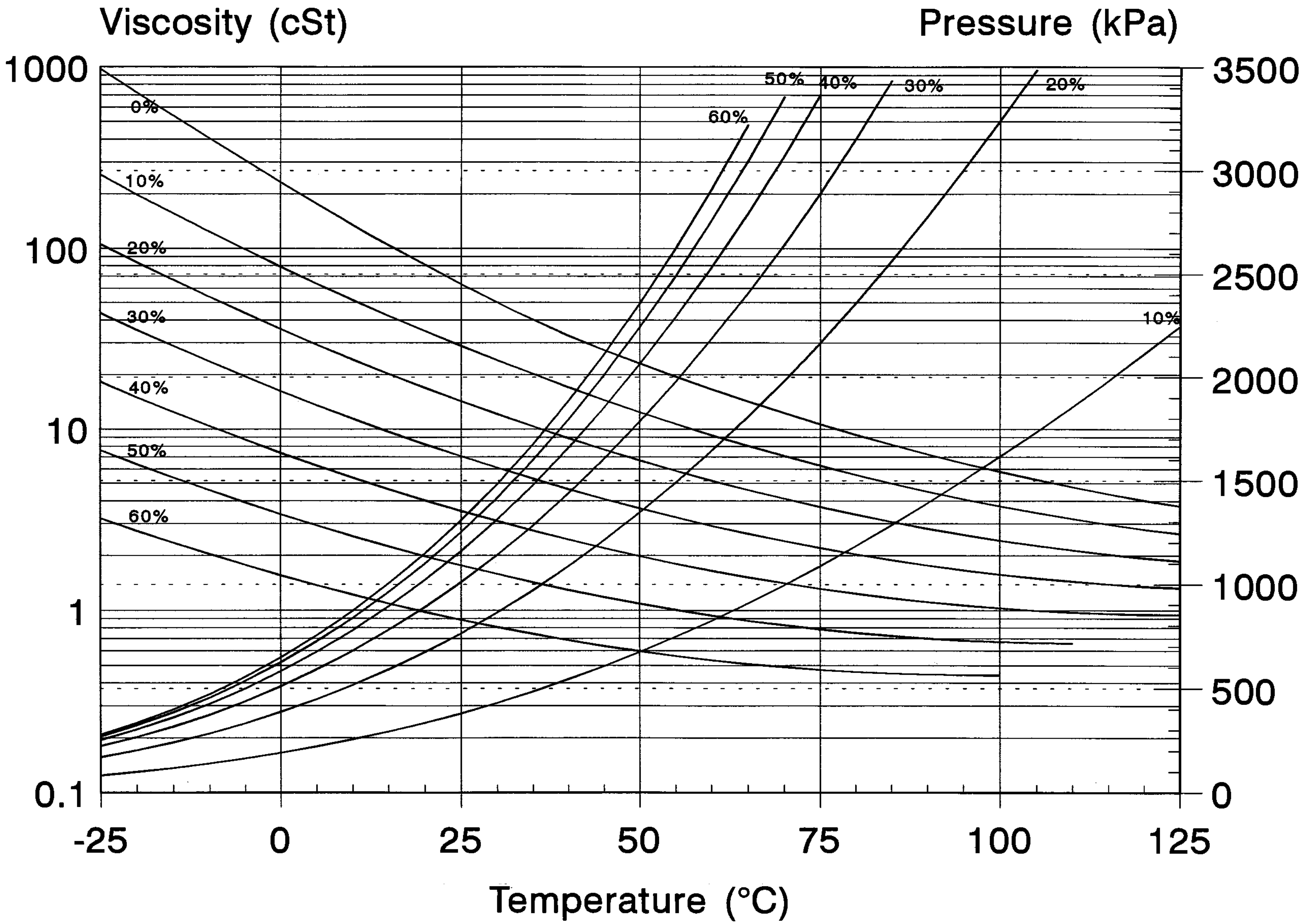
Viscosity vs. Temperature
HFC-125 with EMKARATE RL32S
Figure 19



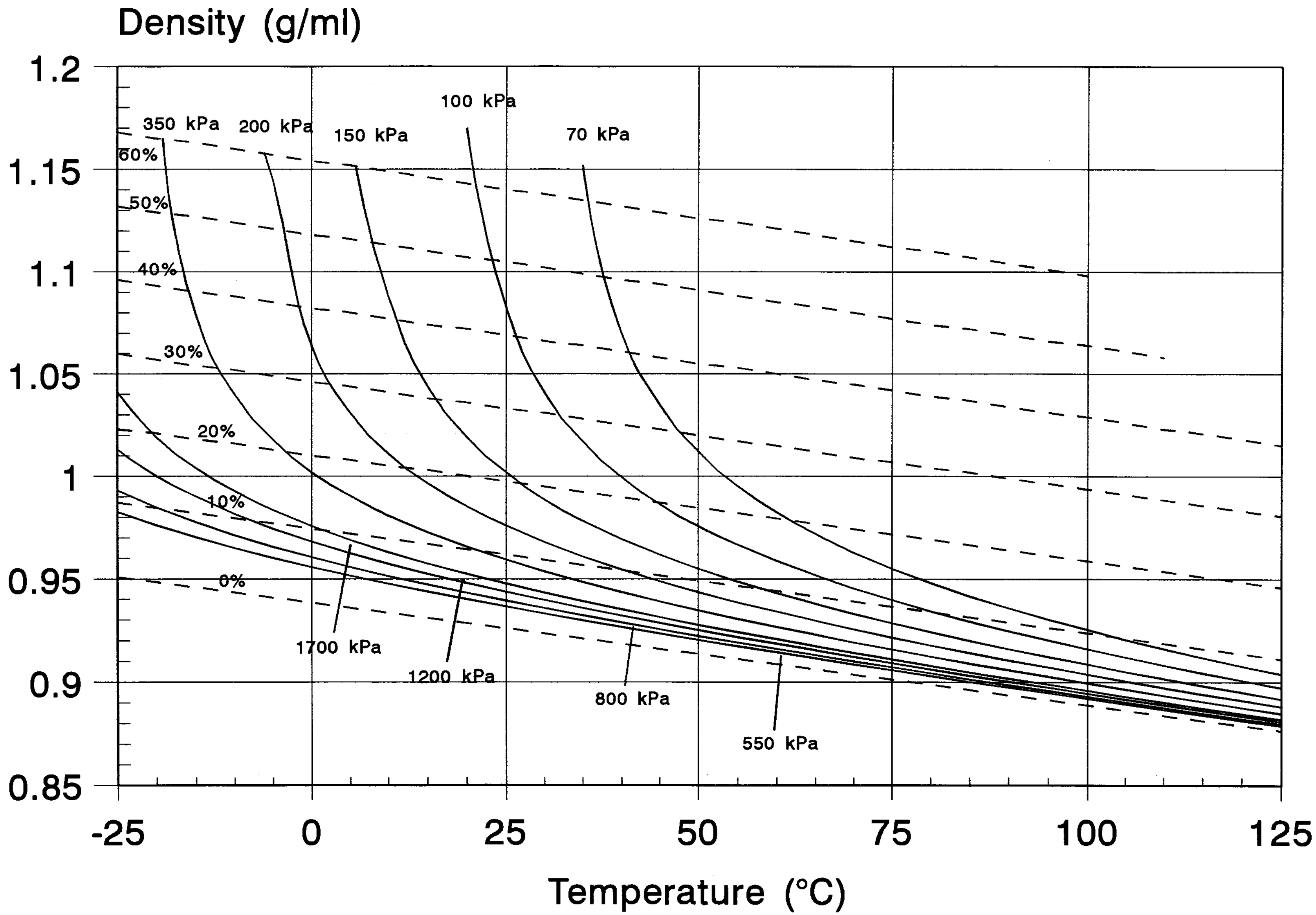
Viscosity and Pressure at Constant Concentrations

HFC-125 with EMKARATE RL32S

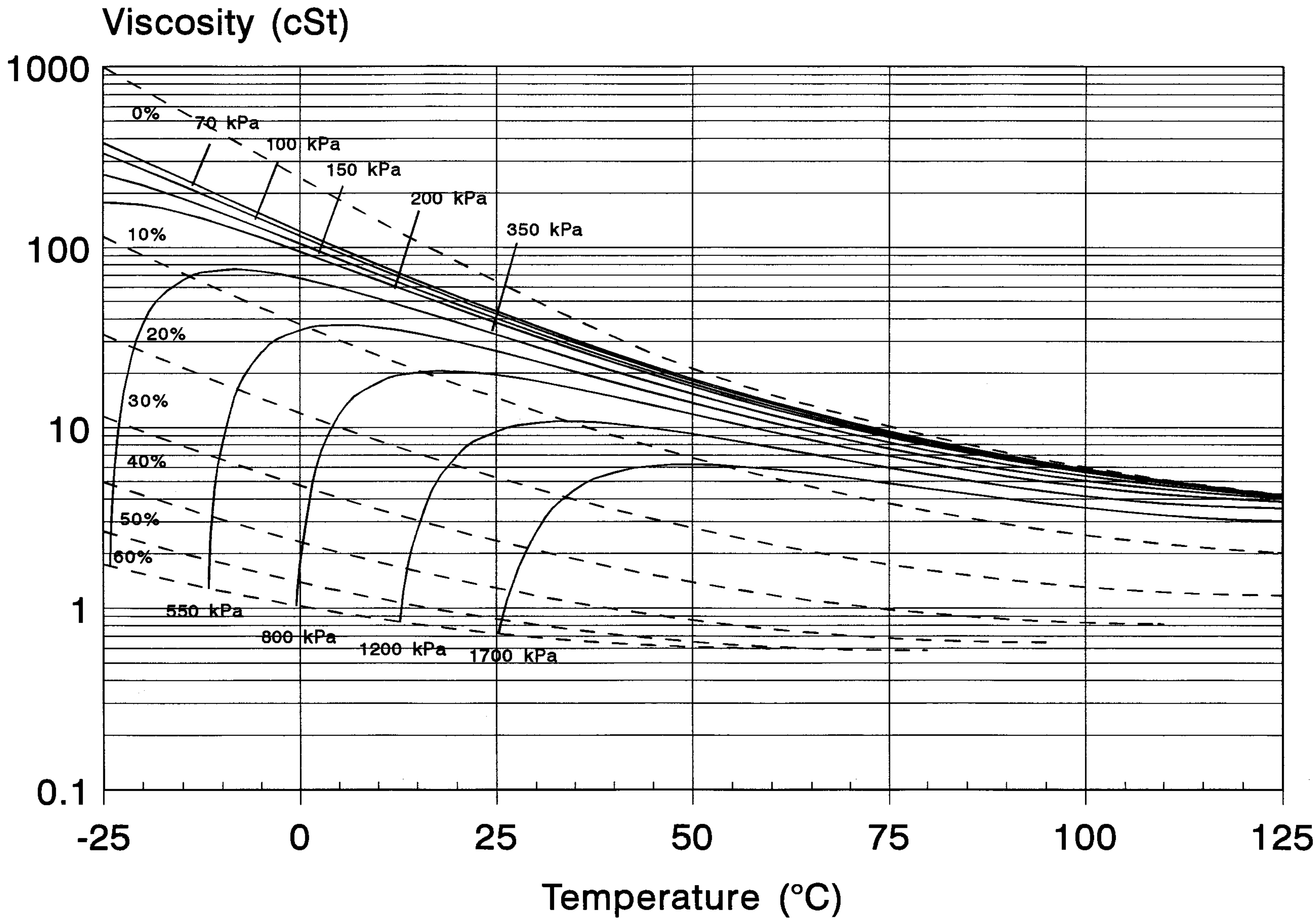
Figure 20



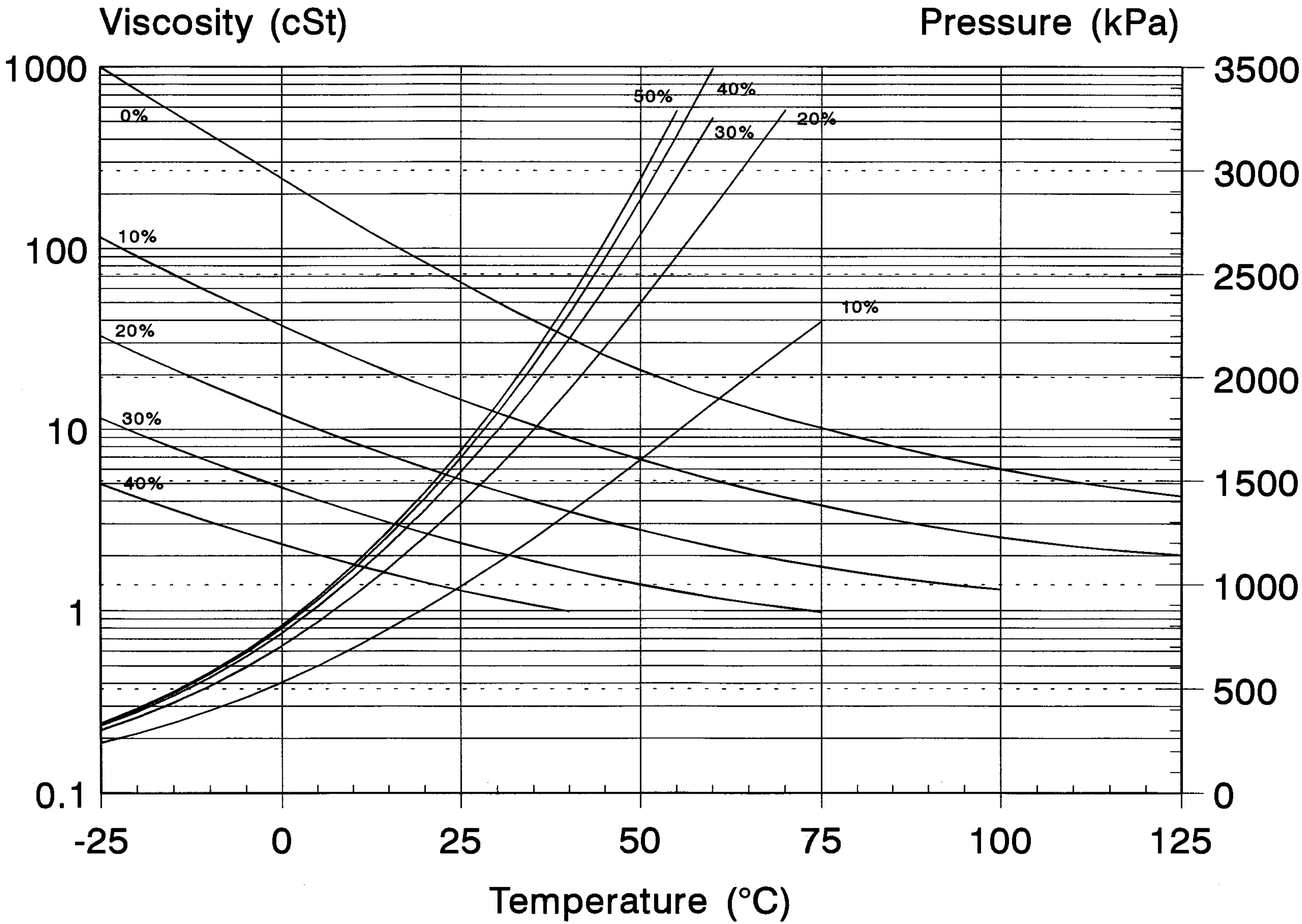
Density vs. Temperature
HFC-125 with EMKARATE RL32S
Figure 21



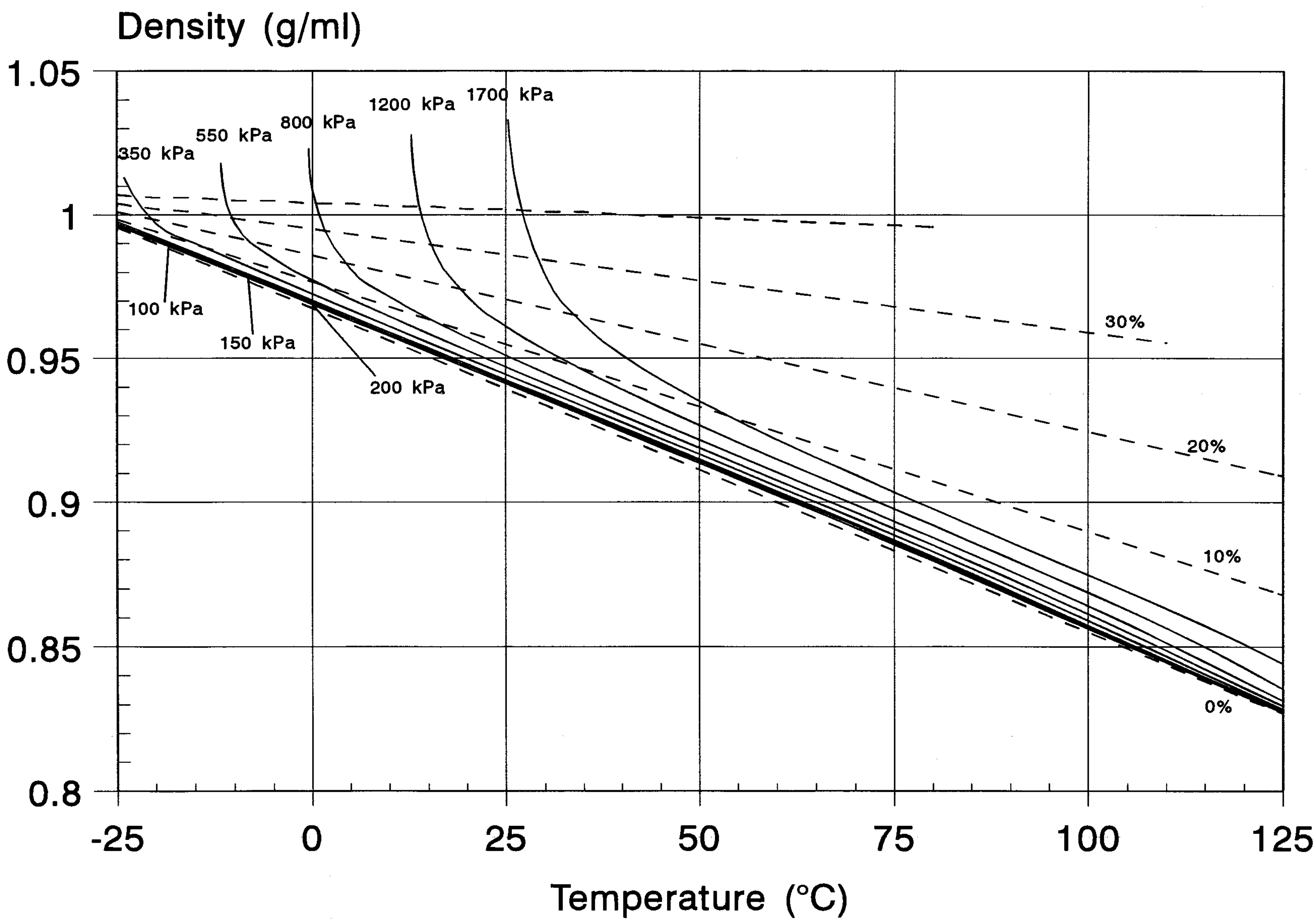
Viscosity vs. Temperature
HFC-32 with EMKARATE RL32S
Figure 22



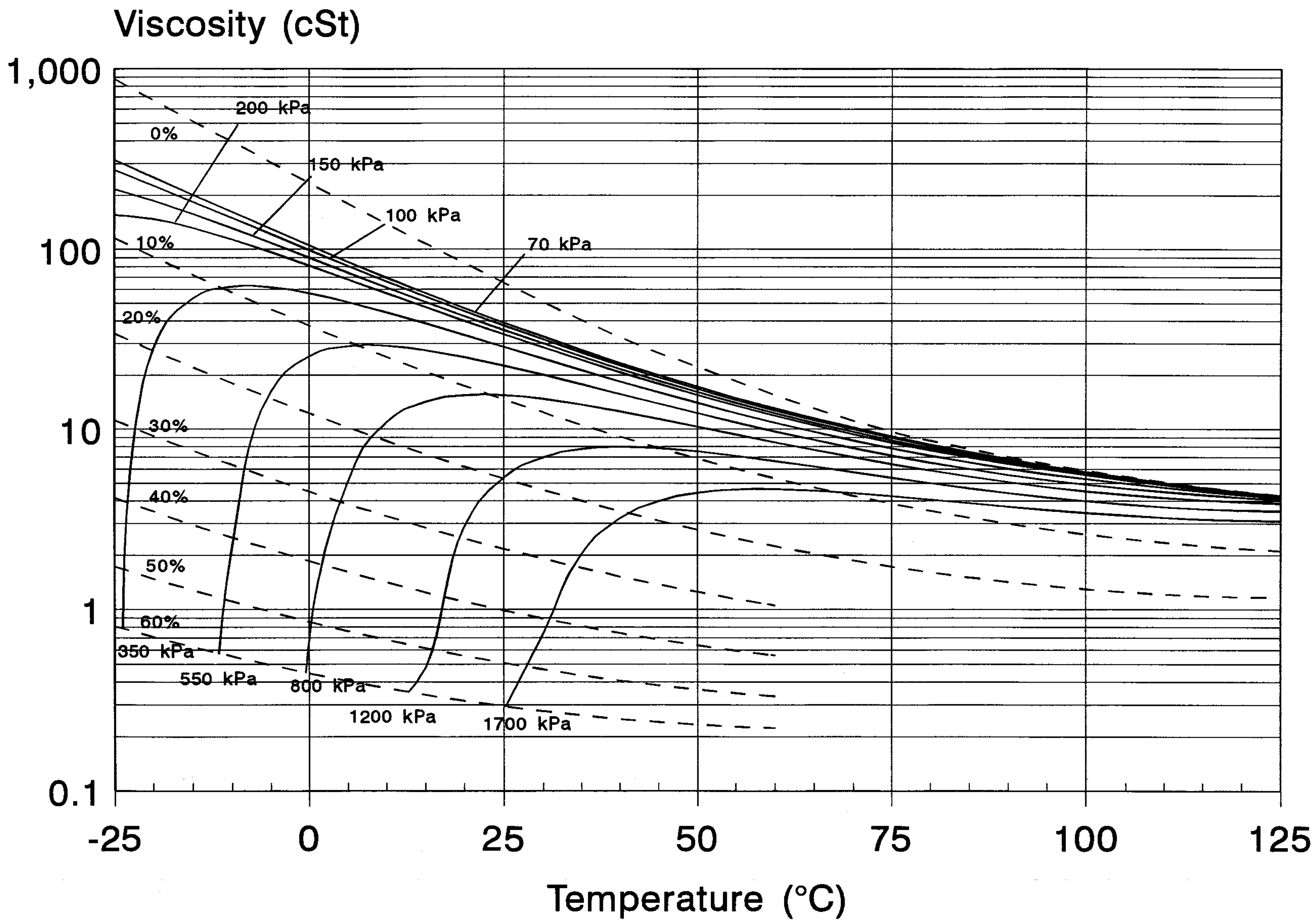
Viscosity and Pressure at Constant Concentrations
HFC-32 with EMKARATE RL32S
Figure 23



Density vs. Temperature
HFC-32 with EMKARATE RL32S
Figure 24



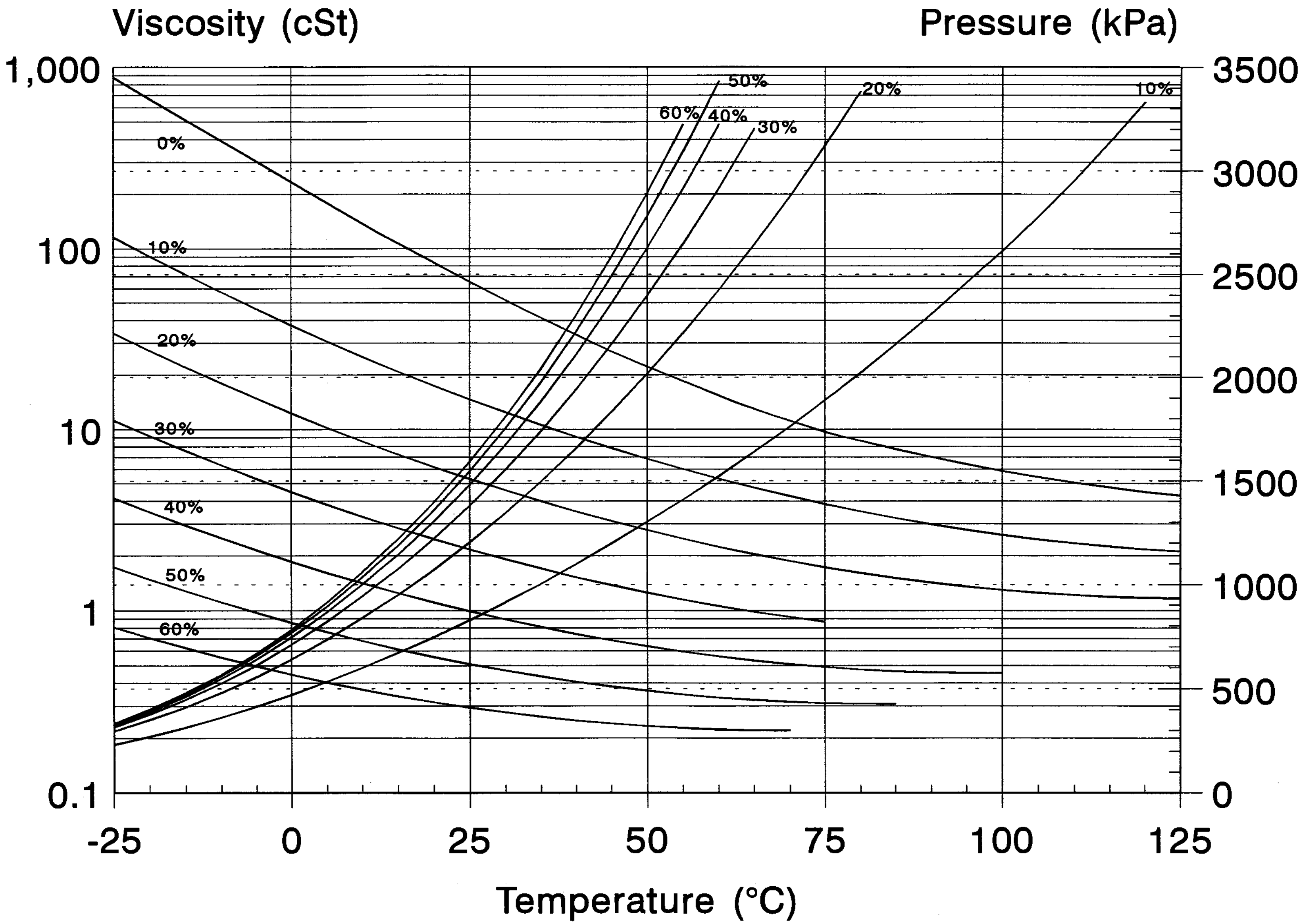
Viscosity vs. Temperature
HFC-32 with Emery 2968A
Figure 25



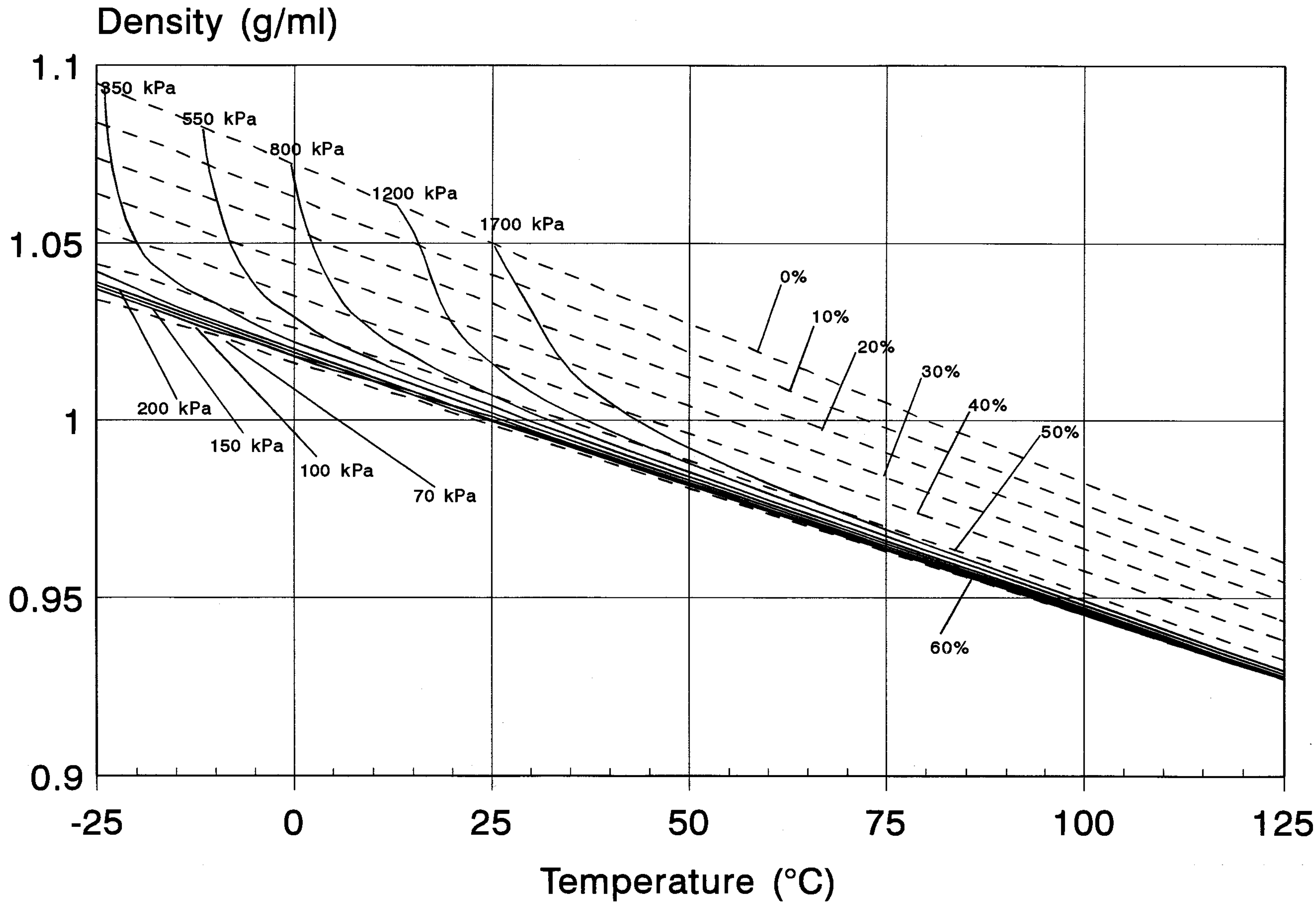
Viscosity and Pressure at Constant Concentrations

HFC-32 with Emery 2968A

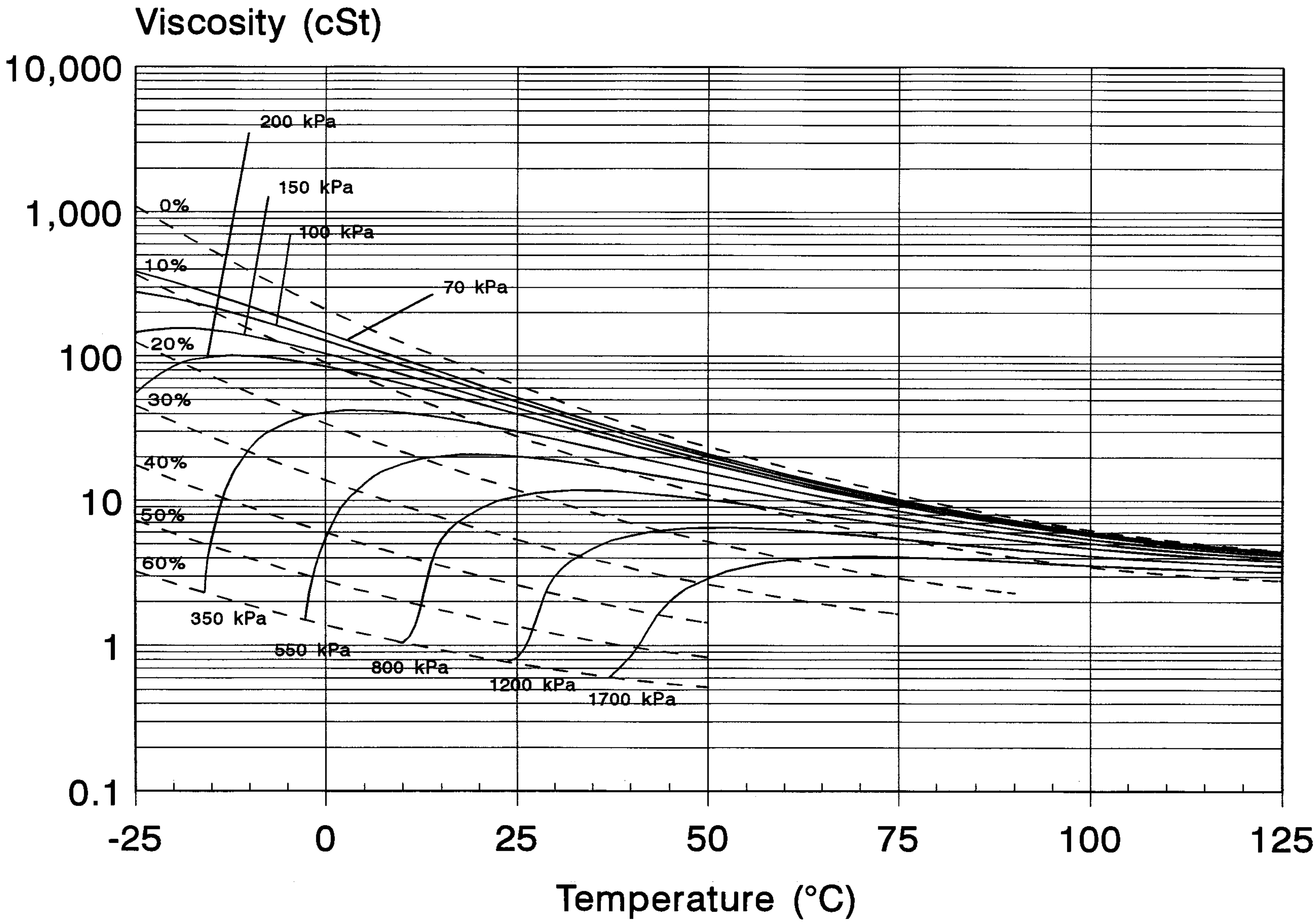
Figure 26



Density vs. Temperature
HFC-32 with Emery 2968A
Figure 27



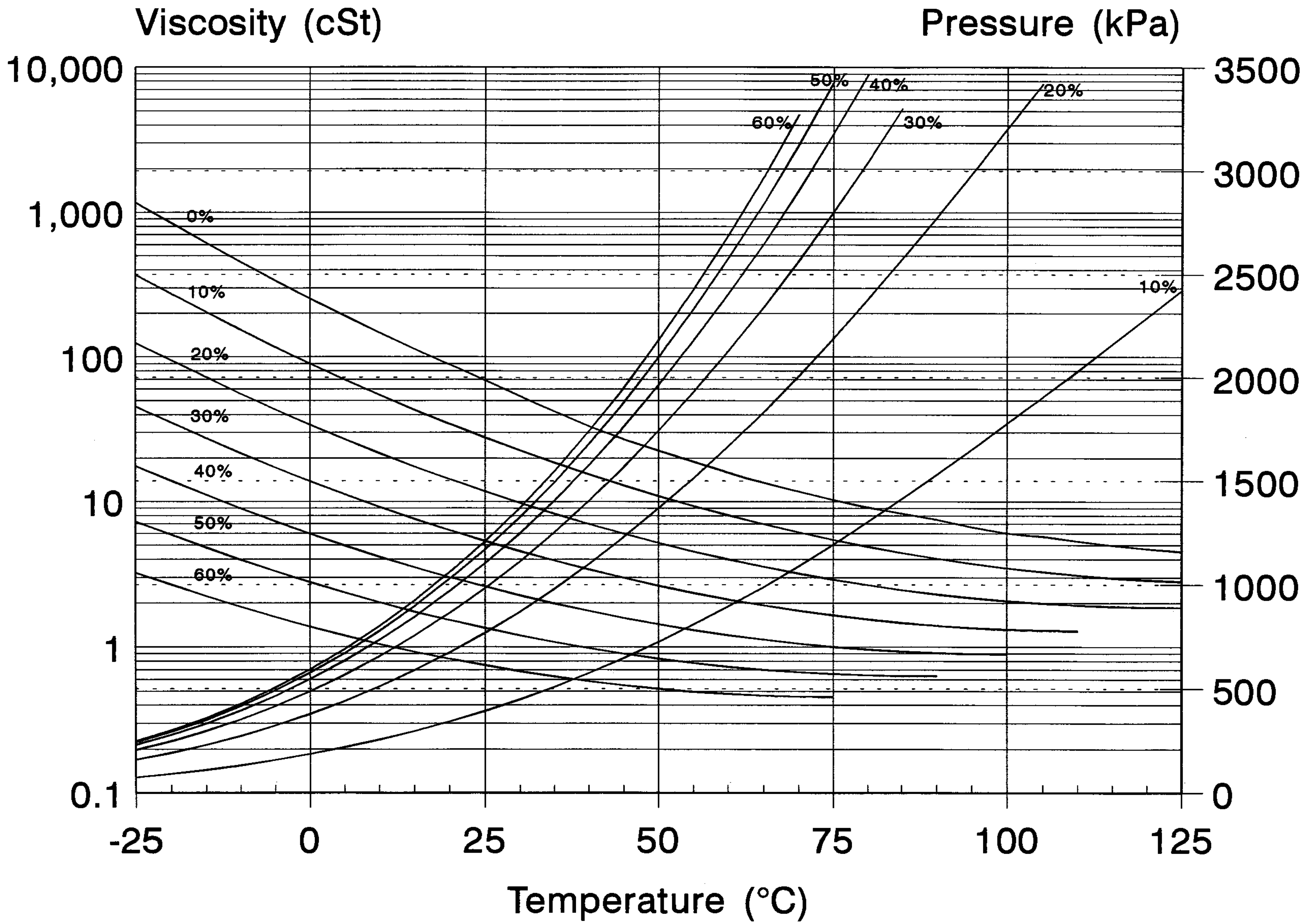
Viscosity vs. Temperature
R-404A with Emery 2968A
Figure 28



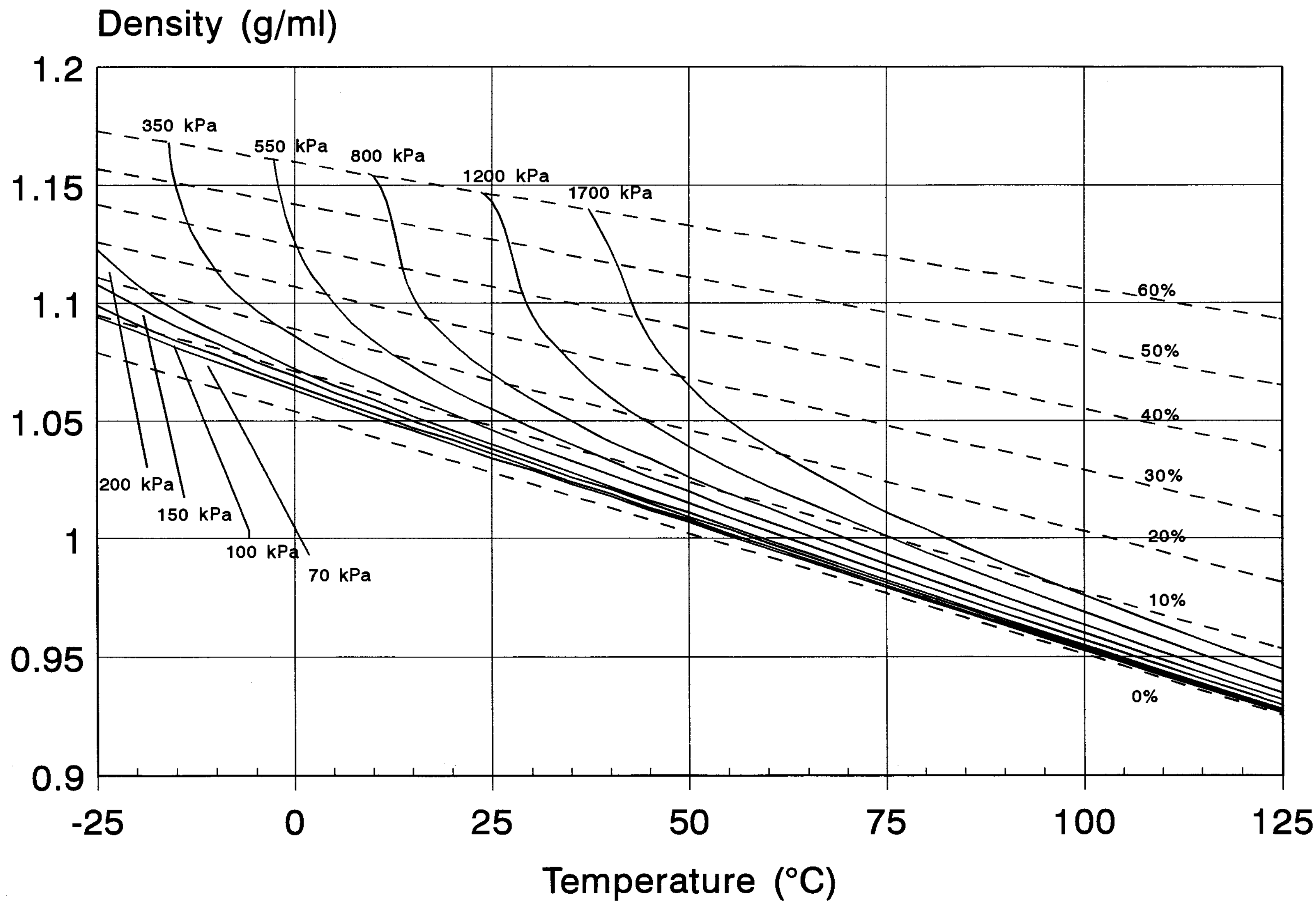
Viscosity and Pressure at Constant Concentrations

R-404A with Emery 2968A

Figure 29



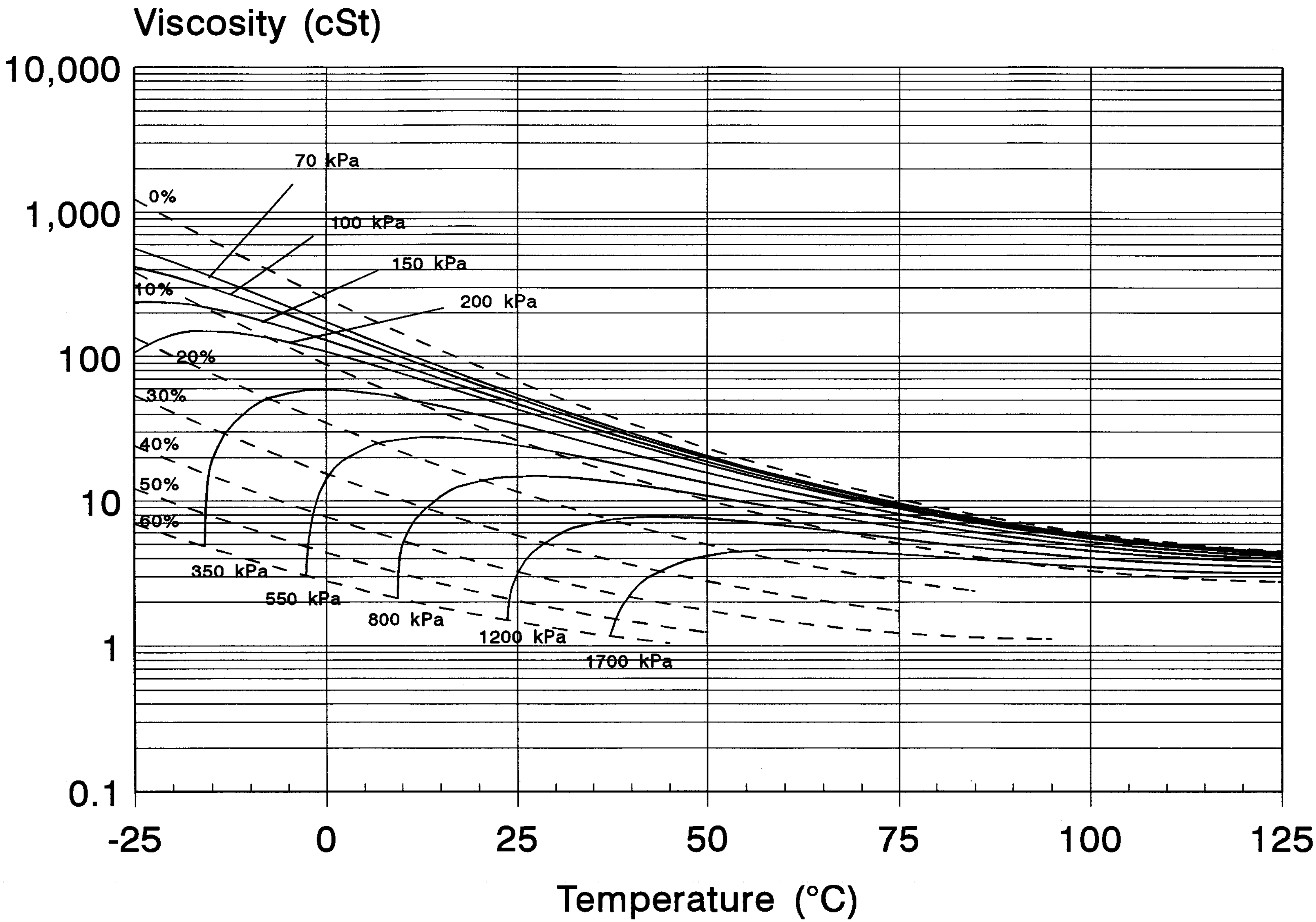
Density vs. Temperature
R-404A with Emry 2968A
Figure 30



Viscosity vs. Temperature

R-404A with EMKARATE RL32S

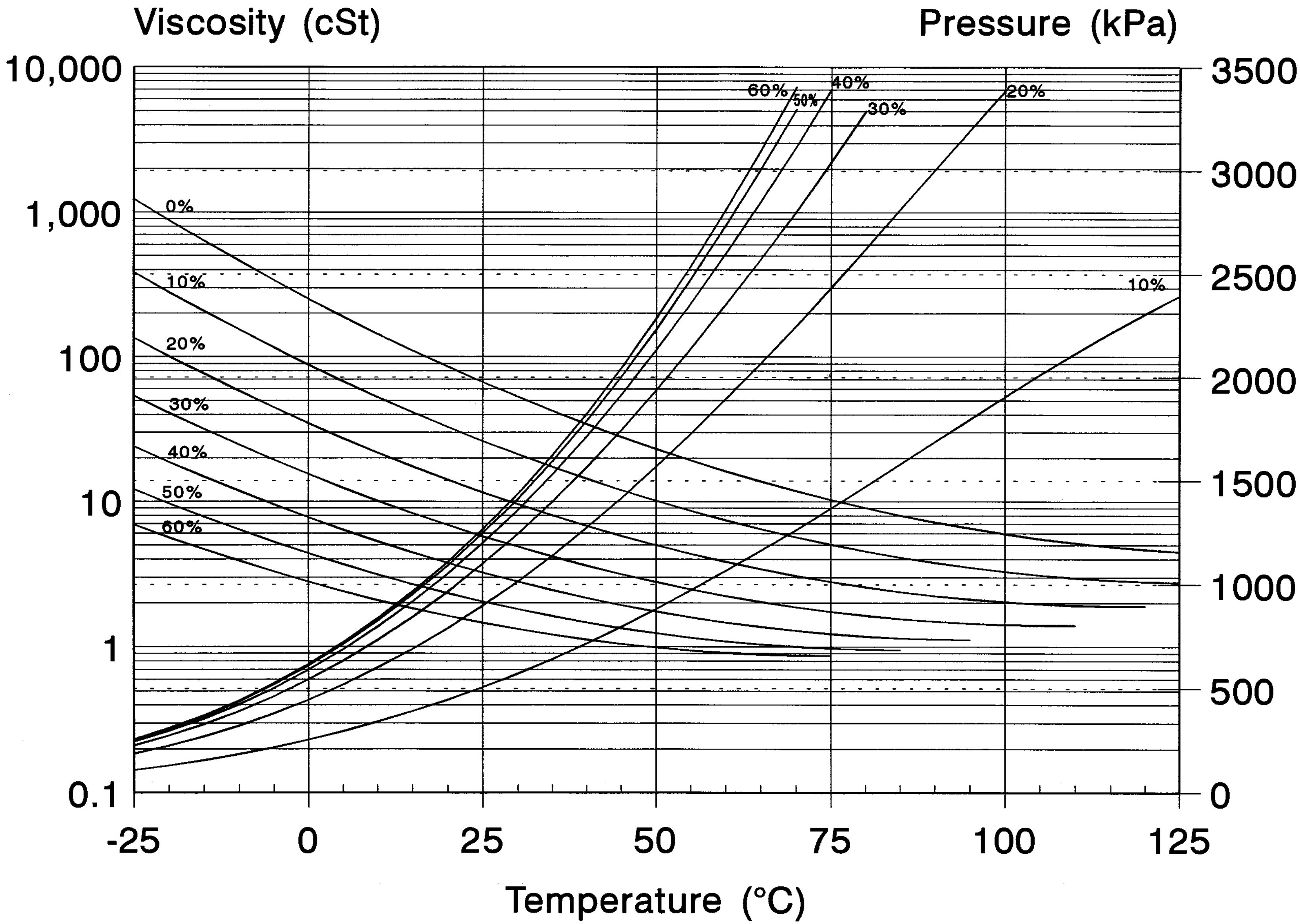
Figure 31



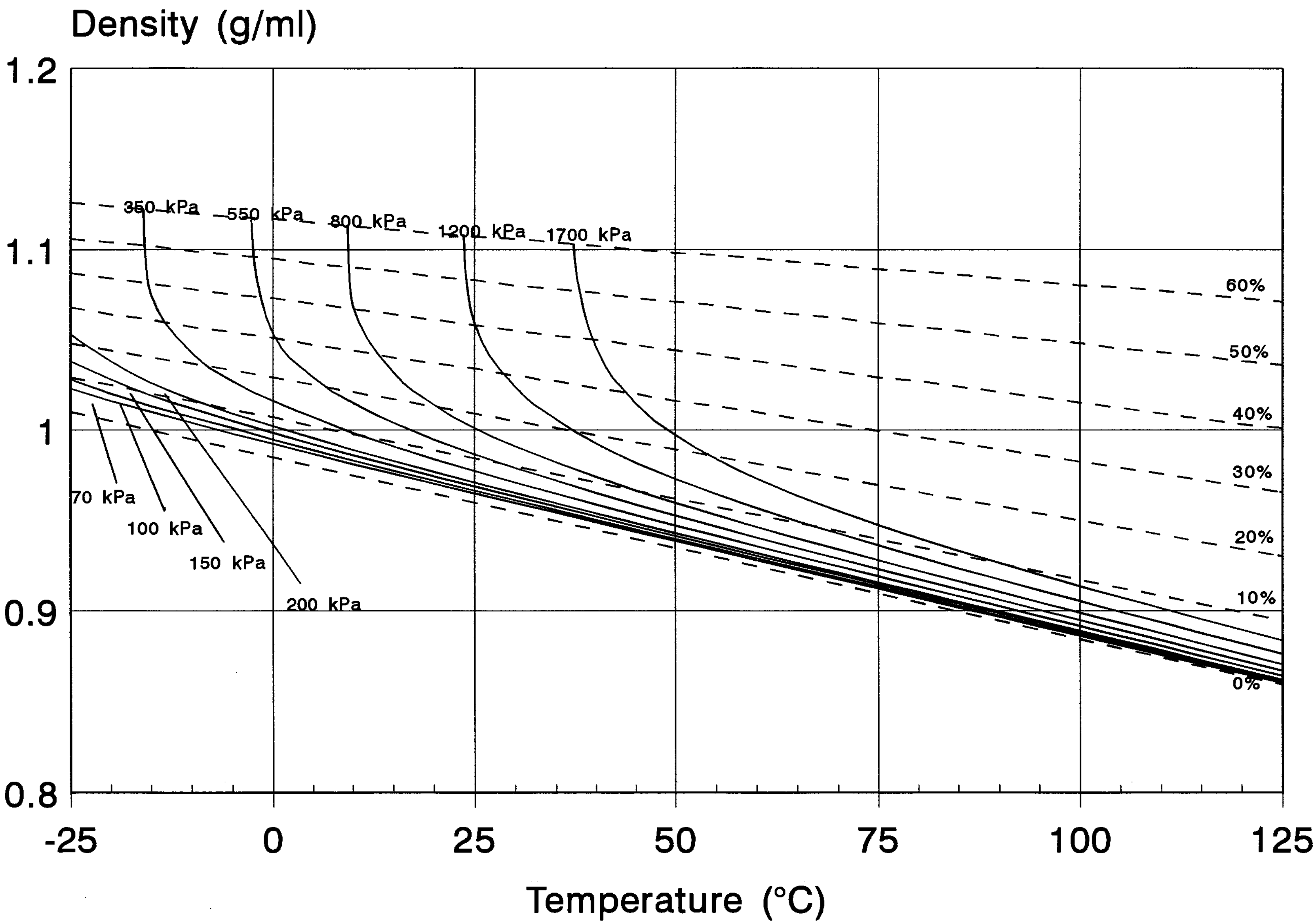
Viscosity and Pressure at Constant Concentrations

R-404A with EMKARATE RL32S

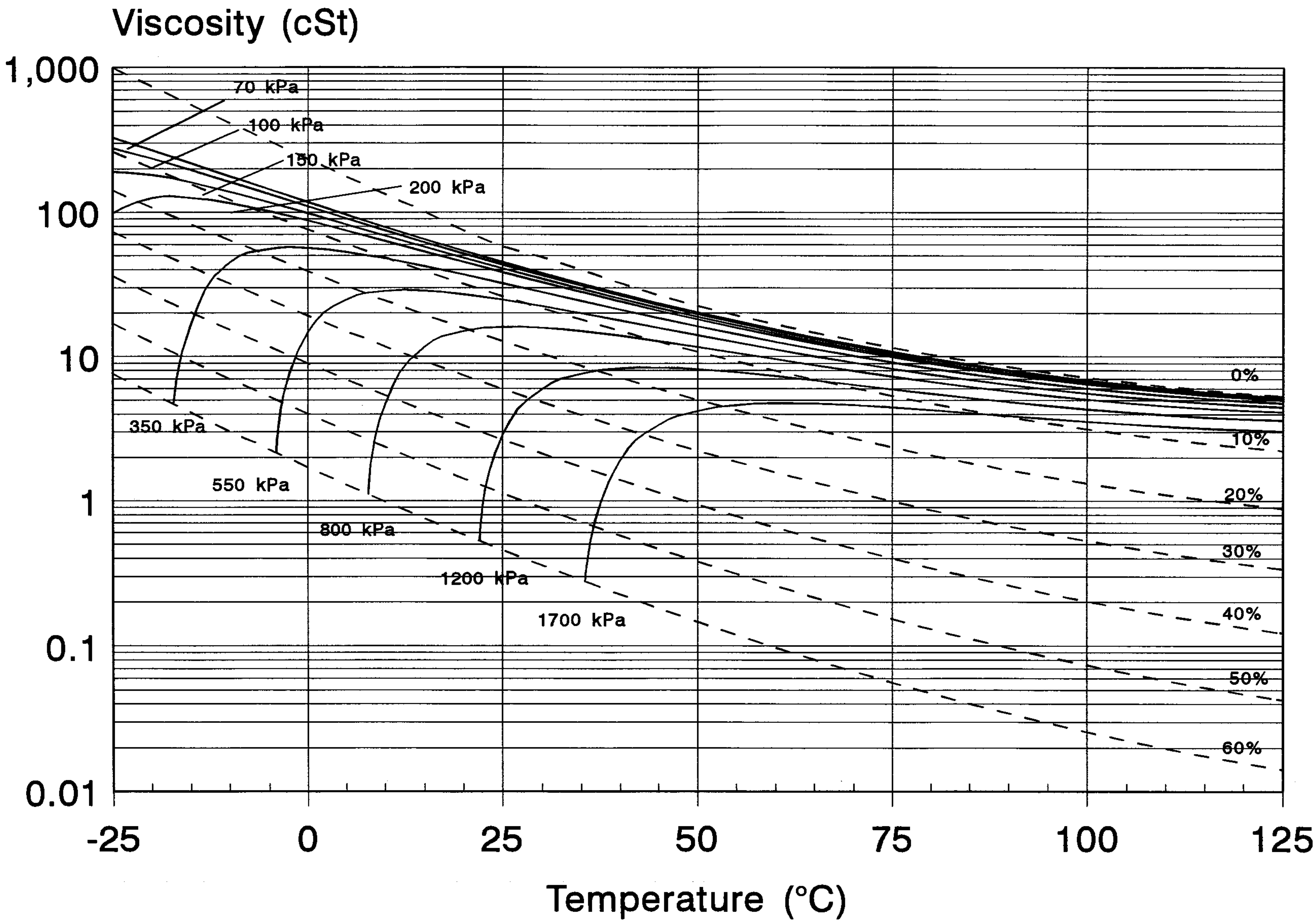
Figure 32



Density vs. Temperature
R-404A with EMKARATE RL32S
Figure 33



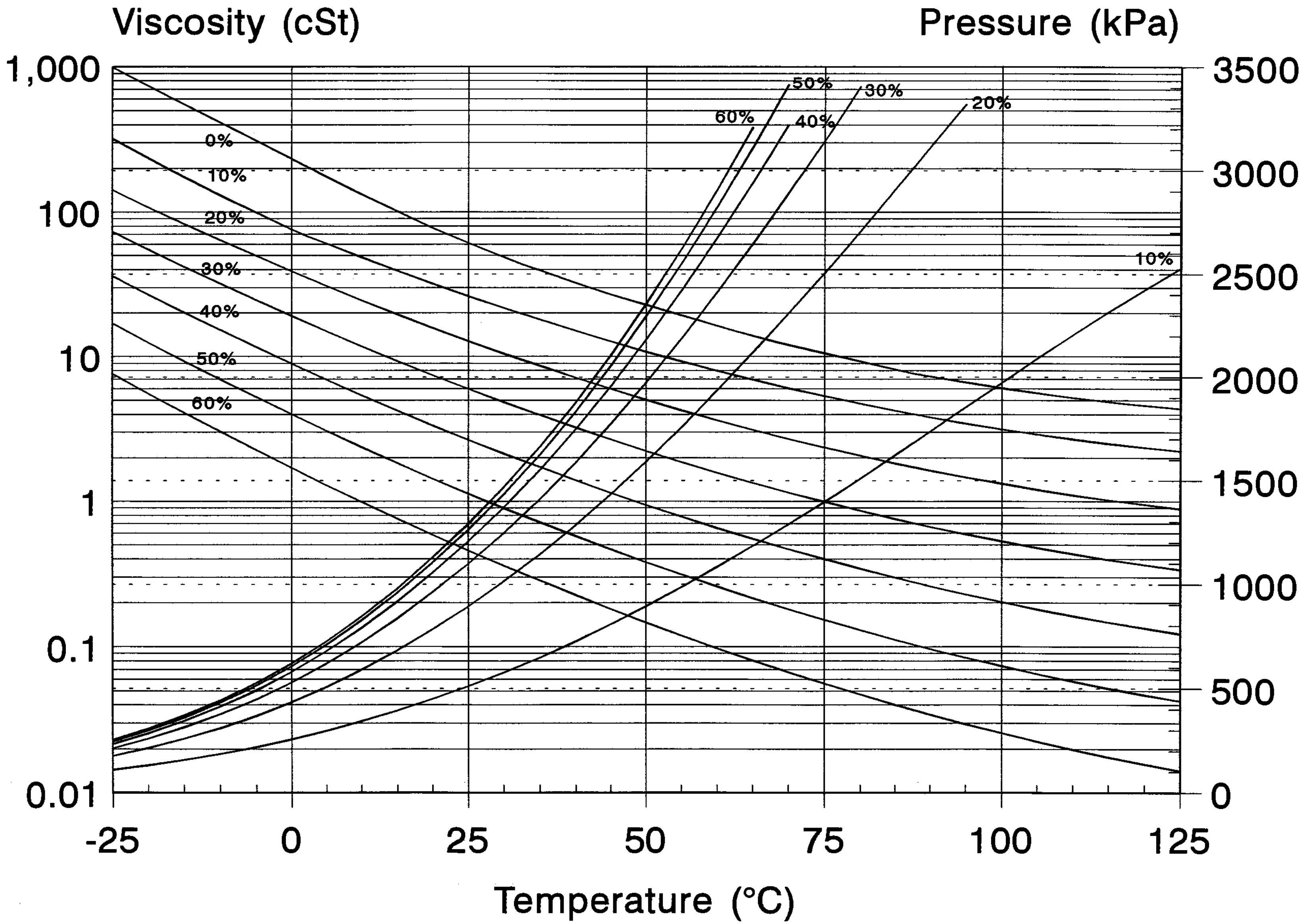
Viscosity vs. Temperature
R-507 with EMKARATE RL32S
Figure 34



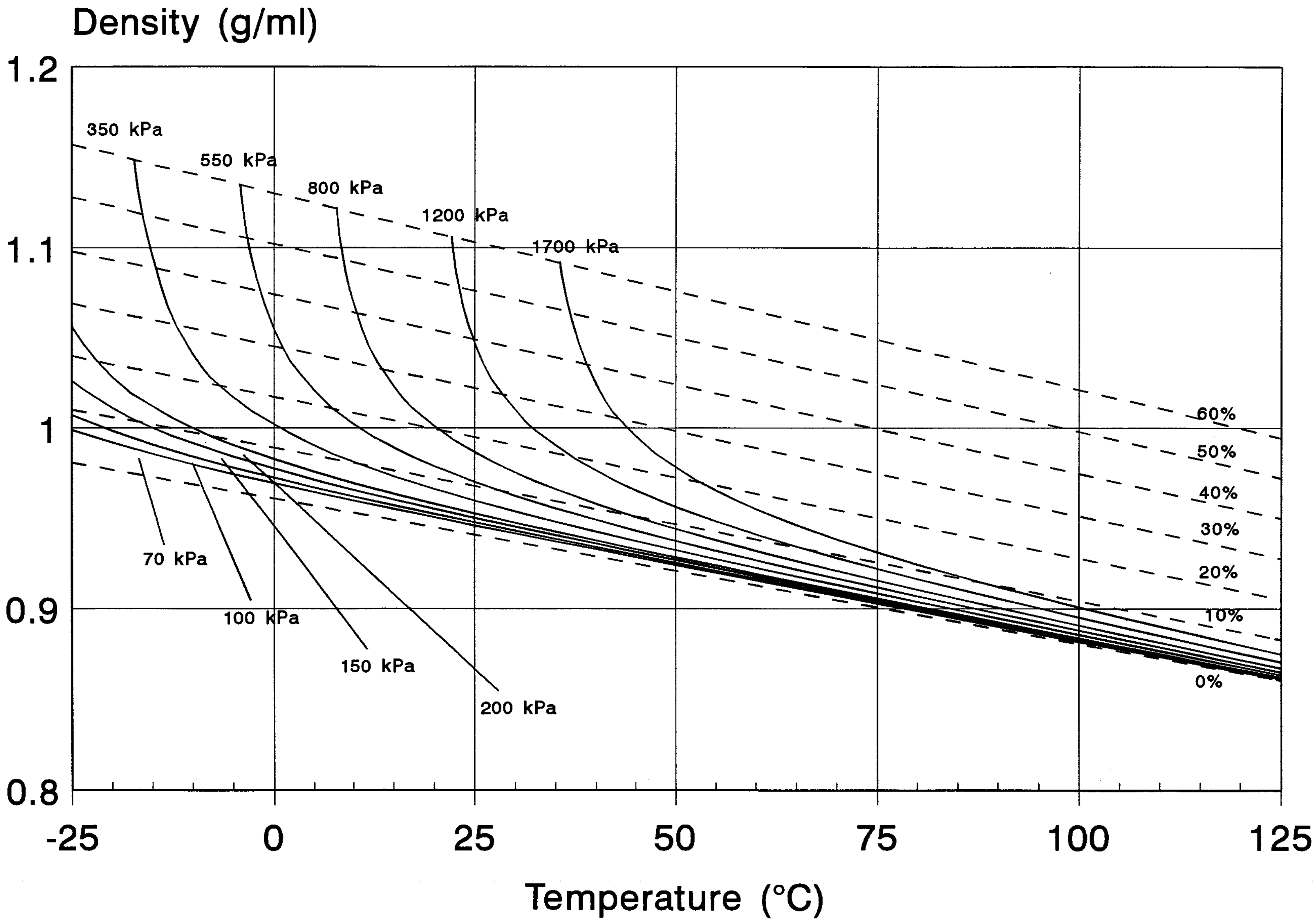
Viscosity and Pressure at Constant Concentrations

R-507 with EMKARATE RL32S

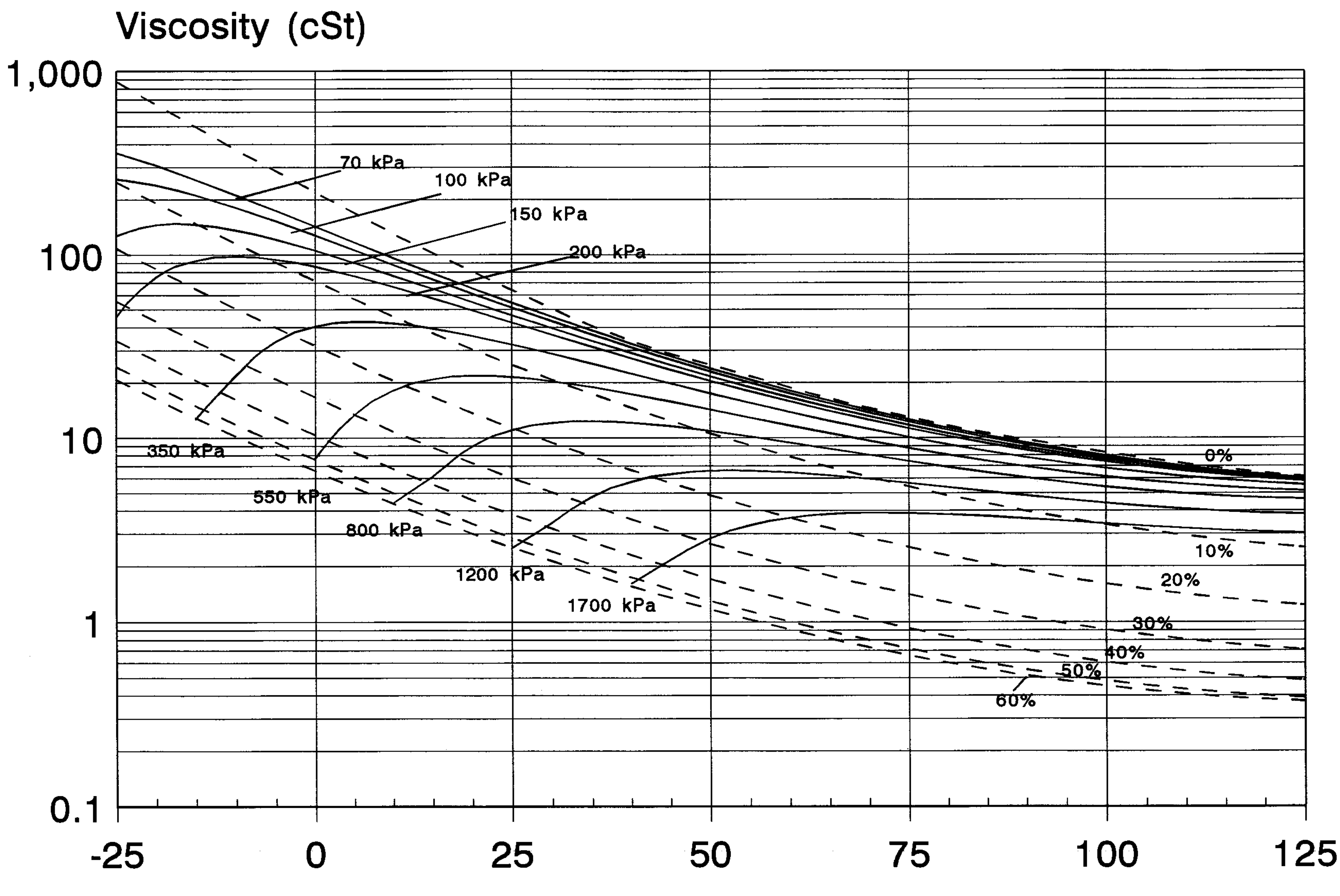
Figure 35



Density vs. Temperature
R-507 with EMKARATE RL32S
Figure 36



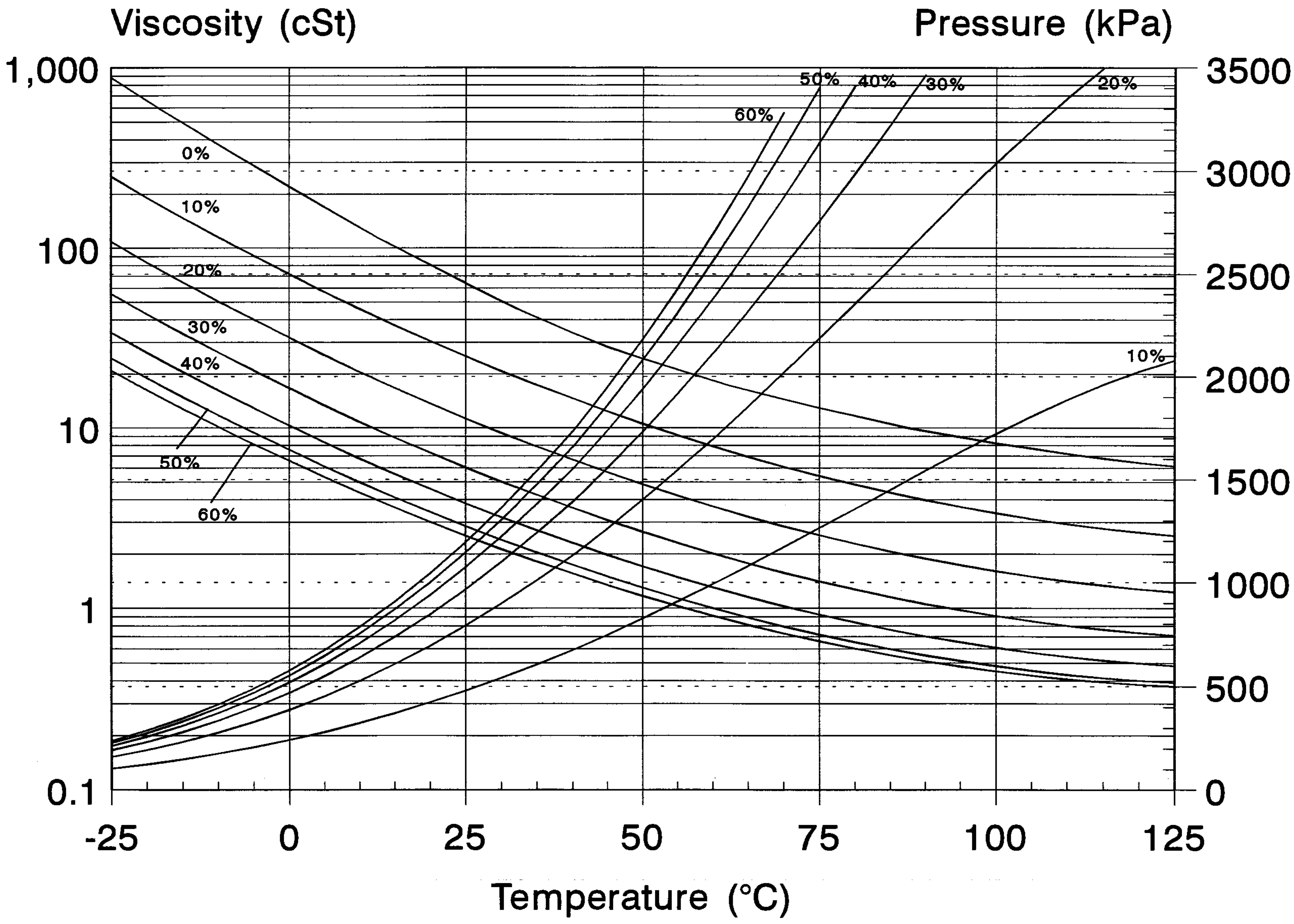
Viscosity vs. Temperature
R-507 with Emery 2968A
Figure 37



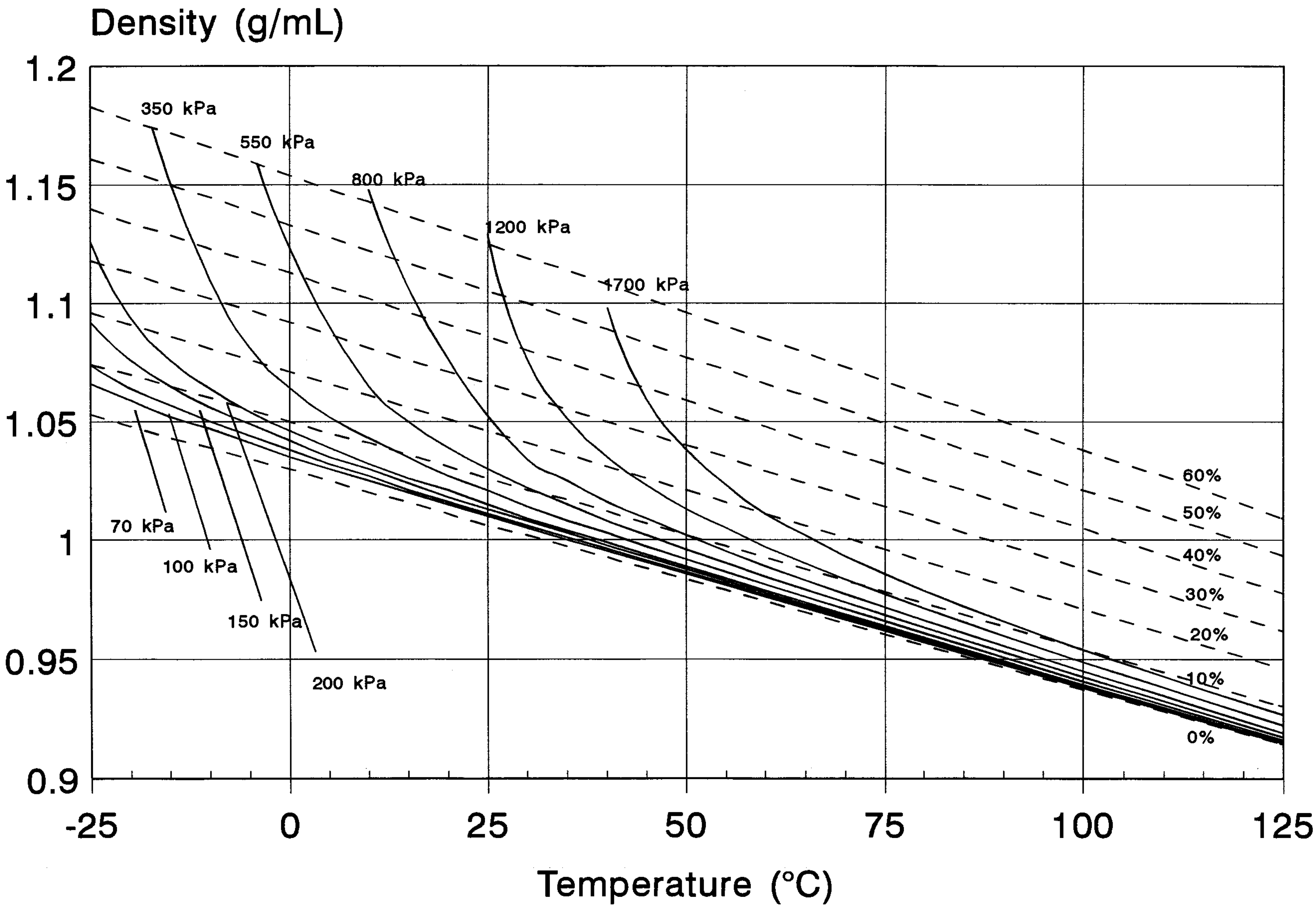
Viscosity and Pressure at Constant Concentrations

R-507 with Emery 2968A

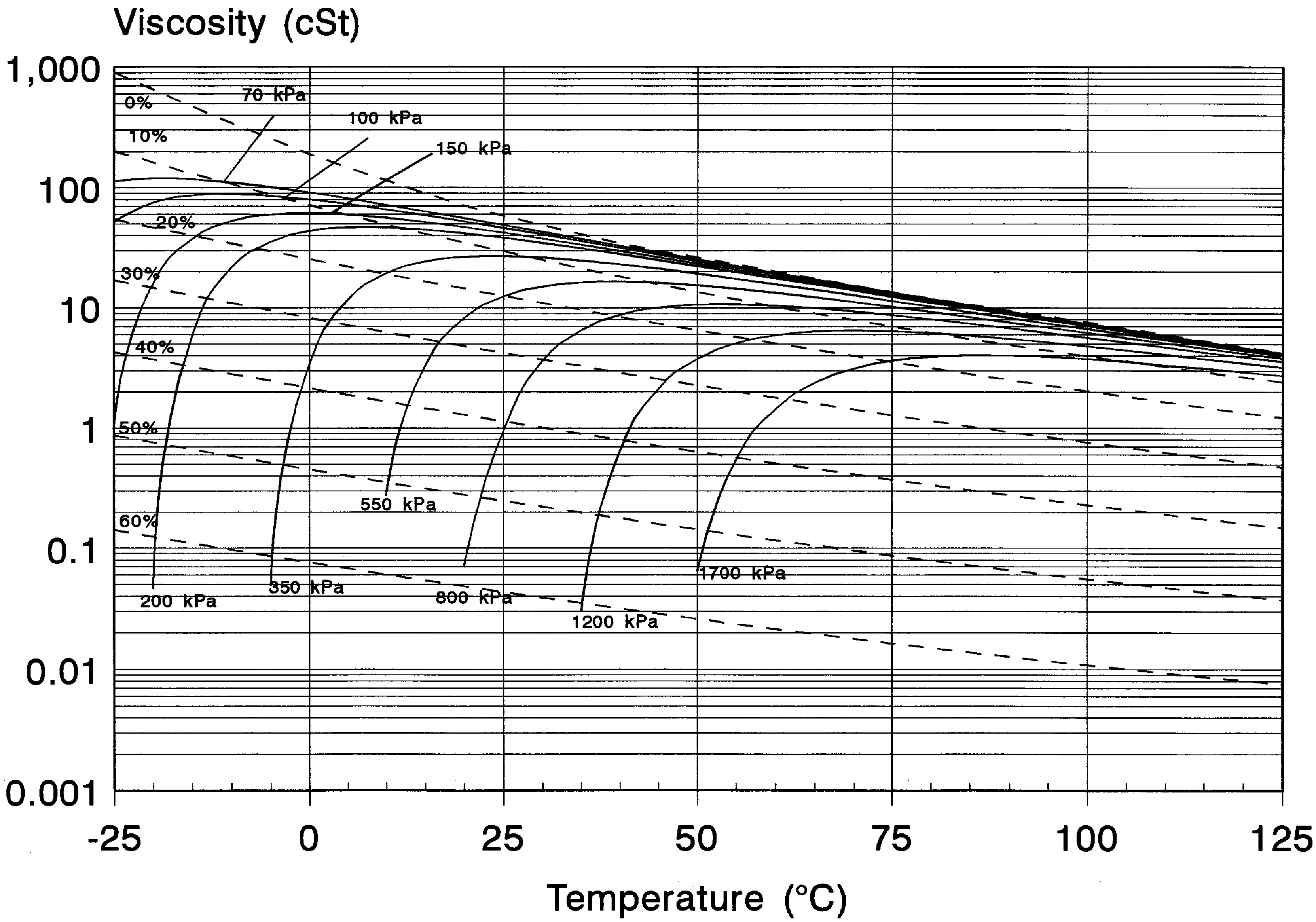
Figure 38



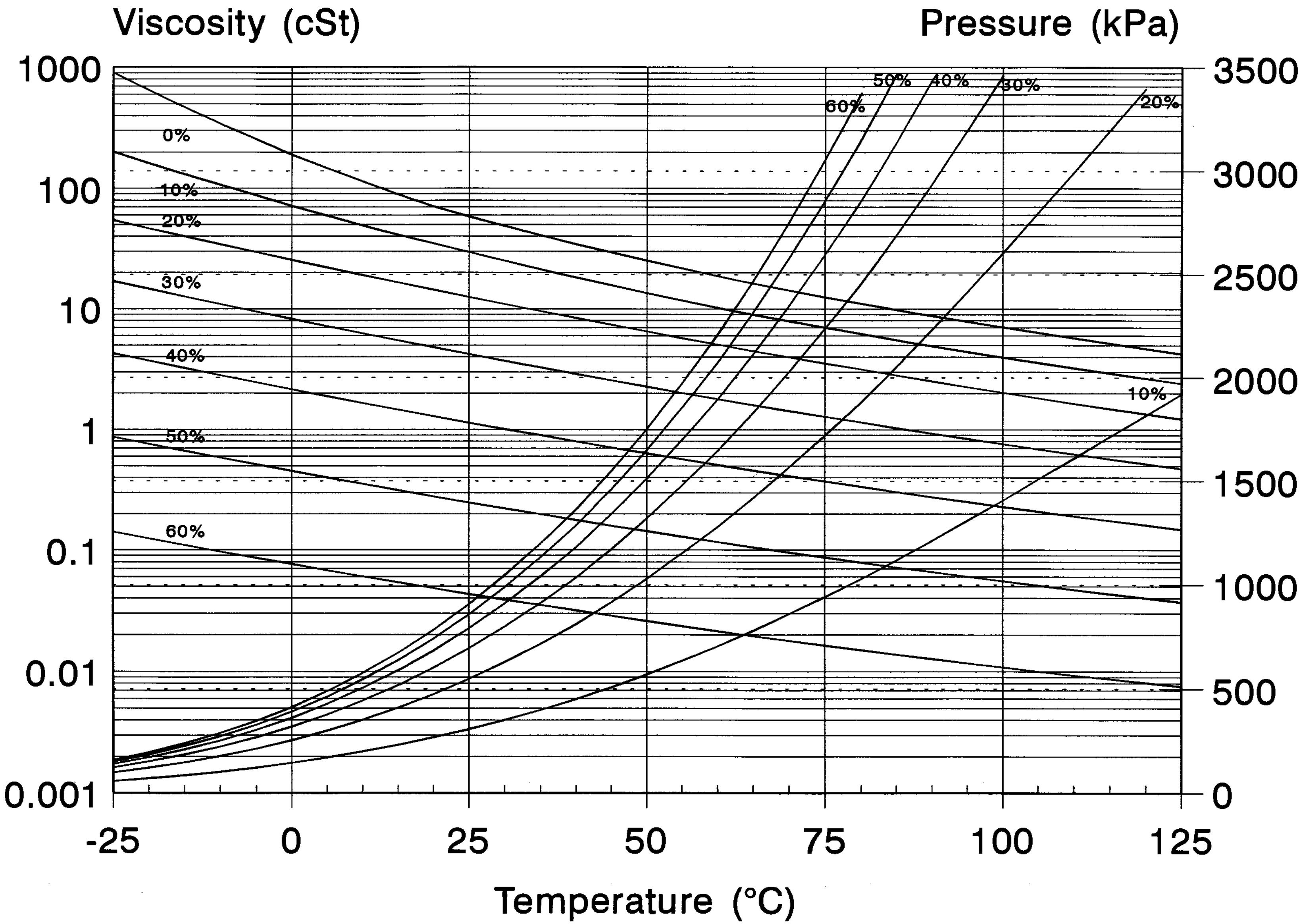
Density vs. Temperature
R-507 with Emery 2968A
Figure 39



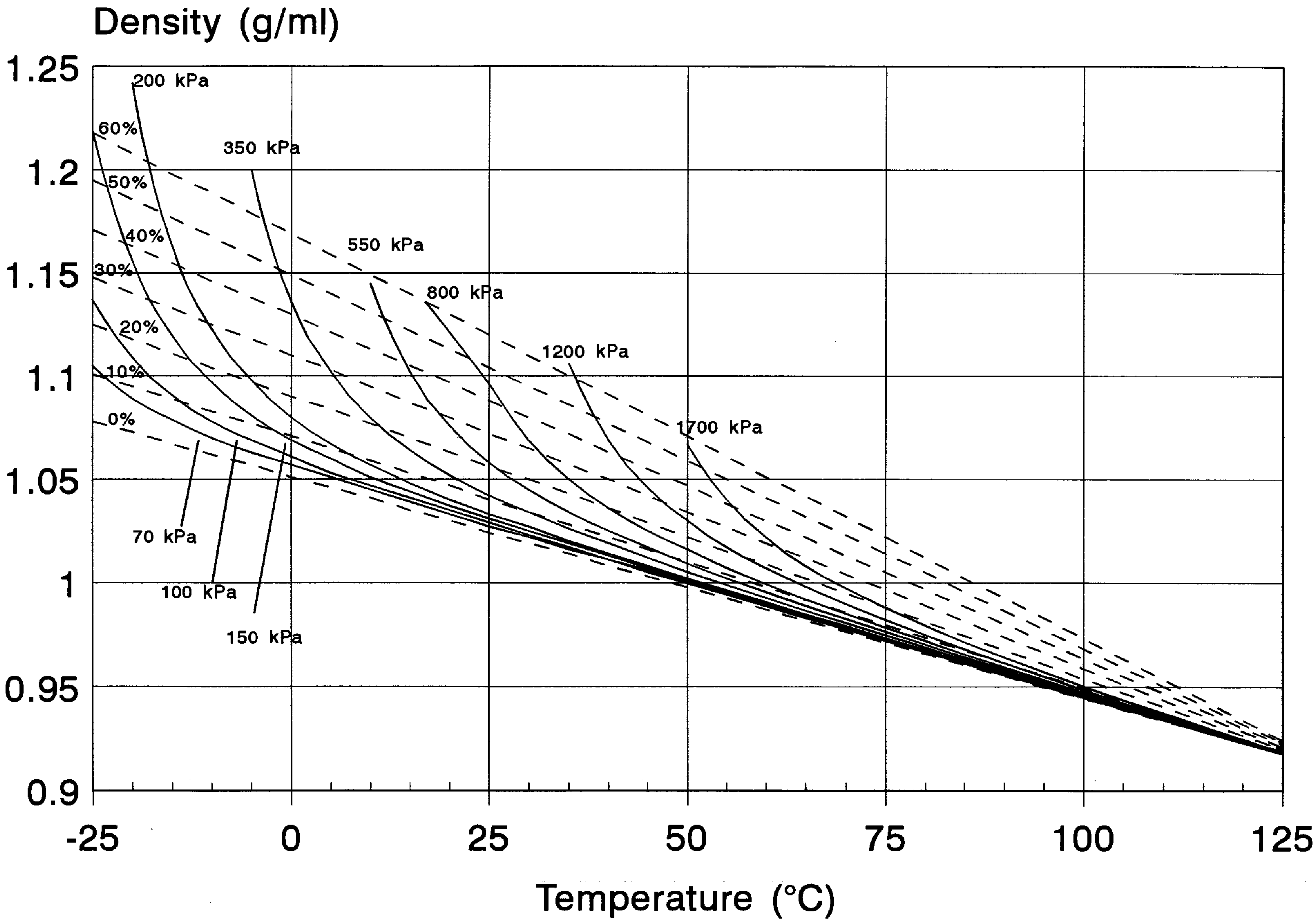
Viscosity vs. Temperature
R-407C with Emery 2968A
Figure 40



Viscosity and Pressure at Constant Concentrations
R-407C with Emery 2968A
Figure 41



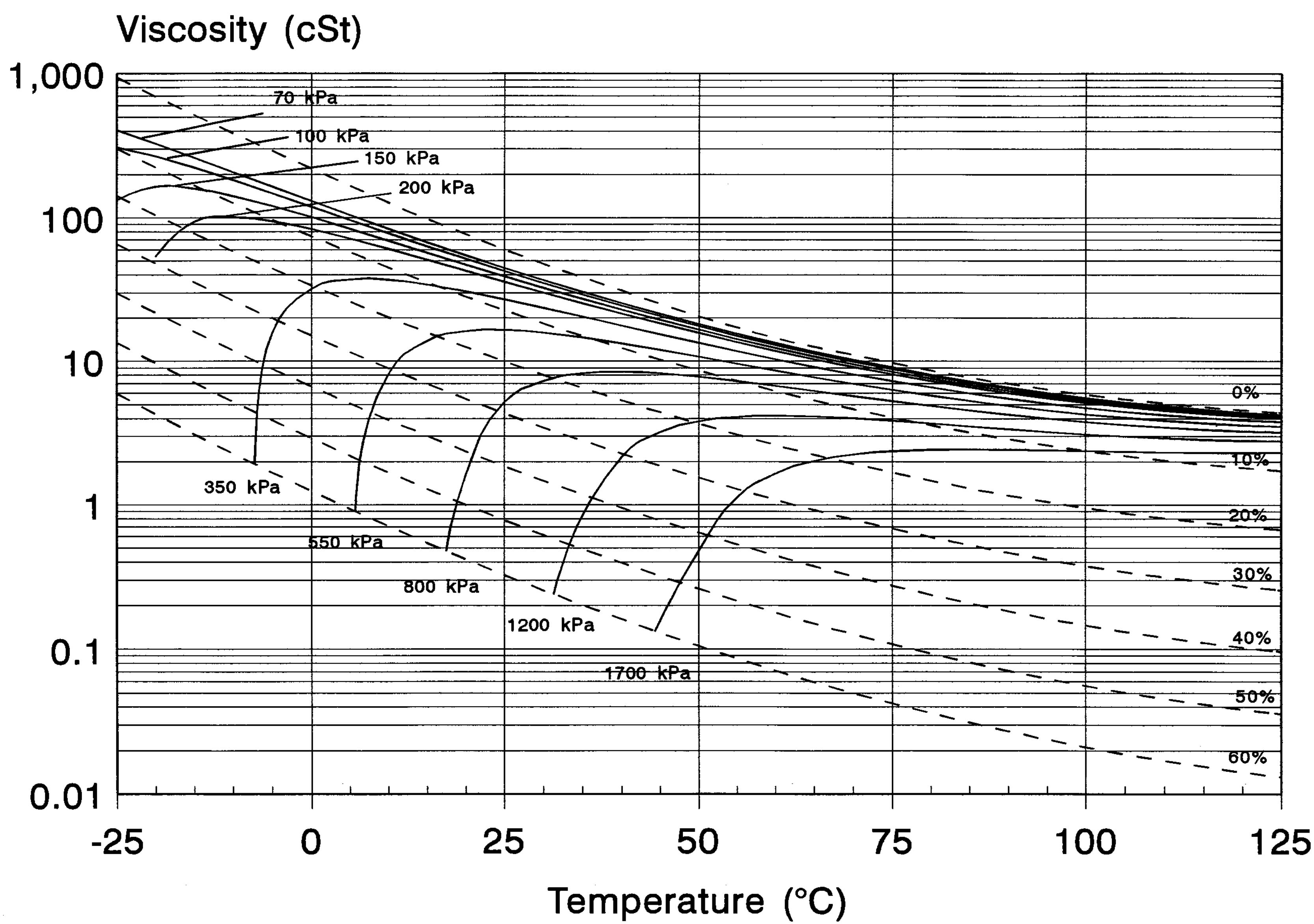
Density vs. Temperature
R-407C with Emery 2968A
Figure 42



Viscosity vs. Temperature

R-407C with EMKARATE RL32S

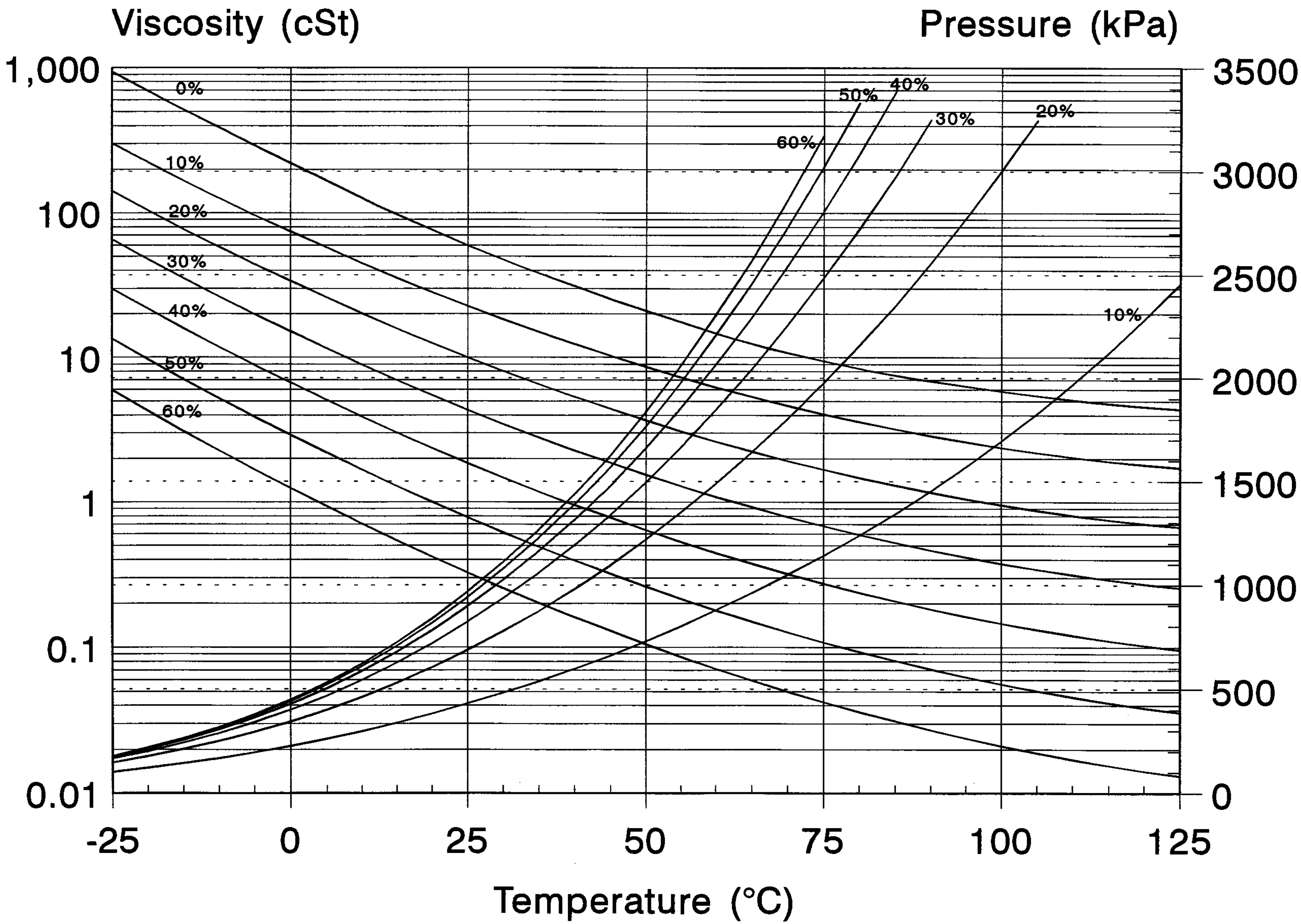
Figure 43



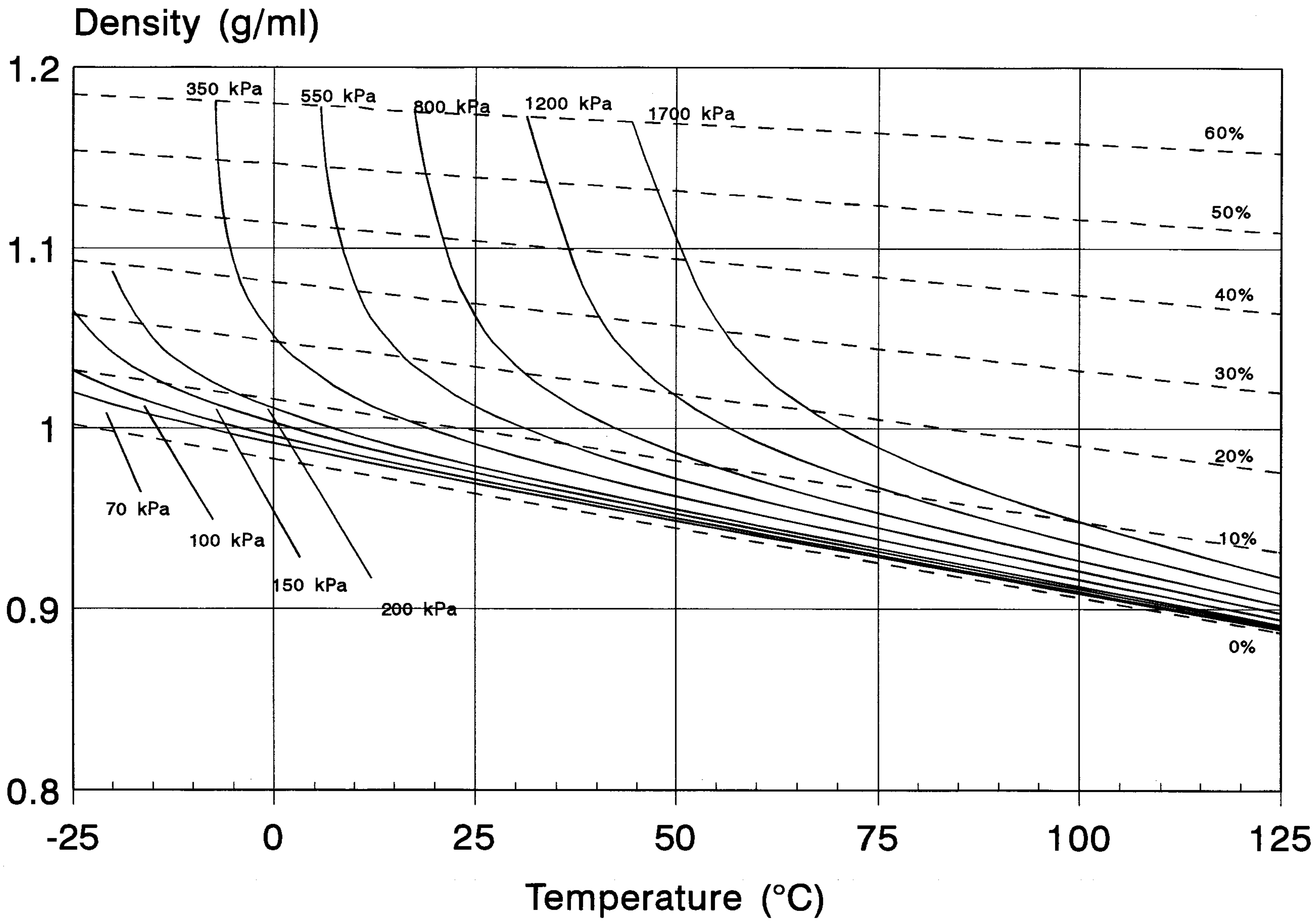
Viscosity and Pressure at Constant Concentrations

R-407C with EMKARATE RL32S

Figure 44



Density vs. Temperature
R-407C with EMKARATE RL32S
Figure 45



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APPENDIX A
Miscibility Screen of Lubricants and Refrigerants

The fluids tested in this project were selected based on data related to the miscibility of four different polyolesters and one alkylbenzene with six refrigerant blends at three different refrigerant/lubricant concentrations.

Alkylbenzene (Lubricant E) was used to determine the miscibility of aromatics. Surprisingly, it appeared partially miscible with R-404A. This miscibility might result from lower temperatures; this suggests a possibility for good oil return and inverse miscibility at higher temperatures and higher R-404A concentrations.

Levels of immiscibility may significantly effect the fractionation of individual gases at different temperatures and pressures. For example, Lubricant B is Emery 2968A, a 32 ISO VG branched acid polyolester, and is believed to be the most miscible. Its very high liquid/liquid miscibility suggests that it will have very little influence on the fractionation of the various gases that compose refrigerant blends. Lubricant C is EMKARATE RL32S, a 32 ISO VG mixed acid polyolester, has been determined to be the least miscible lubricant tested, although its viscosity is close to that of Lubricant B. Consequently, Lubricant C was used in this study to verify the impact of partial liquid miscibility on the gas solubility of various gases in refrigerant blends. Lubricants A and D are in the intermediate range of miscibility. Lubricant F, a mineral oil, was included in order to provide a basis for comparison.

The results of this study suggest that at gas equilibrium conditions, the miscibility of lubricants is not an essential factor in predicting lubricant viscosity reduction.

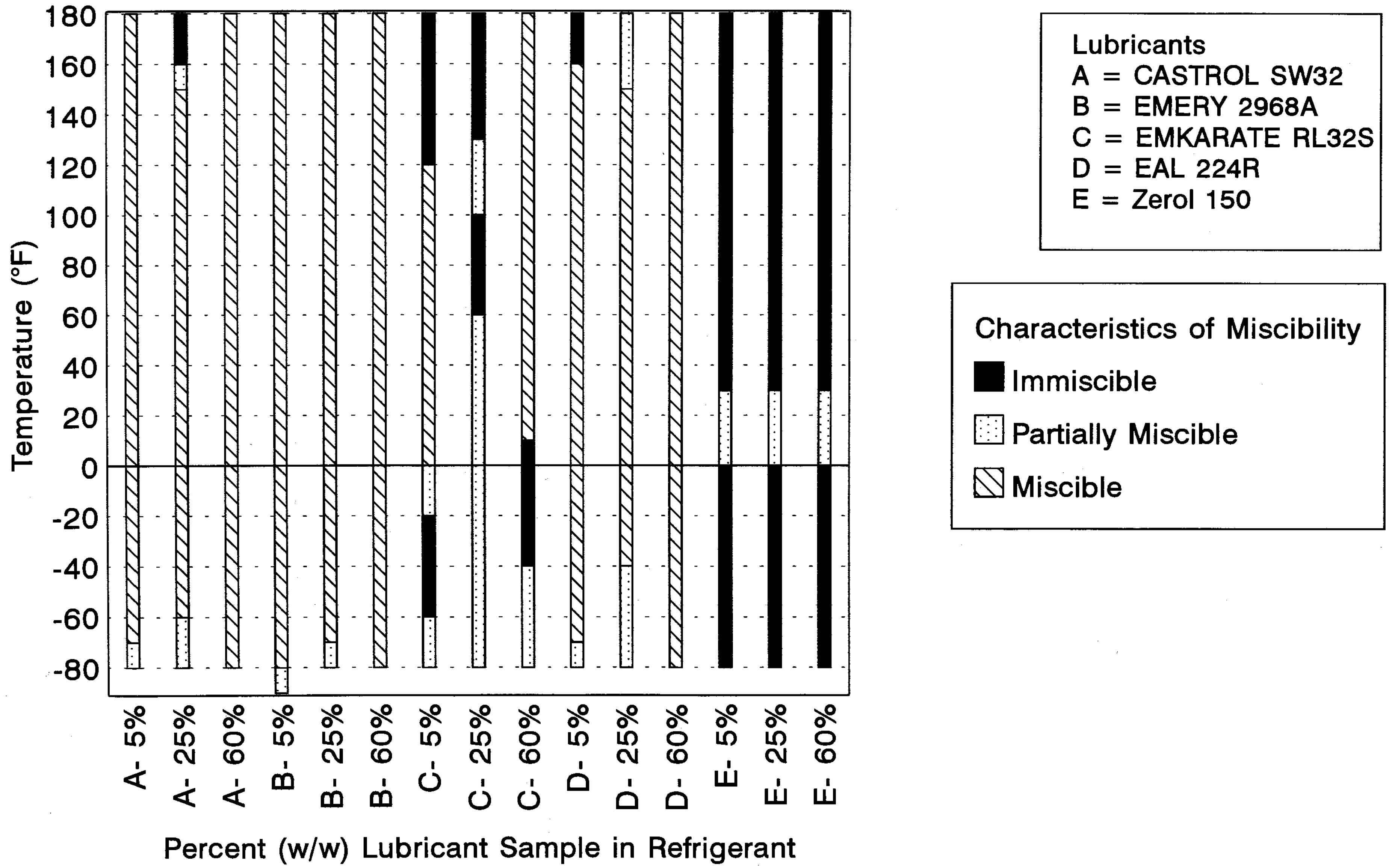
Table A.1
Lubricants Used in Miscibility Tests

Lubricant	Name	Manufacturer	Type	Trademark?
A	Icematic SW32	Castrol	Branched Acid Polyolester	Registered Trademark
B	Emery 2968a	Henkel, Emery Group	Branched Acid Polyolester	Registered Trademark
C	EMKARATE RL-32S	ICI Chemicals and Polymers, Ltd.	Mixed Acid Polyolester	Registered Trademark
D	Arctic EAL 224R	Mobil	Mixed Acid Polyolester	Registered Trademark
E	Shrieve Zerol 150	Shrieve Chemical Company	Alkylbenzene	Registered Trademark
F	Suniso 3GS	Witco Corporation	Naphthenic Mineral Oil	Registered Trademark

Miscibility of Refrigerant Blend

HFC-32 (60%) and HFC-125 (40%)

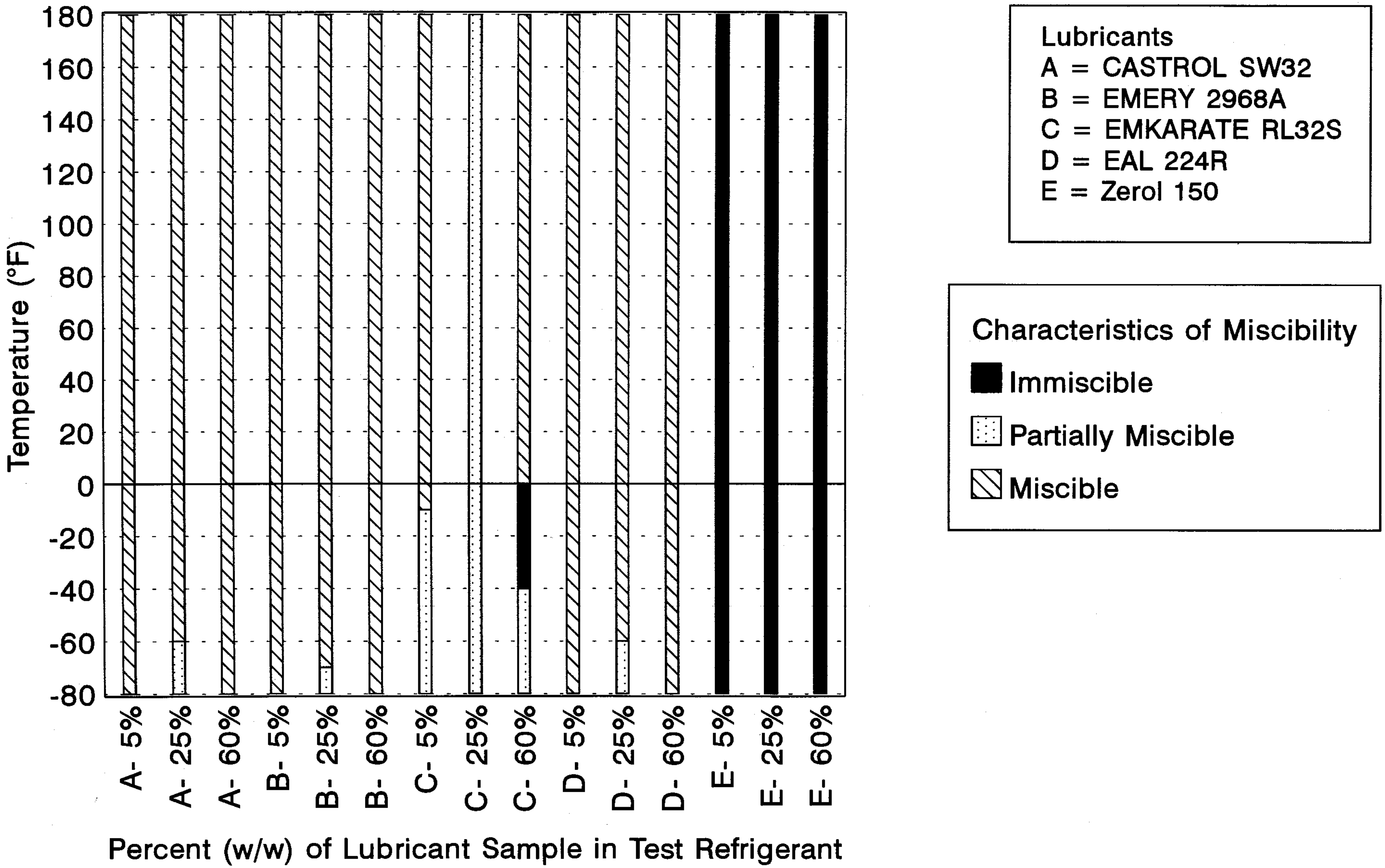
Figure A.1



Miscibility of Refrigerant Blend

HFC-32 (30%) and HFC-134a (70%)

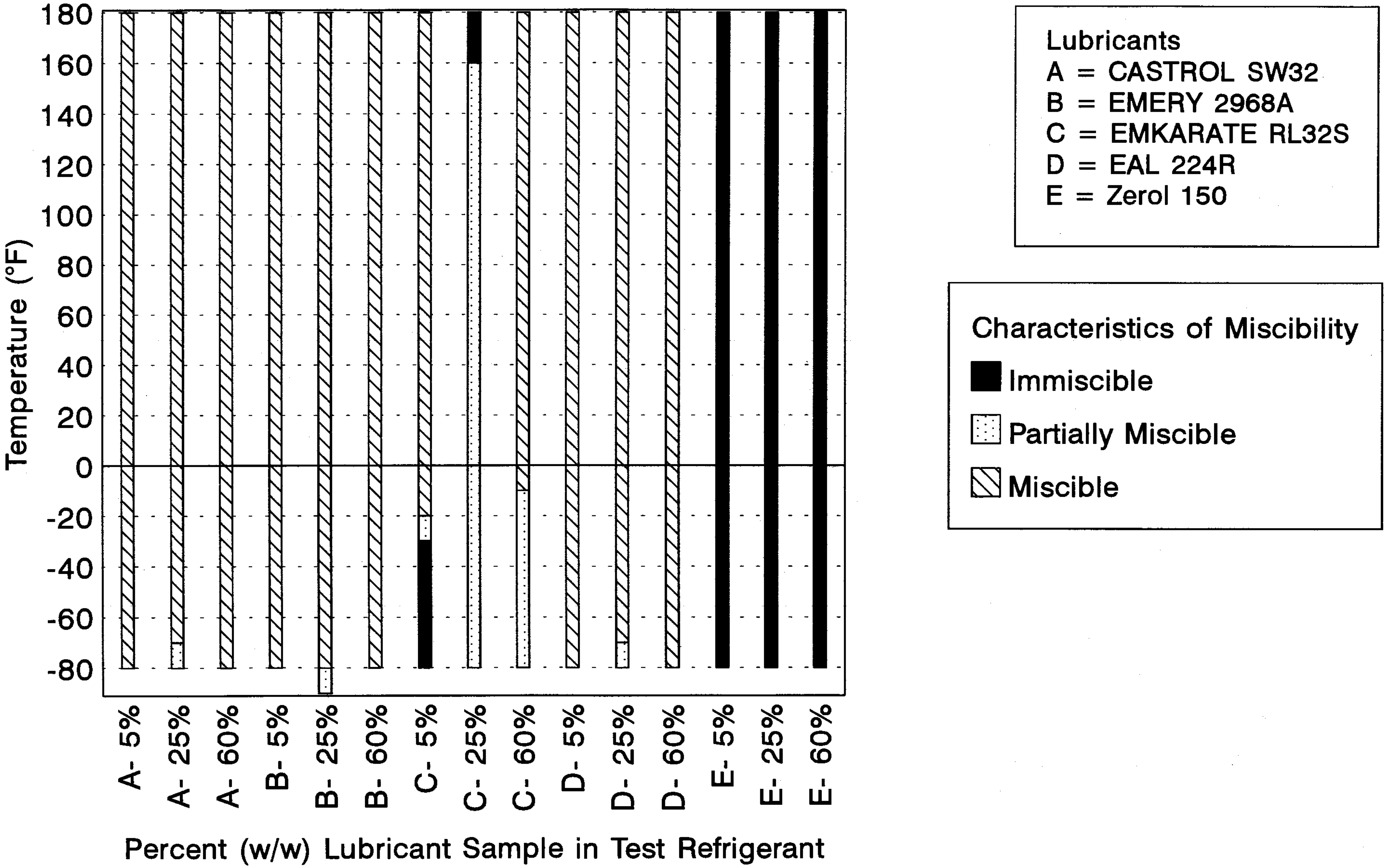
Figure A.2



Miscibility of Refrigerant Blend

HFC-32 (30%), HFC-125 (10%) and HFC-134a (60%)

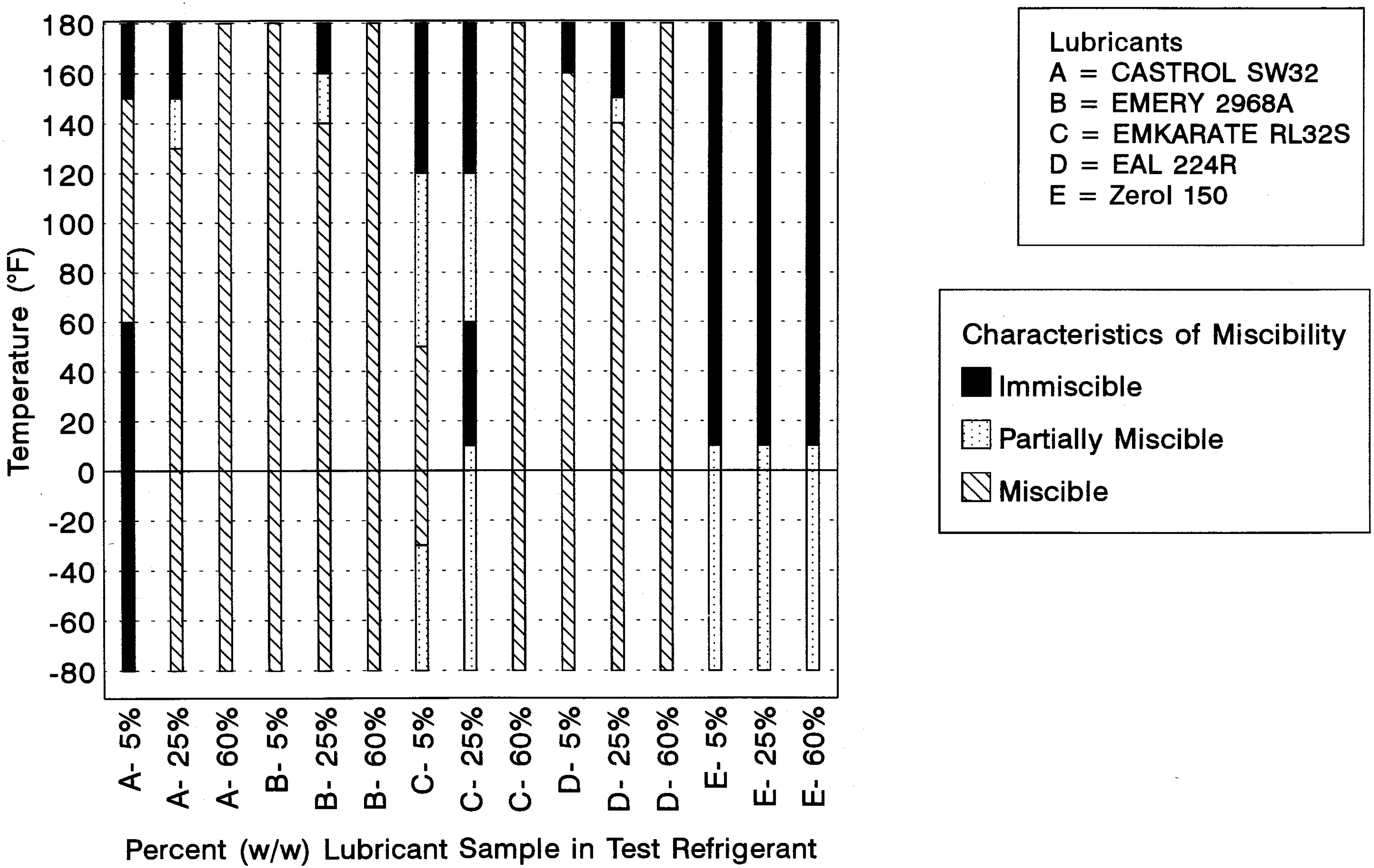
Figure A.3



Miscibility of Refrigerant Blend

R-404A

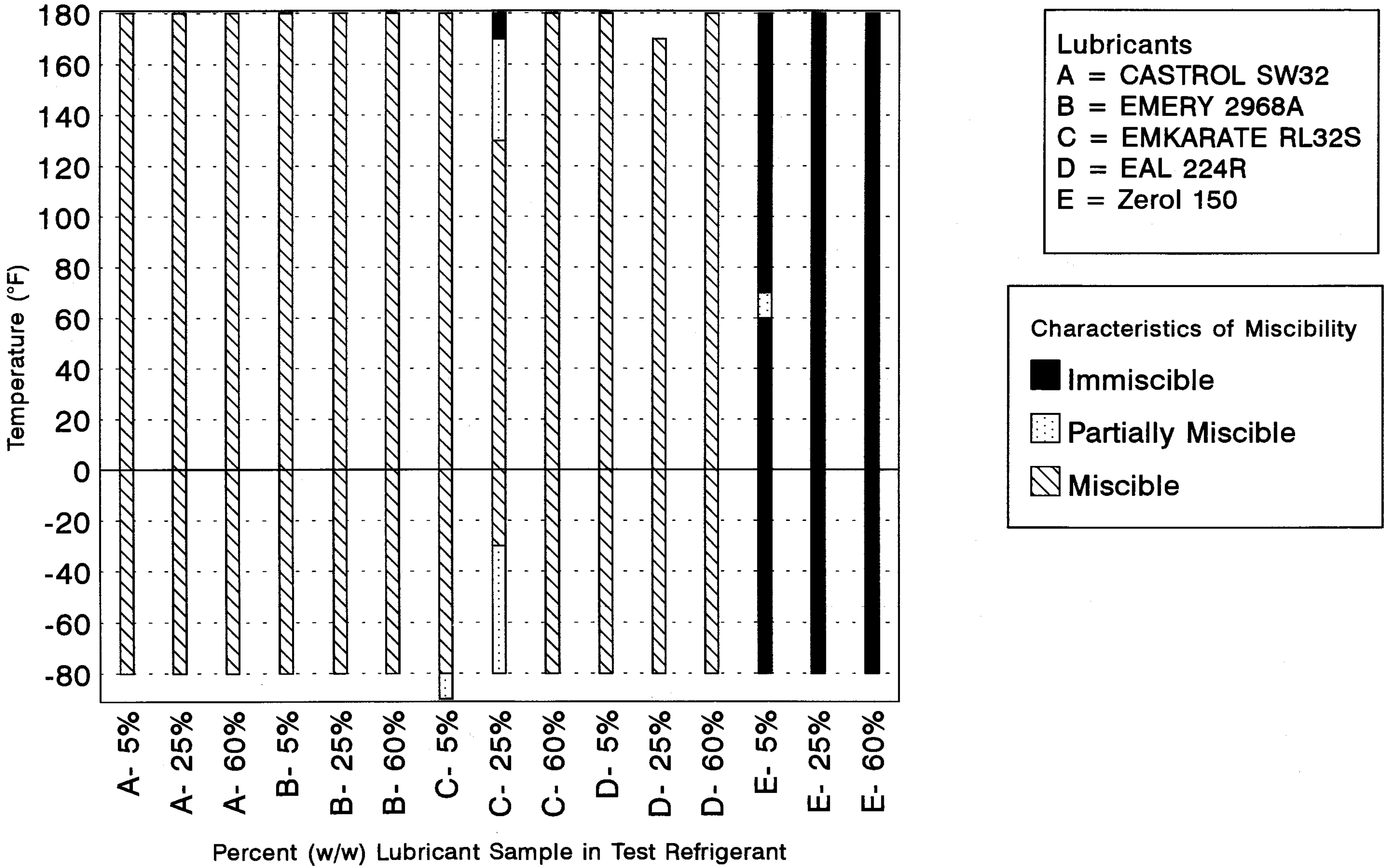
Figure A.4



Miscibility of Refrigerant Blend

HFC-32 (30%), HFC-125 (55%), HFC-134a (20%), and HC-290 (5%)

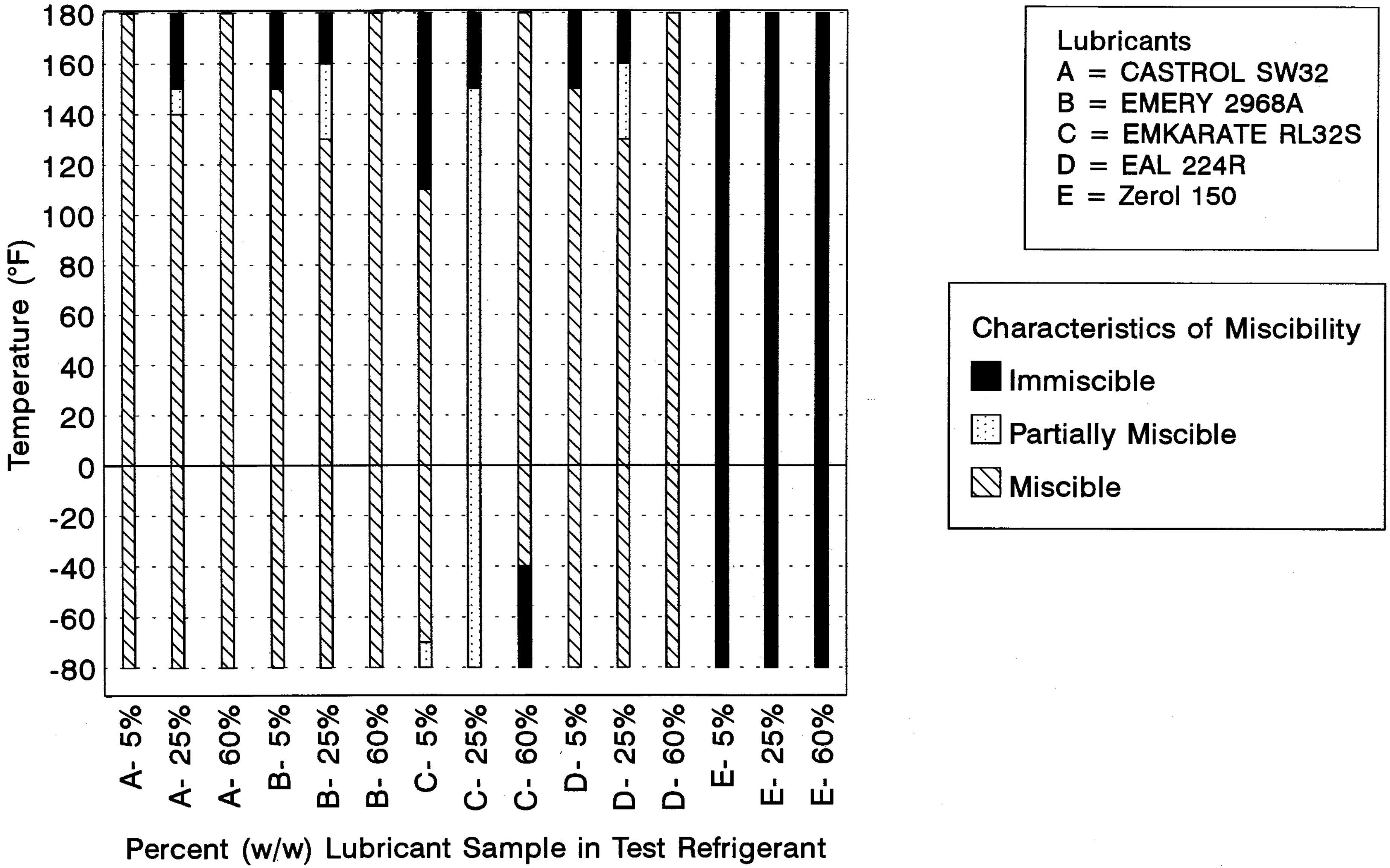
Figure A.5



Miscibility of Refrigerant Blend

HFC-125 (45%) and HFC-143a (55%)

Figure A.6

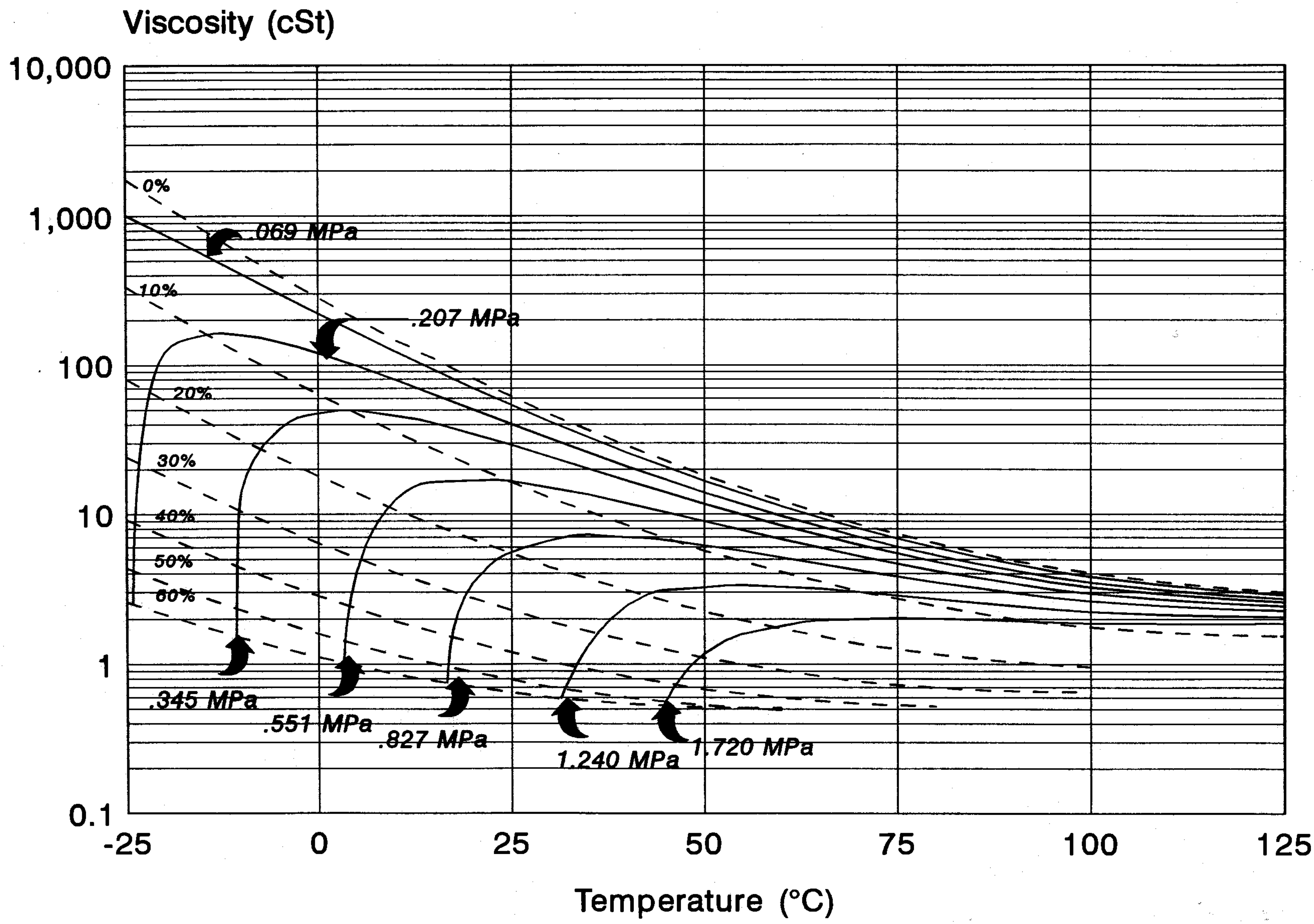


APPENDIX B
Viscosity, Density, and Gas Solubility of 32 ISO VG Mineral Oil with HCFC-22

These measurements were conducted in order to verify the repeatability and accuracy of the viscometer.

The oil used was purchased at Grainger Industrial Supply, in Columbus, Ohio. Isothermal determinations provide a snapshot view of refrigerant/lubricant solubility knees, which are unique to each refrigerant/lubricant combination. The lowest temperature for which viscosities were determined is -20°C (-4°F). Viscosity measurements at -40°C (-40°F) were attempted without success; when refrigerant concentrations exceeded 9%, the fluid became immiscible. Figure B.1 presents viscosity as a function of temperature, and includes isobaric pressure lines. Figure B.2 presents a modified "Daniel plot" that shows viscosity and pressure at constant concentration as a function of temperature. Figure B.3 shows density as a function of temperature at constant concentration. Table B.1 presents density values.

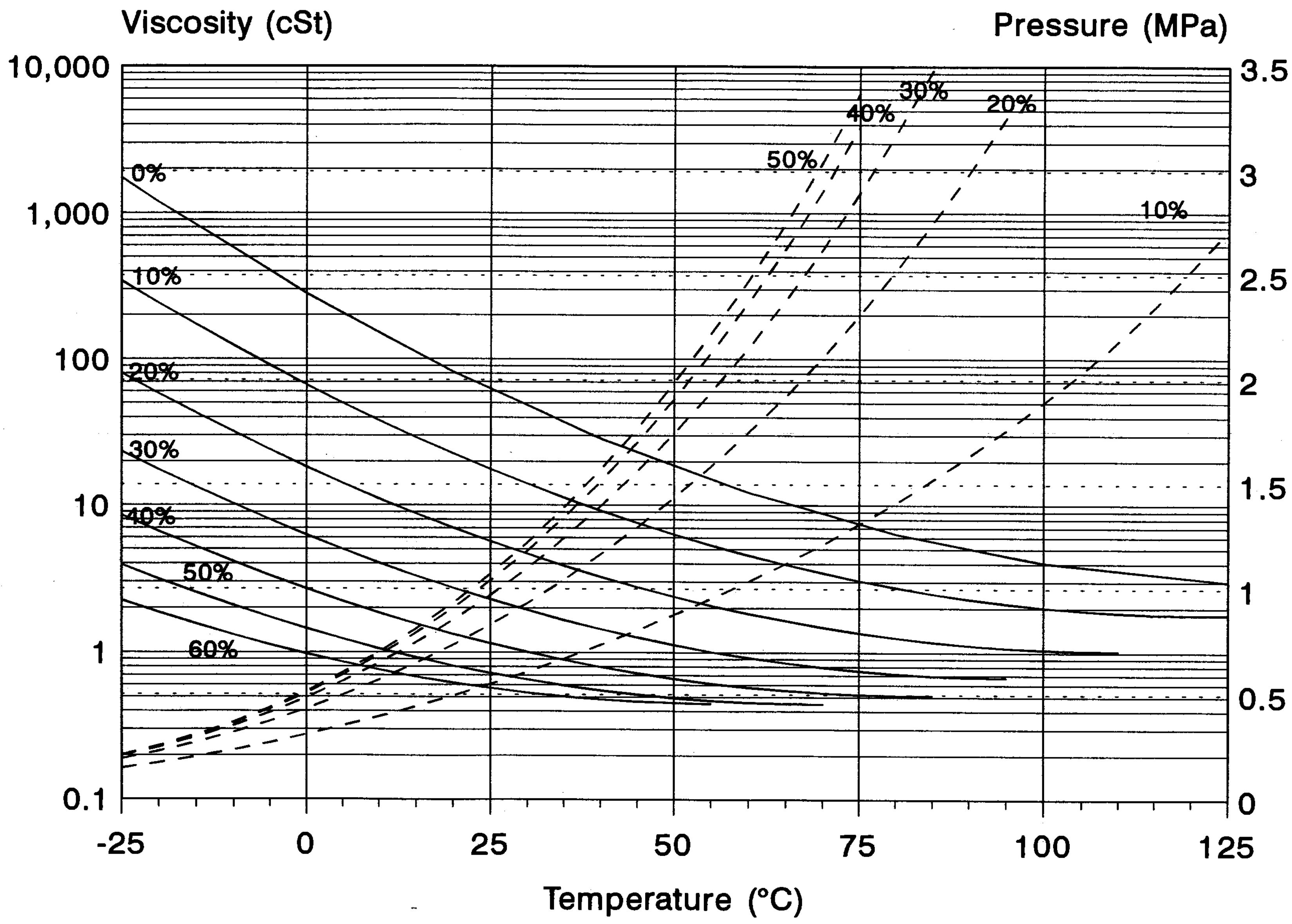
Viscosity vs. Temperature
HCFC-22 in 32 ISO VG Mineral Oil
Figure B.1



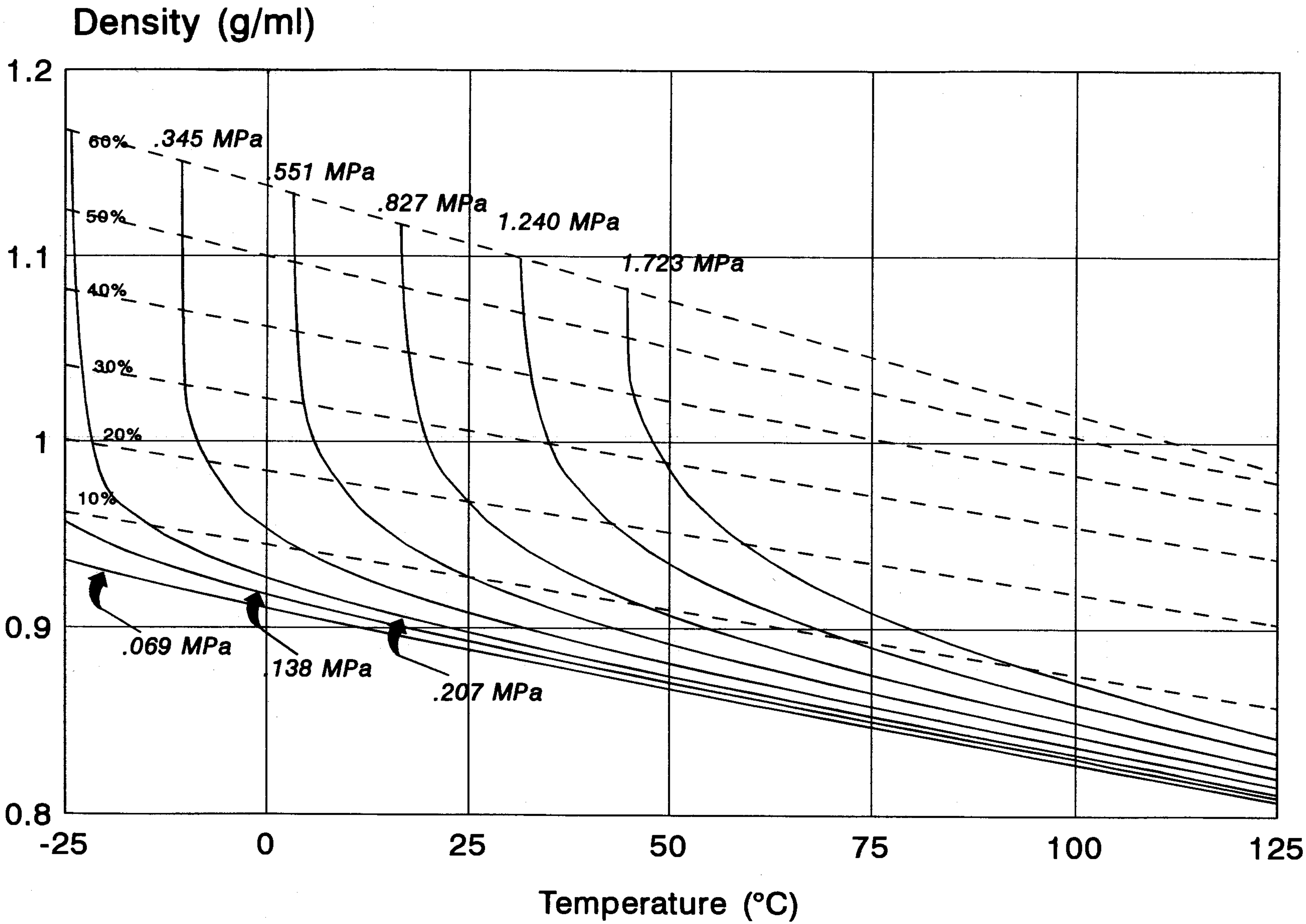
Viscosity and Pressure at Constant Concentrations

HCFC-22 in 32 ISO VG Mineral Oil

Figure B.2



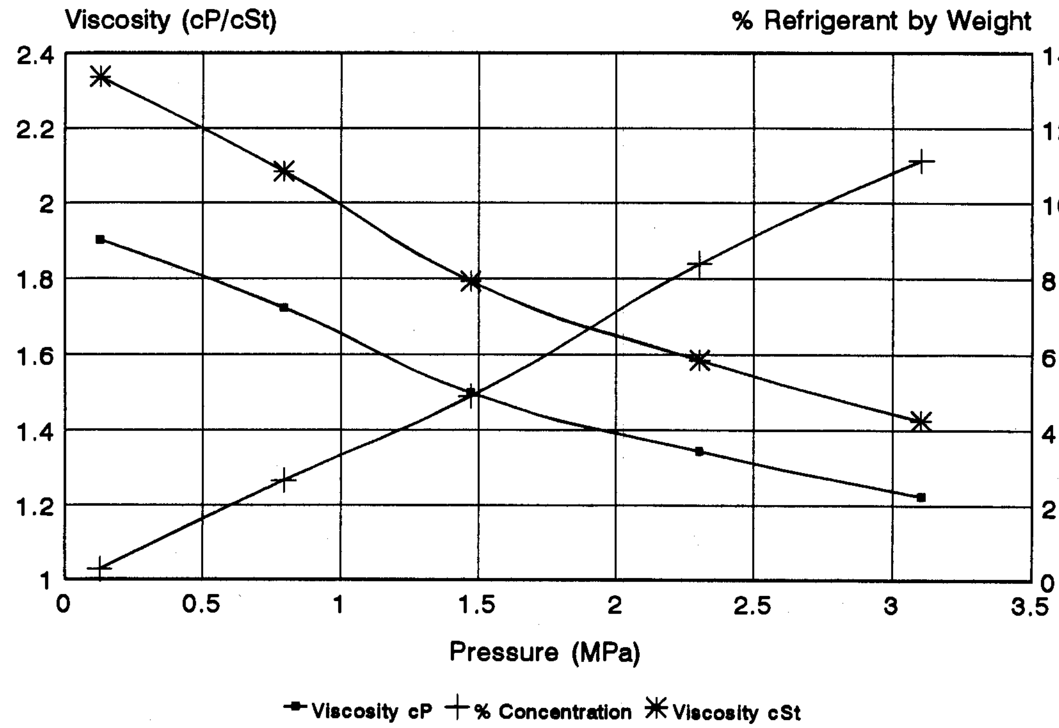
Density vs. Temperature
HCFC-22 in 32 ISO VG Mineral Oil
Figure B.3



Viscosity and Gas Solubility

32 ISO VG Mineral Oil with HCFC-22 at 125°C

Figure B.4

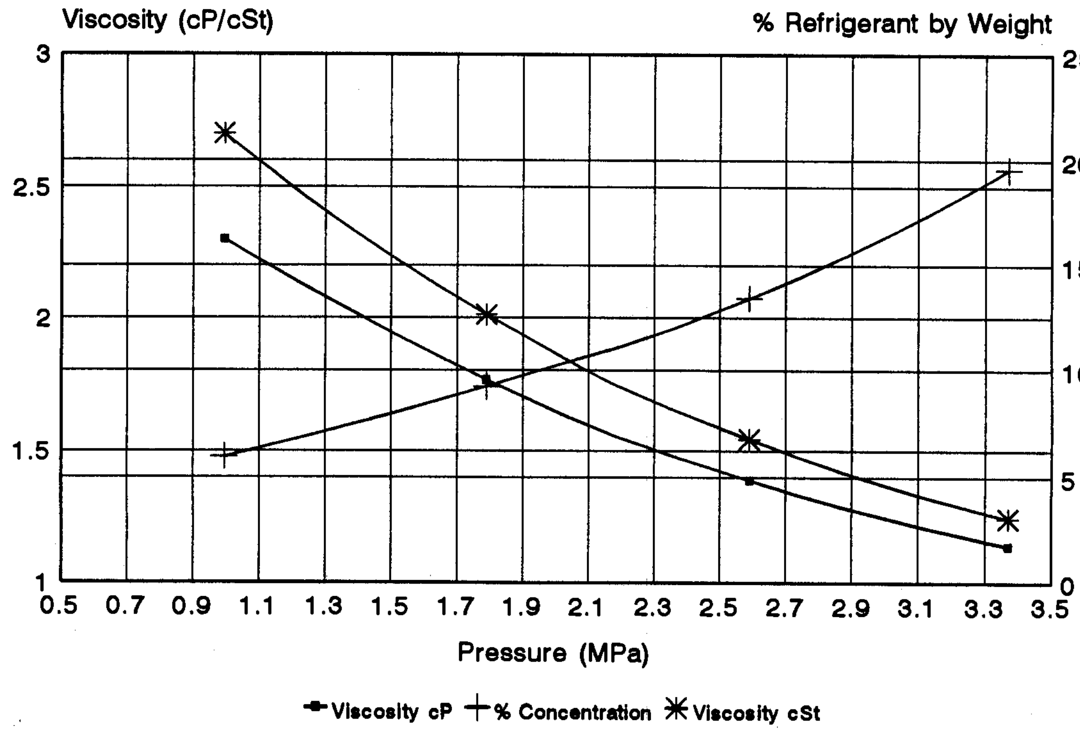


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

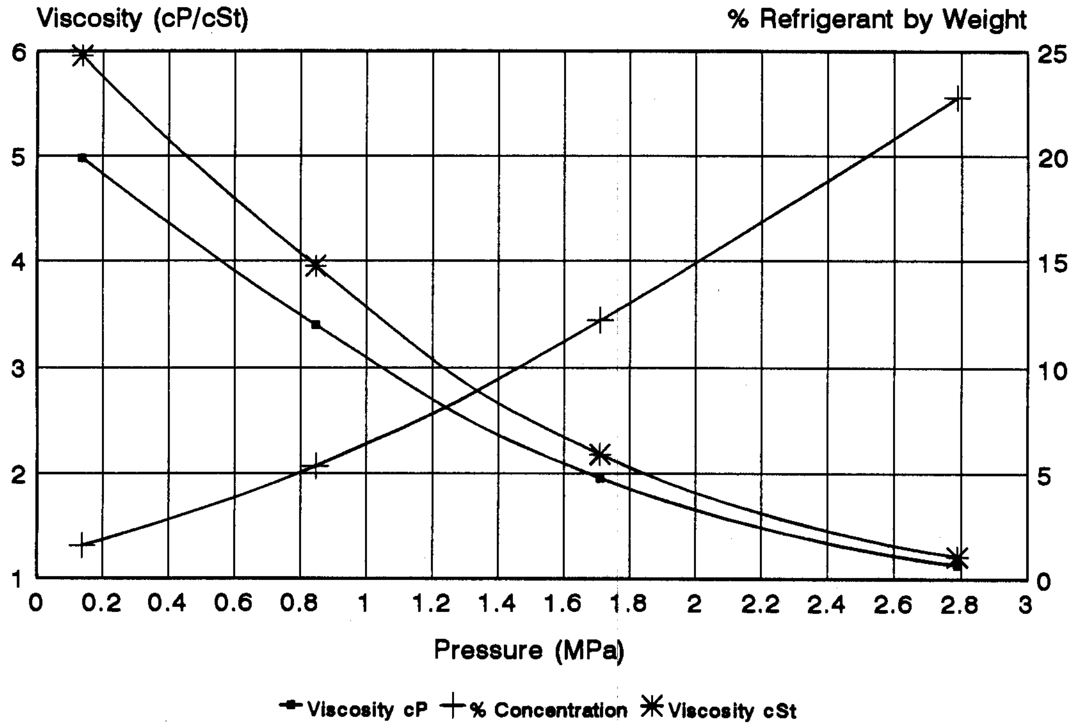
32 ISO VG Mineral Oil with HCFC-22 at 100°C

Figure B.5



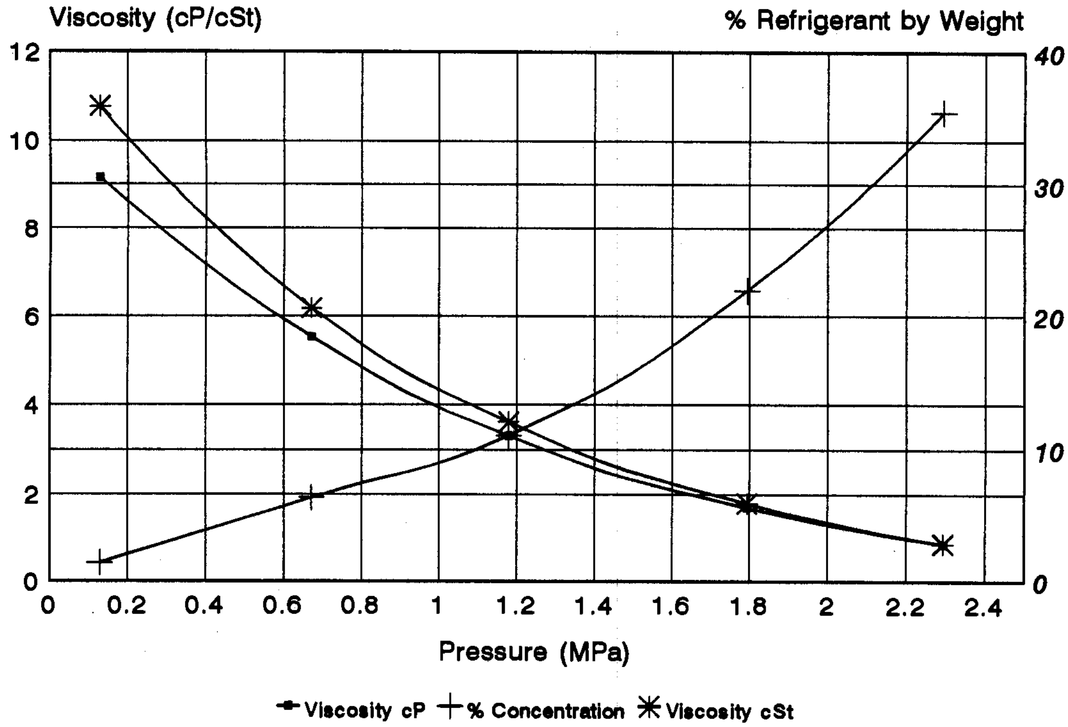
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
32 ISO VG Mineral Oil with HCFC-22 at 80°C
Figure B.6



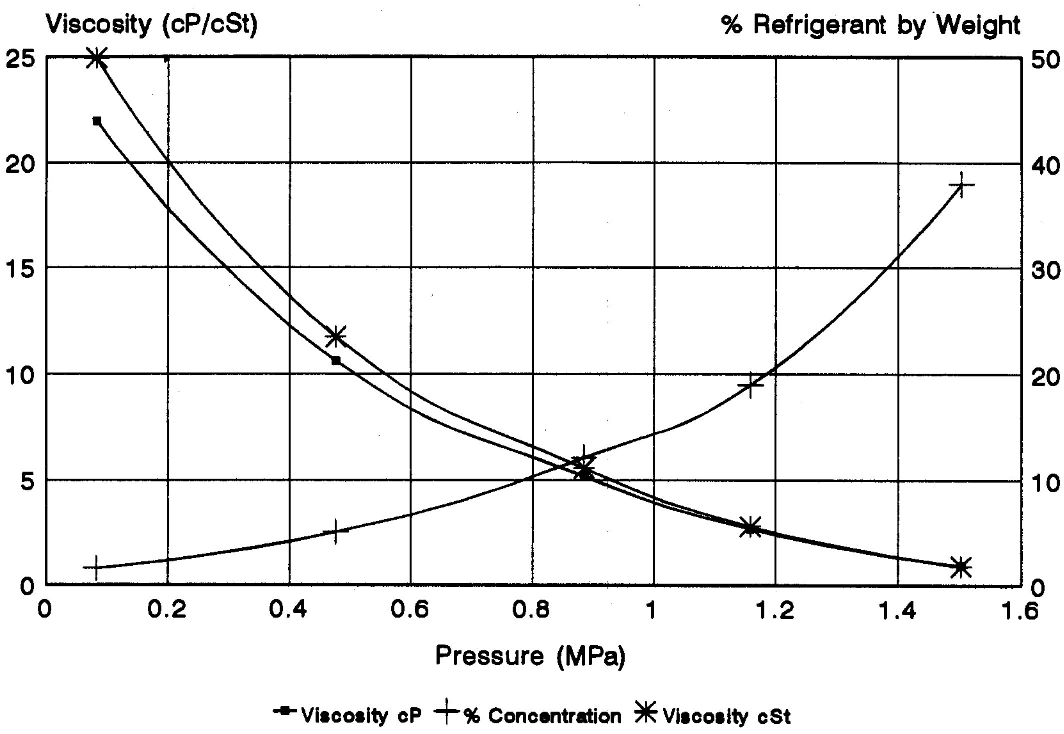
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
32 ISO VG Mineral Oil with HCFC-22 at 60°C
Figure B.7



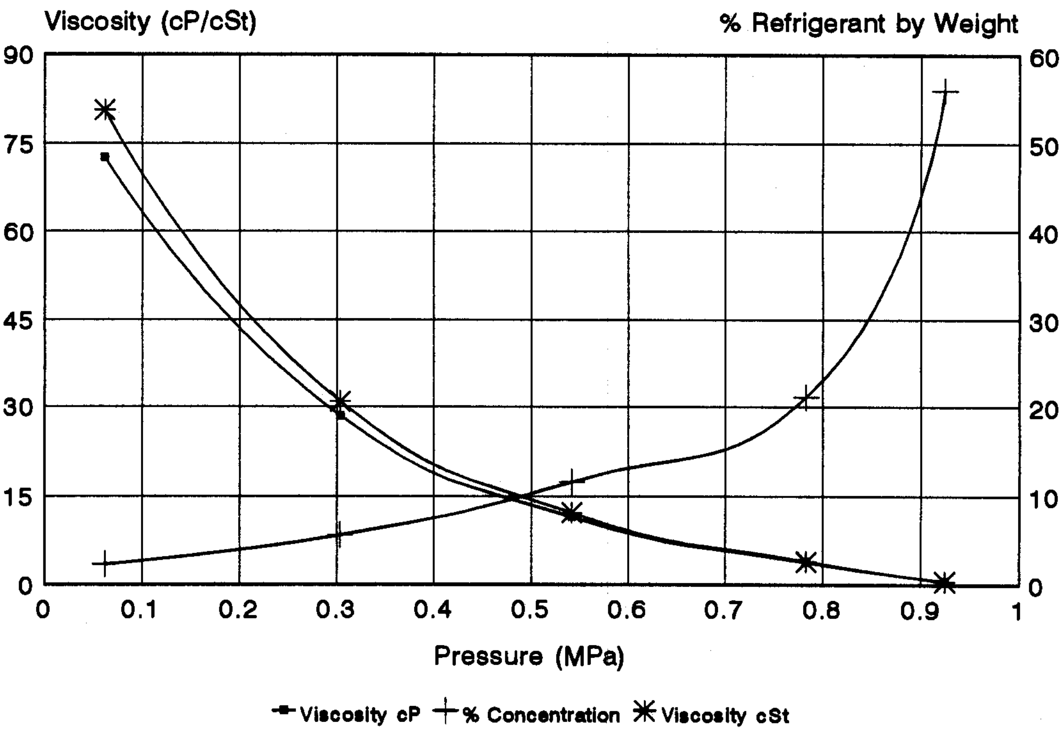
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
32 ISO VG Mineral Oil with HCFC-22 at 40°C
Figure B.8



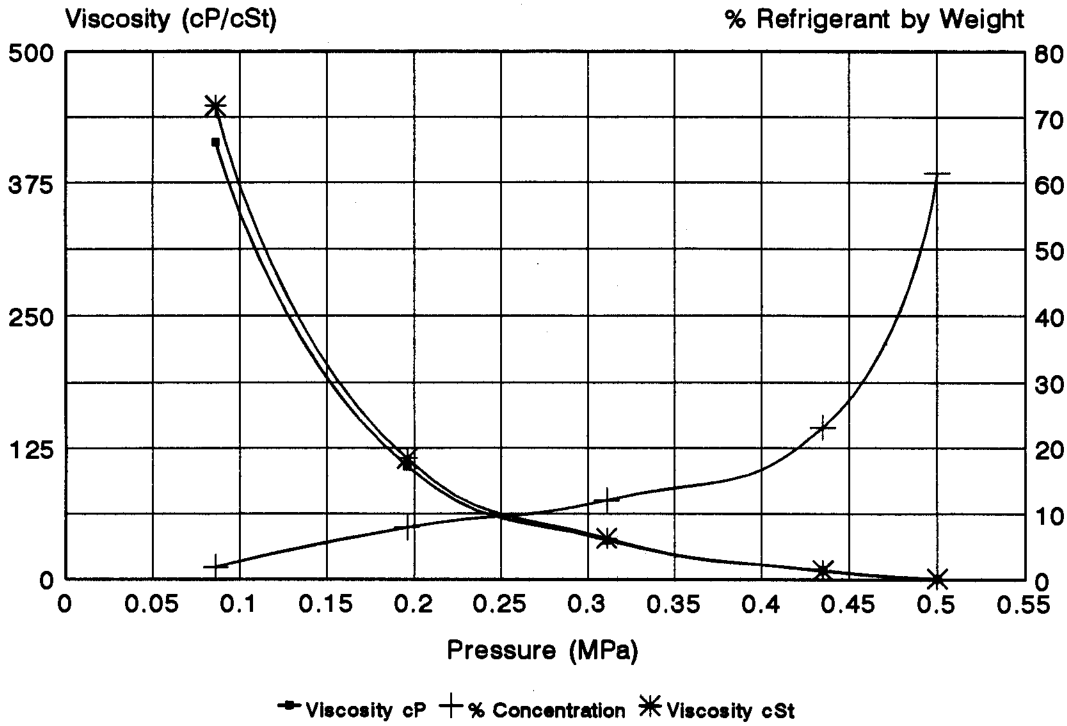
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
32 ISO VG Mineral Oil with HCFC-22 at 20°C
Figure B.9



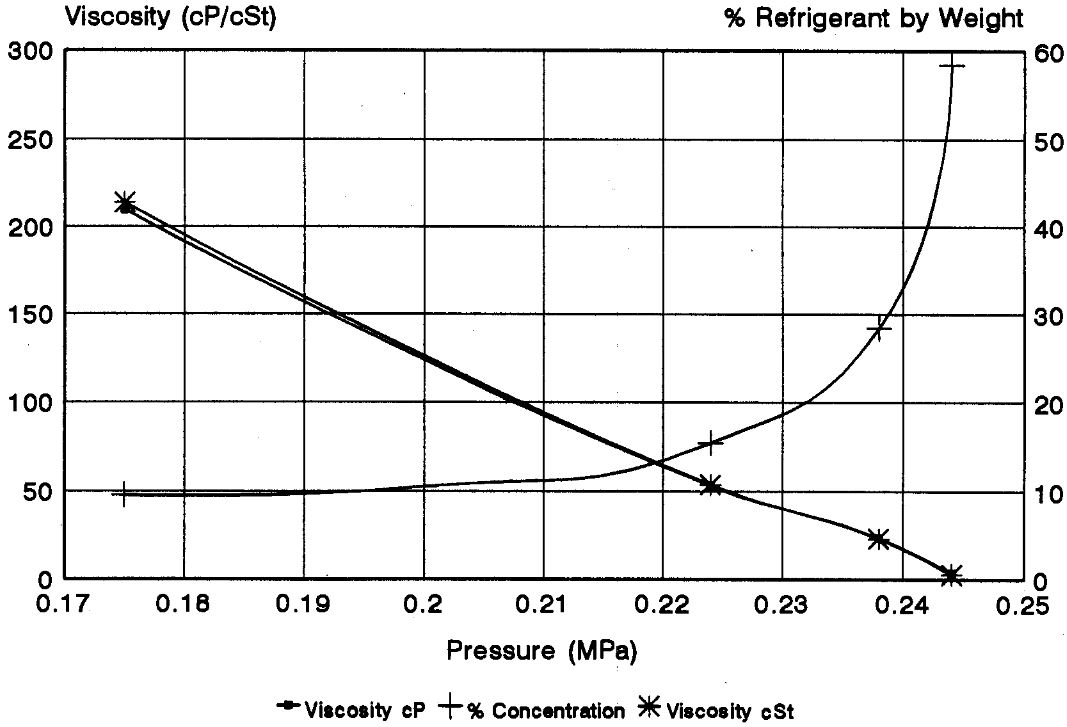
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
32 ISO VG Mineral Oil with HCFC-22 at 0°C
Figure B.10



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
32 ISO VG Mineral Oil with HCFC-22 at -20°C
Figure B.11



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
32 ISO VG Mineral Oil with HCFC−22
Table B.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.8129	18.50	0.128	0.271	1.900	2.338
0.8271	115.00	0.794	2.669	1.725	2.084
0.8368	213.50	1.470	4.906	1.500	1.792
0.8480	334.00	2.305	8.379	1.345	1.586
0.8592	450.00	3.105	11.134	1.225	1.426

100°C (212°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.826	10.00	0.069	1.732	3.231	3.908
0.853	144.00	0.994	5.968	2.301	2.699
0.8779	259.00	1.787	9.261	1.765	2.010
0.8996	375.00	2.588	13.416	1.388	1.543
0.9168	489.00	3.374	19.272	1.140	1.244

80°C (176°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.836	20.00	0.138	1.590	4.982	5.959
0.861	122.50	1.071	5.336	3.403	3.954
0.898	248.00	1.711	12.237	1.958	2.179
0.933	405.00	2.795	22.825	1.133	1.215

60°C (140°F) Temperature
500 psia Saturation Pressure
3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.8502	18.75	0.129	1.406	9.158	10.775
0.8929	97.50	0.673	6.389	5.514	6.176
0.9146	171.00	1.180	11.057	3.307	3.616
0.9437	260.00	1.794	21.928	1.689	1.791
0.9878	332.50	2.294	35.500	0.849	0.860

40°C (104°F) Temperature
222.4 psia Saturation Pressure
1.532 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.8809	12.00	0.083	1.615	21.987	24.958
0.9042	69.00	0.476	5.071	10.630	11.758
0.9303	128.25	0.885	5.878	5.185	5.574
0.9565	168.00	1.159	18.977	2.690	2.813
1.0268	217.75	0.191	38.002	0.938	0.918

20°C (68°F) Temperature
132.0 psia Saturation Pressure
0.909 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.9004	9.00	0.062	2.346	72.070	80.603
0.9221	44.00	0.304	5.619	28.453	30.856
0.9445	78.00	0.538	11.573	11.495	12.171
0.9811	113.50	0.780	21.107	3.839	3.913
1.1060	132.00	0.911	55.534	0.608	0.550

0°C (32°F) Temperature
132.0 psia Saturation Pressure
0.497 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.9228	12.50	0.086	1.891	413.875	448.500
0.9390	28.50	0.197	7.929	107.891	114.961
0.9580	45.00	0.311	12.073	37.507	39.154
1.0065	63.00	0.435	23.106	8.634	8.579
1.1531	72.50	0.500	61.534	0.890	0.772

−20°C (4°F) Temperature
40.3 psia Saturation Pressure
0.277 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.9811	25.50	0.176	9.542	209.777	213.815
0.9908	32.50	0.224	15.426	52.501	53.491
1.0177	34.50	0.238	33.365	23.486	23.077
1.1665	35.50	0.245	58.439	3.398	2.874

Neat Viscosity Check
Oil alone
40°C (104°F)

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
N/A	14.70	0.101	0	N/A	30.160	Oscillating Bob Viscometer
N/A	14.70	0.101	0	N/A	29.25	Cannon Viscometer #300 645T

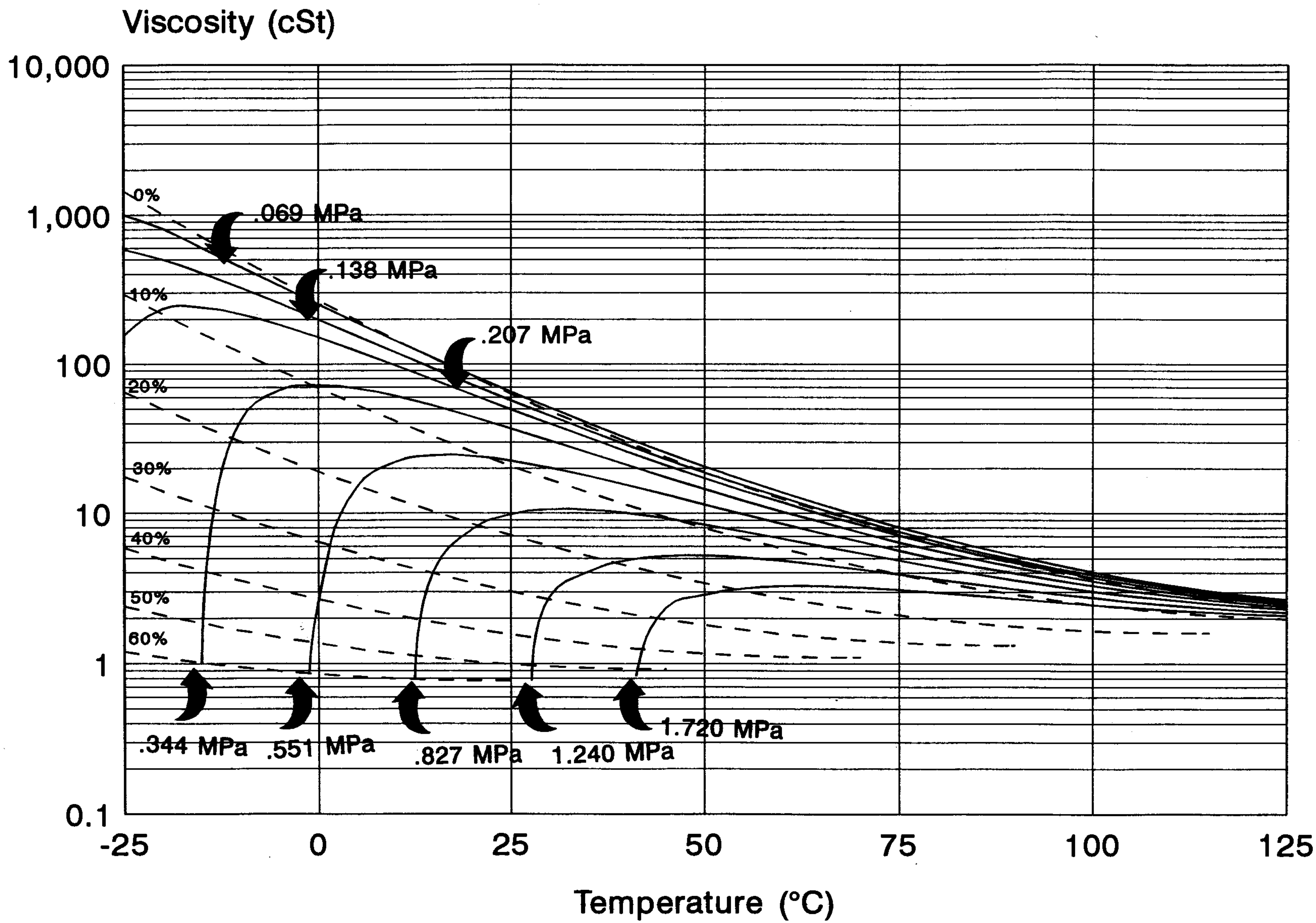
APPENDIX C
Viscosity, Density, Solubility and Gas Fractionation of 32 ISO VG Mineral Oil at Various Temperatures with R-502

Appendix C exhibits the isothermal viscosity, density, and solubility of R-502 in 32 ISO VG mineral oil. Each isothermal plot shows the fractionation of R-502 as percentage R-22 of the total gas in solution. The lowest temperature at which viscosity was determined is -10°C (14°F); the highest is 125°C (257°F) and 3.445 MPa (500 psia). At each test temperature and pressure, R-502 is introduced into the viscometer as liquid and is then purged through the lubricant until the fractionated components reach equilibrium. The equilibrium is maintained by verifying that the refrigerant gas above the lubricant is equal to the composition of the liquid refrigerant. The percent concentration of the total refrigerant represents the total of both gases that are soluble in the fluid at that pressure and temperature. Figure C.1 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure C.2 presents a modified "Daniel plot" that shows viscosity and pressure at constant concentration as a function of temperature. Figure C.3 shows density as a function of temperature at constant concentration.

The tests reported here indicate R-502 fractionation in the mineral oil; the ratio of this fractionation changes with pressure and temperature. At tested pressures and temperatures, the primary component in the solution, R-22, makes up 62% to 68% of the dissolved refrigerant. This conflicts with published data, which shows dramatically lower refrigerant concentrations, and, therefore, higher viscosities at lower pressures. The results presented here are based on gravimetric measurements of the weight of the refrigerant in the oil and are capable of showing the dramatic viscosity and pressure changes that occur with small changes in refrigerant concentrations.

Per ARTI recommendations, the purity of the test oil was verified and additional tests were conducted with samples much larger than the 1 gram samples previously used. The increase in sample size would eliminate any error caused by the retention of lubricant in the viscometer's capillary tube. The results obtained with the large samples were not consistently different from those obtained with small samples.

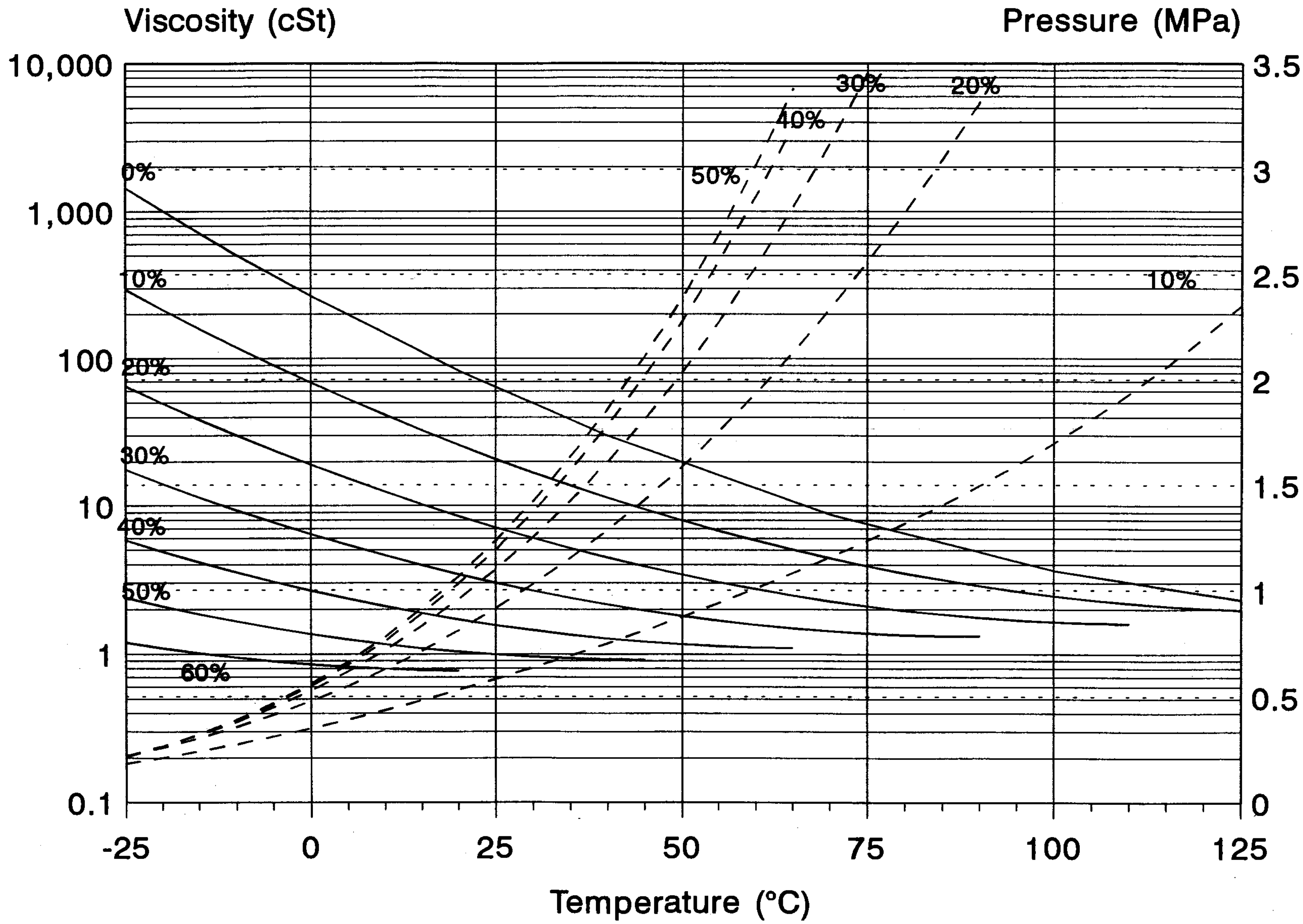
Viscosity vs. Temperature
R-502 in 32 ISO VG Mineral Oil
Figure C.1



Viscosity and Pressure at Constant Concentrations

R-502 in 32 ISO VG Mineral Oil

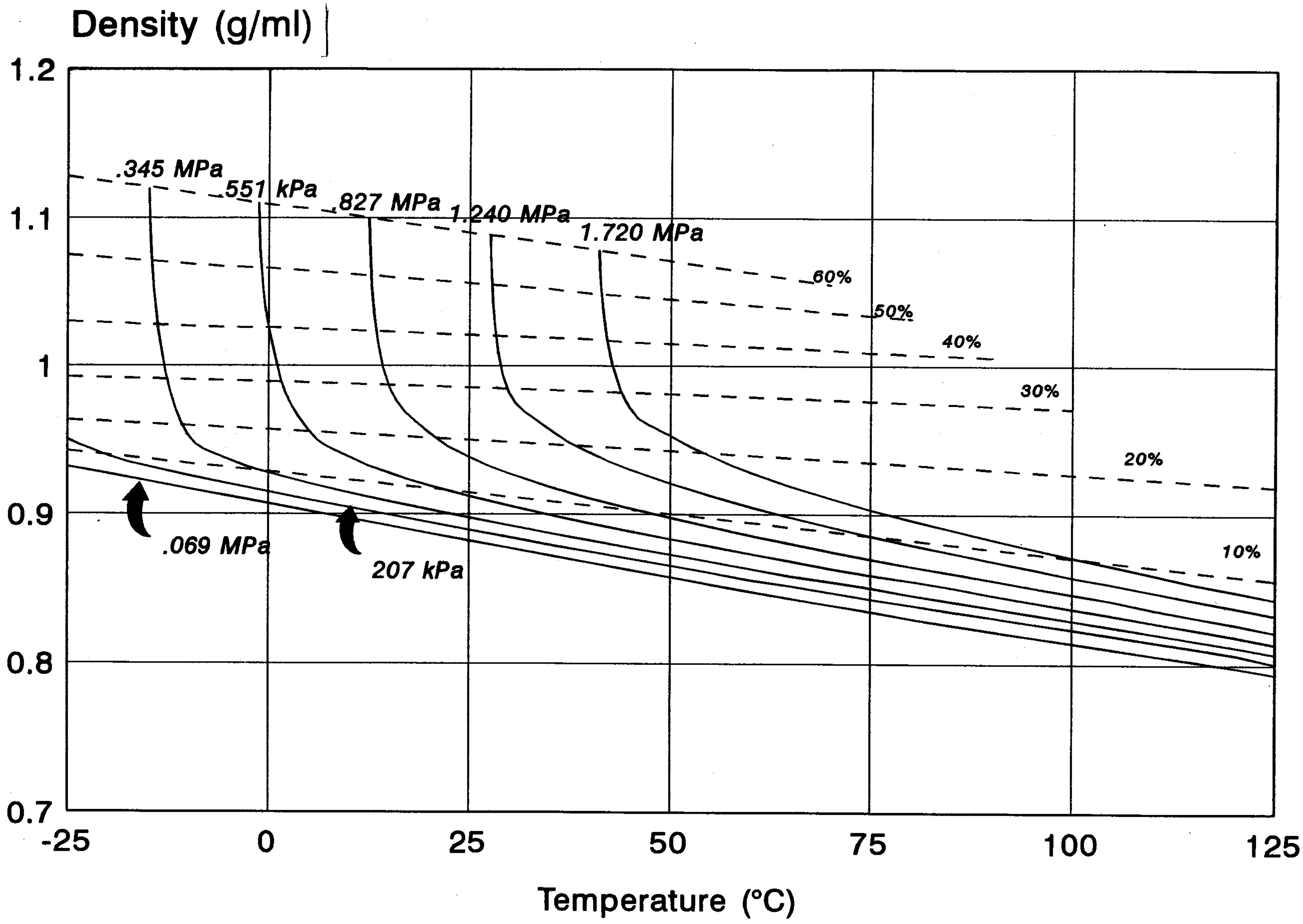
Figure C.2



Density vs. Temperature

R-502 in 32 ISO VG Mineral Oil

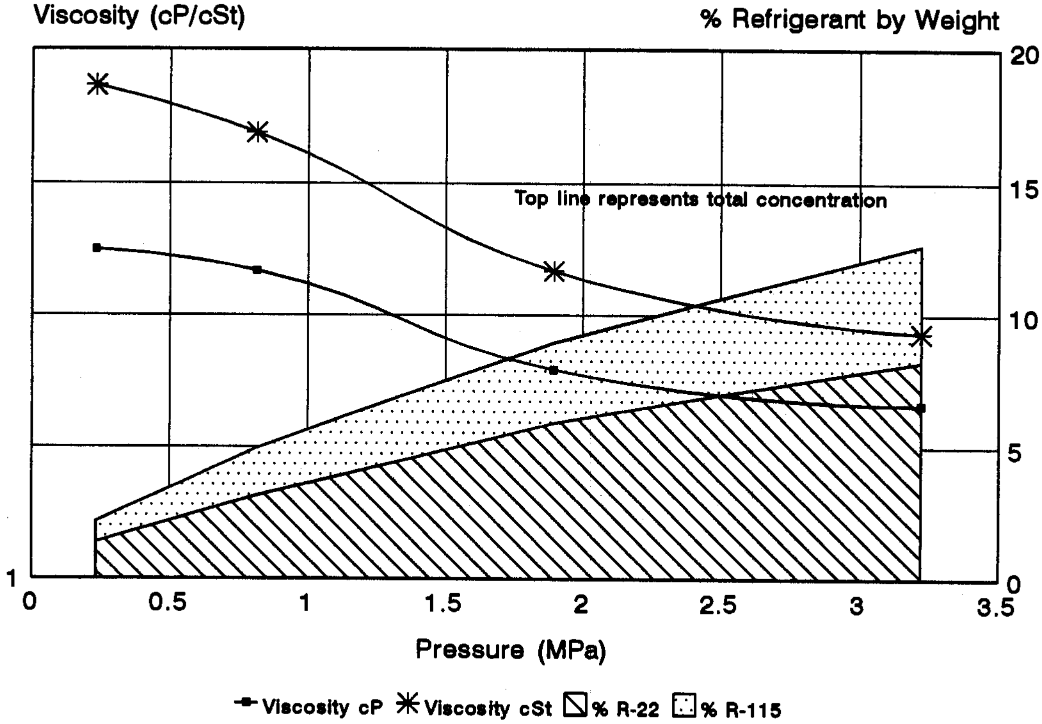
Figure C.3



Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mineral Oil with R-502 at 125°C

Figure C.4



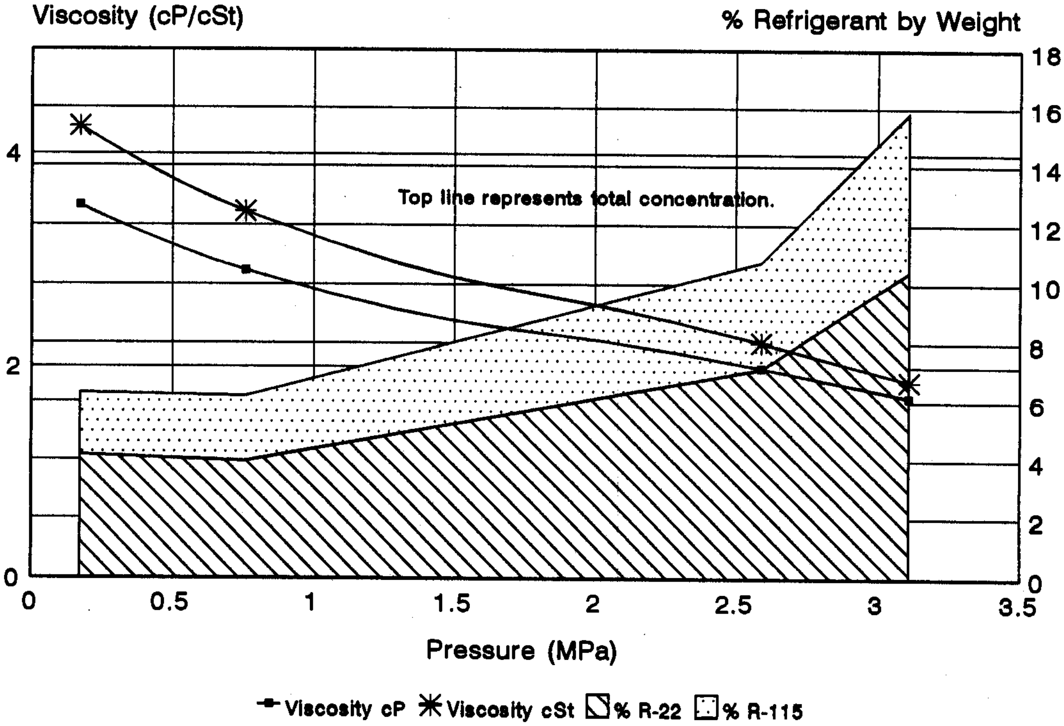
Viscosity via Gas Solubility Equilibrium

Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mineral Oil with R-502 at 100°C

Figure C.5



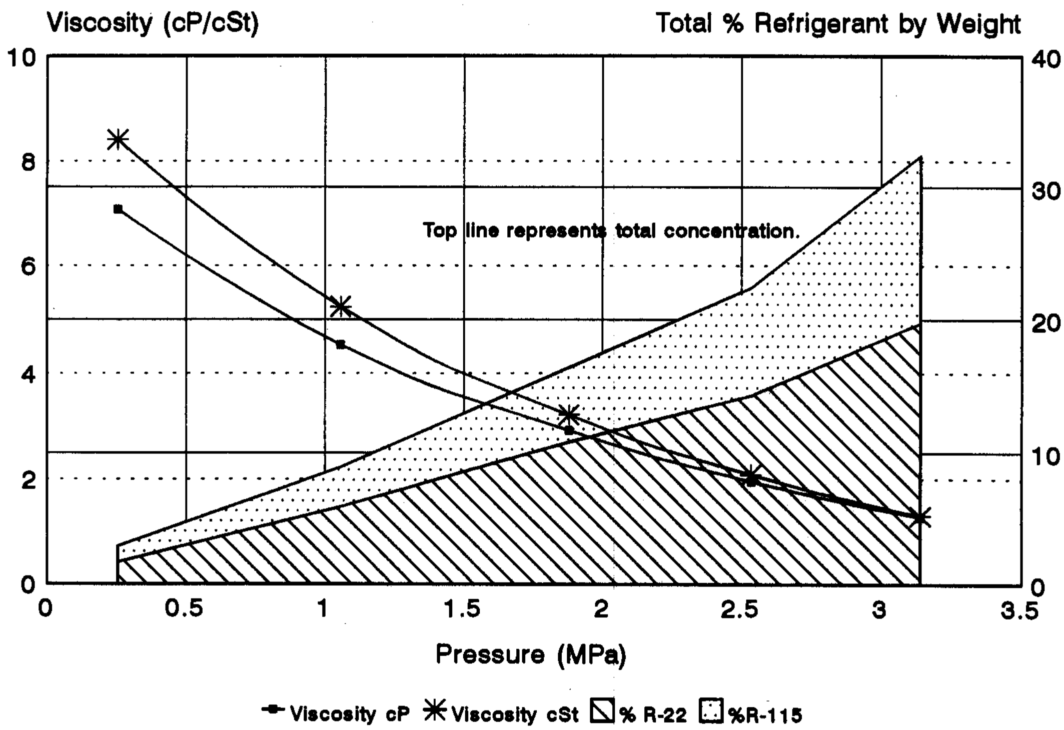
Viscosity via Gas Solubility Equilibrium

Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mineral Oil with R-502 at 70°C

Figure C.6

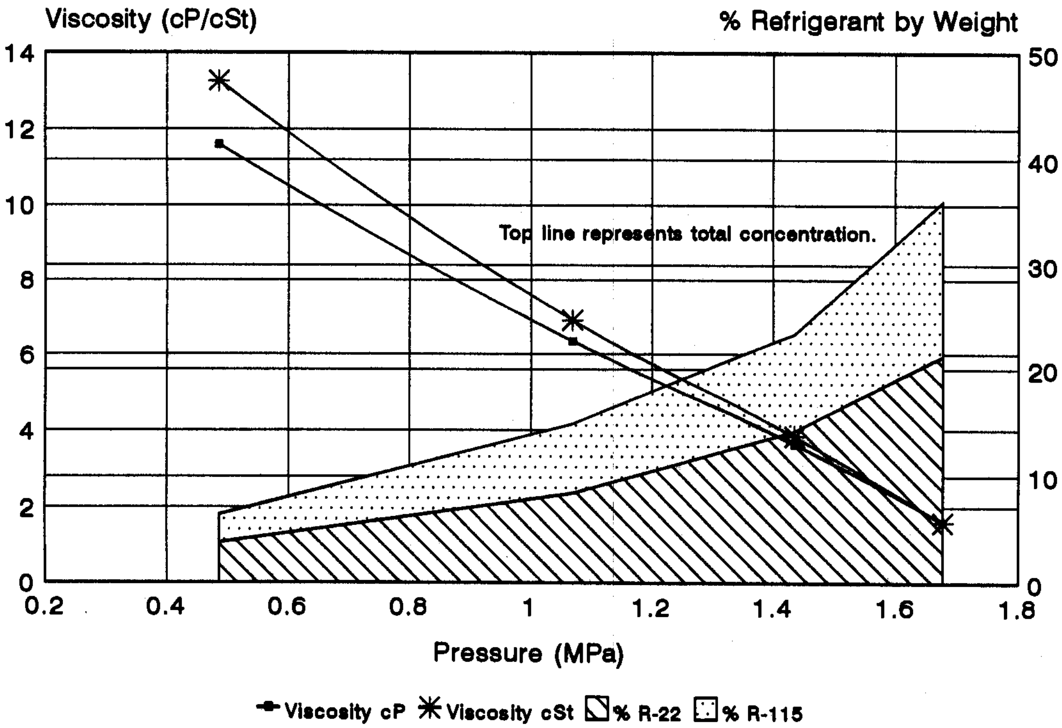


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

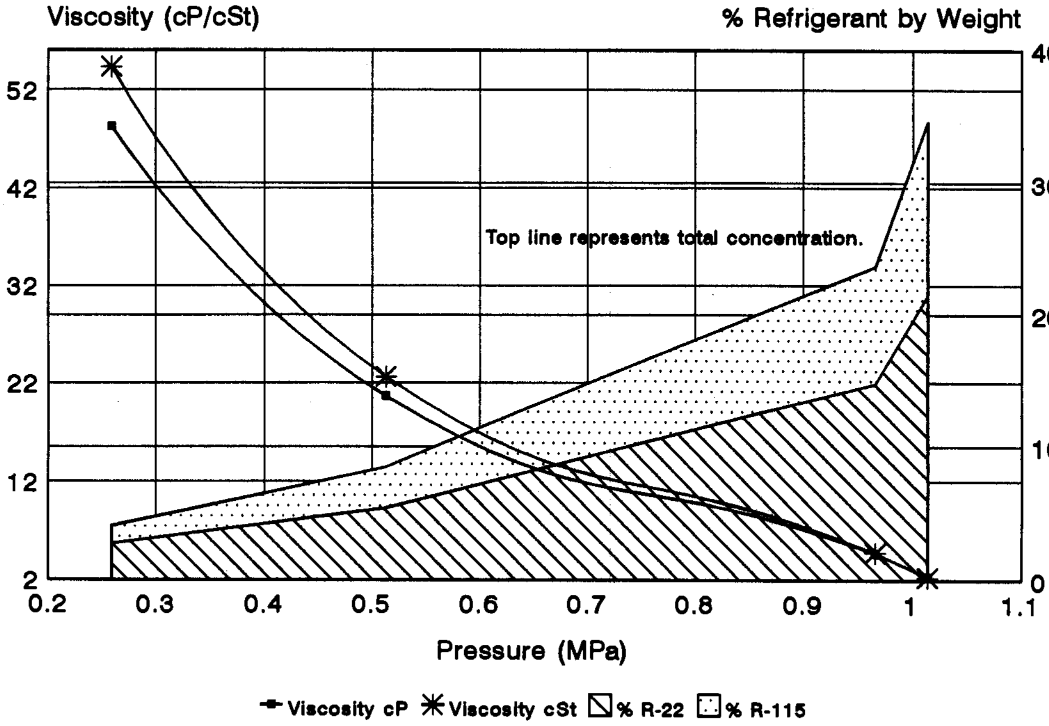
32 ISO VG Mineral Oil with R-502 at 40°C

Figure C.7



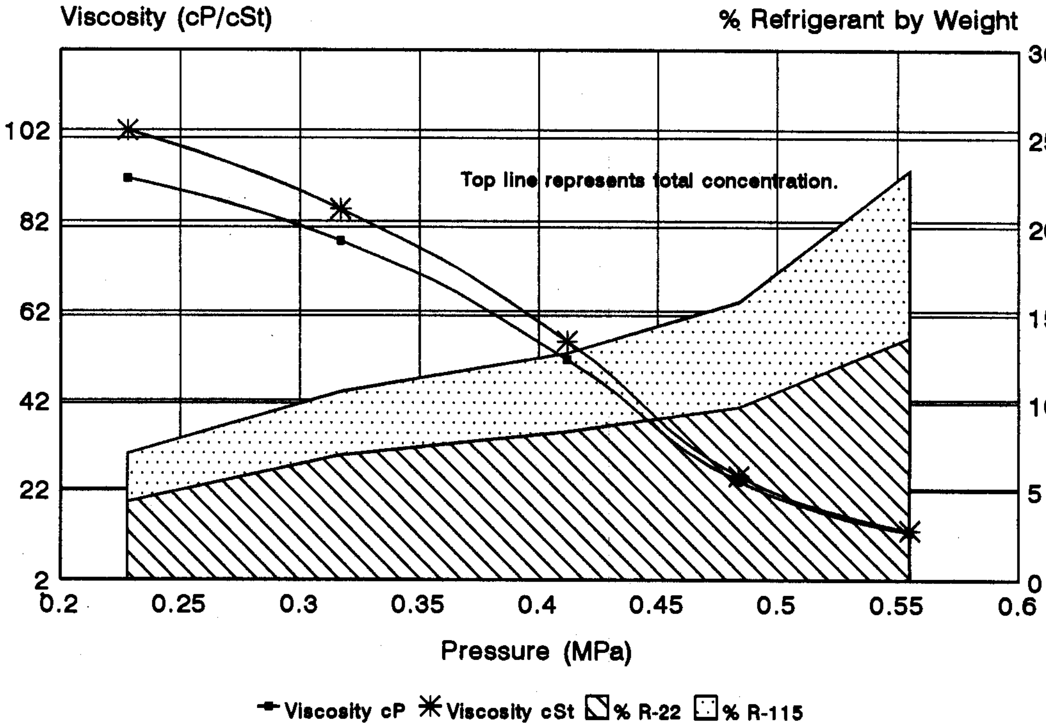
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
32 ISO VG Mineral Oil with R-502 at 20°C
Figure C.8



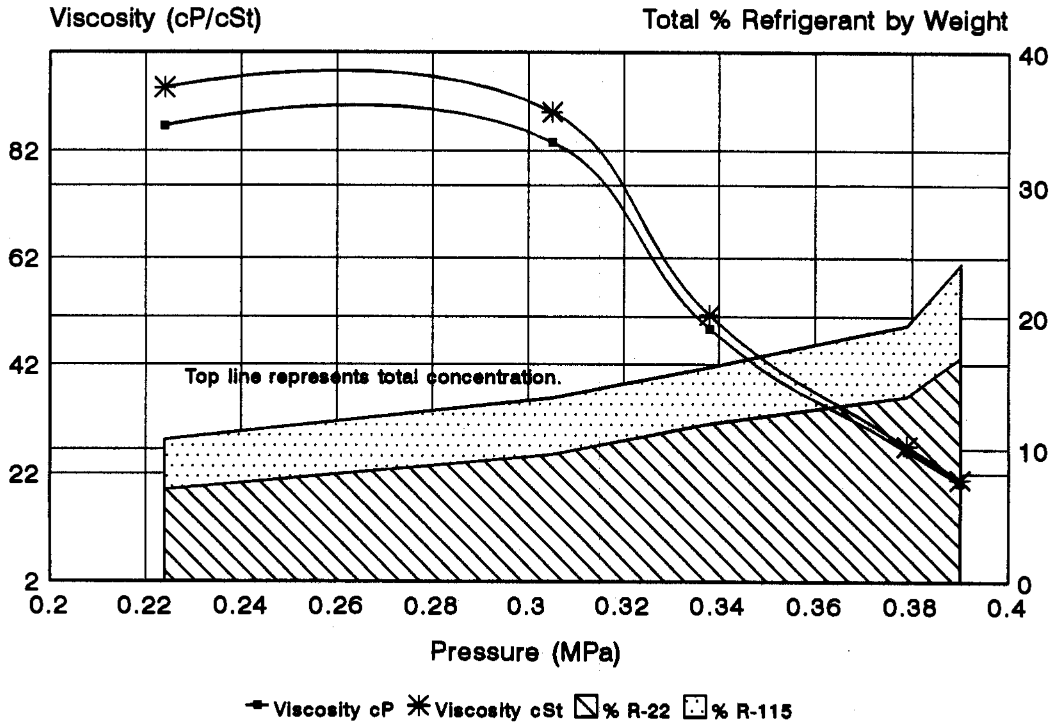
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
32 ISO VG Mineral Oil with R-502 at 0°C
Table C.9



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
32 ISO VG Mineral Oil with R-502 at -10°C
Figure C.10



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, Solubility, and Gas Fractionation
32 ISO VG Mineral Oil with R−502
Table C.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% HCFC−22
0.8073	34.75	0.239775	2.175	1.938	2.400	66.1
0.8273	118.00	0.8142	4.930	1.877	2.269	63.9
0.8488	274.50	1.89405	8.926	1.593	1.876	66.4
0.8785	466.75	3.220575	12.671	1.492	1.733	65.9

80°C (176°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% HCFC−22
0.8259	25.00	0.1725	6.295	4.263	4.263	66.100
0.8399	110.00	0.759	6.189	3.460	3.460	63.900
0.8925	375.50	2.59095	10.755	2.232	2.232	66.400
0.9176	451.00	3.1119	15.819	1.863	1.863	65.900

70°C (158°F) Temperature
467.67 psiaSaturation Pressure
3.22 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% HCFC−22
0.8414	37.00	0.2553	2.884	7.080	8.409	57.600
0.8653	153.00	1.0557	8.888	4.530	5.232	66.300
0.9087	271.00	1.8699	16.452	2.927	3.221	65.800
0.9391	367.50	2.53575	22.332	1.959	2.086	64.000
0.9835	455.00	3.1395	32.430	1.284	1.305	60.850

40°C (104°F) Temperature
243.2 psia Saturation Pressure
1.676 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% HCFC−22
0.8747	70.50	0.48645	6.432	11.599	13.260	59.550
0.9183	155.00	1.0695	14.889	6.348	6.913	56.600
0.9487	208.00	1.4352	23.358	36.500	3.650	60.800
1.0027	243.00	1.6767	36.055	1.613	1.609	59.450

Neat Viscosity Check
Oil alone
40°C (104°F) 14.7 psia (.1013 MPa)

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
N/A	14.7	0.101	0	N/A	30.16	Oscillating Bob Viscometer
N/A	14.7	0.101	0	N/A	29.25	Cannon Viscometer #300 645T

20°C (68°F) Temperature
147.9 psia Saturation Pressure
1.019 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% HCFC−22
0.8889	37.50	0.259	4.083	48.295	54.331	67.50
0.9124	74.50	0.514	8.436	20.602	22.579	64.25
0.9827	140.00	0.966	23.638	4.706	4.789	62.00
1.0286	147.00	1.014	34.676	2.536	2.293	61.80

0°C (32°F) Temperature
83.1 psia Saturation Pressure
0.572 MPa

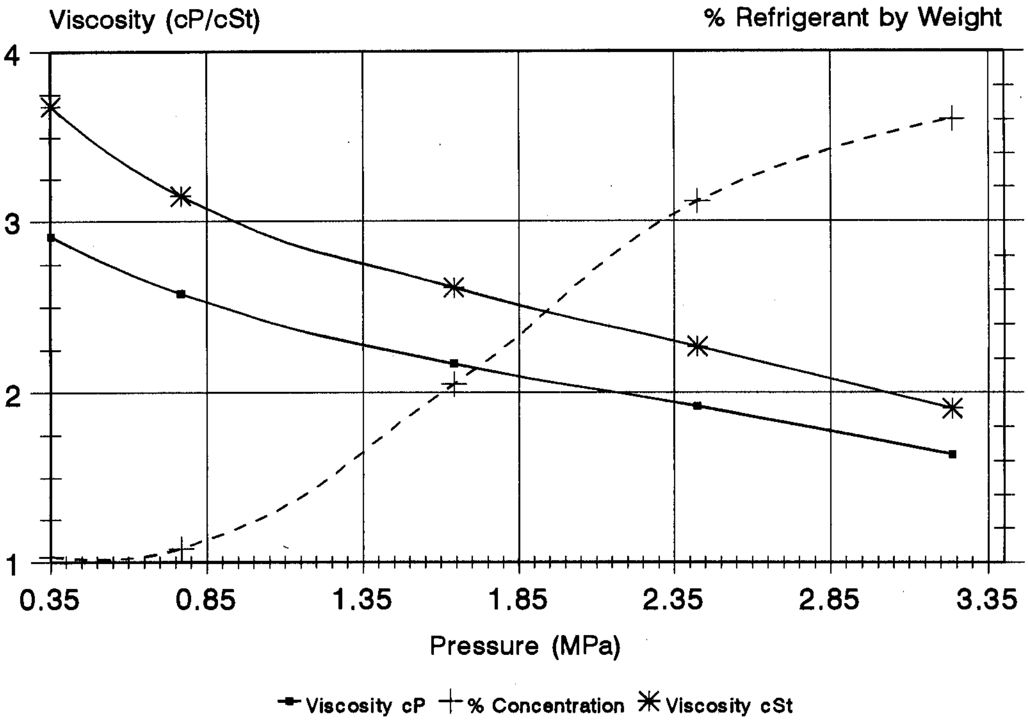
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% HCFC−22
0.8962	33.00	0.228	7.073	101.942	101.942	61.50
0.9169	45.90	0.317	10.664	84.659	84.659	65.25
0.9258	59.75	0.412	12.851	55.281	30.281	65.10
0.9539	70.25	0.485	15.755	24.874	55.281	61.95
0.9728	80.50	0.555	23.191	12.905	24.874	59.30

−10°C (14°F) Temperature
60.1 psia Saturation Pressure
0.414 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% HCFC−22
0.9255	32.50	0.224	10.708	86.521	93.536	64.60
0.9265	40.75	0.281	10.544	123.132	132.903	62.85
0.9384	44.25	0.305	13.822	83.596	89.091	69.90
0.9494	49.00	0.338	16.106	48.671	51.264	73.85
0.9687	55.00	0.38	19.303	26.584	27.021	72.30
0.9708	57.50	0.397	20.286	20.286	20.895	70.20

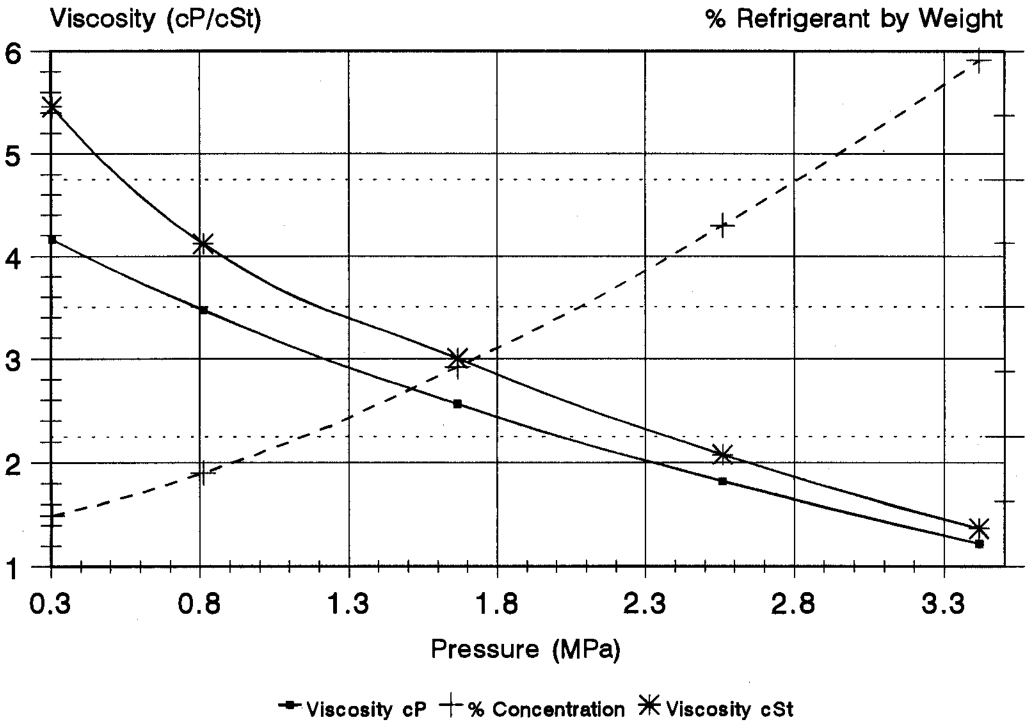
APPENDIX D
Viscosity, Density, and Gas Solubility
of EMKARATE RL32S at Various Temperatures with HFC-134a

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-134a at 125°C
Figure D.1



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-134a at 100°C
Figure D.2

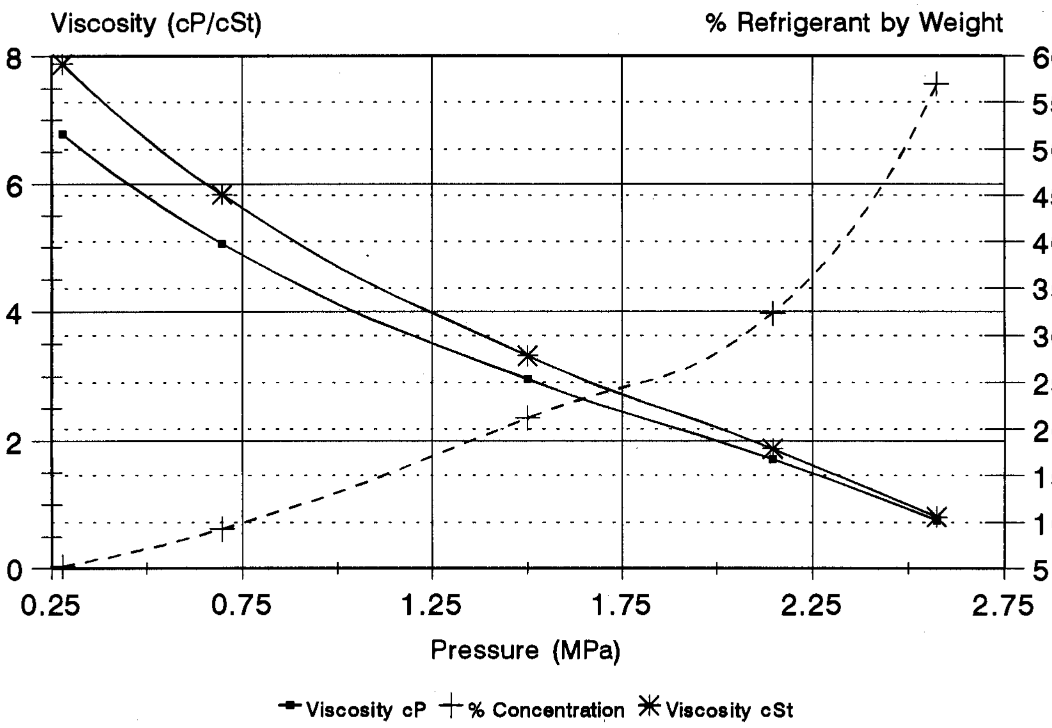


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-134a at 80°C

Figure D.3

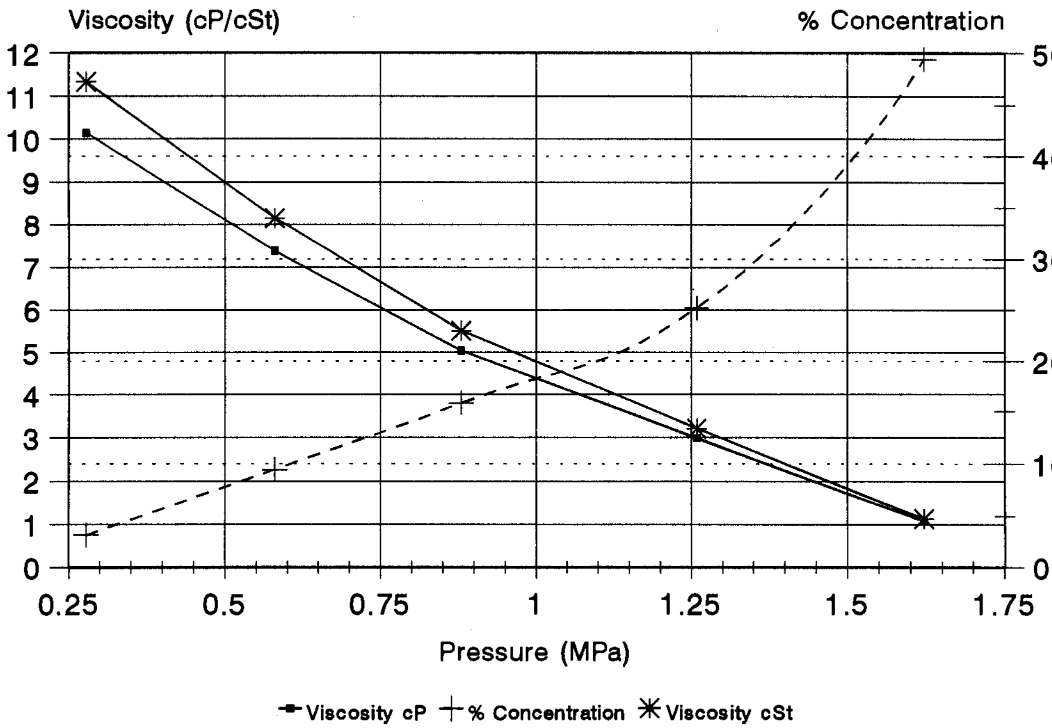


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-134a at 60°C

Figure D.4

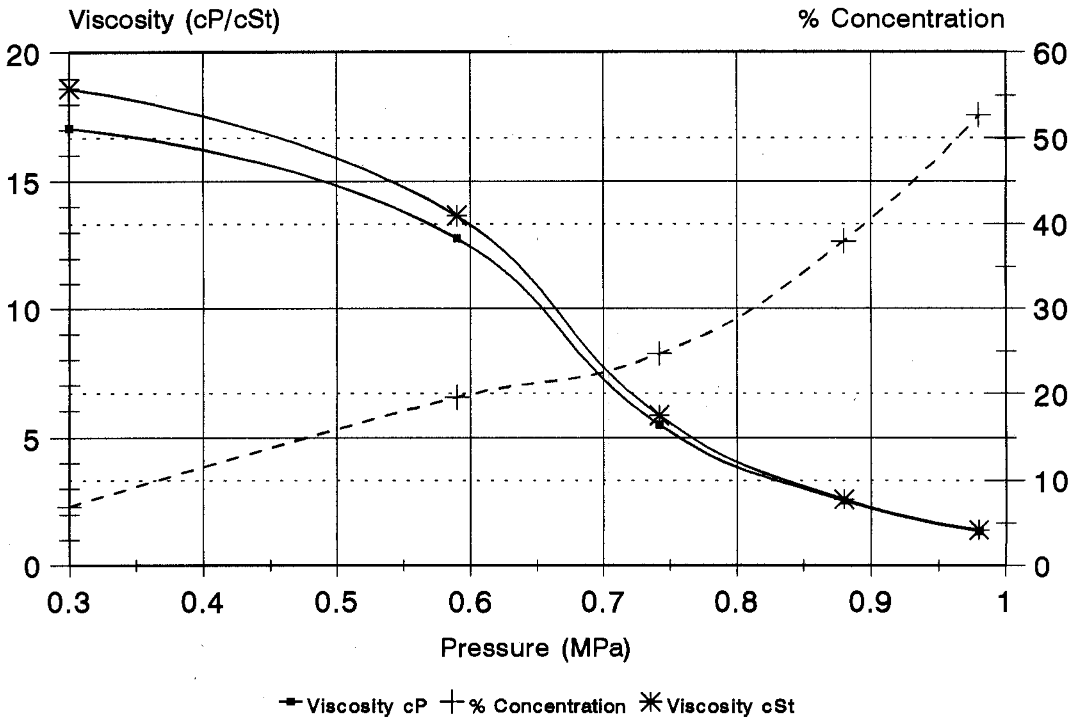


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Solubility

EMKARATE RL32S with HFC-134a at 40°C

Figure D.5

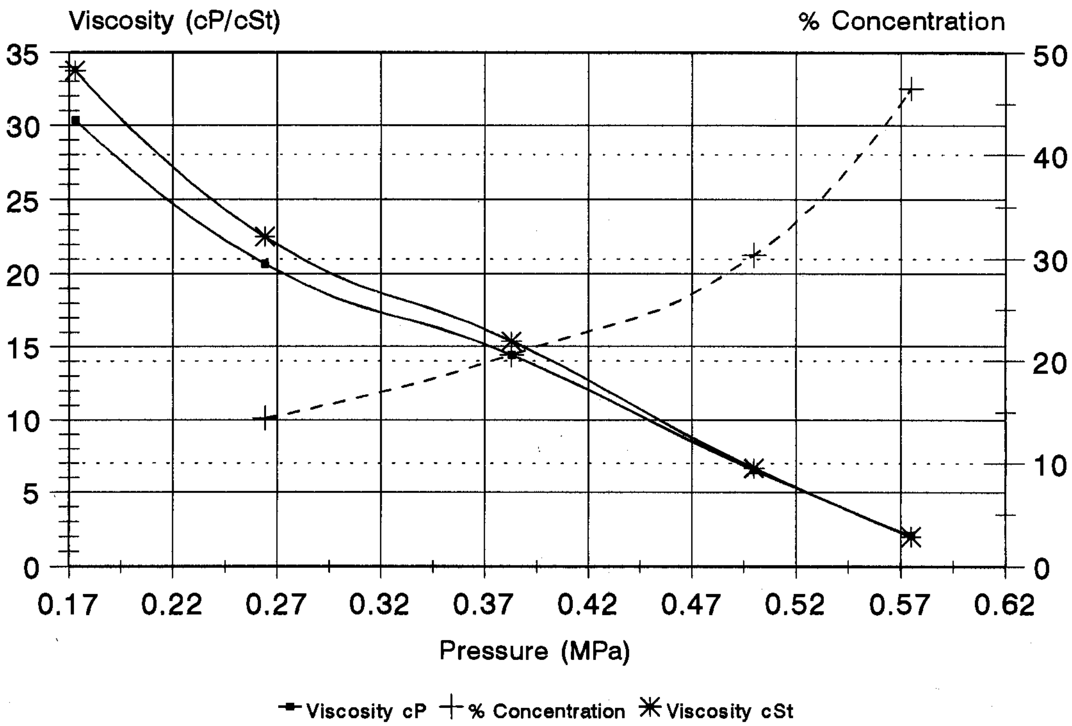


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-134a at 20°C

Figure D.6

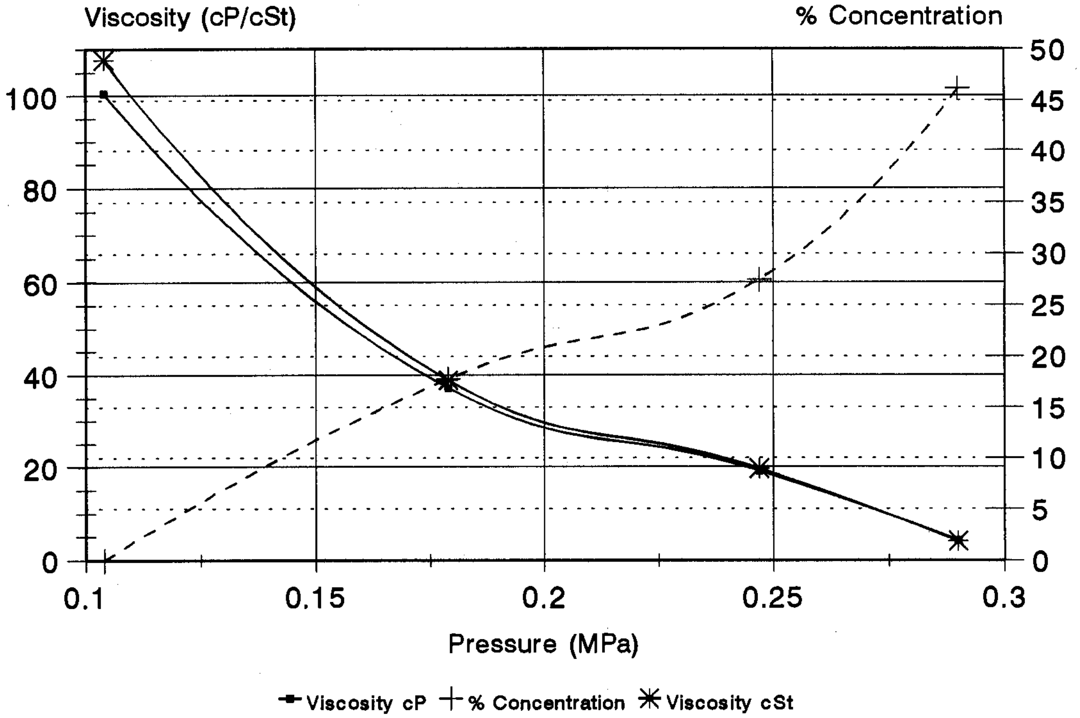


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-134a at 0°C

Figure D.7

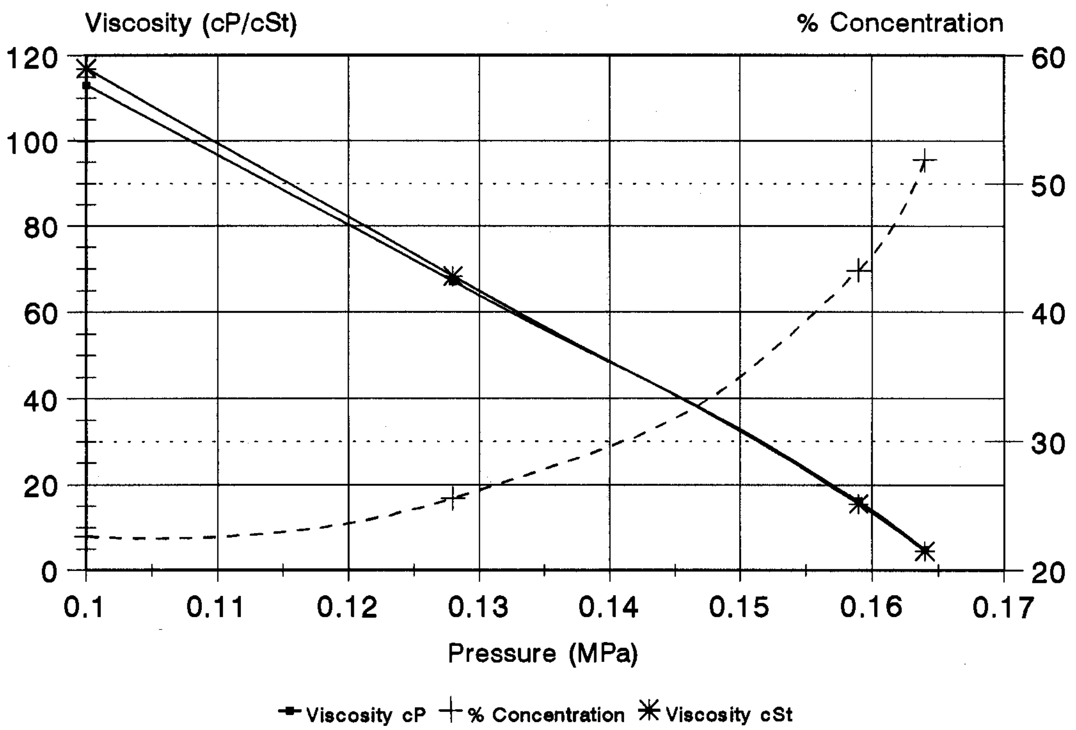


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

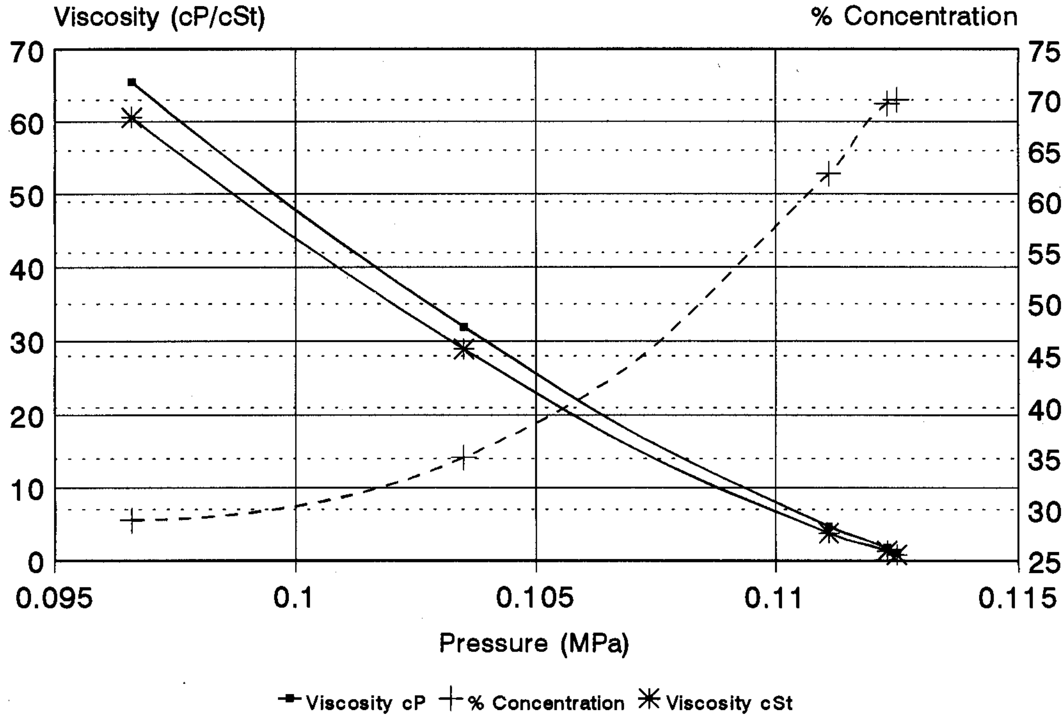
EMKARATE RL32S with HFC-134a at -15°C

Figure D.8



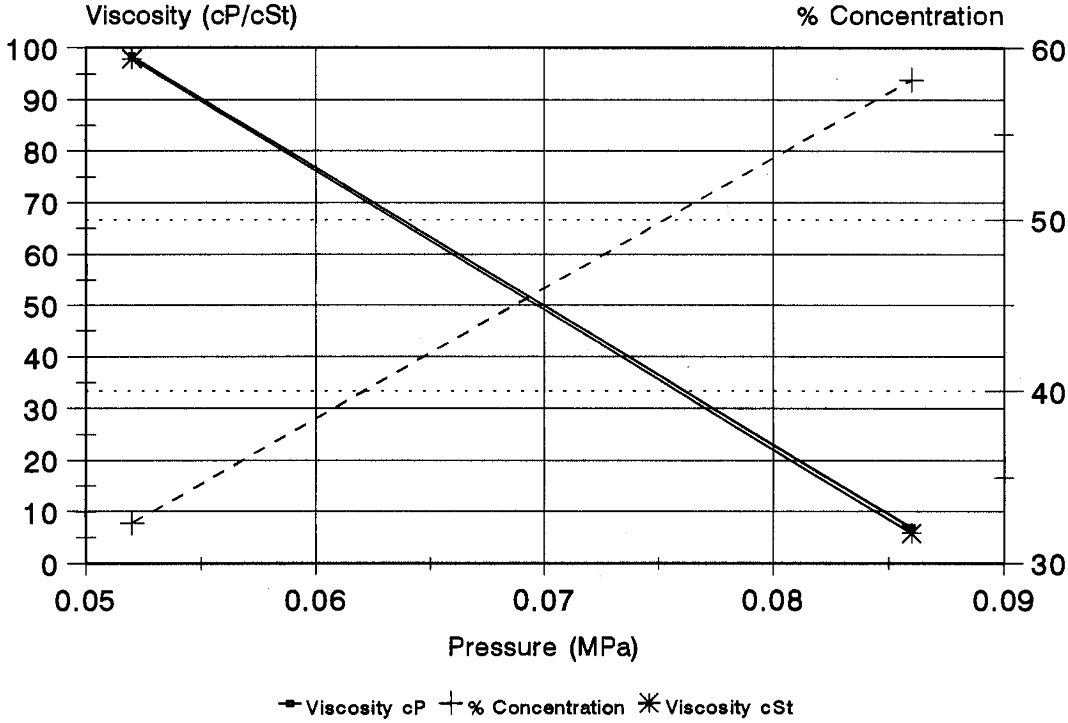
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-134a at -25°C
Figure D.9



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-134a at -30°C
Figure D.10



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
EMKARATE RL32S with HFC−134a
Table D.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.791	51.00	0.352	5.2	2.9	3.7
0.820	111.25	0.768	5.4	2.6	3.1
0.830	238.00	1.642	10.3	2.2	2.6
0.846	351.25	2.424	15.6	1.9	2.3
0.860	469.00	3.236	18.0	1.6	1.9

100°C (212°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.762	44.00	0.304	3.9	4.2	5.5
0.843	117.50	0.811	7.2	3.5	4.1
0.853	241.38	1.666	15.4	2.6	3.0
0.877	371.00	2.560	26.4	1.8	2.1
0.894	495.00	3.415	39.3	1.2	1.4

80°C (176°F) Temperature
382.6 psia Saturation Pressure
2.636 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.861	40.50	0.279	5.2	6.8	7.9
0.868	101.00	0.697	9.3	5.1	5.8
0.891	217.50	1.501	21.2	3.0	3.3
0.913	311.00	2.146	32.3	1.7	1.9
0.940	373.00	2.574	29.2	0.8	0.8

60°C (148°F) Temperature
245.2 psia Saturation Pressure
1.689 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.895	40.25	0.278	3.2	10.2	11.3
0.905	84.00	0.580	9.5	7.4	8.2
0.914	127.50	0.880	15.9	5.0	5.5
0.930	182.50	1.259	25.2	3.0	3.2
0.955	235.00	1.622	49.4	1.1	1.1

40°C (104°F) Temperature
146.5 psia Saturation Pressure
1.009 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.917	43.50	0.300	6.9	17.1	18.6
0.937	85.50	0.590	19.6	12.8	13.6
0.938	107.50	0.742	24.7	5.5	5.8
0.978	127.50	0.880	38.0	2.5	2.6
0.968	142.00	0.980	52.7	1.4	1.4

20°C (168°F) Temperature
83.38 psia Saturation Pressure
0.574 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.900	25.00	0.173	19.8	30.4	33.7
0.918	38.25	0.264	14.5	20.7	22.5
0.940	55.50	0.383	20.6	14.4	15.3
0.981	72.50	0.500	30.4	6.5	6.6
1.028	83.38	0.575	46.5	2.1	2.0

0°C (32°F) Temperature
41.98 psia Saturation Pressure
0.289 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.933	15.00	0.104	0.0	100.4	107.7
0.957	26.00	0.179	17.8	37.2	38.8
0.975	35.75	0.247	27.5	19.2	19.7
1.039	42.00	0.290	46.2	4.3	4.1

−15°C (5°F) Temperature
23.51 psia Saturation Pressure
0.162 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.967	14.50	0.100	22.6	113.1	117.0
0.983	18.50	0.128	25.6	67.1	68.3
1.040	23.00	0.159	43.2	16.2	15.6
1.080	23.70	0.164	51.9	4.8	4.5

−25°C (−13°F) Temperature
16.30 psia Saturetion Pressure
0.112 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.362	16.30	0.1125	70.0	1.1	0.8
1.310	16.28	0.1123	69.6	1.8	1.3
1.245	16.10	0.1111	62.7	4.7	3.8
1.103	15.00	0.1035	35.1	31.9	28.9
1.080	14.00	0.0966	29.0	65.5	60.6

−30°C (−22°F) Temperature
12.20 psia Saturation Pressure
0.084 MPa

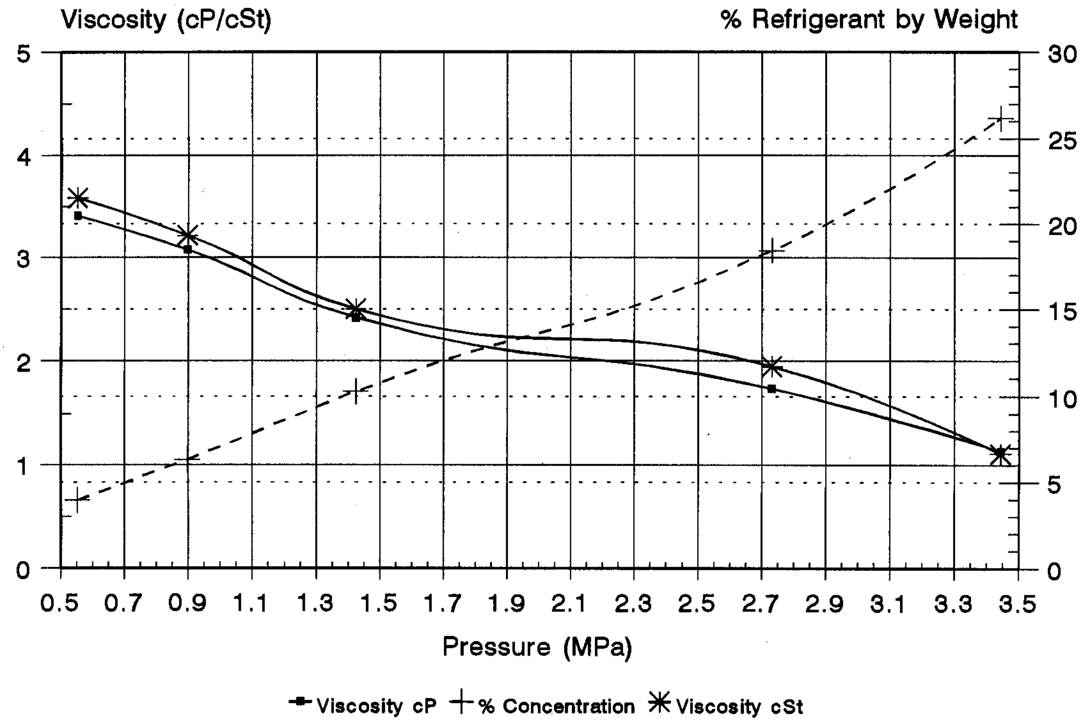
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.005	7.5	0.052	32.3	98.4	97.8
1.178	12.5	0.086	58.2	6.8	5.8

Neat Viscosity Check
Polyolester alone
40°C (104°F) and 14.7 psia (.1012 MPa)

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
0.945	14.7	0.101	0	29.79	31.51	Oscillating Bob
0.957	14.7	0.101	0	29.9	31.24	Cannon Viscometer

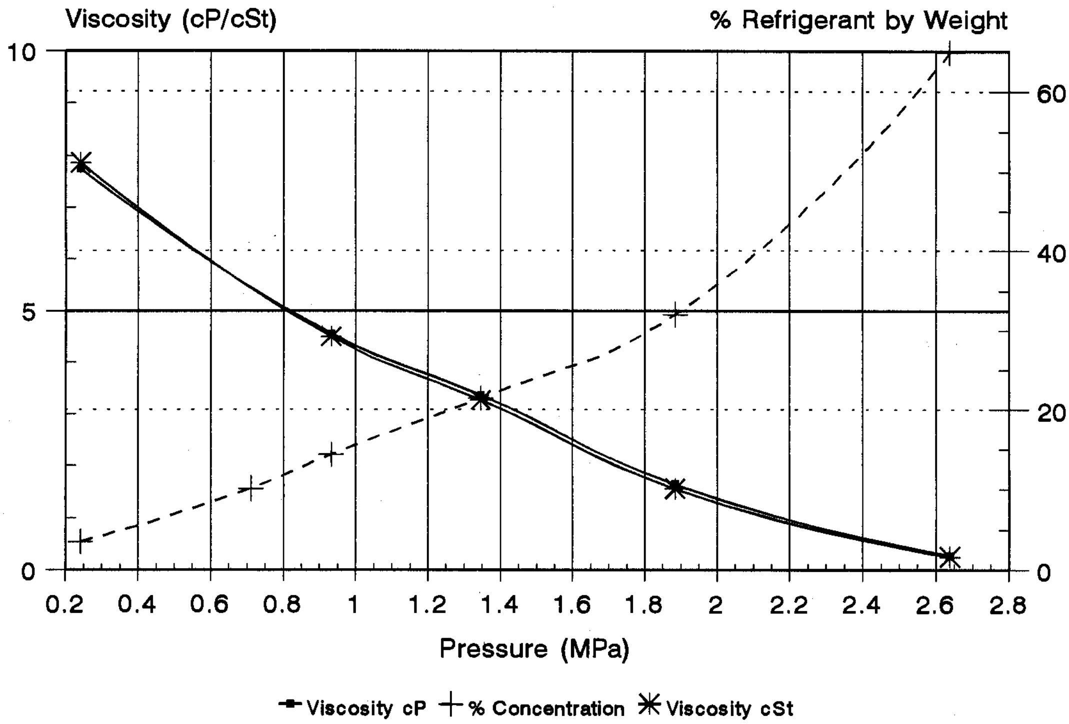
APPENDIX E
Viscosity, Density, and Gas Solubility of Emery 2968A at Various Temperatures with HFC-134a

Viscosity and Gas Solubility
EMERY 2968A with HFC-134a at 125°C
Figure E.1



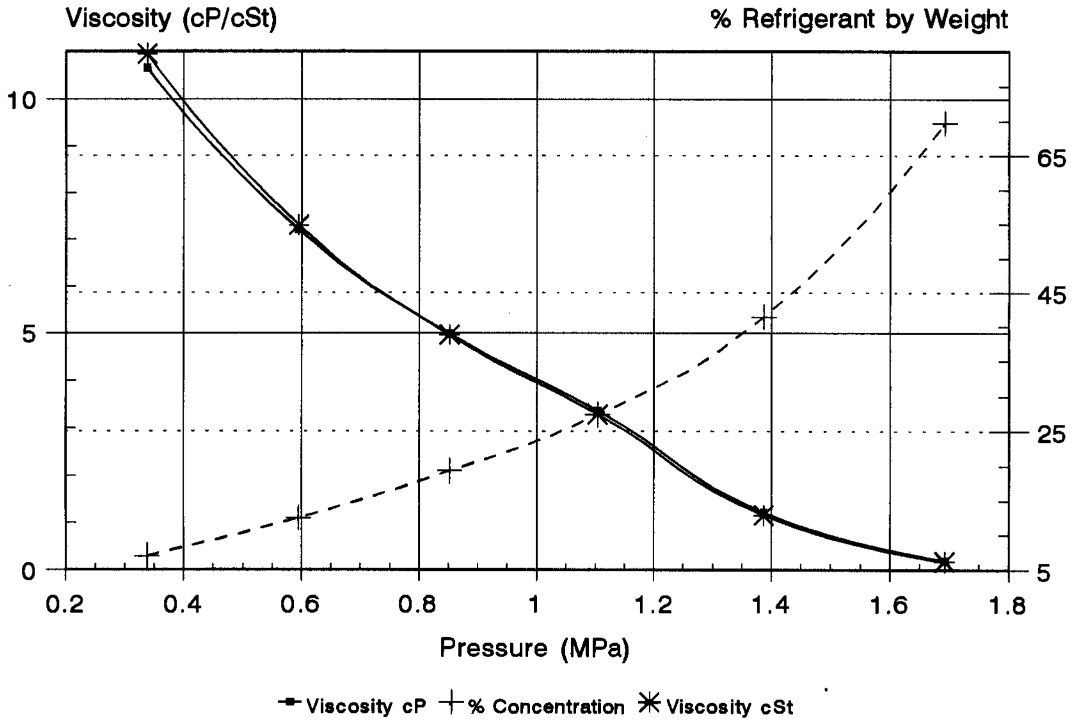
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-134a at 80°C
Figure E.2



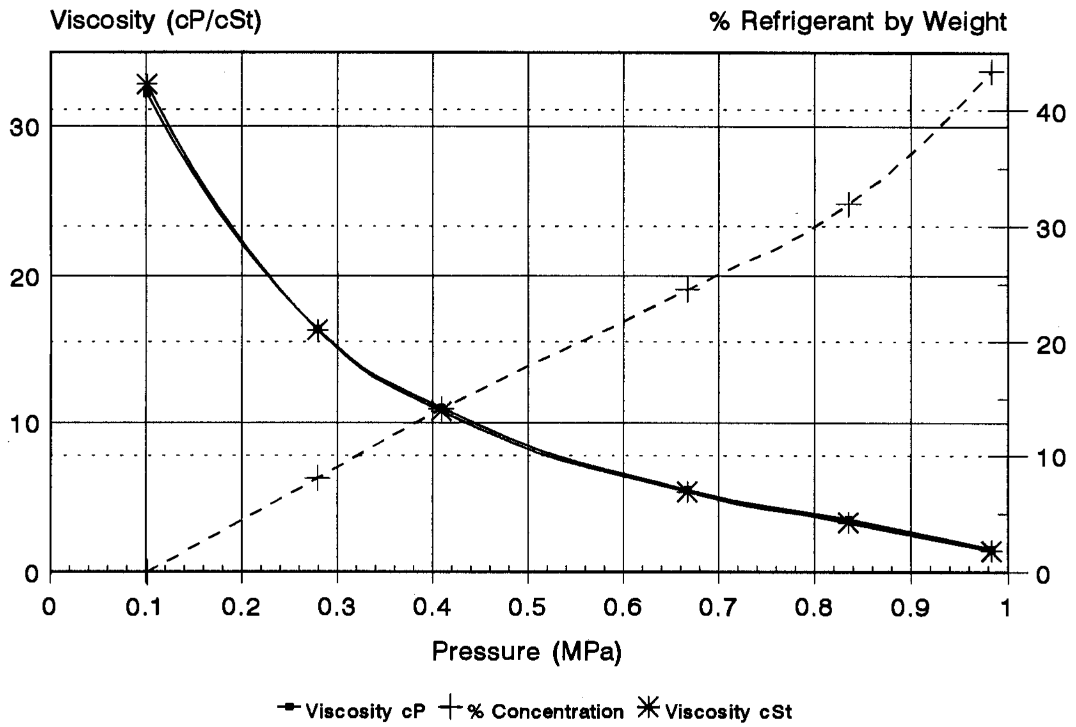
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-134a at 60°C
Figure E.3



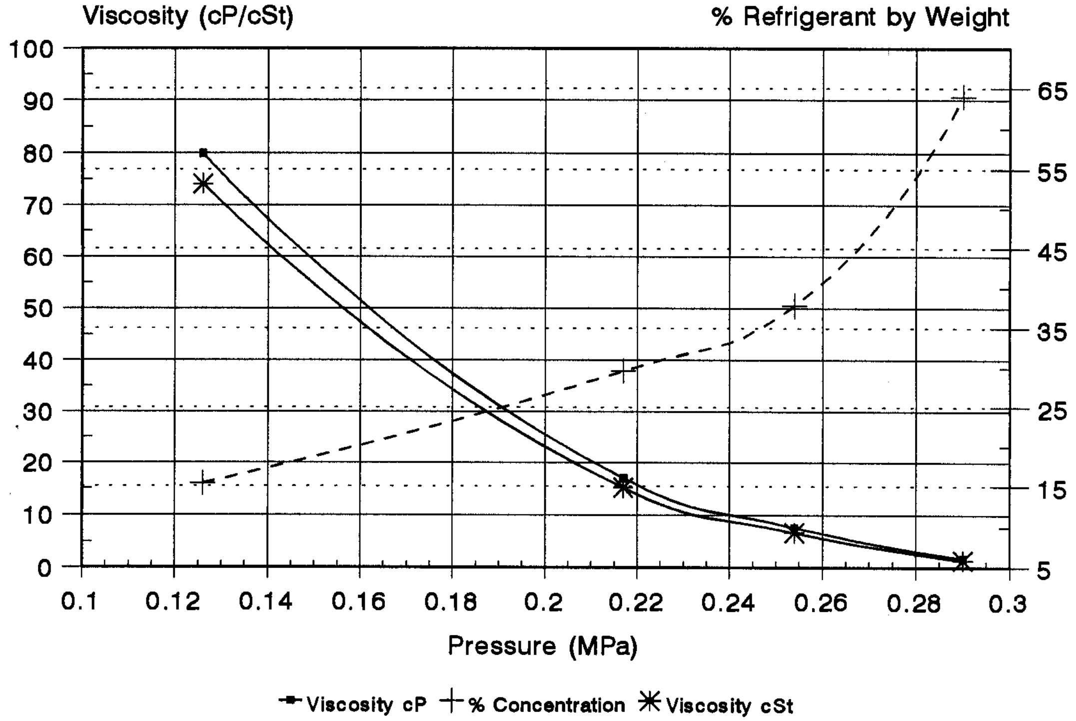
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-134a at 40°C
Figure E.4



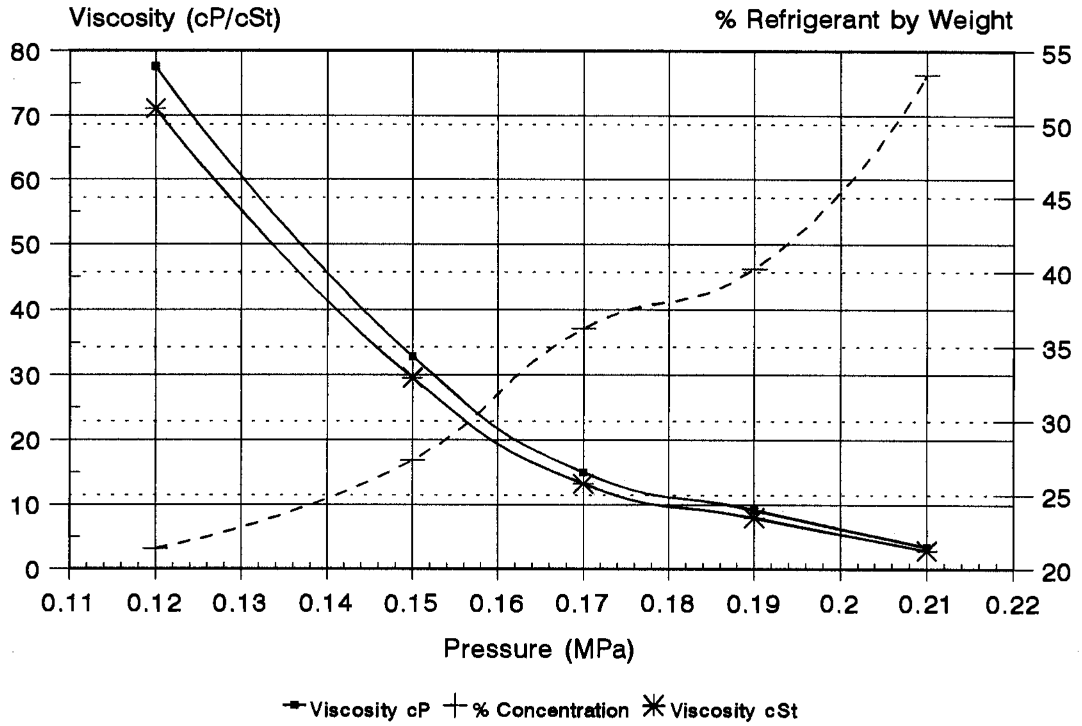
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-134a at 0°C
Figure E.5



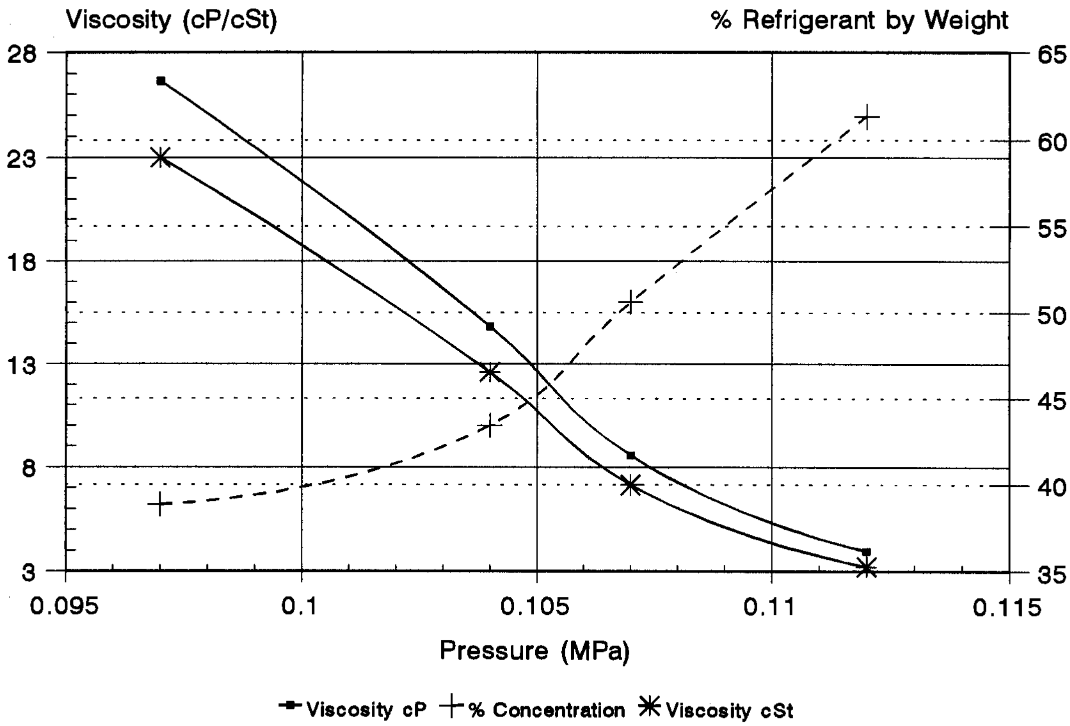
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-134a at -10°C
Figure E.6



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-134a at -25°C
Figure E.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
Emery 2968A with HFC−134a
Table E.1

125°C (257°F) Temperature
>500.0 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.022	499.25	3.44	26.2	1.1	1.1
1.003	396.50	2.74	18.4	1.7	1.7
0.967	206.50	1.42	10.3	2.4	2.5
0.956	130.00	0.90	6.3	3.1	3.2
0.951	80.00	0.55	4.0	3.4	3.6

80°C (176°F) Temperature
382 psia Saturation Pressure
2.63 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.985	35.00	0.24	3.6	7.8	7.9
1.009	103.00	0.71	10.1	5.1	5.1
1.013	135.00	0.93	14.4	4.6	4.5
1.029	195.00	1.35	21.5	3.4	3.3
1.054	272.50	1.88	32.1	1.6	1.6
1.086	382.00	2.64	64.8	0.3	0.3

60.0°C (140°F) Temperature
245.2 psia Saturation Pressure
1.689 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.973	49.00	0.34	7.0	10.7	11.0
0.986	86.75	0.60	12.5	7.2	7.3
1.004	123.50	0.85	19.3	5.0	5.0
1.025	160.50	1.11	27.4	3.4	3.3
1.050	201.25	1.39	41.5	1.2	1.2
1.088	245.2	1.69	69.8	0.2	0.2

40.0°C (104°F) Temperature
147.67 psia Saturation Pressure
1.016 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.000	40.50	0.28	8.0	16.4	16.4
1.013	59.25	0.41	14.1	10.9	10.7
1.035	96.50	0.67	24.5	5.3	5.1
1.058	120.78	0.83	31.9	3.3	3.1
1.066	142.50	0.98	43.4	1.5	1.4

0°C (32°F) Temperature
41.98 psia Saturation Pressure
0.289 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.079	18.25	0.13	15.4	79.8	74.0
1.122	31.50	0.22	26.3	16.9	15.1
1.145	36.75	0.25	37.9	7.6	6.6
1.206	41.98	0.29	64.0	1.7	1.4

−10.0°C (14°F) Temperature
29.78 psia Saturation Pressure
0.205 MPa

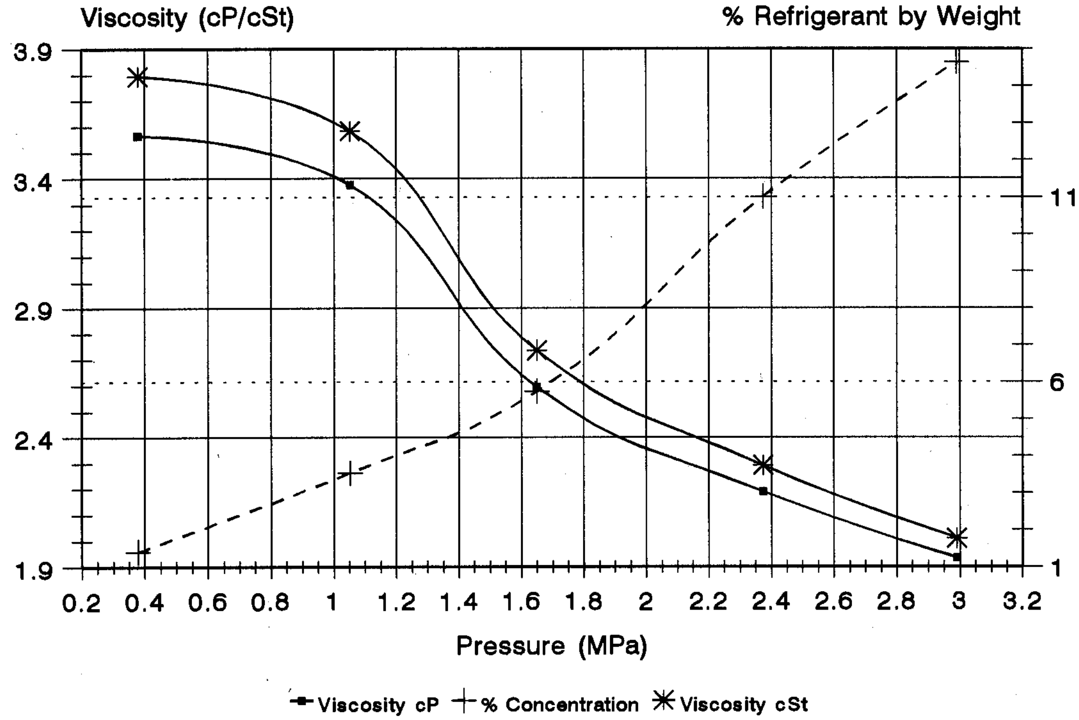
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.197	29.78	0.21	53.4	3.5	2.9
1.154	27	0.19	40.2	9.2	8.0
1.132	25	0.17	36.3	15.0	13.2
1.113	22	0.15	27.4	32.8	29.5
1.092	17	0.12	21.4	77.6	71.0

−25°C (−13°F) Temperature
16.3 psia Saturation Pressure
0.112 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.228	16.30	0.112	61.3	4.0	3.2
1.196	15.50	0.107	50.6	8.6	7.2
1.176	15	0.104	43.4	14.8	12.6
1.159	14	0.097	38.9	26.6	23.0

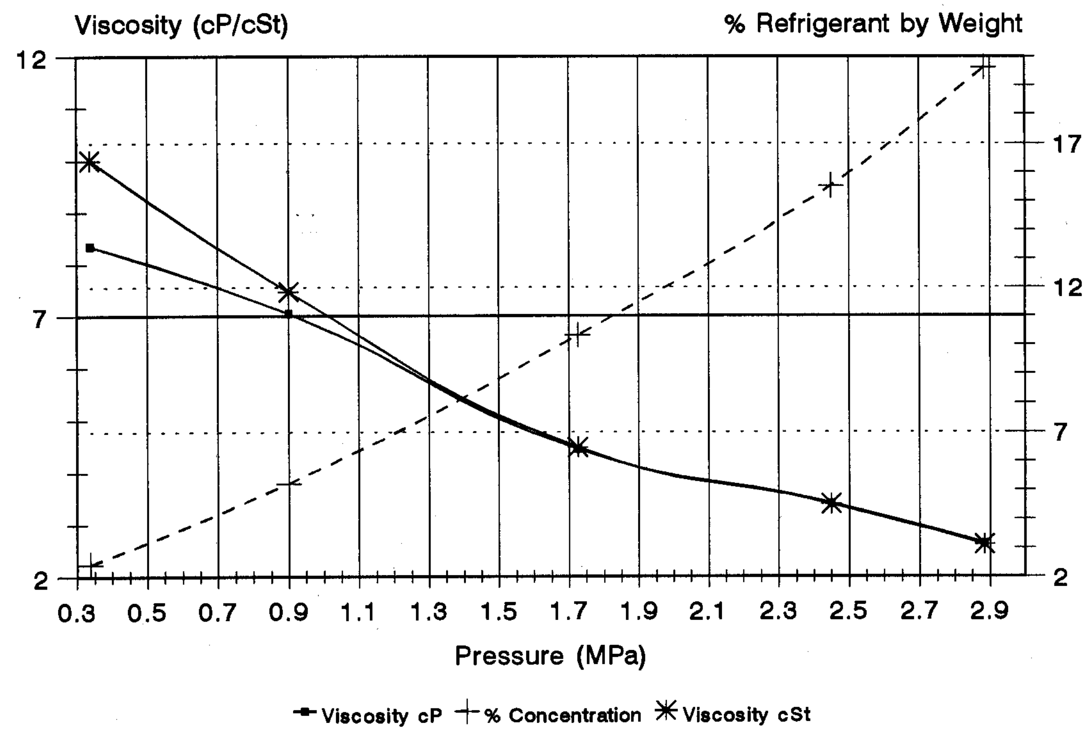
APPENDIX F
Viscosity, Density, and Gas Solubility
of Emery 2968A at Various Temperatures with HFC-143a

Viscosity and Gas Solubility
EMERY 2968A with HFC-143a at 125°C
Figure F.1



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-143a at 80°C
Figure F.2

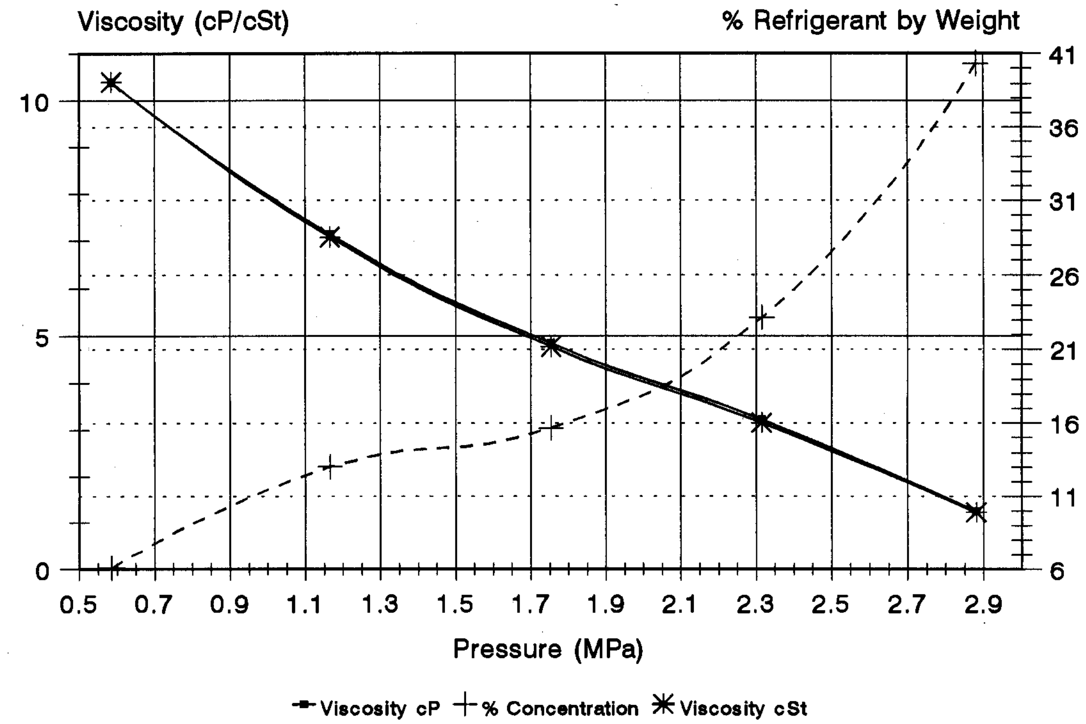


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMERY 2968A with HFC-143a at 60°C

Figure F.3

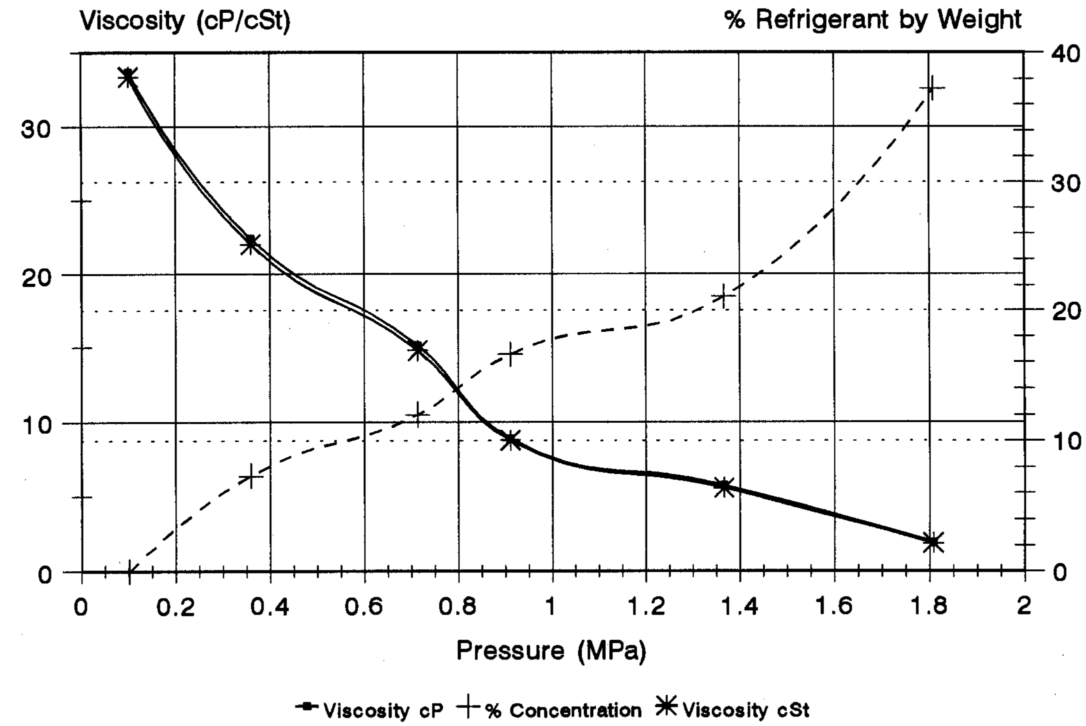


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

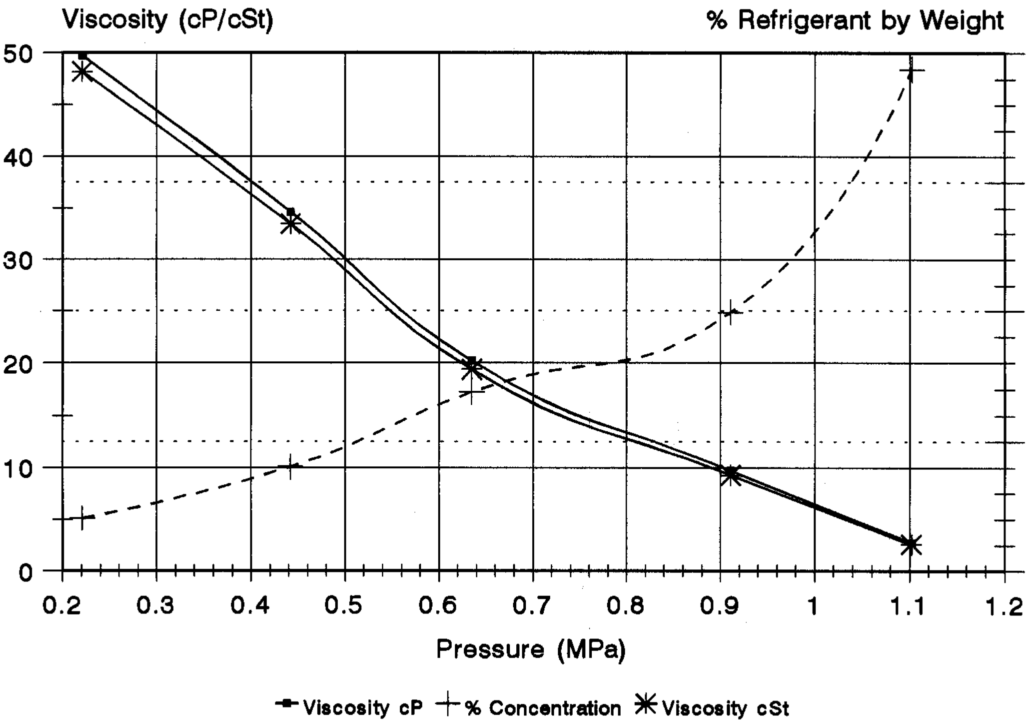
EMERY 2968A with HFC-143a at 40°C

Figure F.4



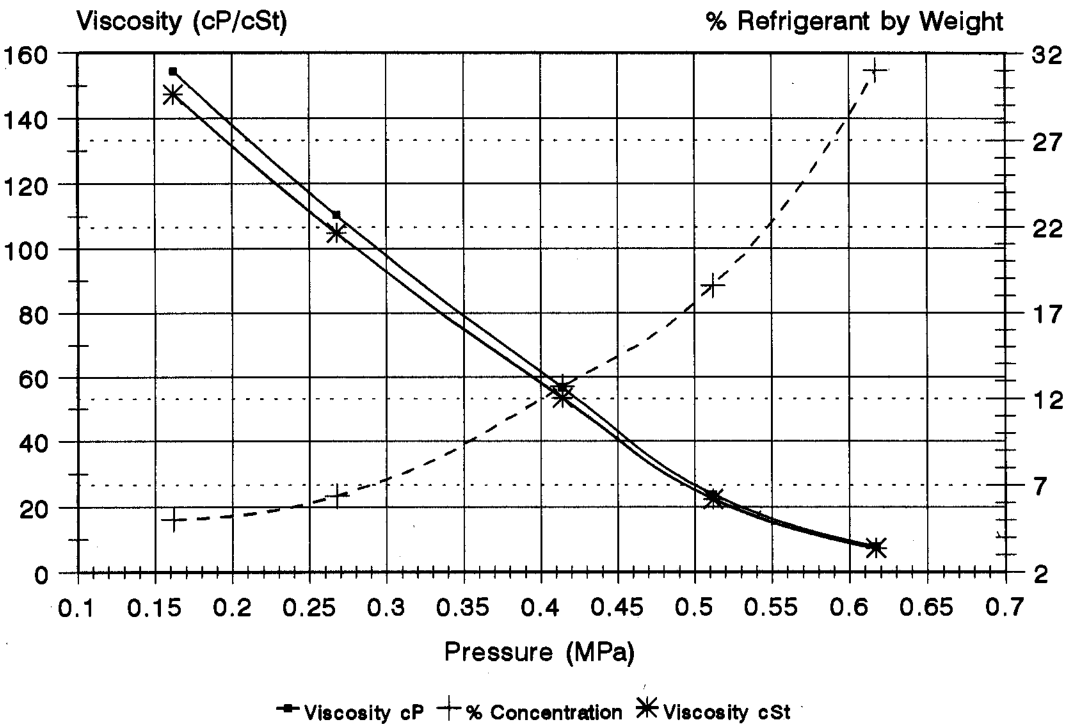
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-143a at 20°C
Figure F.5



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-143a at 0°C
Figure F.6

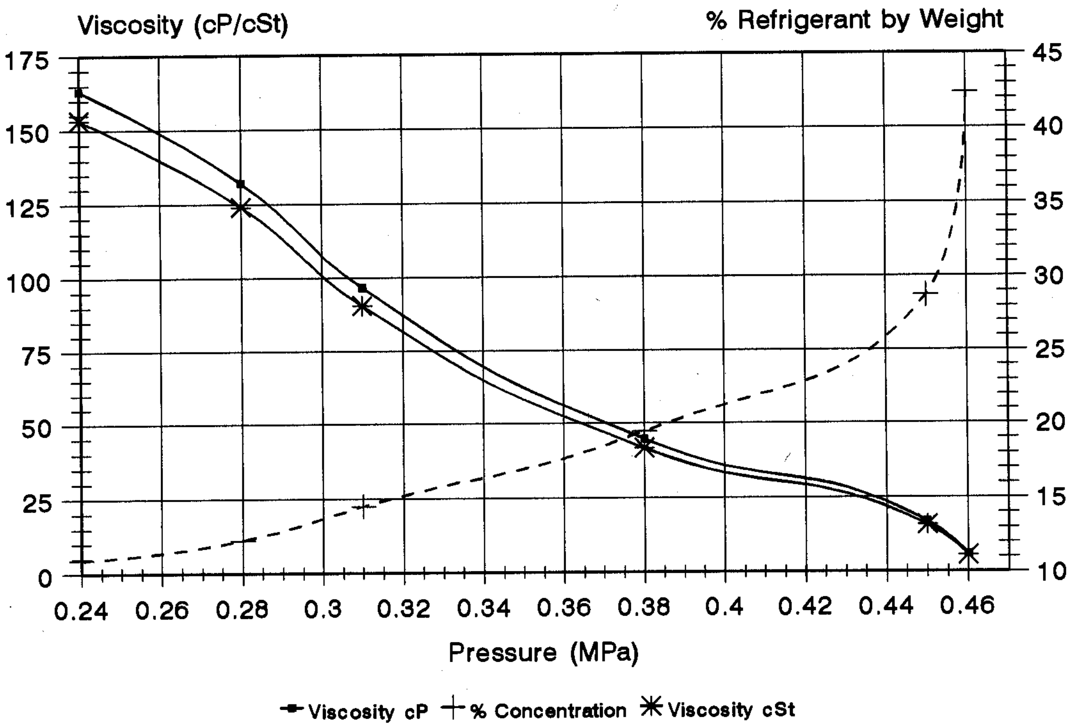


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMERY 2968A with HFC-143a at -10°C

Figure F.7

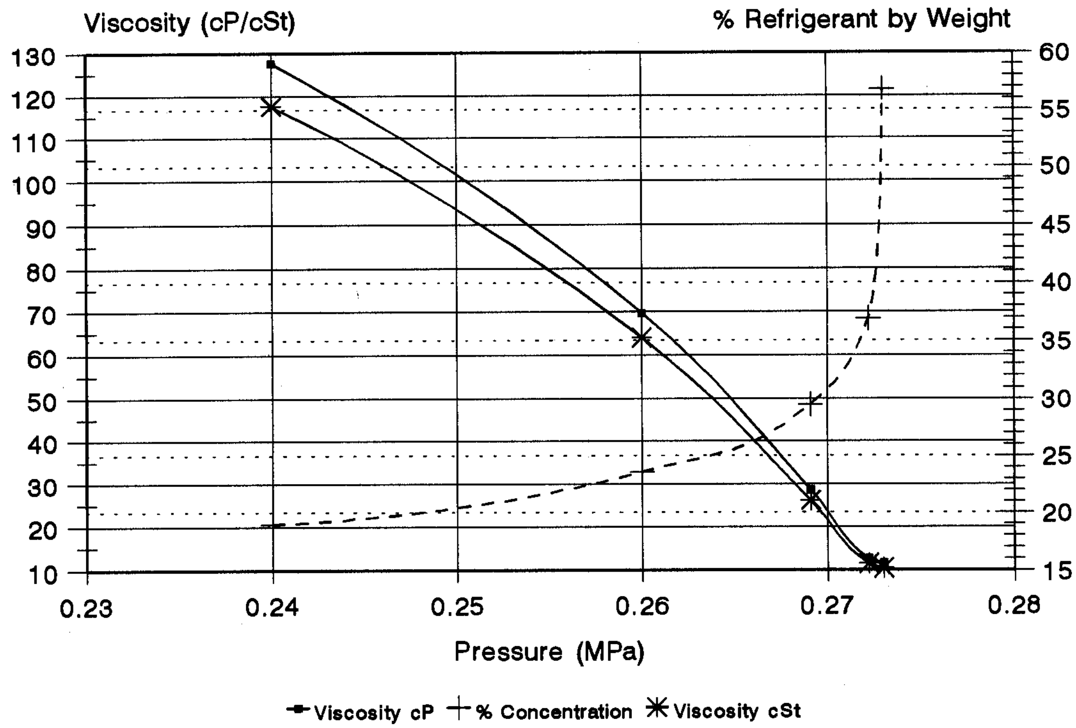


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMERY 2968A with HFC-143a at -25°C

Figure F.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
Emery 2968A with HFC−143a
Table F.1

125°C (257°F) Temperature
>500.0 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.939	55.00	0.38	1.4	3.6	3.8
0.942	152.50	1.05	3.5	3.4	3.6
0.948	239.00	1.65	5.7	2.6	2.7
0.956	344.00	2.37	11.0	2.2	2.3
0.963	433.50	2.99	14.6	1.9	2.0

80°C (176°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.992	250.00	1.72	10.3	4.4	4.5
1.004	355.00	2.45	15.5	3.4	3.4
1.008	418.00	2.88	19.6	2.6	2.6
0.944	130.50	0.90	5.2	7.0	7.5
0.835	49.00	0.34	2.4	8.4	10.0

60°C (140°F) Temperature
417.37 psia Saturation Pressure
2.875 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.014	254.25	1.75	15.7	4.8	4.8
1.022	335.50	2.31	23.2	3.2	3.1
1.022	417.37	2.88	40.3	1.3	1.2
1.008	169.00	1.17	13.0	7.1	7.1
1.000	85.00	0.59	6.1	10.4	10.4

40°C (104°F) Temperature
266.69 psia Saturation Pressure
1.837 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.010	14.70	0.10	0.0	33.7	33.4
1.017	52.00	0.36	7.3	22.4	22.0
1.023	103.50	0.71	12.0	15.1	14.8
1.029	162.00	1.12	16.6	8.9	8.6
1.033	198.00	1.37	21.1	5.8	5.6
1.033	262.00	1.81	37.2	1.9	1.9

20°C (68°F) Temperature
160.30 psia Saturation Pressure
1.104 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.054	160.00	1.10	38.8	2.7	2.6
1.048	132.00	0.91	19.9	9.7	9.3
1.042	92.00	0.63	13.8	20.2	19.4
1.035	64.00	0.44	8.1	34.6	33.4
1.032	32.00	0.22	4.1	49.7	48.2

0°C (32°F) Temperature
89.43 psia Saturation Pressure
.6162 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.047	23.50	0.16	5.0	154.3	147.3
1.053	38.75	0.27	6.4	110.3	104.8
1.061	60.00	0.41	12.7	56.7	53.4
1.064	74.25	0.51	18.6	23.7	22.3
1.072	89.43	0.62	31.0	7.8	7.3

−10°C (14°F) Temperature
66.98 psia Saturation Pressure
.4615 MPa

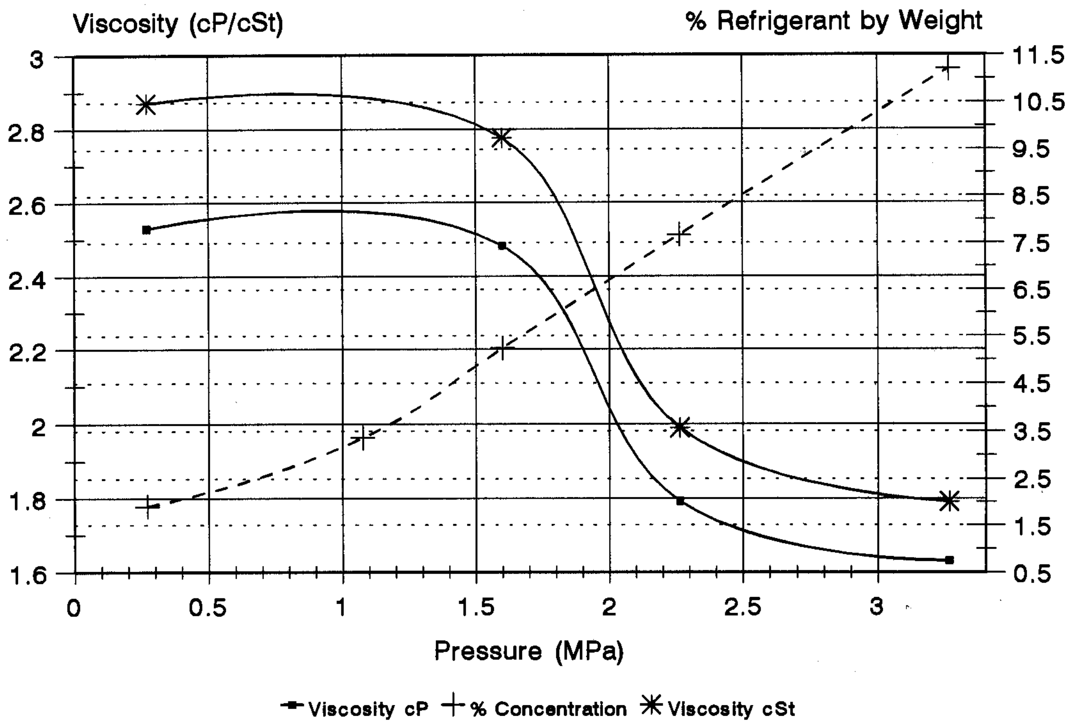
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.086	66.98	0.46	42.3	5.9	5.4
1.079	65.00	0.45	28.7	16.9	15.7
1.073	55.00	0.38	19.5	44.6	41.6
1.069	45.00	0.31	14.5	96.7	90.5
1.065	40.00	0.28	12.2	132.1	124.0
1.064	35.00	0.24	10.9	163.0	153.2

−25°C (−13°F) Temperature
39.57 psia Saturation Pressure
.2726 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.109	39.57	0.2730	56.8	11.6	10.5
1.098	39.55	0.2729	36.9	12.7	11.5
1.096	39.00	0.2691	29.5	28.6	26.1
1.088	37.50	0.26	23.6	69.6	64.0
1.086	35.00	0.24	19.0	127.6	117.5

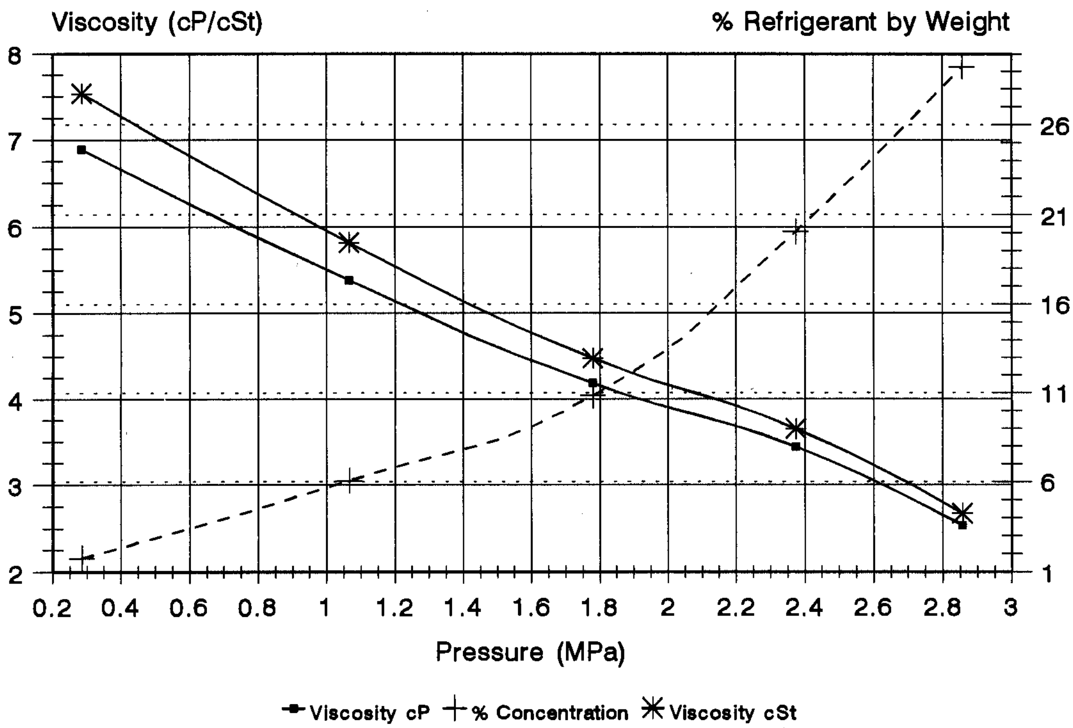
APPENDIX G
Viscosity, Density, and Gas Solubility
of EMKARATE RL32S at Various Temperatures with HFC-143a

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-143a at 125°C
Figure G.1



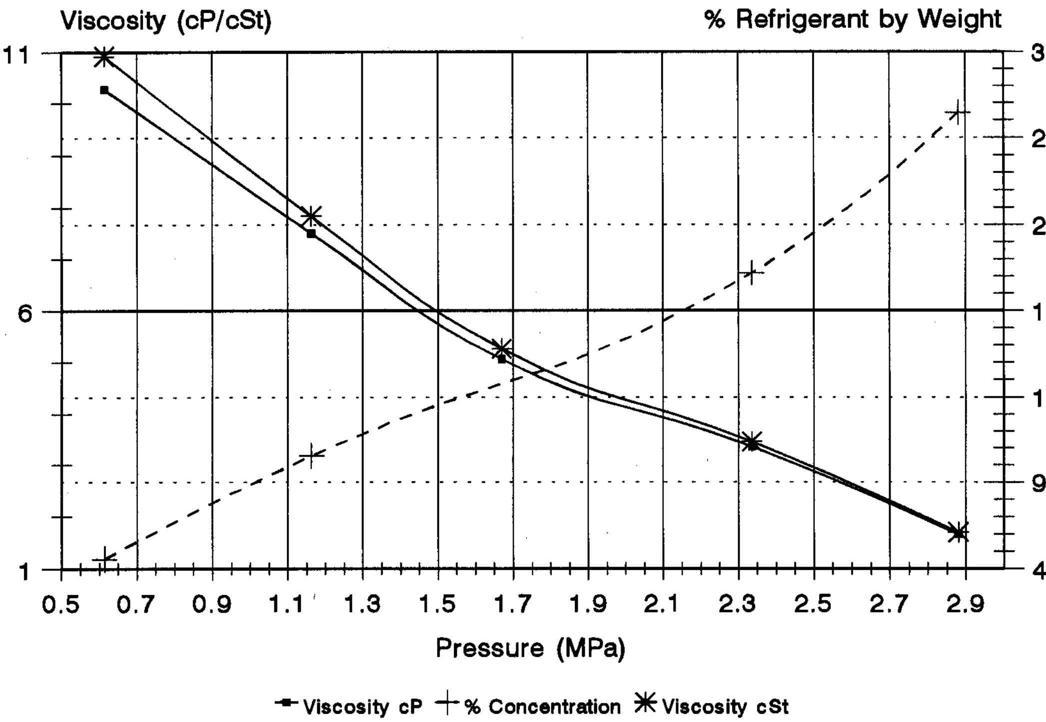
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-143a at 80°C
Figure G.2



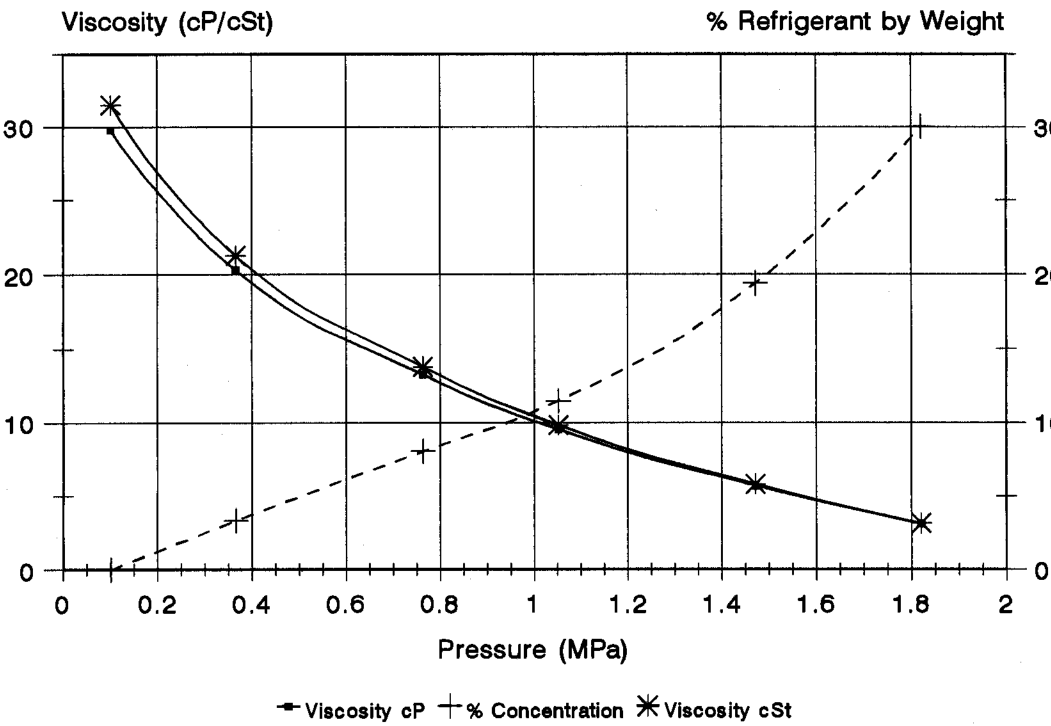
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-143a at 60°C
Figure G.3



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-143a at 40°C
Figure G.4

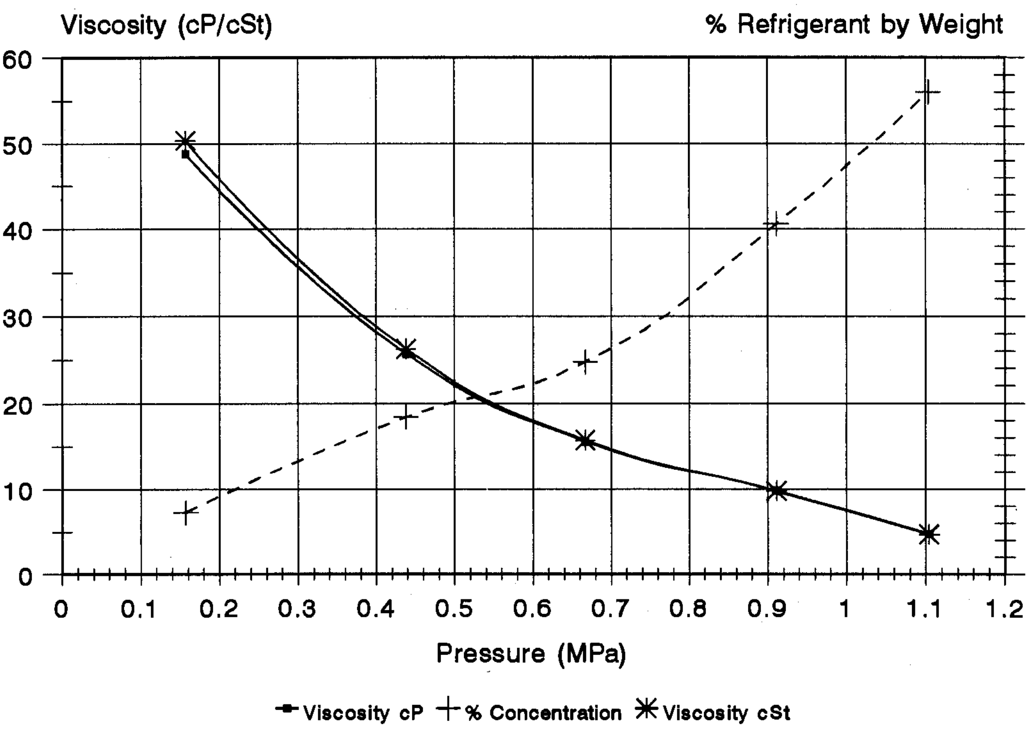


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-143a at 20°C

Figure G.5

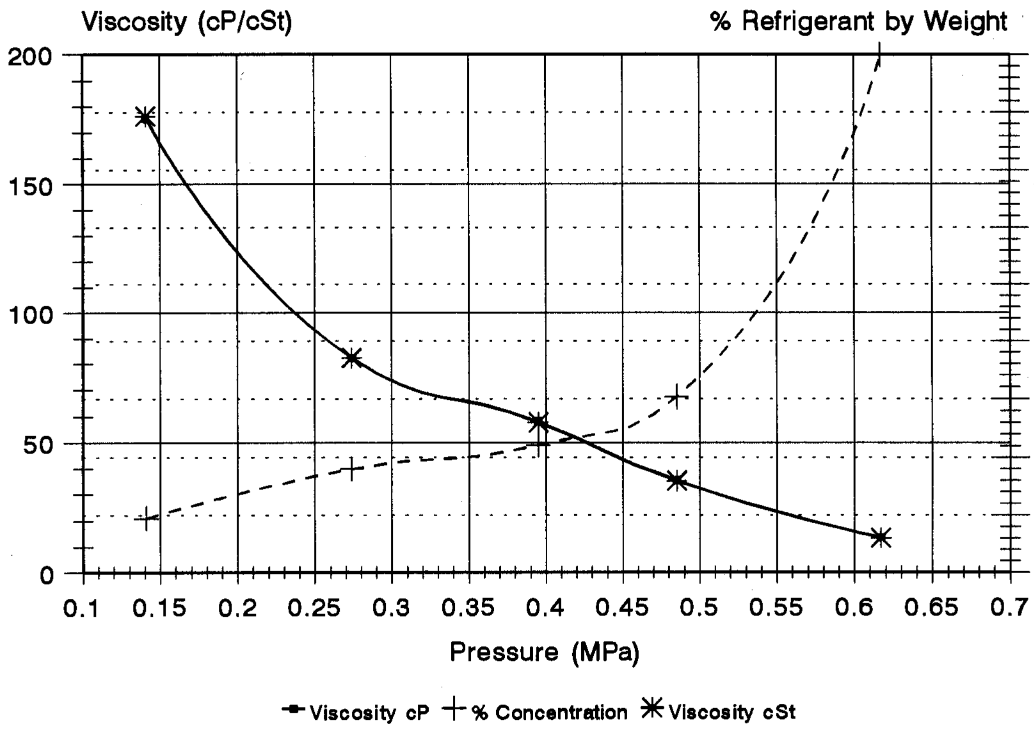


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-143a at 0°C

Figure G.6

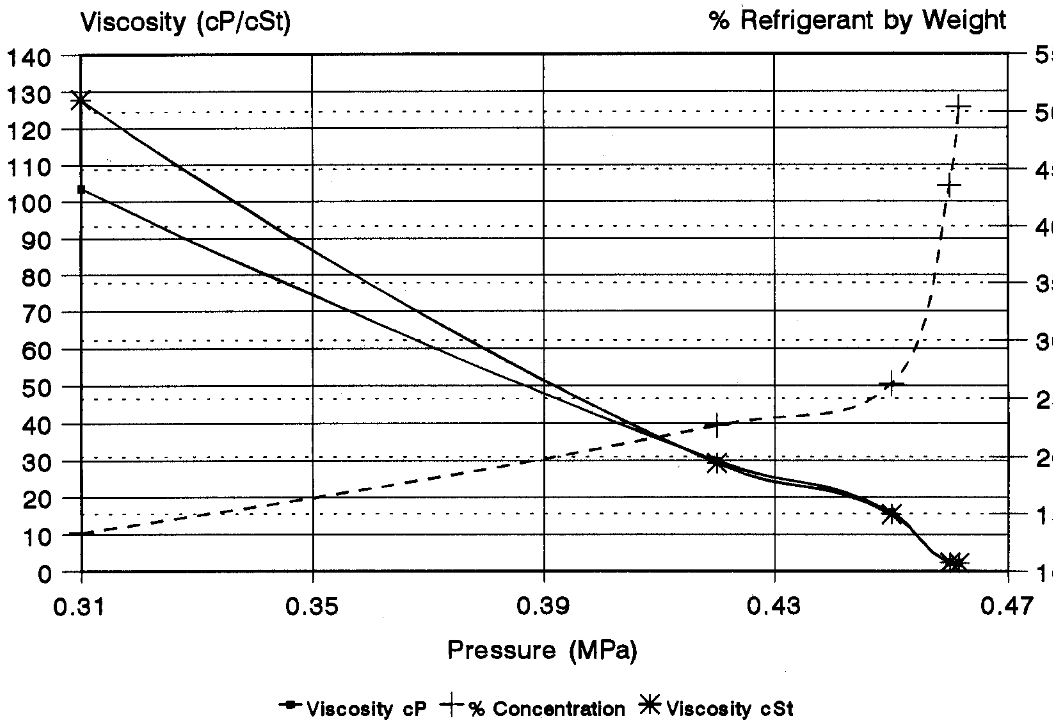


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-143a at -10°C

Figure G.7

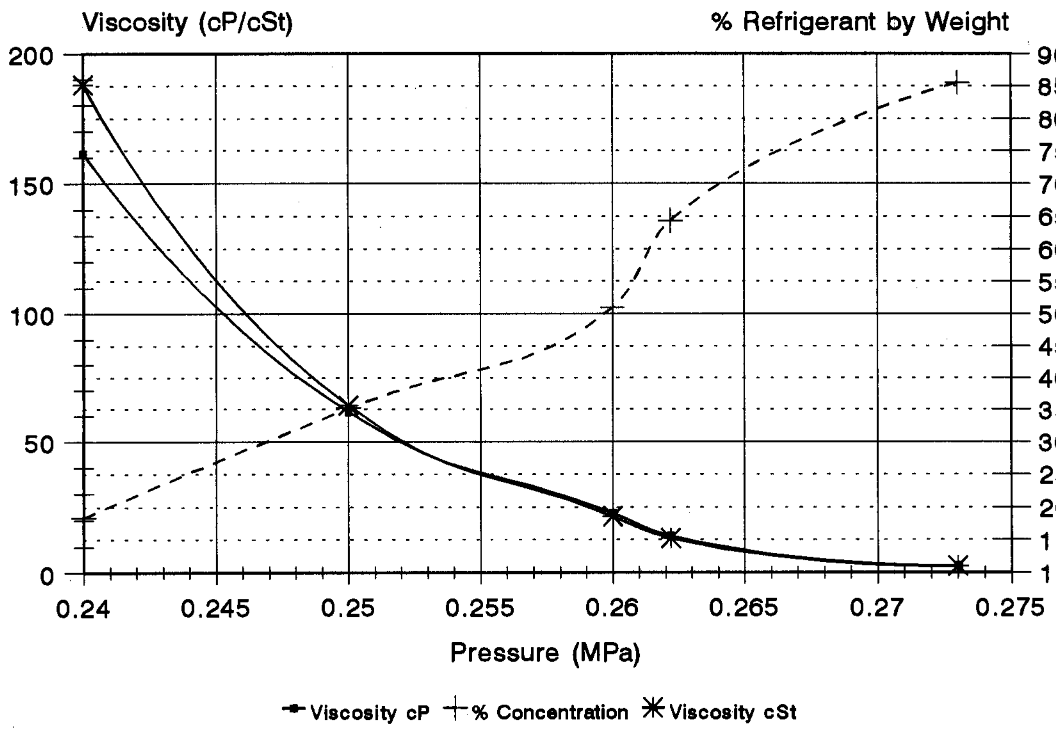


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-143a at -25°C

Figure G.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
EMKARATE RL32S with HFC−143a
Table G.1

125°C (257°F) Temperature
>500.0 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.910	473.00	3.26	11.2	1.6	1.8
0.901	328.00	2.26	7.7	1.8	2.0
0.894	231.75	1.60	5.2	2.5	2.8
0.889	156.00	1.08	3.4	2.6	2.9
0.881	39.25	0.27	1.9	2.5	2.9

20°C (68°F) Temperature
160.30 psia Saturation Pressure
1.104 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.969	22.75	0.16	3.6	48.8	50.3
0.979	63.50	0.44	9.2	25.7	26.3
1.003	132.00	0.91	20.3	9.8	9.8
1.011	160.00	1.10	28.0	4.7	4.7
0.989	96.50	0.67	12.4	15.5	15.7

80°C (176°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.915	41.25	0.28	1.8	6.9	7.5
0.925	154.50	1.07	6.1	5.4	5.8
0.934	258.00	1.78	10.9	4.2	4.5
0.942	344.00	2.37	20.1	3.4	3.7
0.948	414.00	2.86	29.3	2.5	2.7

0°C (32°F) Temperature
89.43 psia Saturation Pressure
.6161 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.015	89.43	0.62	45.0	13.6	13.4
1.010	70.75	0.49	15.1	35.5	35.2
1.006	57.25	0.40	11.1	58.0	57.7
1.001	39.75	0.27	9.0	82.3	82.2
0.996	20.50	0.14	4.7	175.5	176.3

60°C (140°F) Temperature
417.37 psia Saturation Pressure
2.875 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.981	417.37	2.88	30.4	1.7	1.7
0.972	338.50	2.34	21.2	3.4	3.4
0.961	242.50	1.67	17.0	5.1	5.3
0.957	168.50	1.16	10.5	7.5	7.8
0.941	89.00	0.61	4.6	10.3	10.9

−10°C (14°F) Temperature
66.9 psia Saturation Pressure
.4609 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.810	45.00	0.311	13.4	103.5	127.8
1.019	60.50	0.417	22.7	29.8	29.2
1.030	65.00	0.449	26.3	15.8	15.3
1.037	66.75	0.461	43.6	2.5	2.4
1.040	66.90	0.462	50.4	2.4	2.3

40°C (104°F) Temperature
266.69 psia Saturation Pressure
1.837 MPa

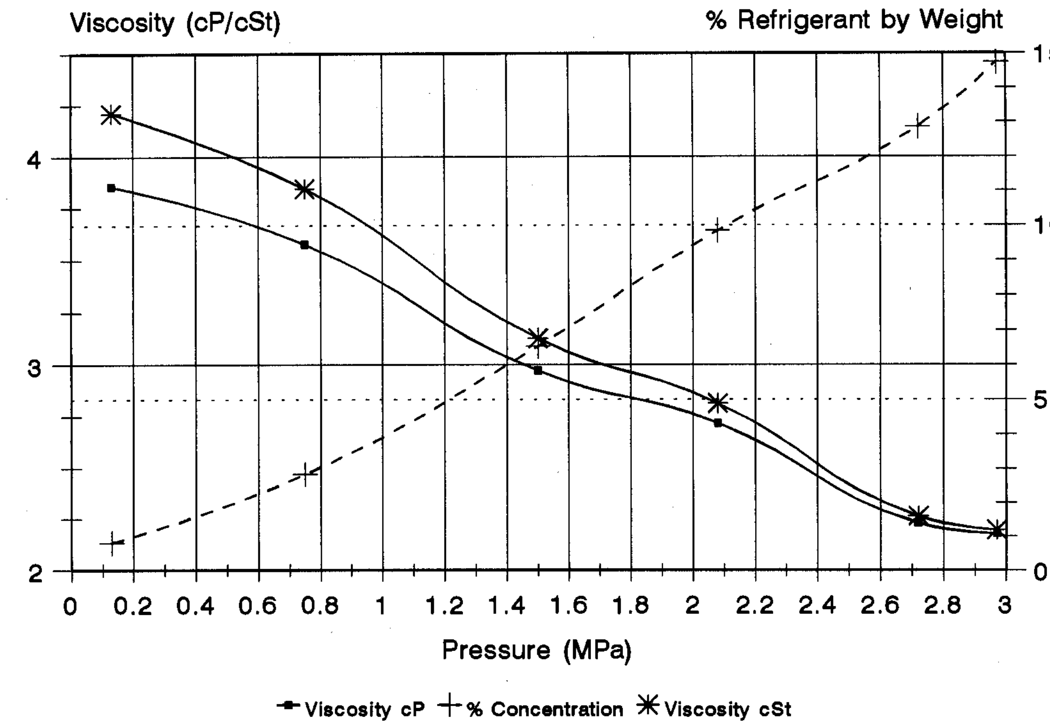
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.945	14.70	0.10	0.0	29.8	31.5
0.954	53.00	0.37	3.3	20.3	21.3
0.961	110.75	0.76	8.1	13.3	13.8
0.969	152.50	1.05	11.5	9.5	9.8
0.982	213.25	1.47	19.4	5.7	5.8

−25°C (−13°F) Temperature
39.57 psia Saturation Pressure
.2726 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.859	35	0.242	18.4	161.4	187.9
0.961	36	0.248	35.2	61.5	64.0
1.061	37	0.255	51.0	22.7	21.4
1.07	38	0.262	64.3	14.0	13.1
1.073	39.57	0.273	85.5	2.6	2.5

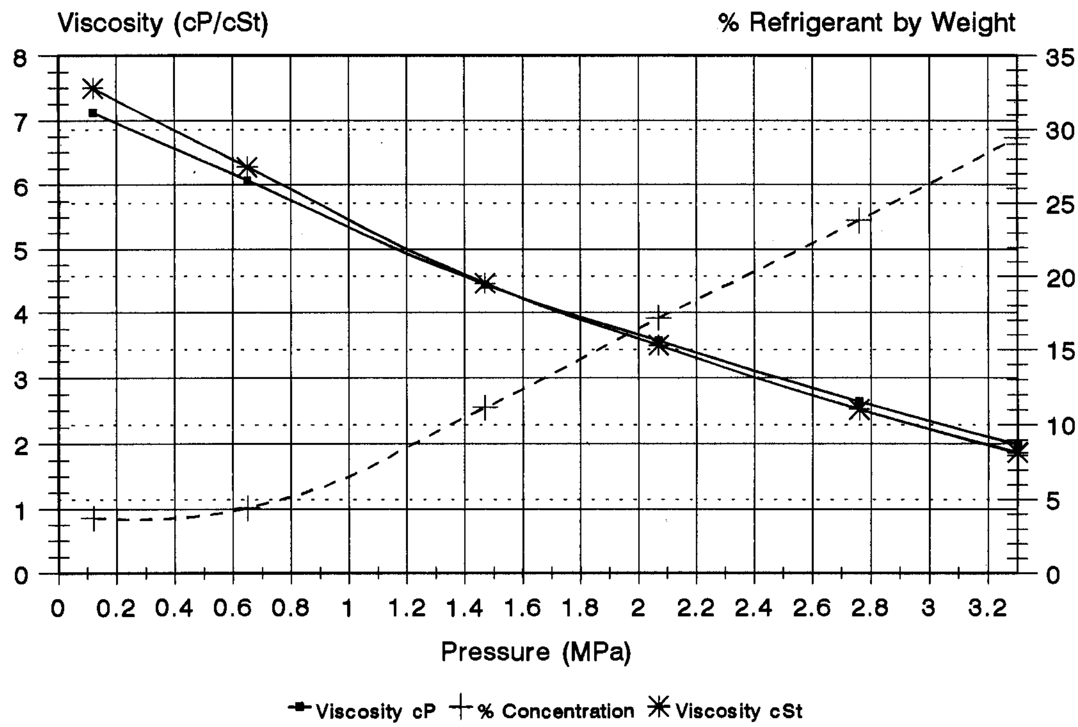
APPENDIX H
Viscosity, Density, and Gas Solubility of Emery 2968A at Various Temperatures with HFC-125

Viscosity and Gas Solubility
EMERY 2968A with HFC-125 at 125°C
Figure H.1



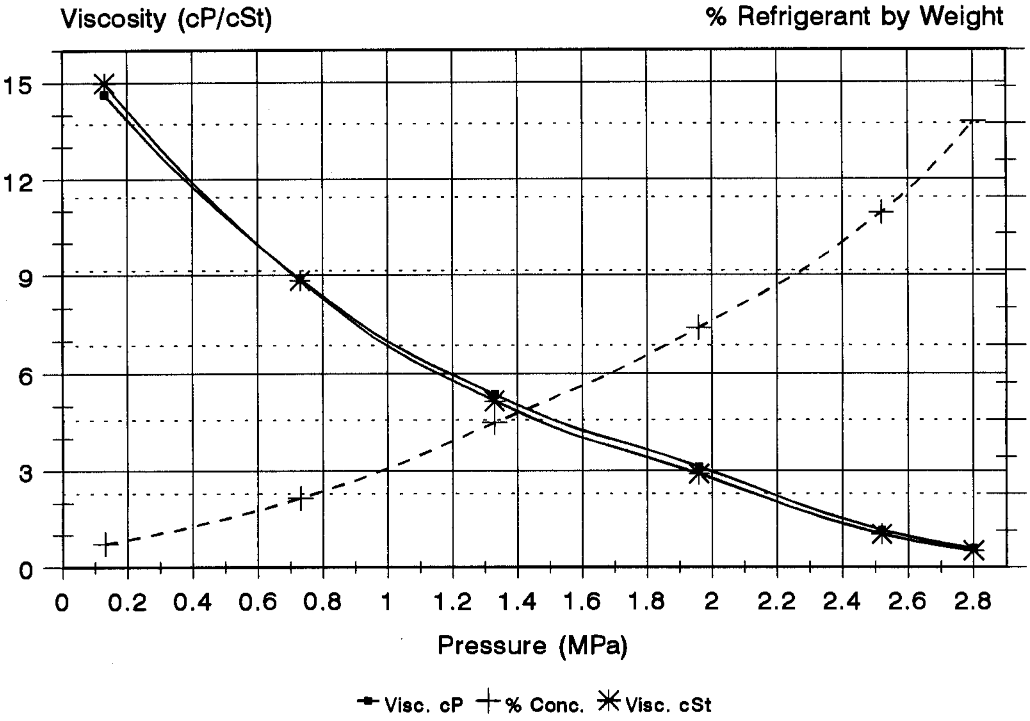
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-125 at 90°C
Figure H.2



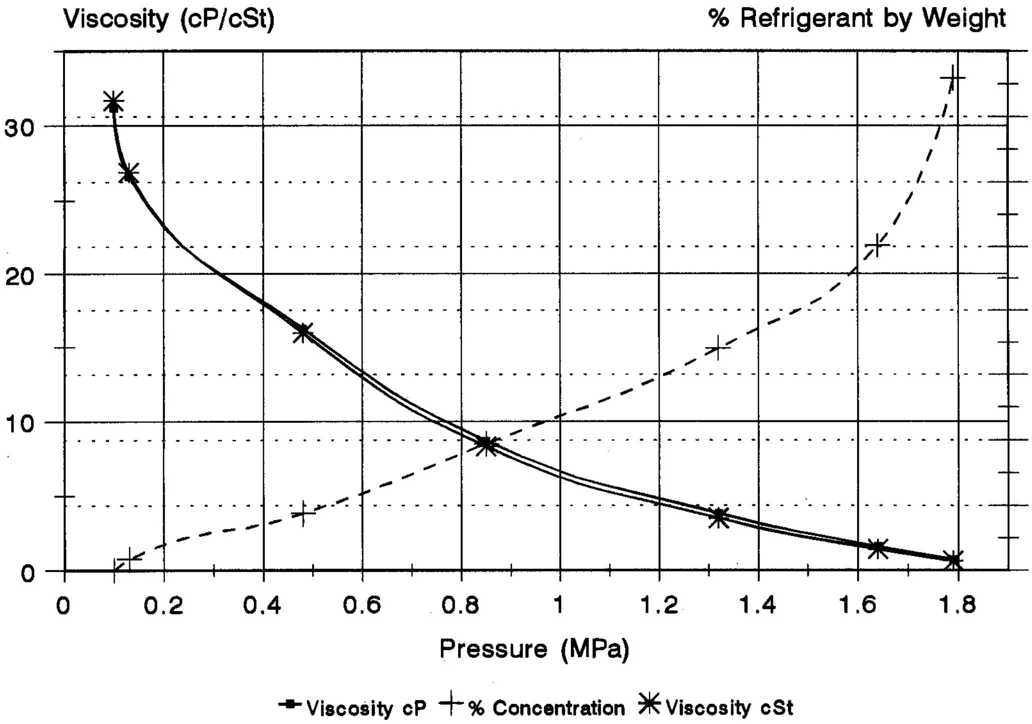
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-125 at 60°C
Figure H.3



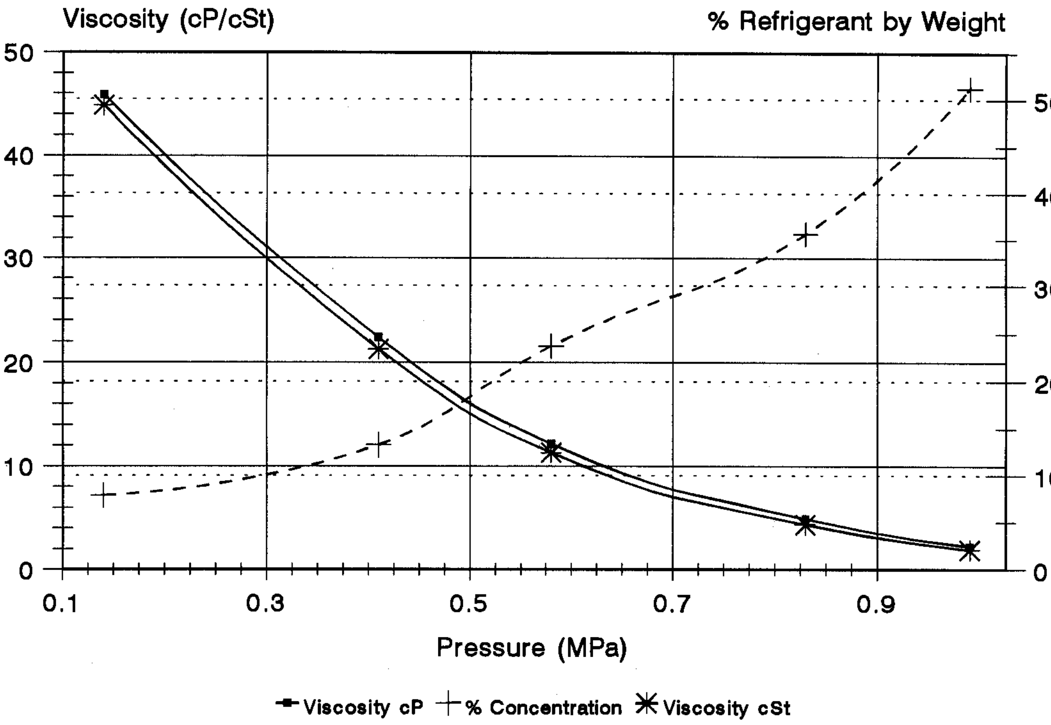
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-125 at 40°C
Figure H.4



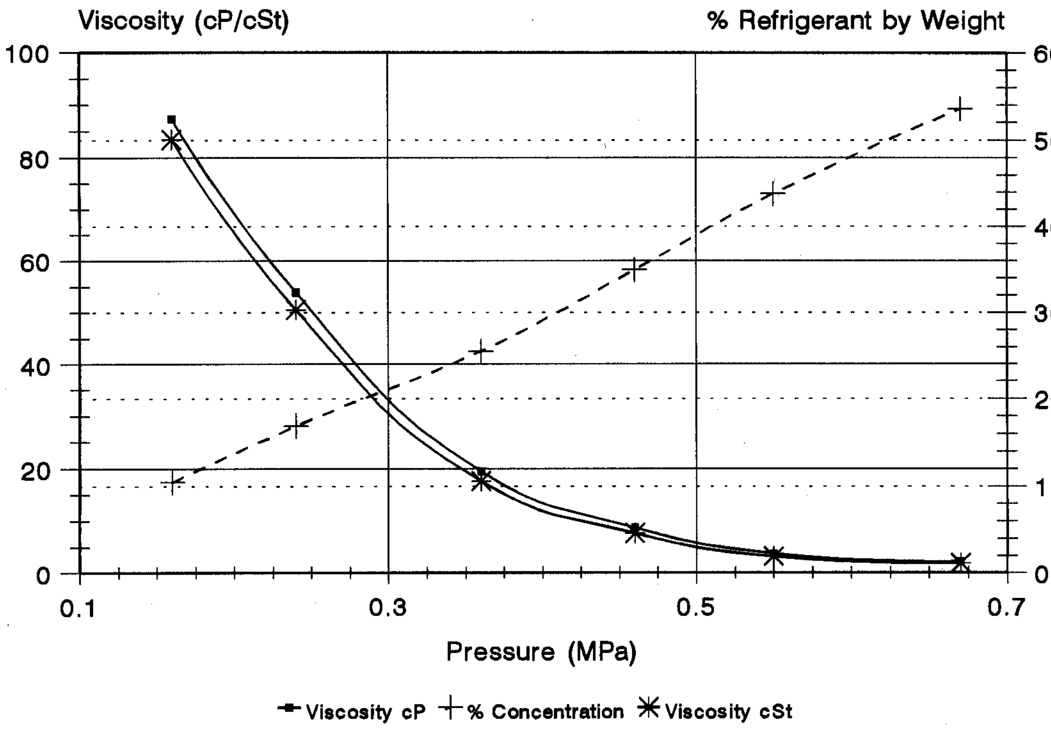
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-125 at 20°C
Figure H.5



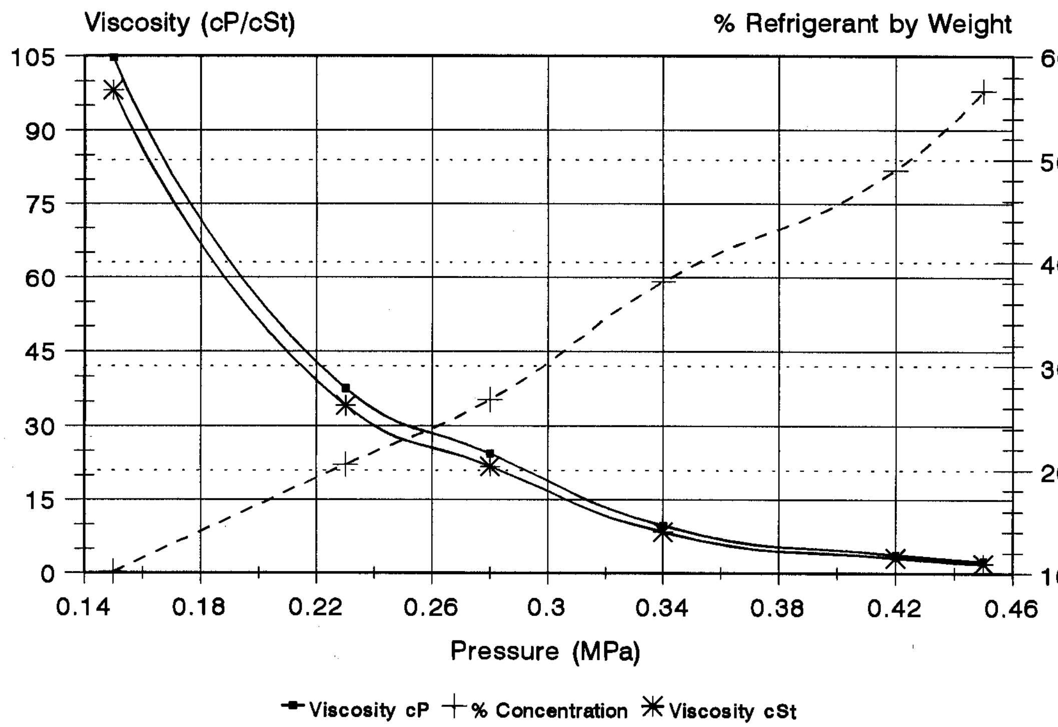
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-125 at 0°C
Figure H.6



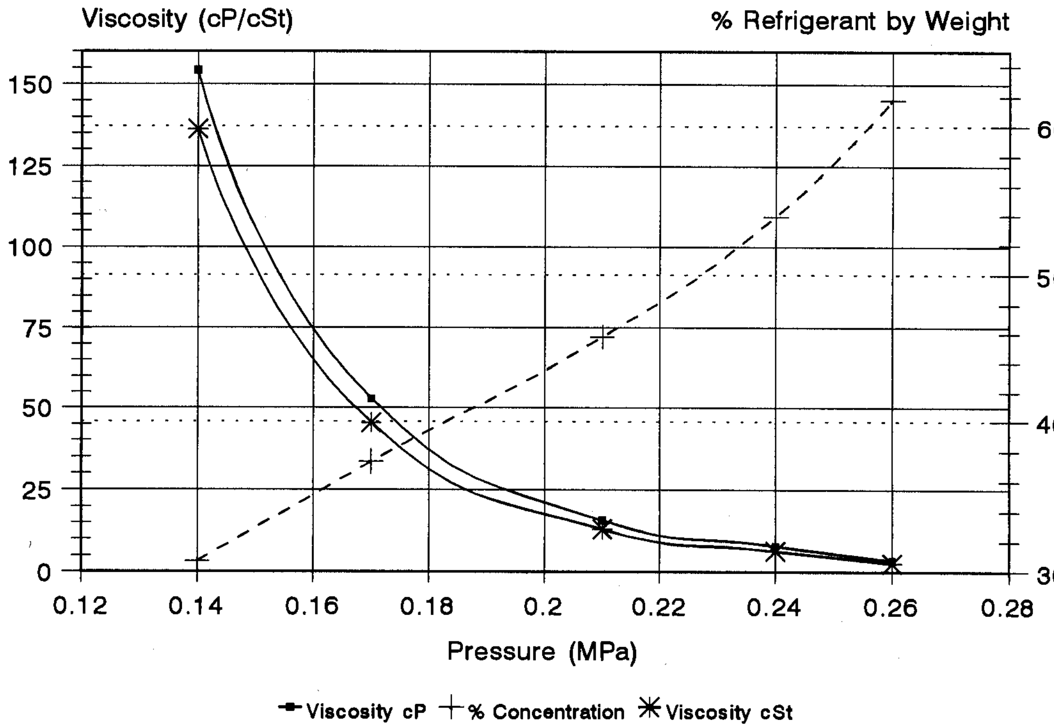
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-125 at -10°C
Figure H.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-125 at -25°C
Figure H.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
Emery 2968A with HFC−125
Table H.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.992	430.50	2.97	14.7	2.2	2.2
0.985	394.00	2.72	11.9	2.2	2.3
0.966	302.00	2.08	9.8	2.7	2.8
0.950	217.00	1.50	6.5	3.0	3.1
0.931	108.50	0.75	2.8	3.6	3.8
0.914	18.25	0.13	0.8	3.9	4.2

90°C (194°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.067	478.00	3.30	29.5	2.0	1.9
1.047	401.00	2.76	23.8	2.6	2.5
1.020	300.50	2.07	17.1	3.6	3.5
0.995	213.75	1.47	11.2	4.4	4.5
0.967	94.00	0.65	4.4	6.1	6.3
0.950	17.50	0.12	3.7	7.1	7.5

60°C (140°F) Temperature
460.03 psia Saturation Pressure
3.169 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.139	406.40	2.80	60.3	0.6	0.5
1.119	366.00	2.52	47.8	1.2	1.0
1.076	284.00	1.96	32.4	3.1	2.9
1.038	193.50	1.33	19.6	5.4	5.2
1.006	105.50	0.73	9.4	8.9	8.8
0.976	19.55	0.13	3.2	14.6	15.0

40°C (104°F) Temperature
292.34 psia Saturation Pressure
2.014 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.984	14.70	0.10	0.0	31.2	31.7
0.989	19.40	0.13	1.8	26.6	26.9
1.019	70.00	0.48	8.7	16.3	16.0
1.047	124.00	0.85	19.5	8.7	8.3
1.095	191.00	1.32	34.1	3.9	3.5
1.141	237.50	1.64	50.2	1.6	1.4
1.164	260.00	1.79	75.9	0.7	0.6

20°C (68°F) Temperature
174.98 psia Saturation Pressure
1.205 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.023	21.00	0.14	7.9	45.9	44.8
1.053	59.00	0.41	13.3	22.4	21.3
1.076	84.00	0.58	23.7	12.2	11.3
1.125	121.00	0.83	35.6	4.9	4.4
1.170	143.10	0.99	51.2	2.2	1.9

0°C (32°F) Temperature
97.16 psia Saturation Pressure
.6694 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.214	97.16	0.67	53.6	2.2	1.8
1.185	80.00	0.55	43.8	3.8	3.2
1.139	66.50	0.46	34.9	8.7	7.7
1.104	52.00	0.36	25.5	19.5	17.7
1.067	35.00	0.24	16.9	53.9	50.5
1.047	22.50	0.16	10.5	87.3	83.4

−10°C (14°F) Temperature
69.97 psia Saturation Pressure
.4820 MPa

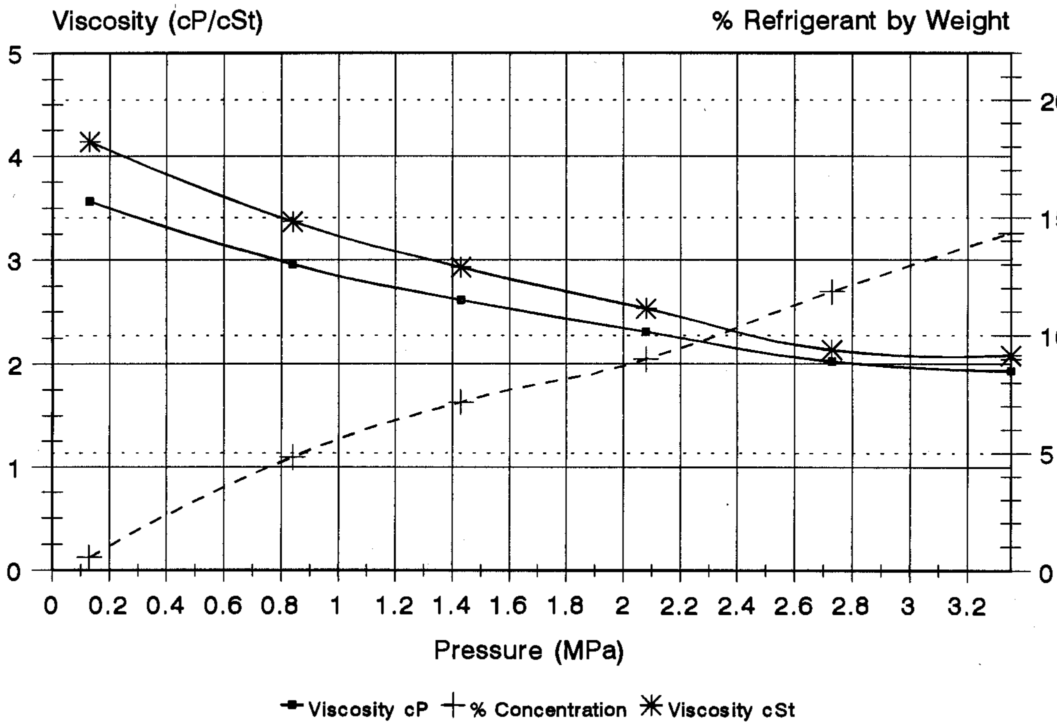
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.227	65.00	0.45	56.7	2.4	2.0
1.208	61.00	0.42	49.0	3.8	3.1
1.158	50.00	0.34	38.1	9.8	8.4
1.119	40.50	0.28	26.8	24.4	21.8
1.101	33.20	0.23	20.6	37.6	34.1
1.066	22.40	0.15	10.1	104.7	98.2

−25°C (−13°F) Temperature
37.86 psia Saturation Pressure
.2608 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.288	37.86	0.26	61.8	3.4	2.6
1.240	35.00	0.24	54.0	7.9	6.4
1.209	31.00	0.21	48.8	15.8	13.0
1.165	25.00	0.17	37.3	52.9	45.4
1.132	21.00	0.14	30.7	154.2	136.2

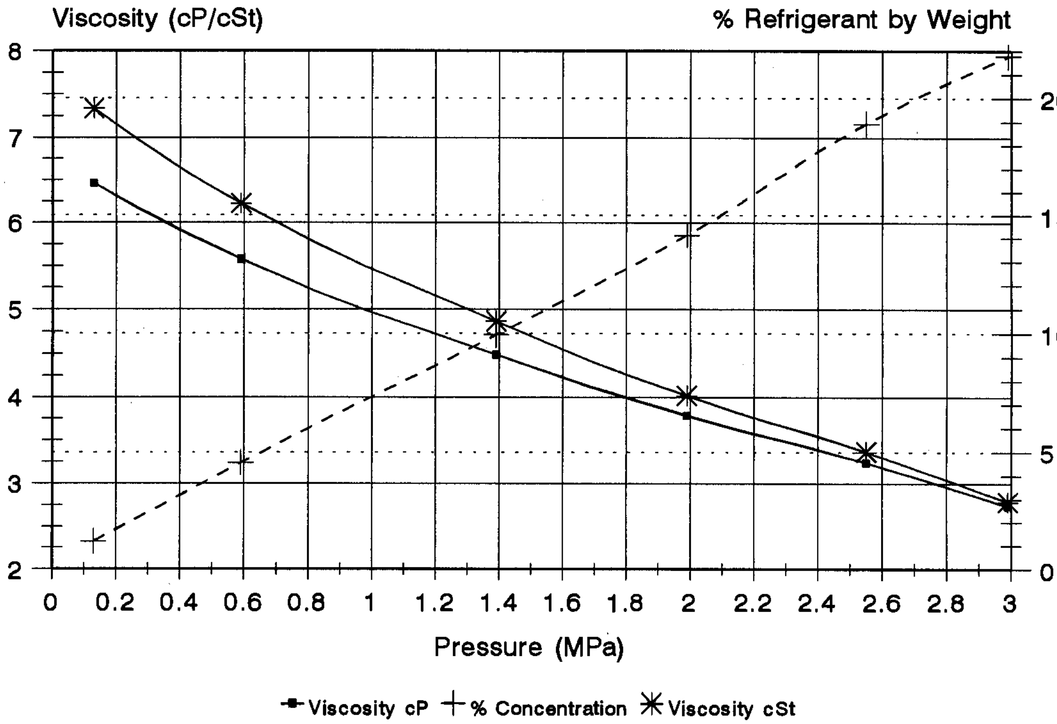
APPENDIX I
Viscosity, Density, and Gas Solubility
of EMKARATE RL32S at Various Temperatures with HFC-125

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-125 at 125°C
Figure I.1



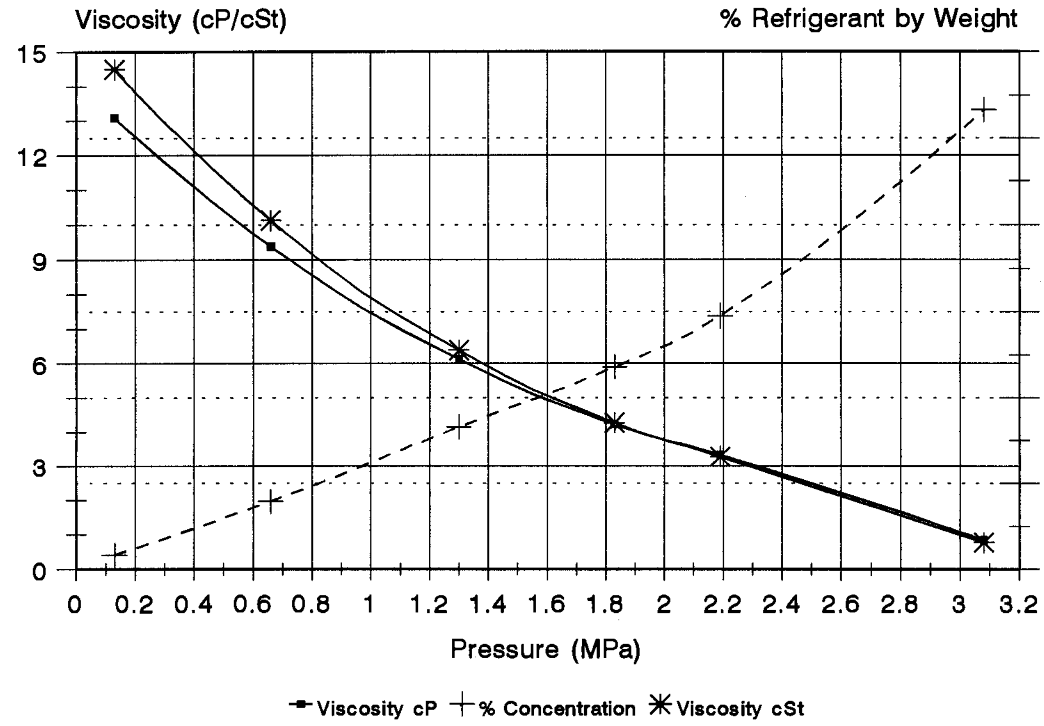
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-125 at 90°C
Figure I.2



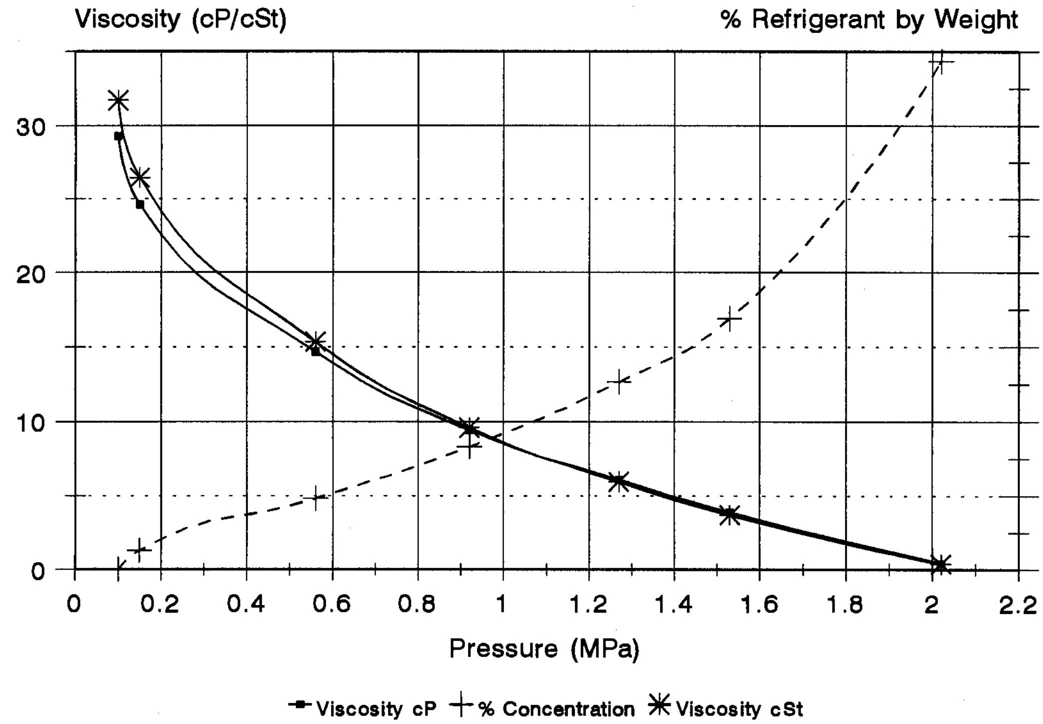
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-125 at 60°C
Figure I.3



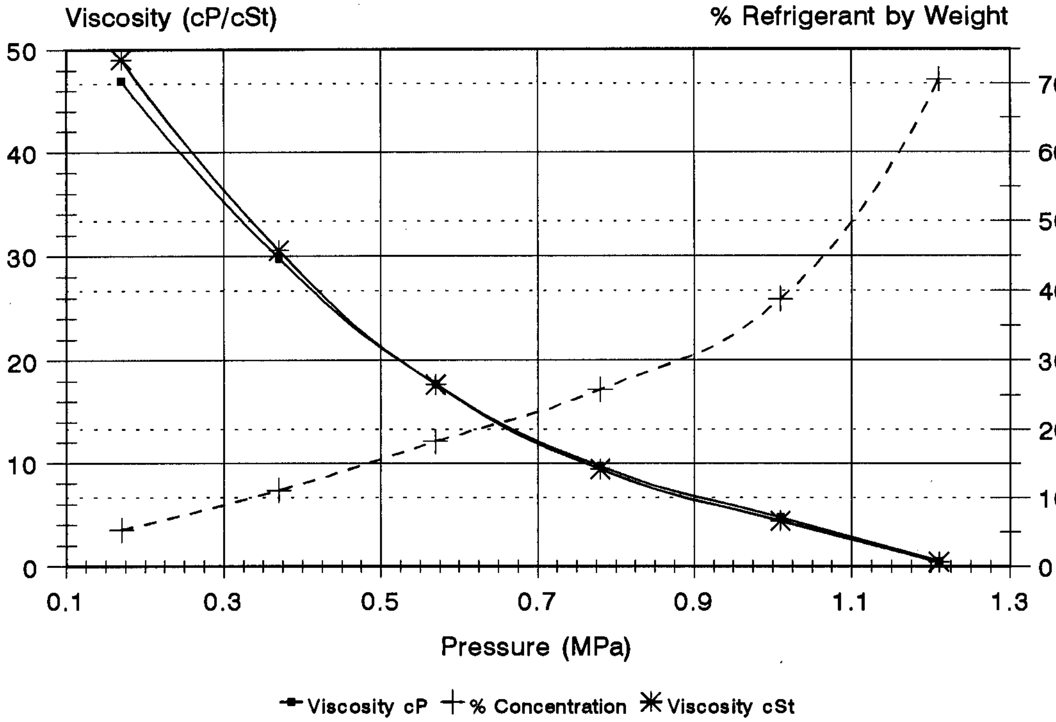
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-125 at 40°C
Figure I.4



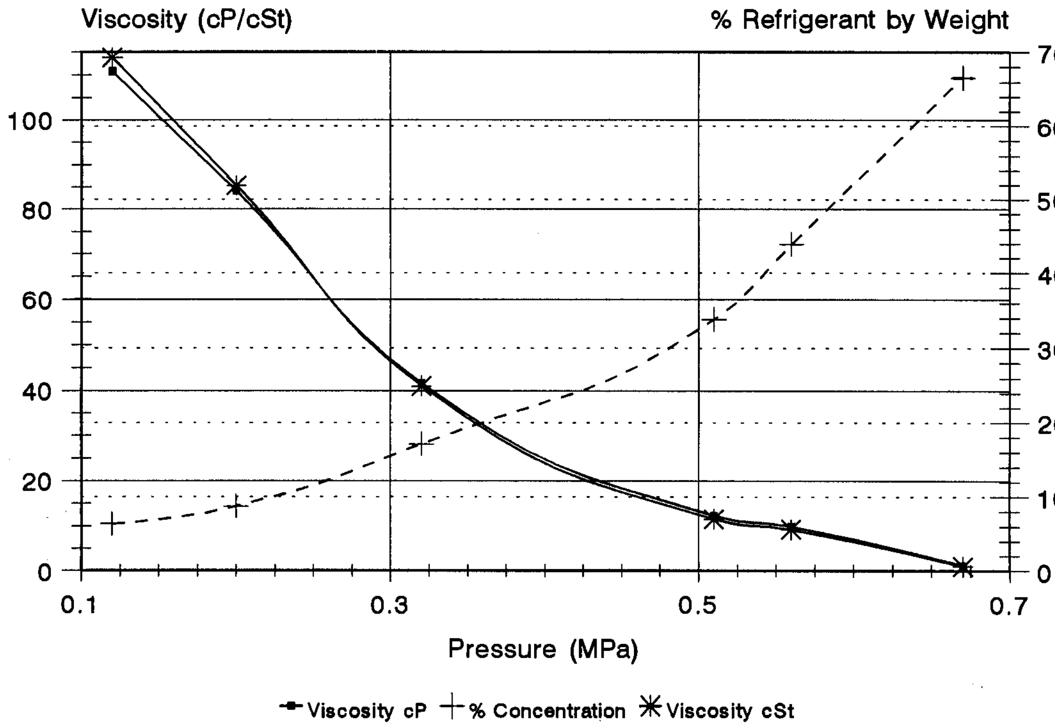
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-125 at 20°C
Figure I.5



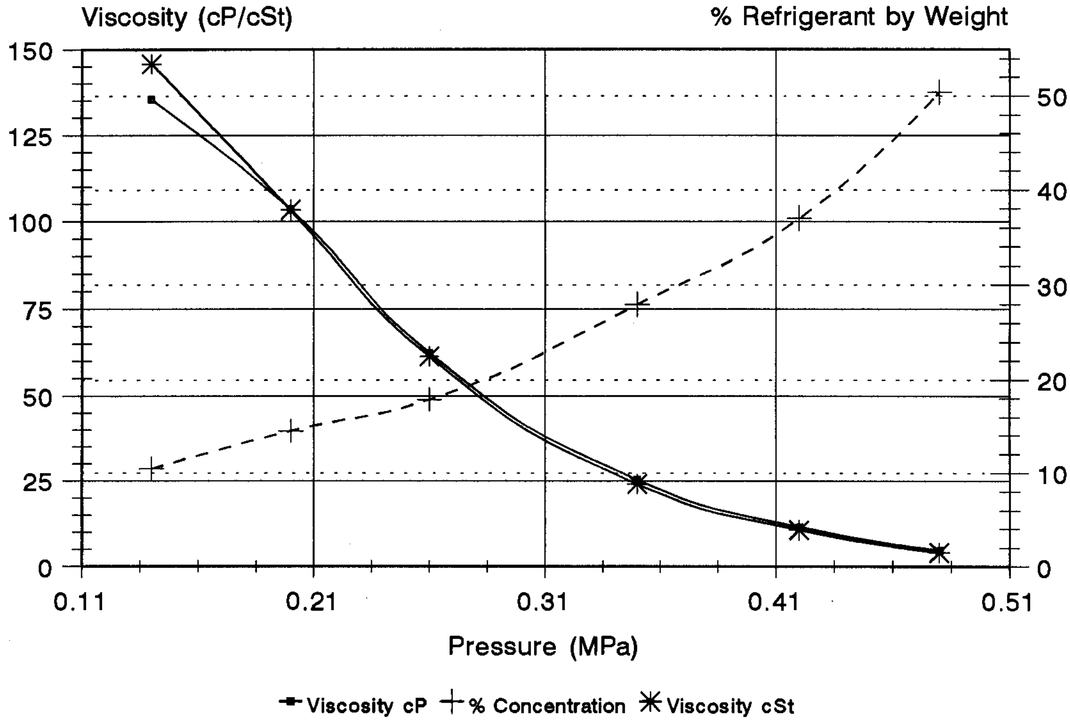
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-125 at 0°C
Figure I.6



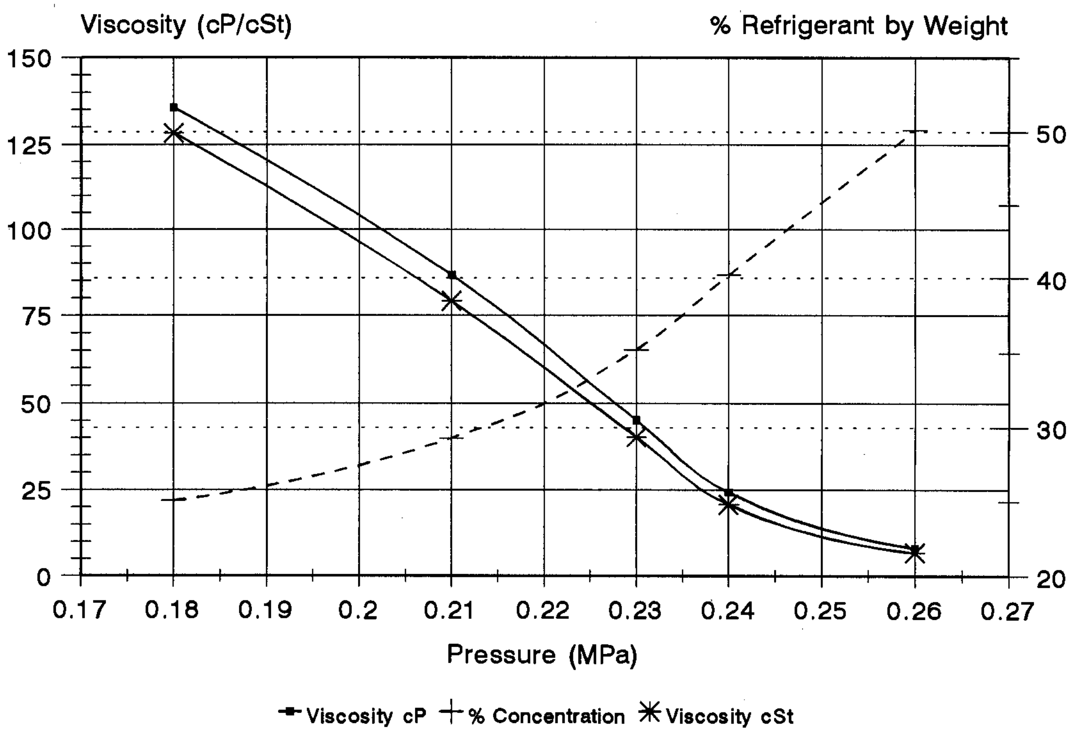
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-125 at -10°C
Figure I.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-125 at -25°C
Figure I.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
EMKARATE RL32S with HFC−125
Table I.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.948	485.80	3.35	14.3	2.0	2.1
0.929	396.25	2.73	11.9	1.9	2.1
0.912	301.40	2.08	9.0	2.3	2.5
0.892	208.00	1.43	7.2	2.6	2.9
0.878	122.00	0.84	4.8	3.0	3.4
0.862	19.00	0.13	0.5	3.6	4.1

90°C (194°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.982	433.00	2.99	21.8	2.7	2.8
0.963	370.50	2.55	18.9	3.2	3.4
0.942	289.00	1.99	14.1	3.8	4.0
0.922	201.75	1.39	9.9	4.5	4.9
0.895	85.75	0.59	4.5	5.6	6.2
0.881	18.50	0.13	1.2	6.5	7.3

60°C (140°F) Temperature
460.03 psia Saturation Pressure
3.169 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.092	446.00	3.08	53.3	0.8	0.8
1.016	317.00	2.19	29.5	3.3	3.3
0.989	265.50	1.83	23.6	4.2	4.3
0.960	189.00	1.30	16.6	6.1	6.4
0.926	95.50	0.66	7.9	9.4	10.1
0.903	19.25	0.13	1.7	13.1	14.5

40°C (104°F) Temperature
292.34 psia Saturation Pressure
2.014 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.923	14.70	0.10	0.0	29.3	31.7
0.931	21.25	0.15	2.6	24.6	26.4
0.957	81.00	0.56	9.7	14.7	15.3
0.982	133.50	0.92	16.6	9.4	9.6
1.020	184.00	1.27	25.3	6.1	6.0
1.050	222.00	1.53	33.8	3.9	3.7
1.144	292.34	2.02	68.7	0.4	0.4

20°C (68°F) Temperature
174.98 psia Saturation Pressure
1.205 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.186	174.98	1.21	70.6	0.5	0.4
1.076	146.50	1.01	38.9	4.7	4.4
1.031	112.50	0.78	25.8	9.7	9.4
1.003	82.75	0.57	18.2	17.7	17.7
0.976	53.00	0.37	11.0	29.8	30.5
0.957	24.50	0.17	5.3	46.9	49.0

0°C (32°F) Temperature
97.16 psia Saturation Pressure
.6694 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.973	17.50	0.12	6.4	110.7	113.8
0.985	29.50	0.20	8.8	84.0	85.3
1.016	47.00	0.32	17.1	41.7	41.0
1.070	74.50	0.51	33.8	12.4	11.6
1.076	81.00	0.56	43.7	9.9	9.2
1.188	97.16	0.67	66.6	1.1	1.0

−10°C (14°F)Temperature
37.86 psia Saturation Pressure
.2608 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.141	69.97	0.48	50.4	4.6	4.1
1.080	60.75	0.42	37.0	11.5	10.7
1.051	50.50	0.35	28.0	25.2	24.0
1.016	37.00	0.26	17.9	62.3	61.3
1.001	29.00	0.20	14.5	103.4	103.2
0.929	20.50	0.14	10.4	135.5	145.8

−25°C (−13°F) Temperature
37.86 psia Saturation Pressure
.2608 MPa

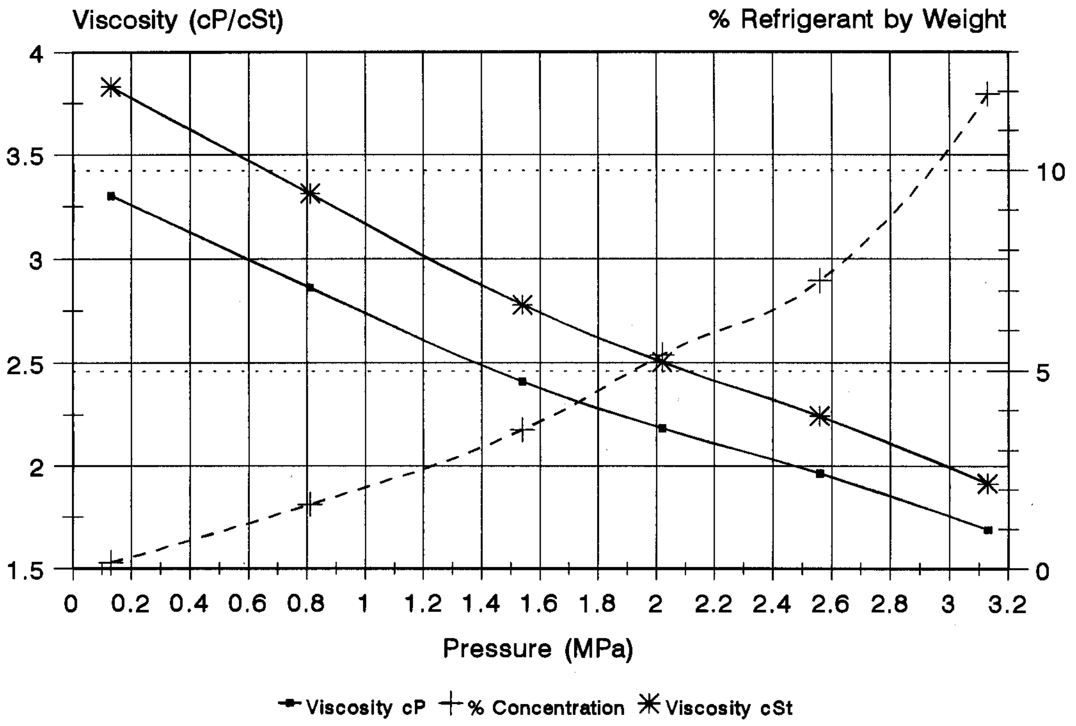
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.197	37.86	0.26	50.1	8.2	6.8
1.169	35.00	0.24	40.2	24.2	20.7
1.122	33.50	0.23	35.2	45.0	40.1
1.095	30.00	0.21	29.3	86.6	79.0
1.057	26.00	0.18	25.1	135.6	128.3

APPENDIX J
Viscosity, Density, and Gas Solubility of EMKARATE RL32S at Various Temperatures with HFC-32

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-32 at 125°C

Figure J.1



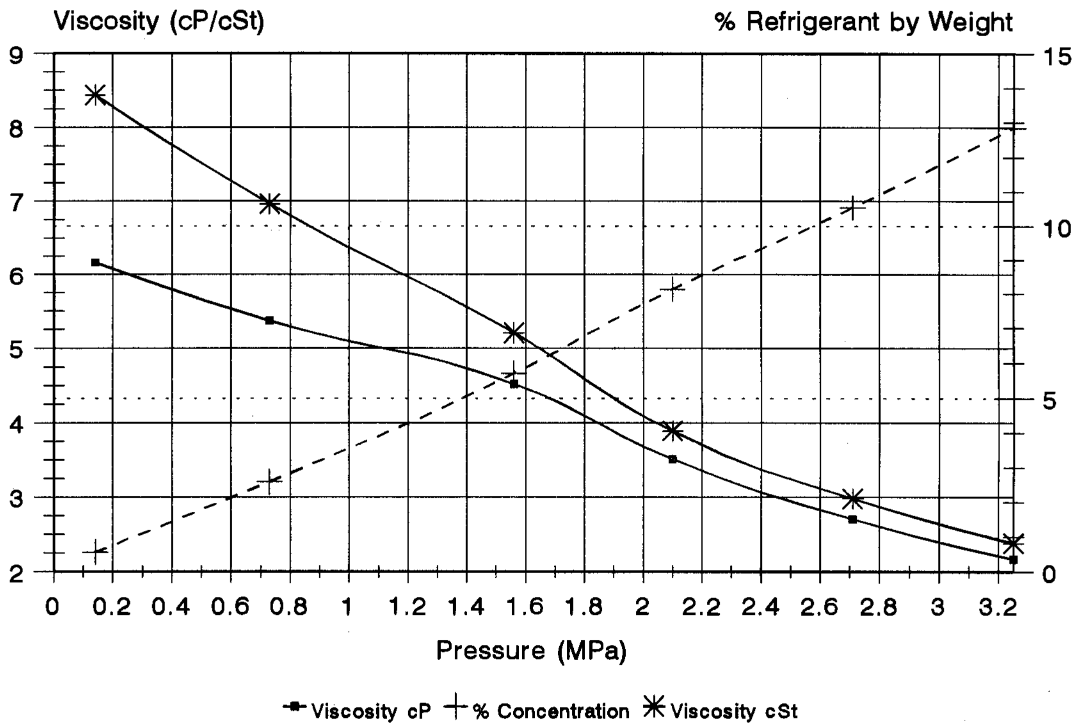
Viscosity via Gas Solubility Equilibrium

Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-32 at 90°C

Figure J.2



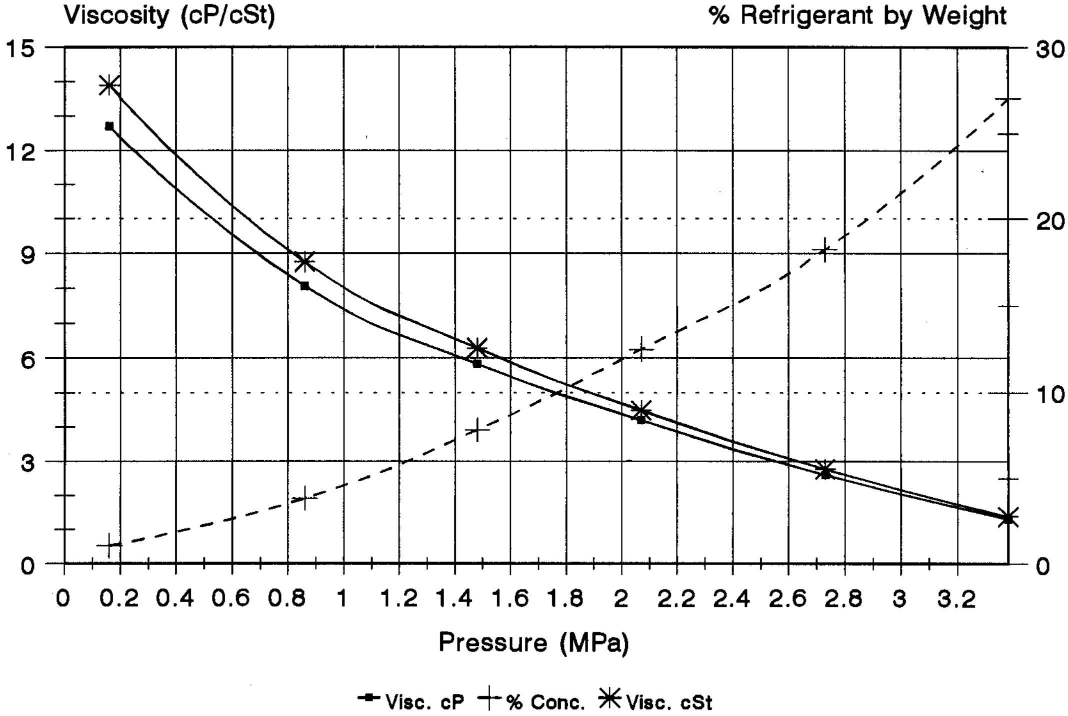
Viscosity via Gas Solubility Equilibrium

Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

EMKARATE RL32S with HFC-32 at 60°C

Figure J.3

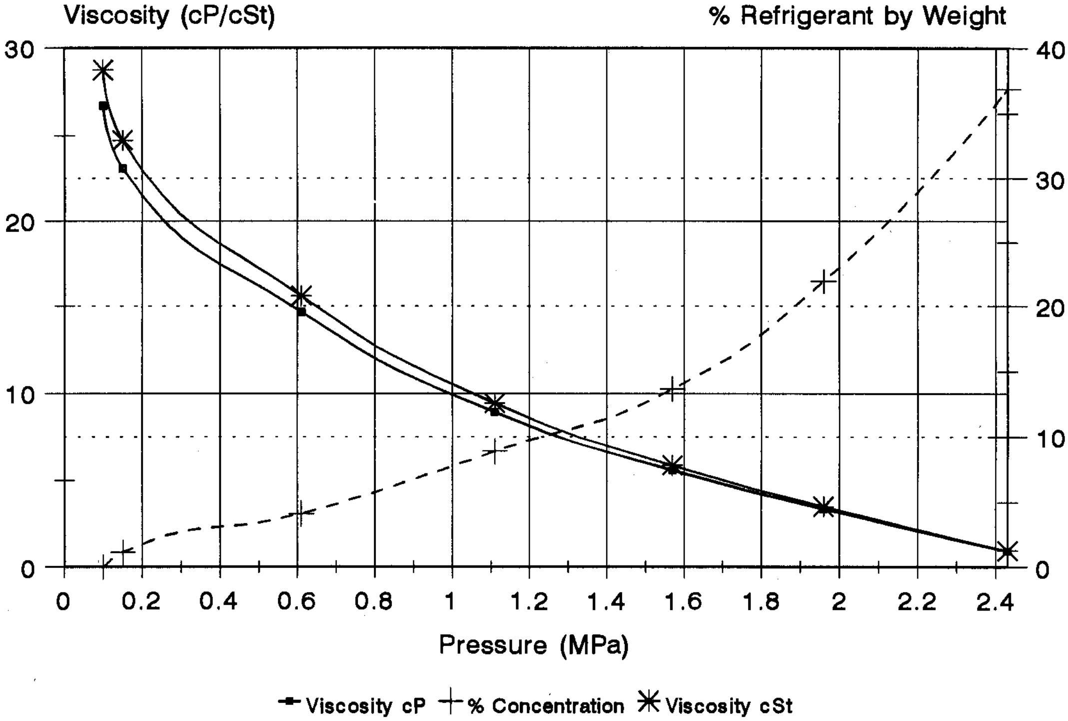


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

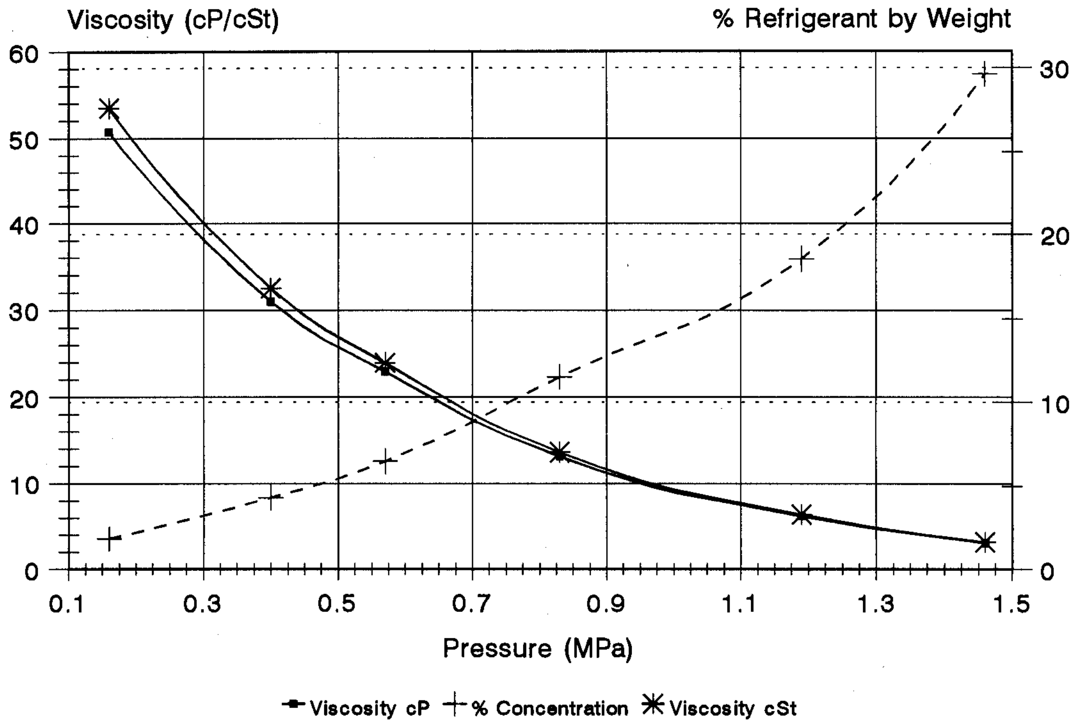
EMKARATE RL32S with HFC-32 at 40°C

Figure J.4



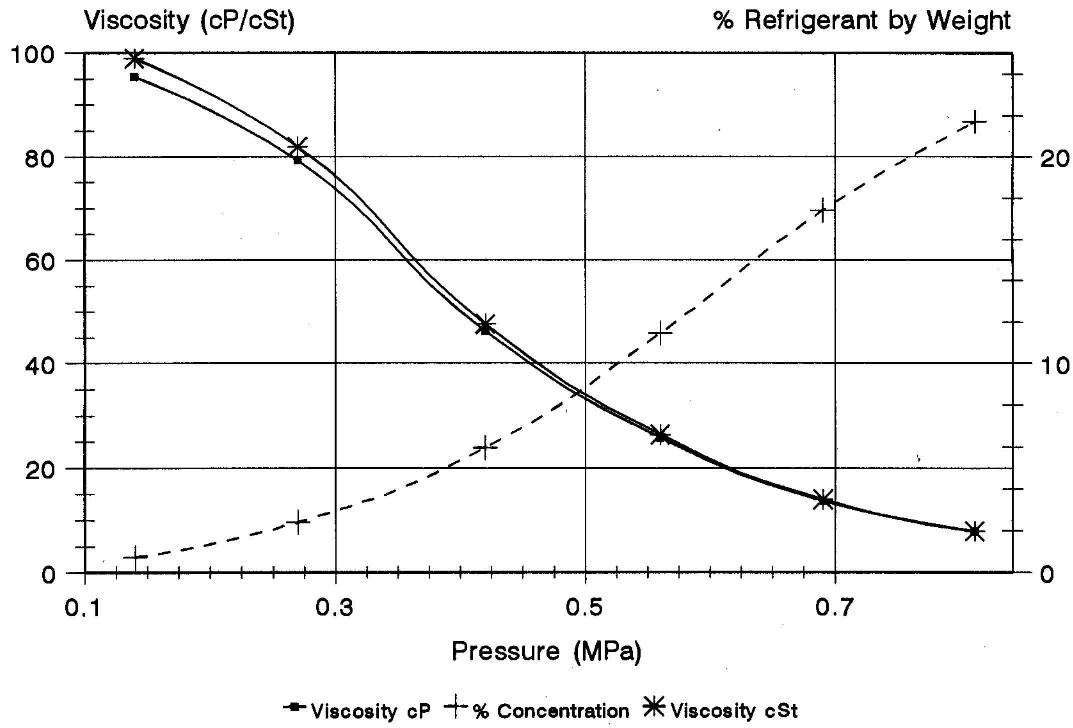
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-32 at 20°C
Figure J.5



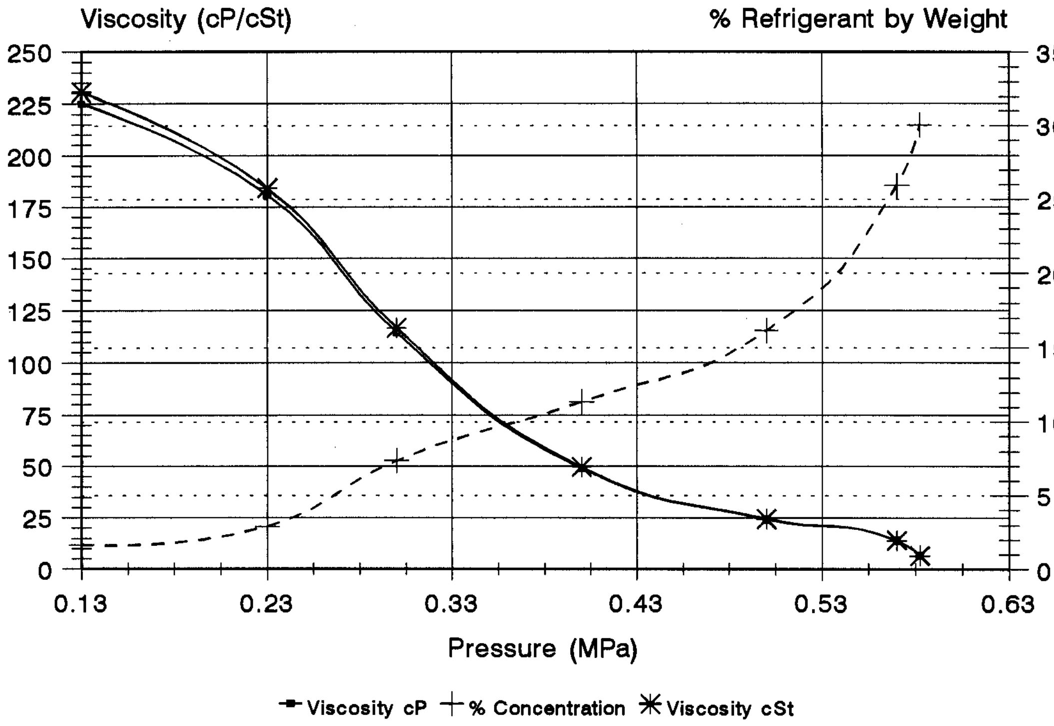
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-32 at 0°C
Figure J.6



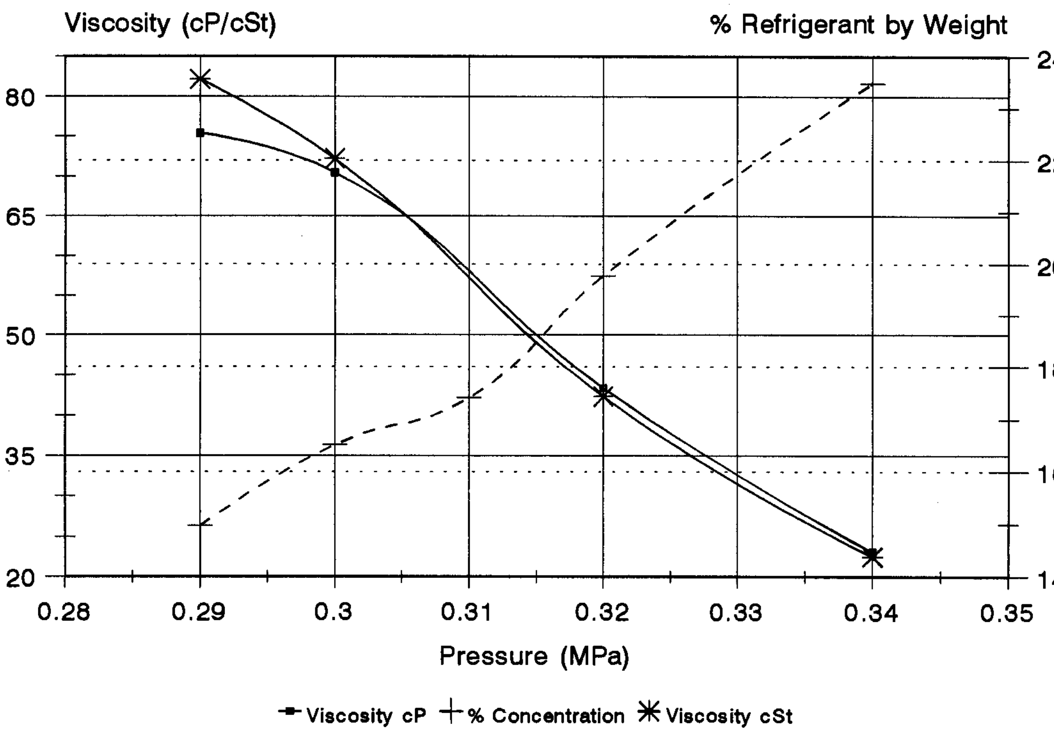
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-32 at -10°C
Figure J.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMKARATE RL32S with HFC-32 at -25°C
Figure J.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
EMKARATE RL32S with HFC−32
Table J.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.882	454.25	3.13	11.9	1.7	1.9
0.876	372.00	2.56	7.3	2.0	2.2
0.872	293.50	2.02	5.4	2.2	2.5
0.867	223.50	1.54	3.5	2.4	2.8
0.865	117.00	0.81	1.6	2.9	3.3
0.862	19.50	0.13	0.1	3.3	3.8

90°C (194°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.912	472.00	3.25	12.8	2.2	2.4
0.907	392.50	2.71	10.5	2.7	3.0
0.903	305.00	2.10	8.1	3.5	3.9
0.869	226.50	1.56	5.7	4.5	5.2
0.771	106.00	0.73	2.6	5.4	7.0
0.731	20.00	0.14	0.6	6.2	8.4

60°C (140°F) Temperature
571.47 psia Saturation Pressure
3.937 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.948	490.50	3.38	27.0	1.3	1.4
0.941	396.50	2.73	18.2	2.6	2.8
0.935	300.50	2.07	12.5	4.2	4.5
0.928	214.00	1.48	7.8	5.8	6.3
0.922	125.00	0.86	3.8	8.1	8.8
0.914	22.50	0.16	1.0	12.7	13.9

40°C (104°F) Temperature
359.46 psia Saturation Pressure
2.476 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.929	14.70	0.10	0.0	26.7	28.7
0.934	22.00	0.15	1.2	23.1	24.7
0.939	88.00	0.61	4.1	14.6	15.6
0.945	160.50	1.11	8.9	8.9	9.4
0.951	228.25	1.57	13.6	5.6	5.9

20°C (68°F) Temperature
213.67 psia Saturation Pressure
1.472 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.982	211.50	1.46	29.6	3.1	3.2
0.973	173.00	1.19	18.5	6.2	6.4
0.964	120.00	0.83	11.5	13.1	13.6
0.957	83.00	0.57	6.5	22.9	24.0
0.954	58.50	0.40	4.3	31.0	32.5
0.948	23.40	0.16	1.8	50.7	53.5

0°C (32°F) Temperature
117.3 psia Saturation Pressure
.8082 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.991	117.00	0.81	21.7	7.8	7.9
0.984	100.00	0.69	17.4	13.8	14.1
0.978	81.00	0.56	11.5	25.8	26.4
0.972	60.50	0.42	6.0	46.3	47.6
0.967	39.00	0.27	2.4	79.3	82.0
0.964	20.90	0.14	0.7	95.4	98.9

−10°C (14°F) Temperature
84.37 psia Saturation Pressure
.5813 MPa

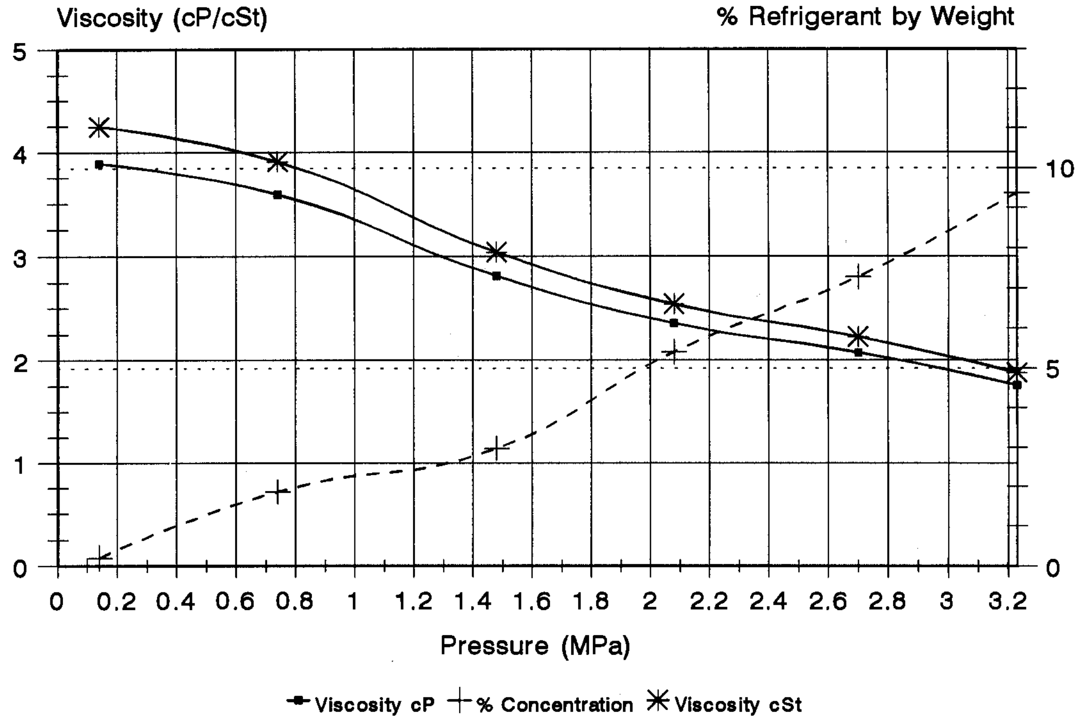
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.976	19.00	0.13	1.6	225.1	230.6
0.978	33.00	0.23	2.9	180.9	184.0
0.981	43.50	0.30	7.4	114.6	116.8
0.988	58.00	0.40	11.4	49.0	49.6
0.994	72.50	0.50	16.2	24.3	24.4
1.004	82.00	0.57	26.0	14.1	14.1
1.025	84.37	0.58	30.1	6.8	6.7

−25°C (−13°F) Temperature
48.67 psia Saturation Pressure
.3353 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.026	48.67	0.34	23.5	23.1	22.5
1.025	46.50	0.32	19.8	43.4	42.3
1.003	45.00	0.31	17.4	65.5 (not plotted)	65.3
0.976	44.00	0.30	16.5	70.4	72.2
0.918	42.50	0.29	15.0	75.4	82.1

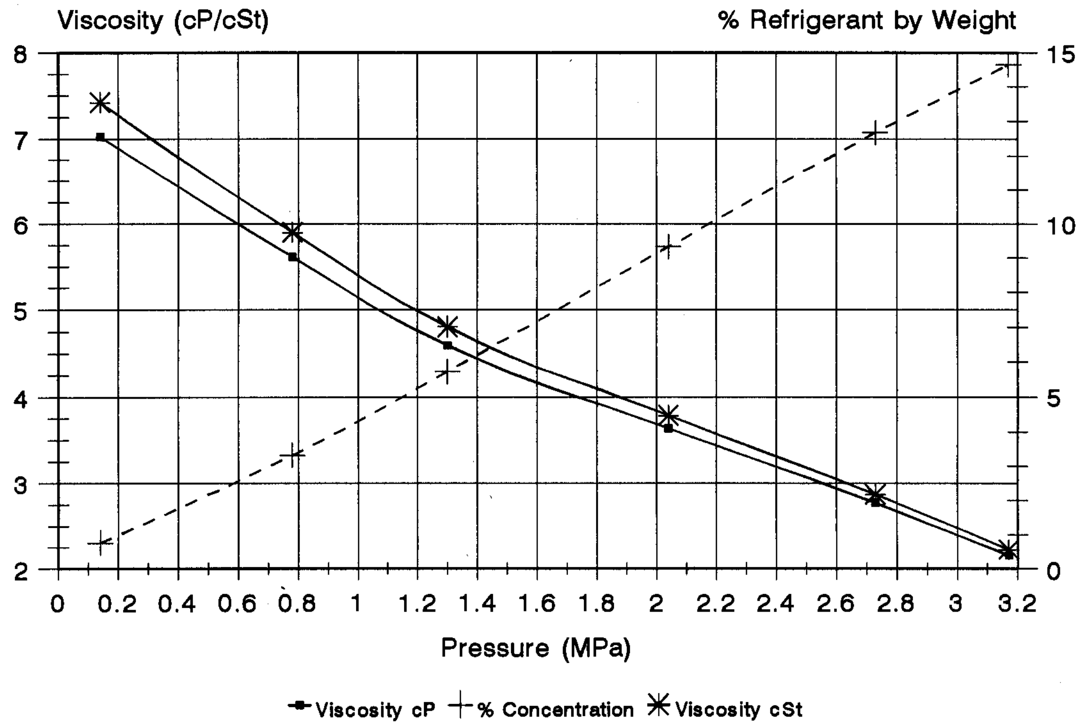
APPENDIX K
Viscosity, Density, and Gas Solubility of Emery 2968A at Various Temperatures with HFC-32

Viscosity and Gas Solubility
EMERY 2968A with HFC-32 at 125°C
Figure K.1



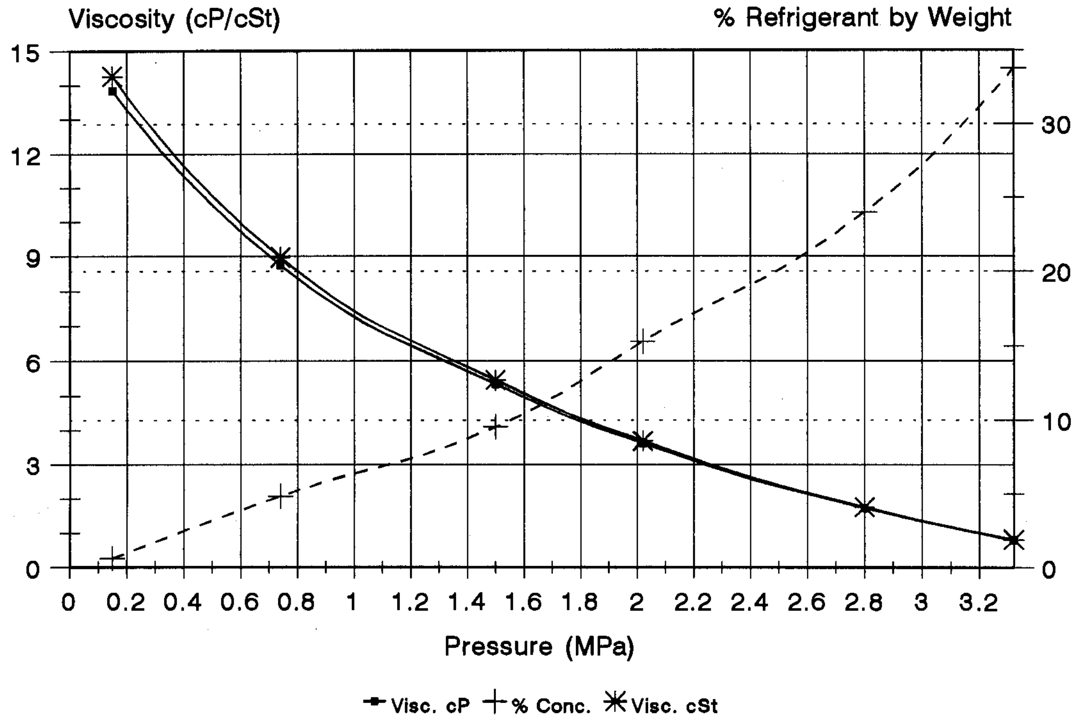
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-32 at 90°C
Figure K.2



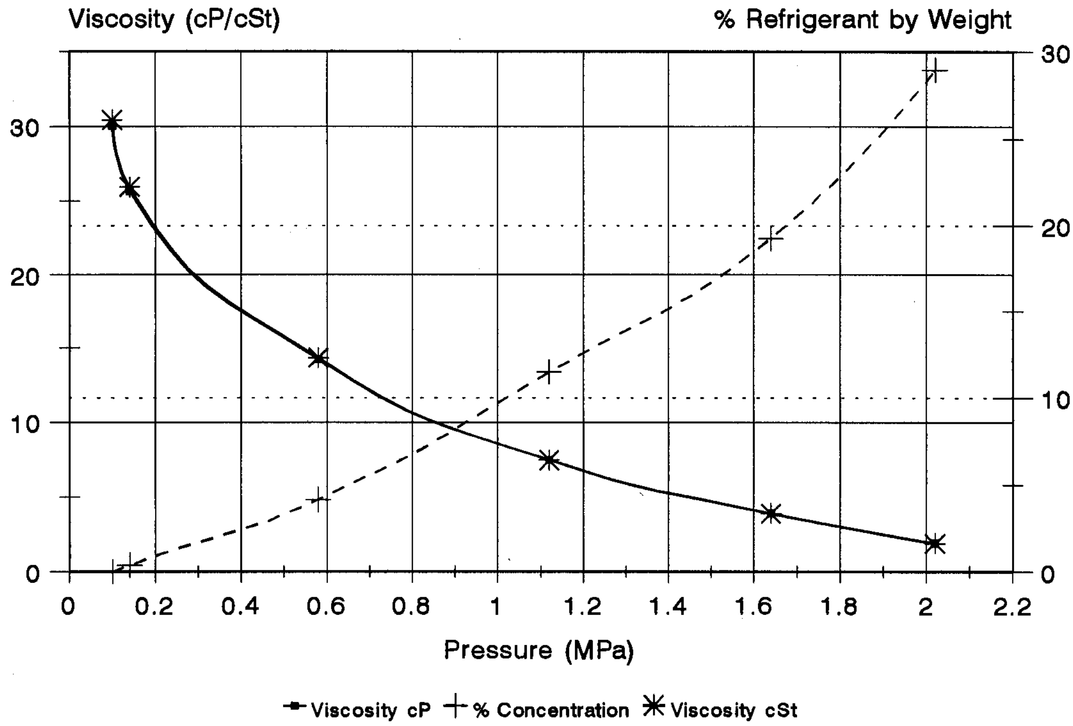
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-32 at 60°C
Figure K.3



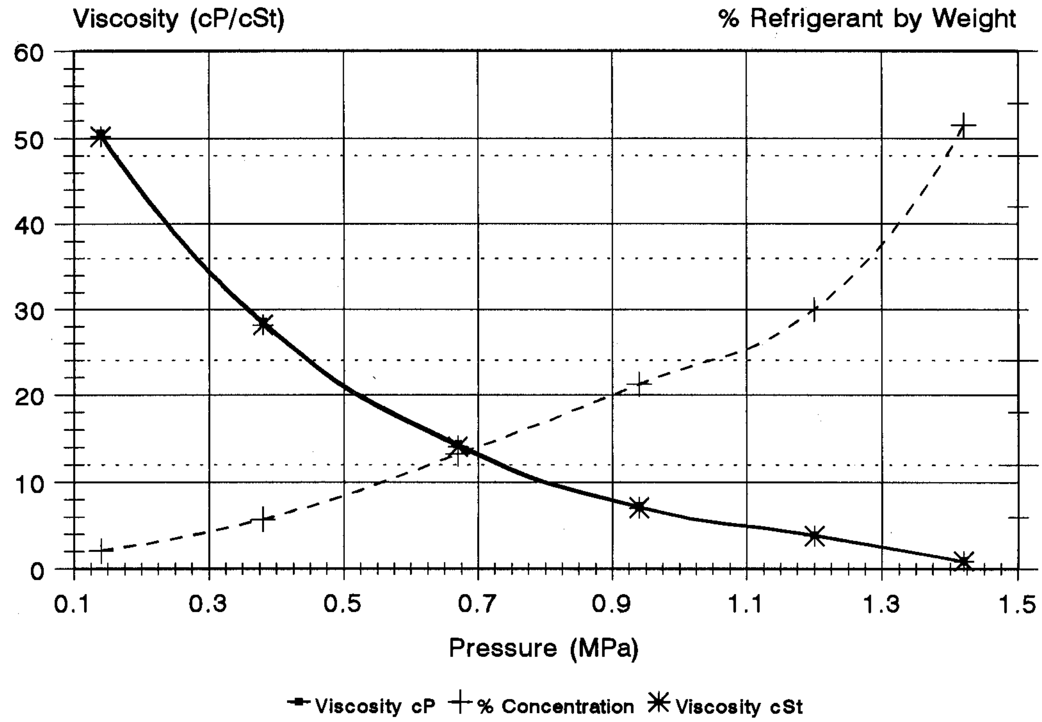
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-32 at 40°C
Figure K.4



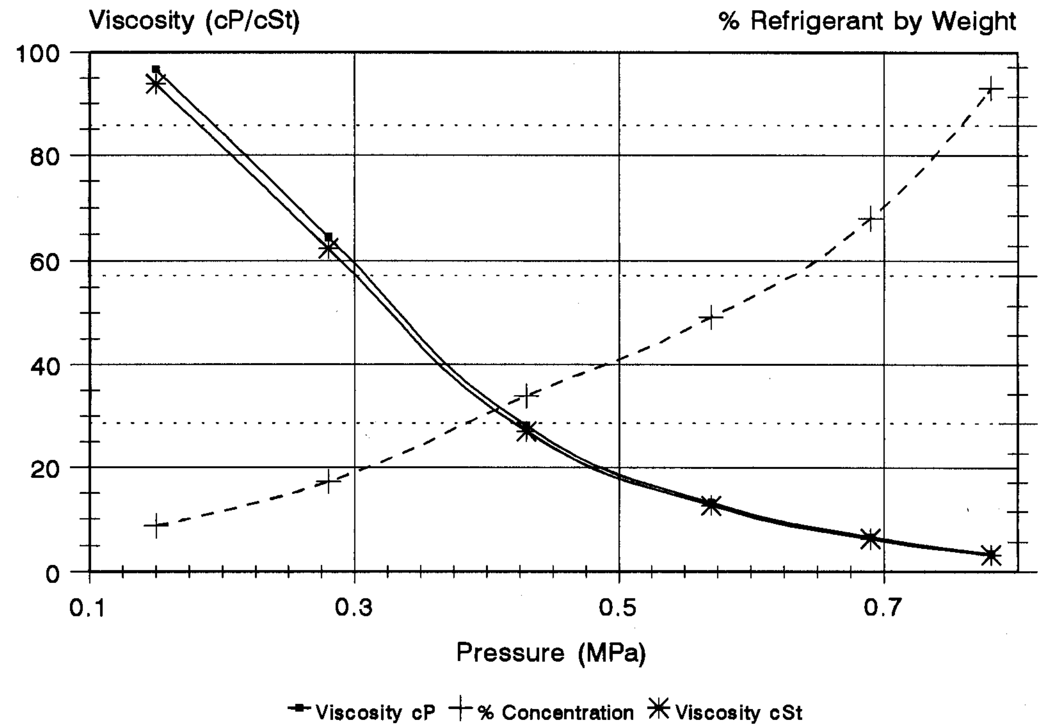
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-32 at 20°C
Figure K.5



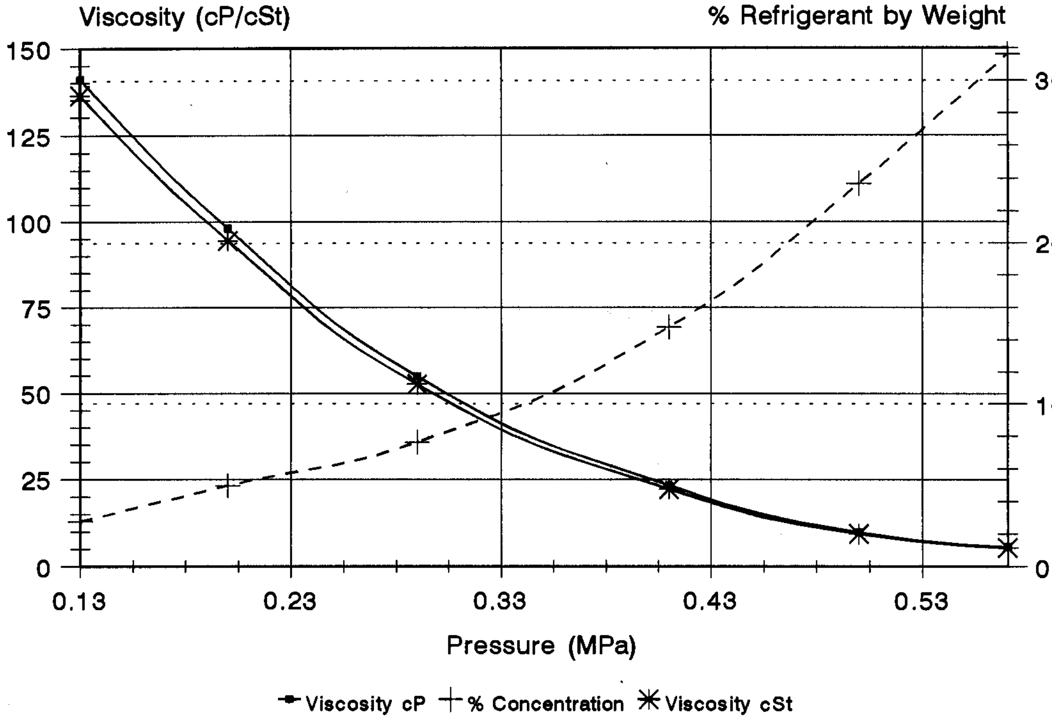
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-32 at 0°C
Figure K.6



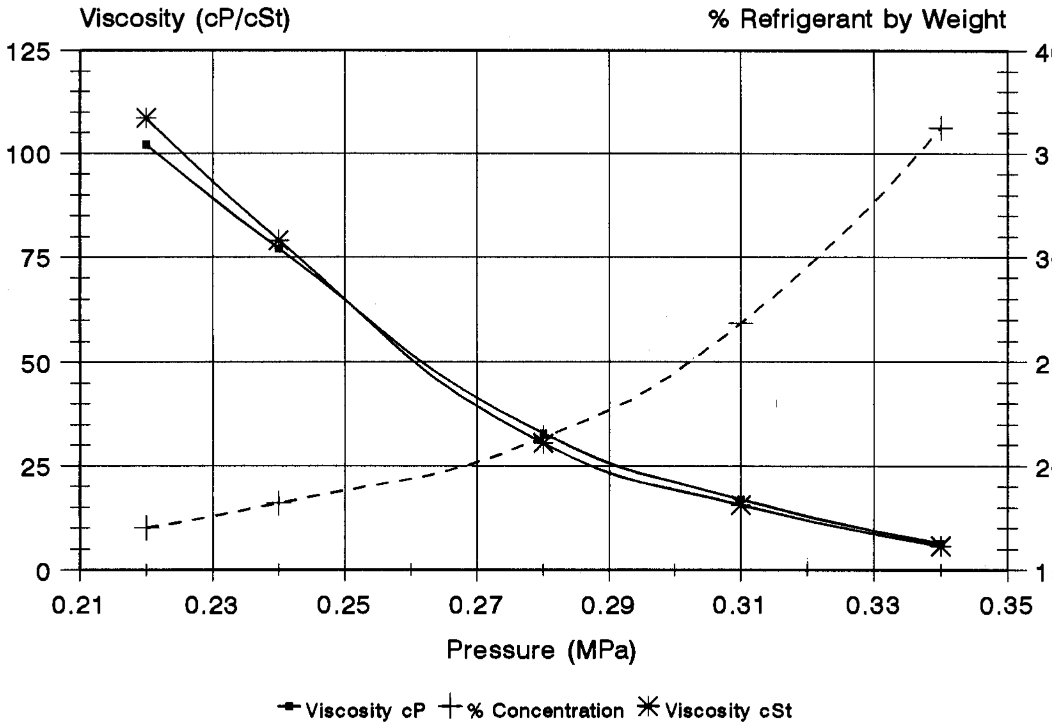
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-32 at -10°C
Figure K.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility
EMERY 2968A with HFC-32 at -25°C
Figure K.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
Emery 2968A with HFC−32
Table K.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.937	468.00	3.23	9.4	1.8	1.9
0.932	392.00	2.70	7.3	2.1	2.2
0.928	301.00	2.08	5.4	2.4	2.5
0.925	214.00	1.48	3.0	2.8	3.0
0.919	108.00	0.74	1.9	3.6	3.9
0.916	20.50	0.14	0.2	3.9	4.2

90°C (194°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.969	460.00	3.17	14.7	2.2	2.2
0.966	396.00	2.73	12.7	2.8	2.9
0.961	296.00	2.04	9.3	3.6	3.8
0.956	189.00	1.30	5.7	4.6	4.8
0.951	113.50	0.78	3.3	5.6	5.9
0.947	20.00	0.14	0.8	7.0	7.4

60°C (140°F) Temperature
571.47 psia Saturation Pressure
3.937 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.988	481.50	3.32	33.8	0.8	0.8
0.985	405.50	2.80	24.0	1.7	1.8
0.982	293.00	2.02	15.3	3.6	3.7
0.979	217.00	1.50	9.6	5.3	5.5
0.976	108.00	0.74	4.9	8.8	9.0
0.970	22.00	0.15	0.6	13.8	14.3

40°C (104°F) Temperature
359.46 psia Saturation Pressure
2.476 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.988	14.70	0.10	0.0	30.1	30.4
0.989	20.50	0.14	0.4	25.7	25.9
0.994	83.50	0.58	4.2	14.2	14.3
1.003	163.00	1.12	11.4	7.5	7.5
1.007	237.50	1.64	19.3	4.0	3.9

20°C (68°F) Temperature
213.67 psia Saturation Pressure
1.472 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.029	206.50	1.42	43.0	0.9	0.9
1.026	173.50	1.20	25.0	3.9	3.8
1.022	136.50	0.94	17.7	7.2	7.1
1.020	96.50	0.67	11.0	14.3	14.1
1.013	55.00	0.38	4.8	28.6	28.2
1.008	21.00	0.14	1.8	50.6	50.2

0°C (32°F) Temperature
117.83 psia Saturation Pressure
.8118 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.031	22.00	0.15	3.1	96.7	93.8
1.035	40.00	0.28	6.0	64.5	62.3
1.038	62.00	0.43	11.9	28.0	27.0
1.042	83.00	0.57	17.2	13.2	12.6
1.045	100.00	0.69	23.8	6.5	6.3
1.051	113.50	0.78	32.6	3.4	3.3

−10°C (14°F) Termperature
84.45 psia Saturation Pressure
.5818 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.057	82.00	0.57	31.6	5.7	5.3
1.054	73.00	0.50	23.7	9.9	9.4
1.050	59.00	0.41	14.8	23.3	22.2
1.044	42.50	0.29	7.6	54.9	52.6
1.038	29.00	0.20	4.9	98.1	94.5
1.035	19.50	0.13	2.8	141.1	136.3

−25°C (−13°F) Temperature
48.67 psia Saturation Pressure
.3353 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.094	48.67	0.34	36.2	6.3	5.8
1.087	45.00	0.31	26.9	17.0	15.6
1.080	40.00	0.28	21.4	32.9	30.4
0.974	35.00	0.24	18.2	77.0	79.1
0.940	32.50	0.22	17.0	102.0	108.5

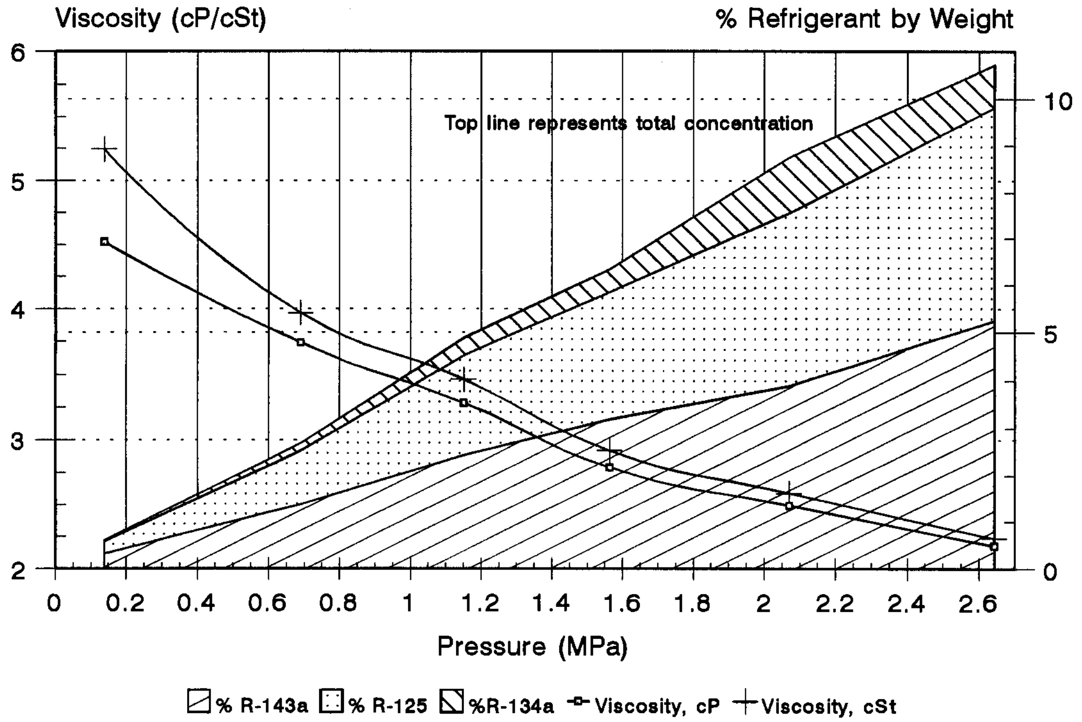
APPENDIX L
Viscosity, Density, Solubility, and Gas Fractionation of Emery 2968A at Various Temperatures with R-404A

In the following graphs, the shaded areas indicate the concentrations of the blend components. These areas are cumulative, not overlapped. For example, in Figure L.1, the concentration in the lubricant of HFC-143a alone is slightly more than five percent. The concentration of HFC-125 is slightly less than five percent. The concentration of HFC-134a is approximately one percent. These areas are stacked on top of one another. The top line represents the total concentration of R-404A, at slightly less than eleven percent.

Viscosity, Solubility, and Gas Fractionation

EMERY 2968A with R-404A at 125°C

Figure L.1

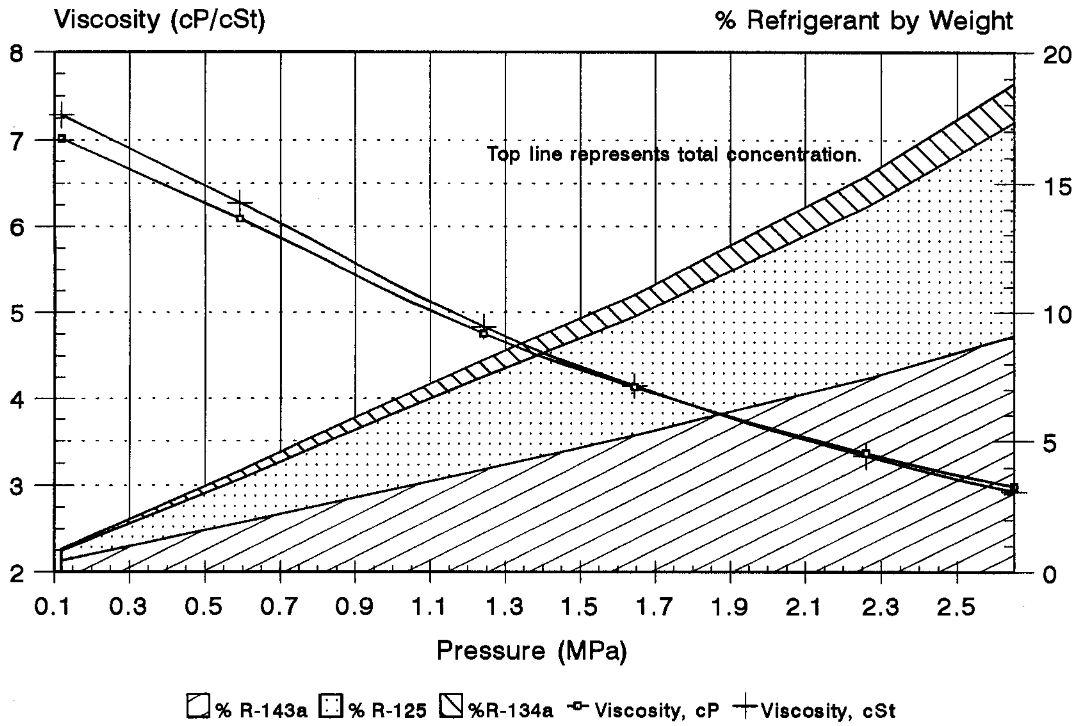


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

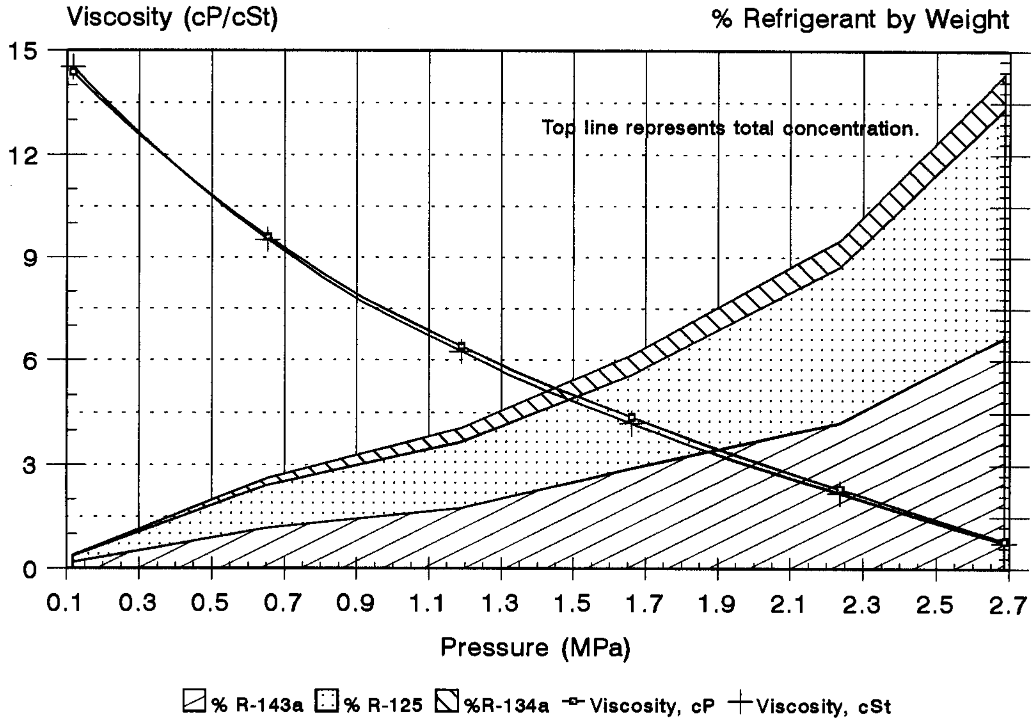
EMERY 2968A with R-404A at 90°C

Figure L.2



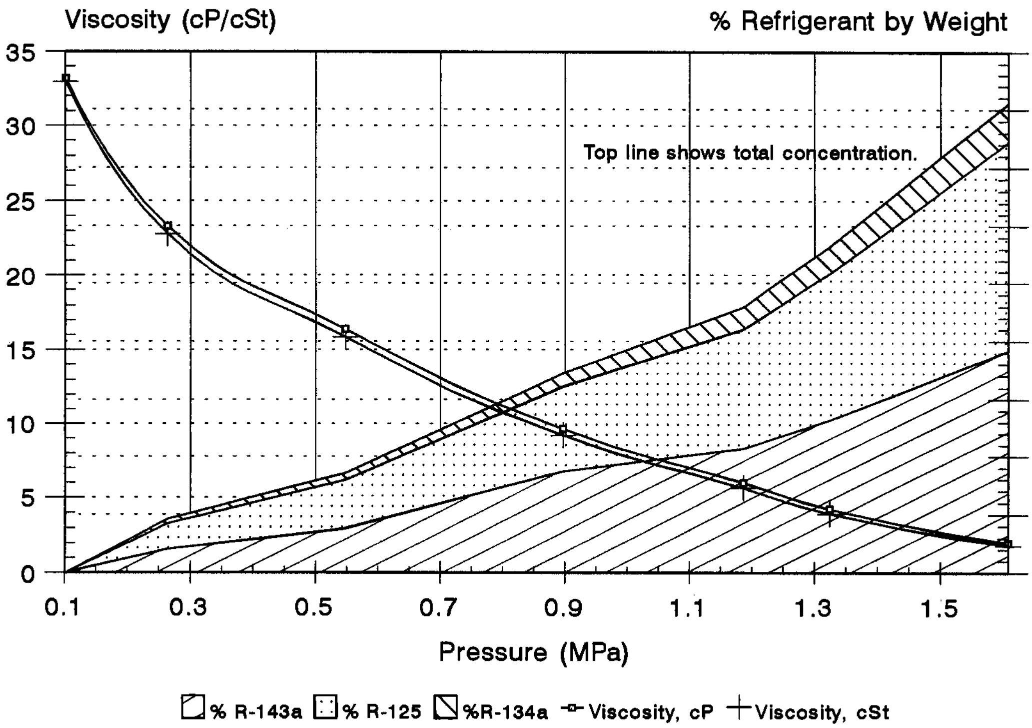
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-404A at 60°C
Figure L.3



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

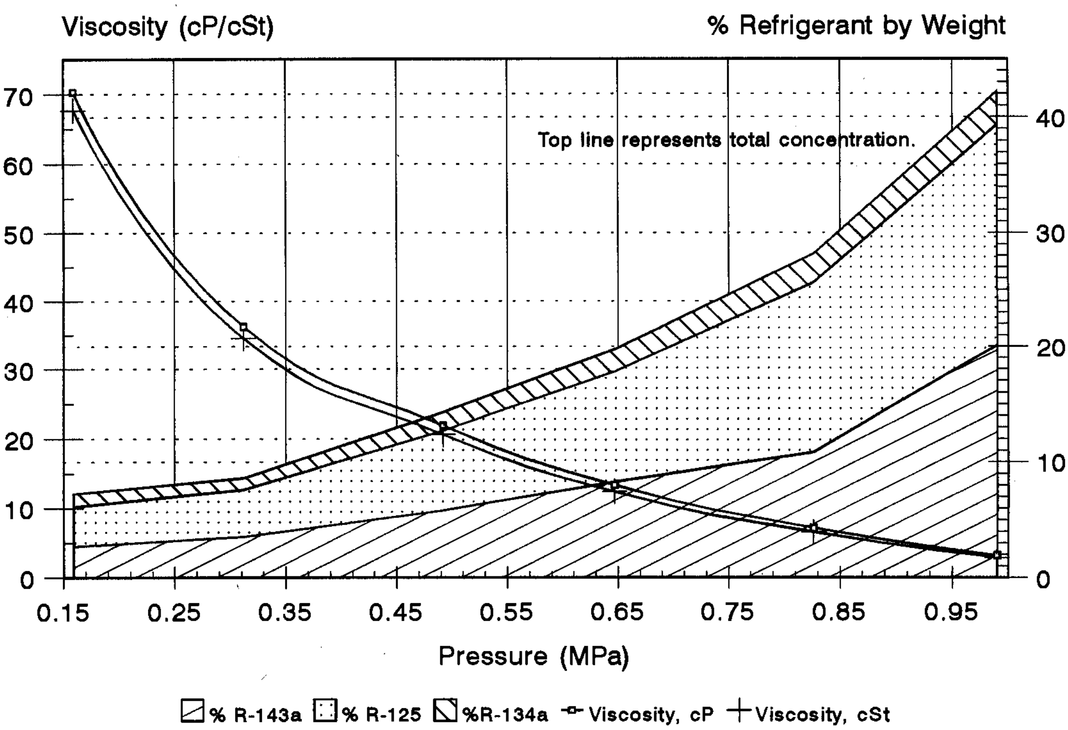
Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-404A at 40°C
Figure L.4



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-404A at 20°C

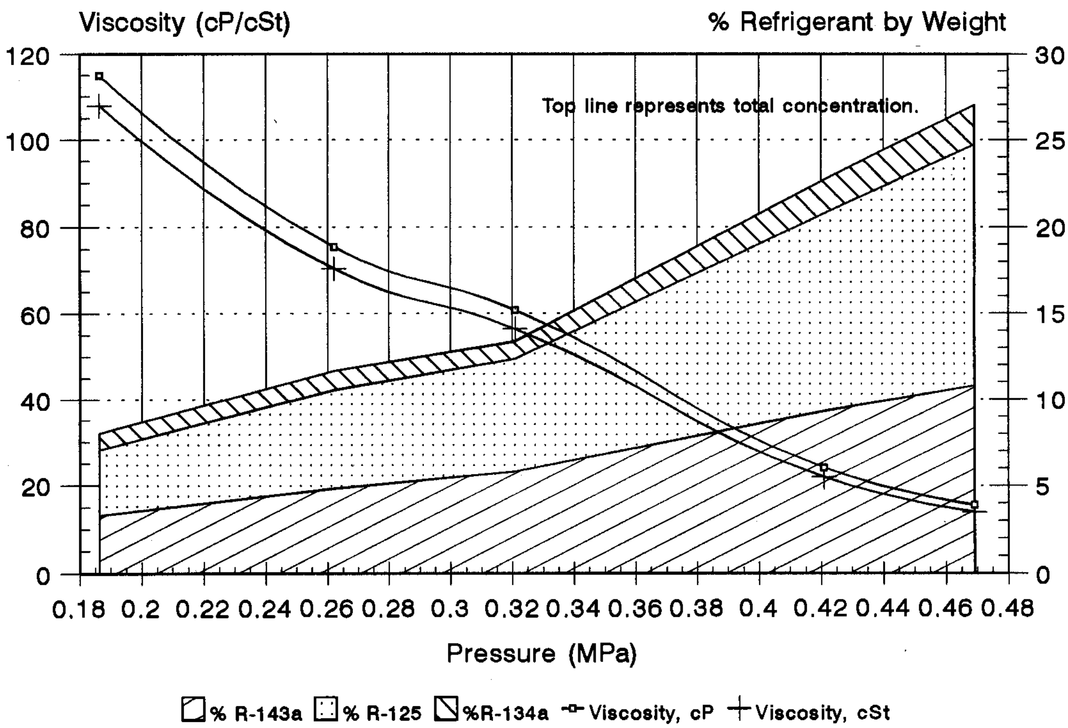
Figure L.5



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-404A at 0°C

Figure L.6

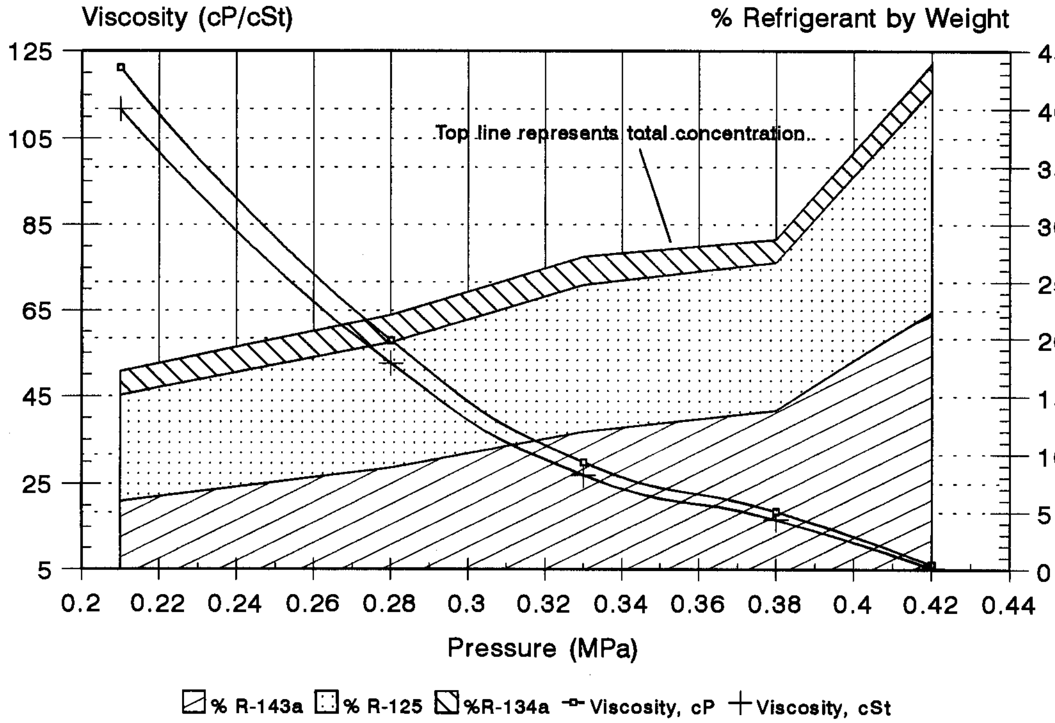


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

EMERY 2968A with R-404A at -10°C

Figure L.7

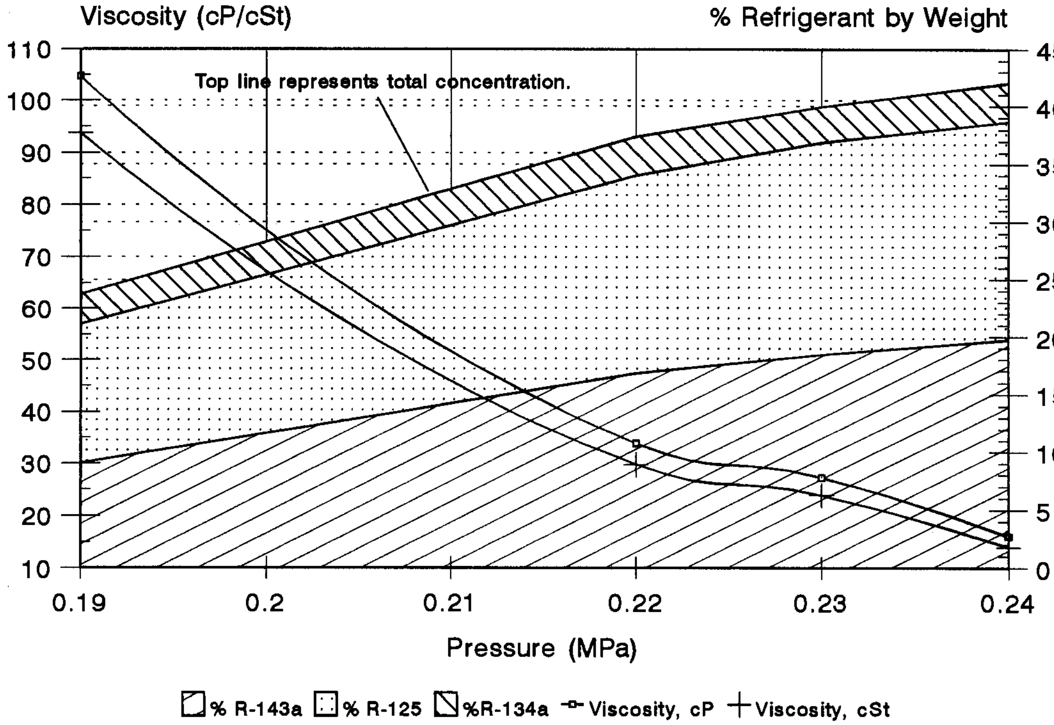


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

EMERY 2968A with R-404A at -25°C

Figure L.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
Emery 2968A with R-404A
Table L.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.862	20.00	0.14	0.6 (42/52/6)*	4.5	5.3
0.942	100.00	0.69	2.7 (43/51/6)*	3.7	4.0
0.948	166.75	1.15	4.9 (43/50/7)	3.3	3.5
0.956	226.50	1.56	6.3 (42/50/8)*	2.8	2.9
0.963	300.00	2.07	8.8 (42/44/14)*	2.5	2.6
0.975	383.00	2.64	10.7 (43/49/8)*	2.2	2.2

* Ratio of components (HFC-125/143a/134a) as percent by weight.

90°C (194°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.963	17.25	0.12	0.9 (43/49/8)*	7.0	7.3
0.970	86.00	0.59	3.9 (43/49/8)*	6.1	6.3
0.984	180.50	1.25	8.2 (44/48/8)*	4.8	4.8
0.997	238.50	1.65	10.7 (43/49/8)*	4.1	4.1
1.010	327.50	2.26	15.3 (43/49/8)*	3.4	3.3
1.020	384.00	2.65	18.8 (44/48/8)*	3.0	2.9

* Ratio of components (HFC-125/143a/134a) as percent by weight.

60°C (140°F) Temperature
416.7 psia Saturation Pressure
2.871 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.989	17.00	0.12	1.3 (47/45/8)*	14.4	14.5
1.008	94.75	0.65	8.7 (47/45/8)*	9.6	9.5
1.025	172.50	1.19	13.5 (47/43/10)*	6.4	6.3
1.044	240.75	1.66	20.5 (44/47/9)*	4.4	4.2
1.058	324.25	2.24	31.7 (48/44/8)*	2.3	2.2
1.075	389.25	2.69	47.8 (47/46/7)*	0.8	0.8

* Ratio of components (HFC-125/143a/134a) as percent by weight.

40°C (104°F) Temperature
263.7 psia Saturation Pressure
1.817 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.008	14.70	0.10	0.0 (0/0/0)*	33.2	32.9
1.023	38.25	0.26	4.6 (47/44/9)*	23.3	22.8
1.033	79.50	0.55	8.5 (49/44/7)*	16.4	15.8
1.048	130.00	0.90	17.2 (43/50/7)*	9.7	9.2
1.063	171.25	1.18	22.9 (45/47/8)*	6.0	5.6
1.079	192.00	1.32	28.3 (45/47/8)*	4.3	4.0
1.088	233.00	1.61	40.5 (45/47/8)*	2.0	1.8

* Ratio of components (HFC-125/143a/134a) as percent by weight.

20°C (68°F) Temperature
158.7 psia Saturation Pressure
1.093 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.038	23.00	0.16	7.2 (47/37/16)*	70.3	67.7
1.050	45.25	0.31	8.6 (48/41/11)*	36.3	34.5
1.061	71.25	0.49	14.3 (48/41/11)*	21.9	20.6
1.078	93.75	0.65	19.8 (48/42/10)*	13.3	12.4
1.088	119.75	0.83	28.1 (53/38/9)*	7.2	6.6
1.105	143.50	0.99	42.2 (46/47/7)*	3.2	2.9

* Ratio of components (HFC-125/143a/134a) as percent by weight.

0°C (32°F) Temperature
72.3 psia Saturation Pressure
.4981 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.066	27.00	0.19	8.0 (47/41/12)*	114.9	107.8
1.072	38.00	0.26	11.7 (49/41/10)*	75.4	70.4
1.078	46.50	0.32	13.4 (49/43/8)*	60.8	56.4
1.098	61.00	0.42	22.7 (51/41/8)*	24.1	21.9
1.110	68.00	0.47	27.0 (52/40/8)*	15.5	14.0

* Ratio of components (HFC-125/143a/134a) as percent by weight.

-10°C (14°F) Temperature
63.45 psia Saturation Pressure
.4372 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.145	61.00	0.42	43.9 (44/51/5)*	6.1	5.3
1.113	55.00	0.38	28.7 (45/48/7)*	18.5	16.6
1.109	48.00	0.33	27.2 (47/44/9)*	29.8	26.9
1.103	40.00	0.28	22.1 (49/40/11)*	57.8	52.4
1.085	30.00	0.21	17.1 (53/35/12)*	121.2	111.7

* Ratio of components (HFC-125/143a/134a) as percent by weight.

-25°C (-13°F) Temperature
36.92 psia Saturation Pressure
.2544 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.150	35.50	0.24	42.0 (45/47/8)*	16.1	14.0
1.141	33.00	0.23	38.4 (48/48/8)*	27.3	23.9
1.137	32.00	0.22	37.4 (46/45/9)*	33.9	29.8
1.117	27.00	0.19	23.8 (51/38/11)*	104.7	93.7

* Ratio of components (HFC-125/143a/134a) as percent by weight.

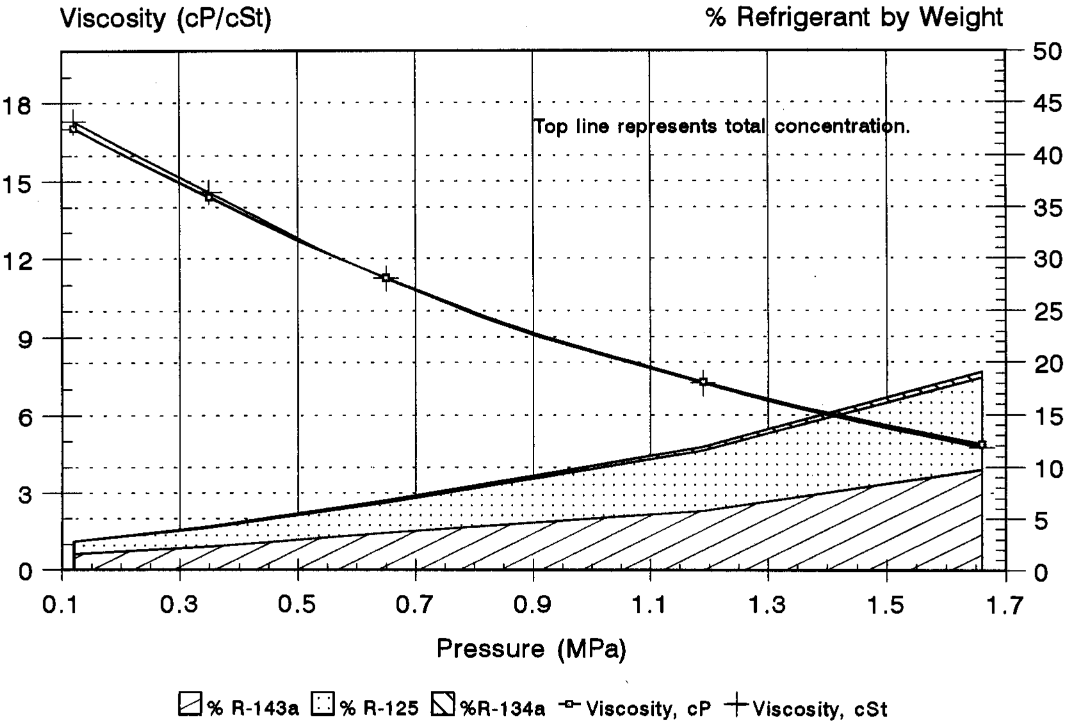
Raw Data: Unpurged Viscosity, Density, and Solubility
Emery 2968A with R−404A
Table L.2

60°C (140°F) Temperature 416.7 psia Saturation Pressure 2.87 MPa			Obtained October and November 1994			
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.* Viscometer headspace	% Refrig. Conc.* solubilized gas in lube	Viscosity cP	Viscosity cSt
0.985	17.00	0.12	2.8		17.0	17.3
			(44/54/2)	(44/54/2)		
0.987	50.00	0.35	4.2		14.4	14.6
			(44/54/2)	(44/54/2)		
1.002	94.75	0.65	6.8		11.2	11.2
			(44/53/3)	(44/53/3)		
1.007	172.50	1.19	11.8		7.3	7.2
			(45/53/2)	(49/49/2)		
1.027	240.00	1.66	19.1		4.9	4.7
			(46/51/3)	(46/51/3)		

* Data indicates ratio of wt% conc. in the order 125/143a/134a

Viscosity, Solubility, and Gas Fractionation, UNPURGED
EMERY 2968A with R-404A at 60°C

Figure L.9



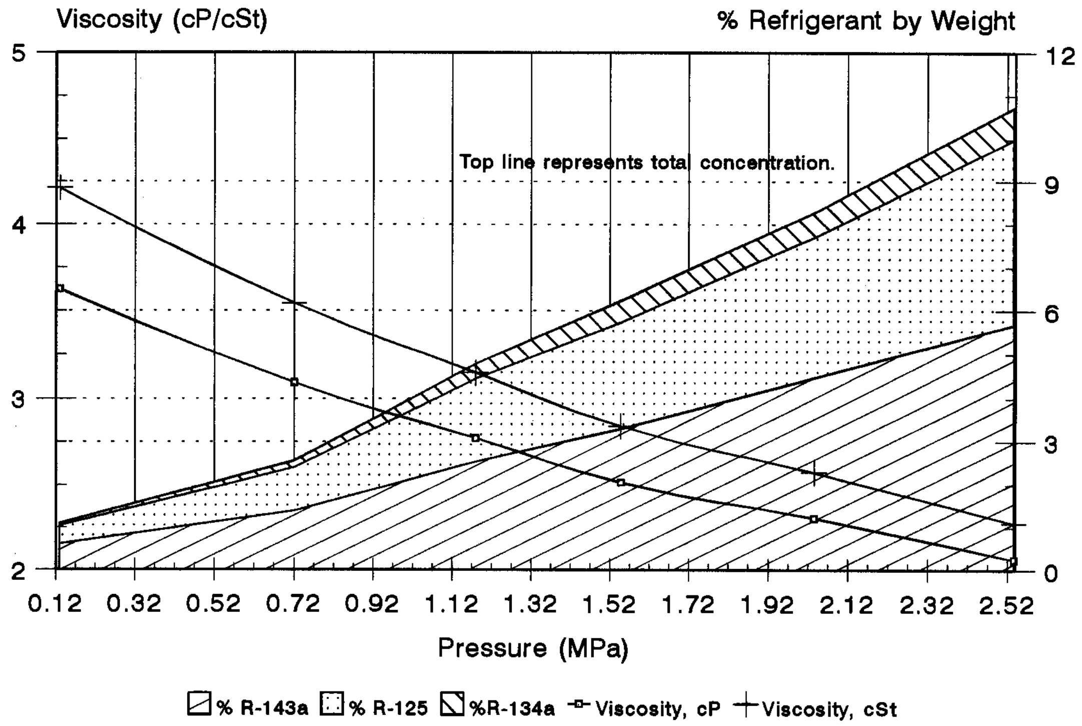
Viscosity via Gas Solubility Equilibrium

Oil degassed to 20 Millitorr

APPENDIX M
Viscosity, Density, Solubility, and Gas Fractionation of EMKARATE RL32S at Various Temperatures with R-404A

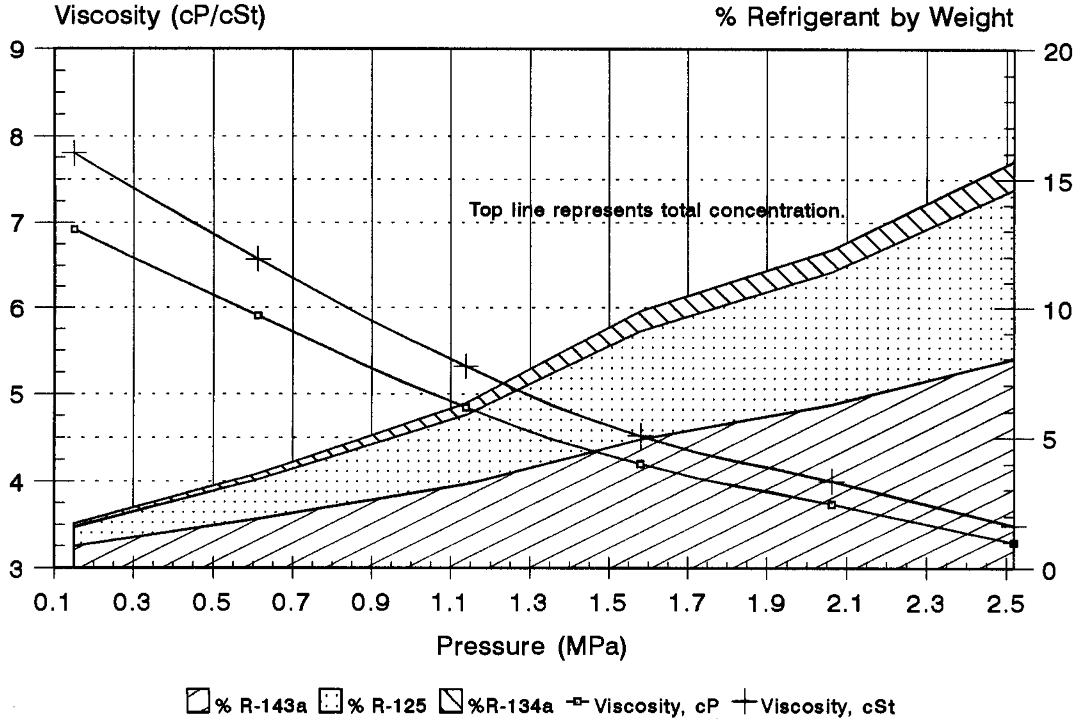
In the following graphs, the shaded areas indicate the concentrations of the blend components. These areas are cumulative, not overlapped. For example, in Figure M.1, the concentration in the lubricant of HFC-143a alone is slightly less than six percent. The concentration of HFC-125 is slightly more than four percent. The concentration of HFC-134a is approximately one percent. These areas are stacked on top of one another. The top line represents the total concentration of R-404A, at slightly less than eleven percent.

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-404A at 125°C
Figure M.1



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

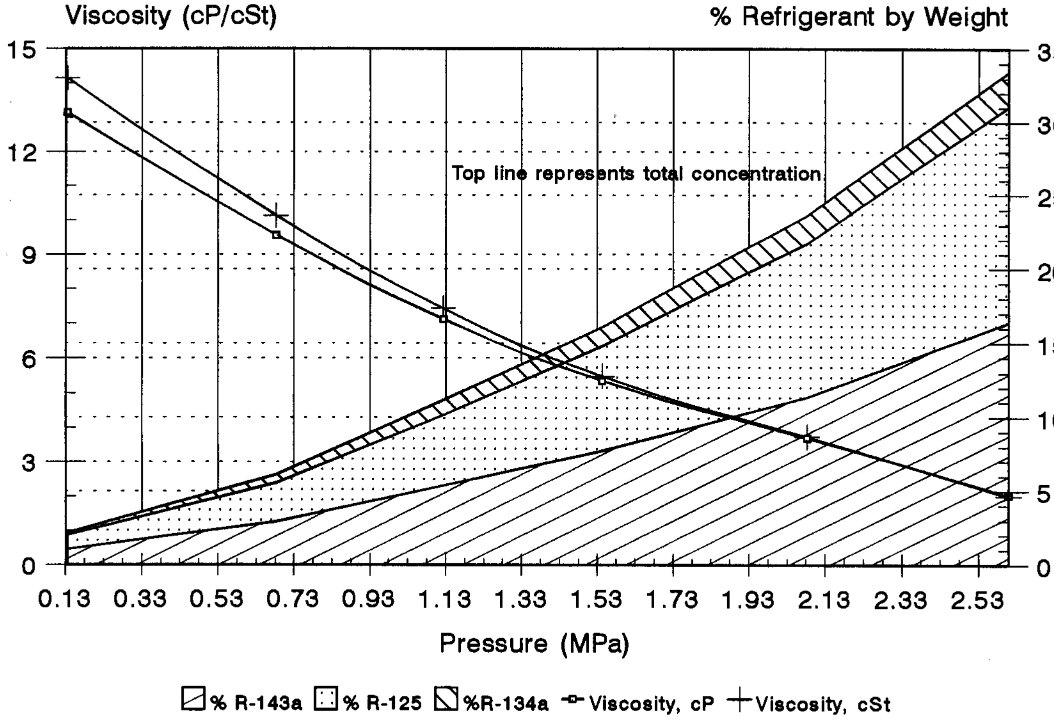
Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-404A at 90°C
Figure M.2



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-404A at 60°C

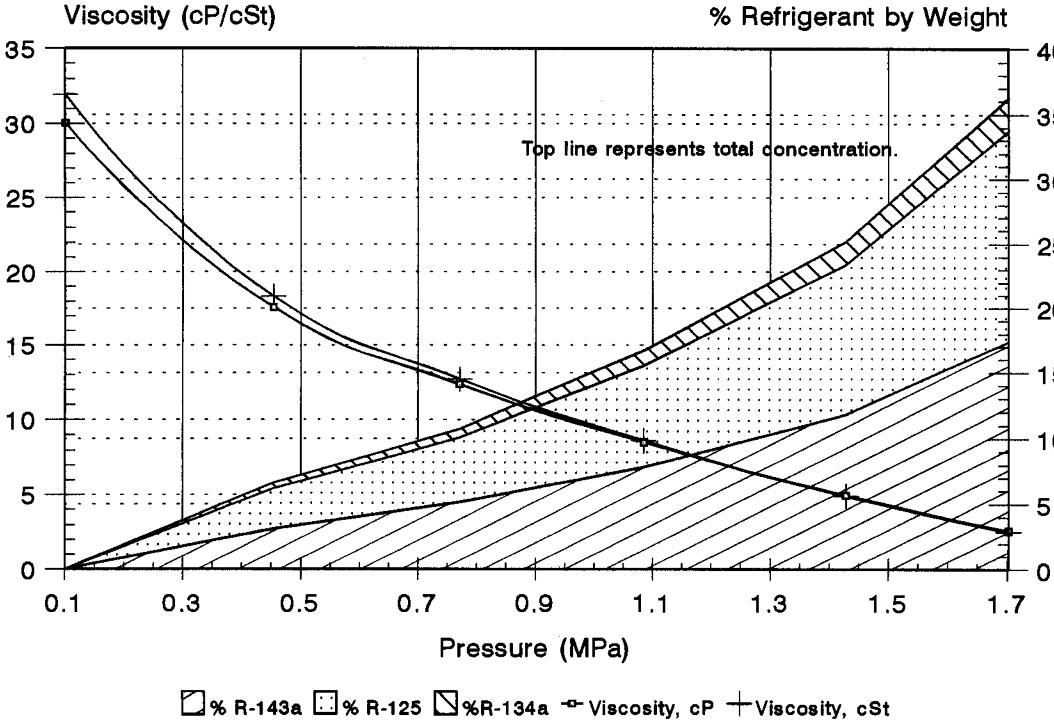
Figure M.3



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

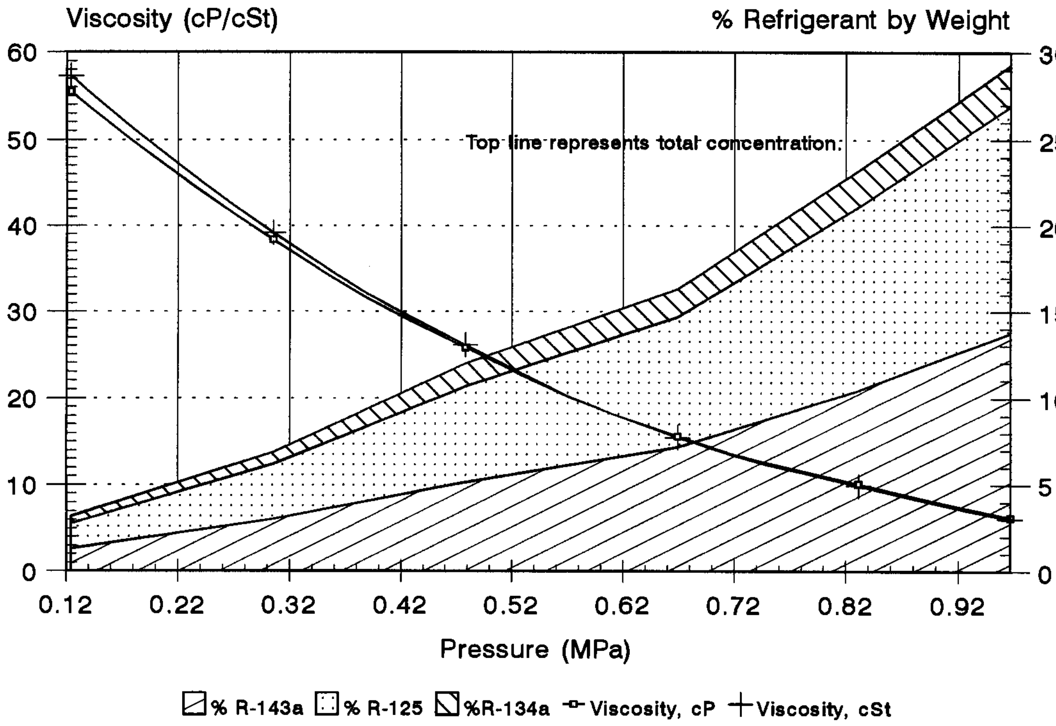
Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-404A at 40°C

Figure M.4



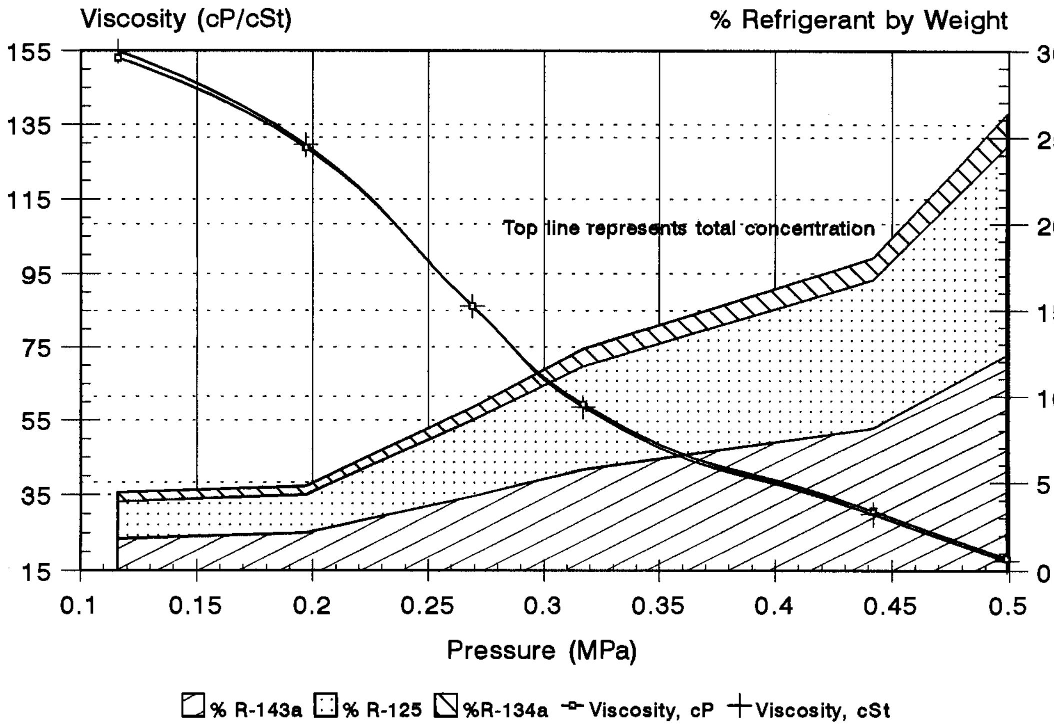
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-404A at 20°C
Figure M.5



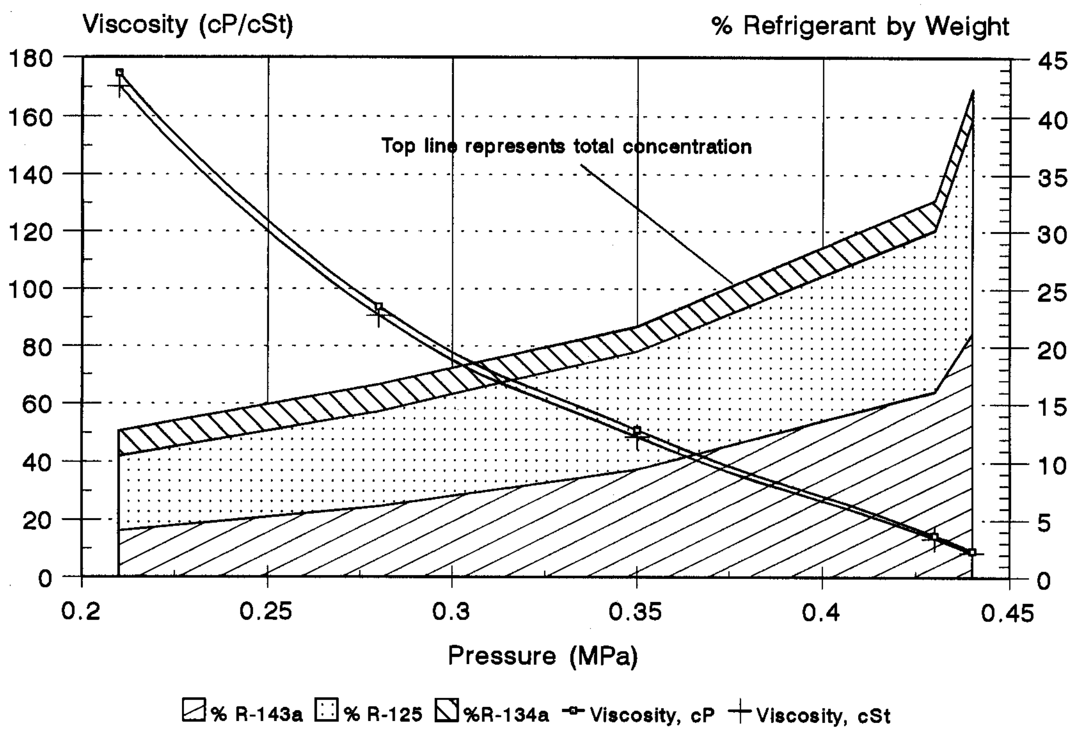
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-404A at 0°C
Figure M.6



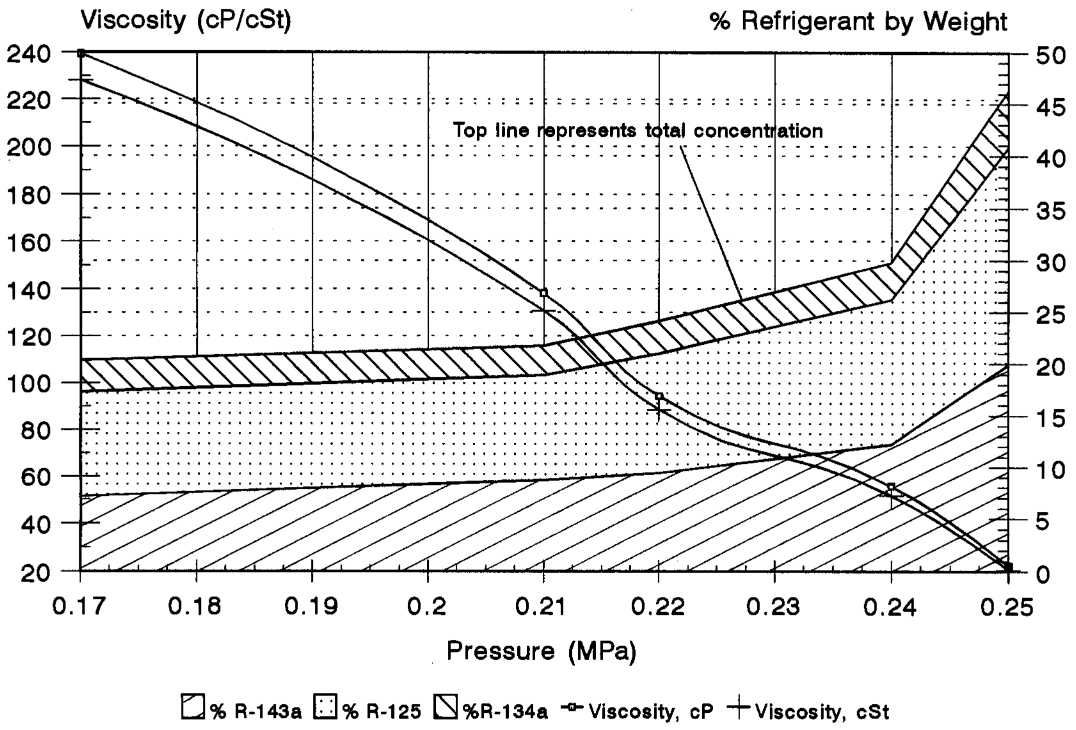
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-404A at -10°C
Figure M.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-404A at -25°C
Figure M.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
EMKARATE RL32S with R−404A
Table M.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.860	18.75	0.13	1.1 (39/55/6)*	3.6	4.2
0.872	104.50	0.72	2.6 (40/54/6)*	3.1	3.5
0.881	171.00	1.18	4.8 (40/53/7)*	2.8	3.1
0.885	224.25	1.55	6.2 (39/53/8)*	2.5	2.8
0.895	295.00	2.04	8.3 (39/54/7)*	2.3	2.6
0.906	367.50	2.54	10.7 (40/53/7)*	2.1	2.3

* Ratio of components (HFC−125/143a/134a) as percent by weight.

90°C (194°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.887	21.75	0.15	1.7 (43/49/8)*	6.9	7.8
0.898	88.75	0.61	3.6 (42/52/6)*	5.9	6.6
0.912	165.00	1.14	6.3 (42/51/7)*	4.8	5.3
0.929	229.25	1.58	9.9 (42/50/8)*	4.2	4.5
0.934	299.00	2.06	12.3 (42/51/7)*	3.7	4.0
0.944	365.00	2.52	15.7 (42/51/7)*	3.3	3.5

* Ratio of components (HFC−125/143a/134a) as percent by weight.

60°C (140°F) Temperature
416.7 psia Saturation Pressure
2.871 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.929	19.50	0.13	2.2 (43/49/8)*	13.2	14.2
0.944	99.00	0.68	6.1 (43/48/9)*	9.6	10.1
0.956	163.00	1.12	11.2 (43/48/9)*	7.1	7.4
0.976	223.50	1.54	16.1 (44/48/8)*	5.3	5.5
0.991	302.00	2.08	23.7 (44/48/8)*	3.7	3.7
1.016	378.00	2.61	33.4 (44/49/7)*	2.0	2.0

* Ratio of components (HFC−125/143a/134a) as percent by weight.

40°C (104°F) Temperature
263.7 psia Saturation Pressure
1.817 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.941	14.70	0.10	0.0 (0/0/0)*	30.1	31.9
0.947	19.25	0.13	2.4 (44/50/6)*	26.2	27.7
0.959	65.75	0.45	6.6 (46/47/7)*	17.6	18.3
0.972	111.75	0.77	10.7 (46/48/6)*	12.3	12.7
0.986	157.25	1.09	16.7 (46/47/7)*	8.5	8.6
1.008	207.00	1.43	25.2 (46/47/7)*	5.0	4.9
1.031	246.75	1.70	36.3 (45/48/7)*	2.6	2.5

* Ratio of components (HFC−125/143a/134a) as percent by weight.

20°C (68°F) Temperature
158.7 psia Saturation Pressure
1.093 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.969	16.00	0.12	3.2 (46/41/13)*	55.5	57.3
0.979	44.25	0.31	6.9 (46/44/10)*	38.4	39.2
0.988	69.25	0.48	12.0 (46/43/11)*	25.8	26.1
1.007	97.00	0.67	16.3 (46/44/10)*	15.6	15.5
1.019	120.50	0.83	23.2 (46/45/9)*	10.1	9.9
1.032	140.00	0.97	29.3 (45/47/8)*	6.2	6.0

* Ratio of components (HFC−125/143a/134a) as percent by weight.

0°C (32°F) Temperature
72.3 psia Saturation Pressure
.4981 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.988	16.75	0.12	4.4 (41/47/12)	153.0	154.9
0.994	28.50	0.20	4.8 (45/45/10)	126.8	129.6
1.001	39.00	0.27	9.3 (45/47/8)	86.3	86.2
1.013	46.00	0.32	12.8 (45/47/8)	59.4	58.6
1.028	64.00	0.44	18.0 (45/48/7)	30.8	30.0
1.042	72.30	0.50	26.3 (47/46/7)	18.3	17.6

* wt % is listed in parentheses in the order HFC−143a/125/134a

−10°C (14°F) Temperature
63.45 psia Saturation Pressure
.4371 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.060	63.45	0.44	42.4 (44/50/6)*	9.4	8.7
1.078	63.00	0.43	32.7 (43/49/8)*	14.7	13.6
1.047	50.00	0.35	21.7 (47/43/10)*	50.9	46.6
1.033	40.00	0.28	16.6 (49/37/14)*	93.6	90.8
1.025	30.00	0.21	12.6 (51/32/17)*	174.7	170.4

* Ratio of components (HFC−125/143a/134a) as percent by weight.

−25°C (−13°F) Temperature
36.92 psia Saturation Pressure
.2544 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.081	36.92	0.25	46.3 (45/43/12)*	22.4	20.7
1.078	35.00	0.24	29.8 (47/41/12)*	55.8	51.7
1.067	32.50	0.22	24.2 (48/39/13)*	94.3	88.4
1.057	30.00	0.21	21.8 (47/40/13)*	138.2	130.7
1.049	25.00	0.17	20.4 (50/35/15)*	239.3	228.1

* Ratio of components (HFC−125/143a/134a) as percent by weight.

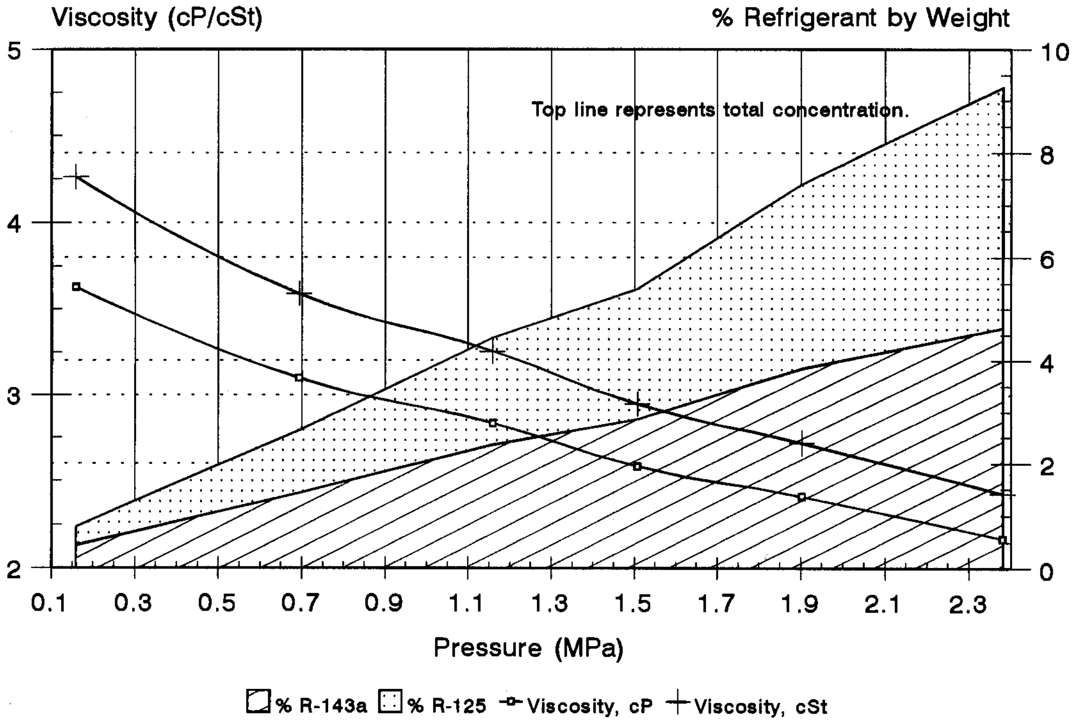
APPENDIX N
Viscosity, Density, Solubility, and Gas Fractionation of EMKARATE RL32S at Various Temperatures with R-507

In the following graphs, the shaded areas indicate the concentrations of the blend components. These areas are cumulative, not overlapped. For example, in Figure N.1, the concentration in the lubricant of HFC-143a alone is slightly more than four percent. The concentration of HFC-125 is slightly more than five percent. These areas are stacked on top of one another. The top line represents the total concentration of R-507, at slightly more than nine percent.

Viscosity, Solubility, and Gas Fractionation

EMKARATE RL32S with R-507 at 125°C

Figure N.1

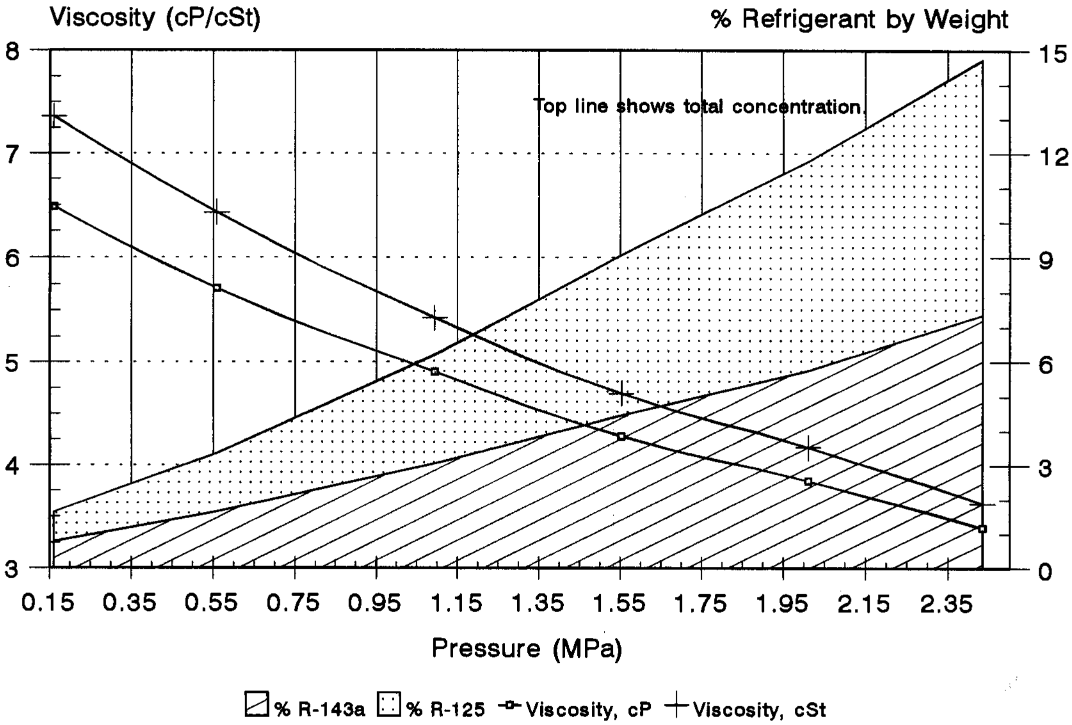


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

EMKARATE RL32S with R-507 at 90°C

Figure N.2

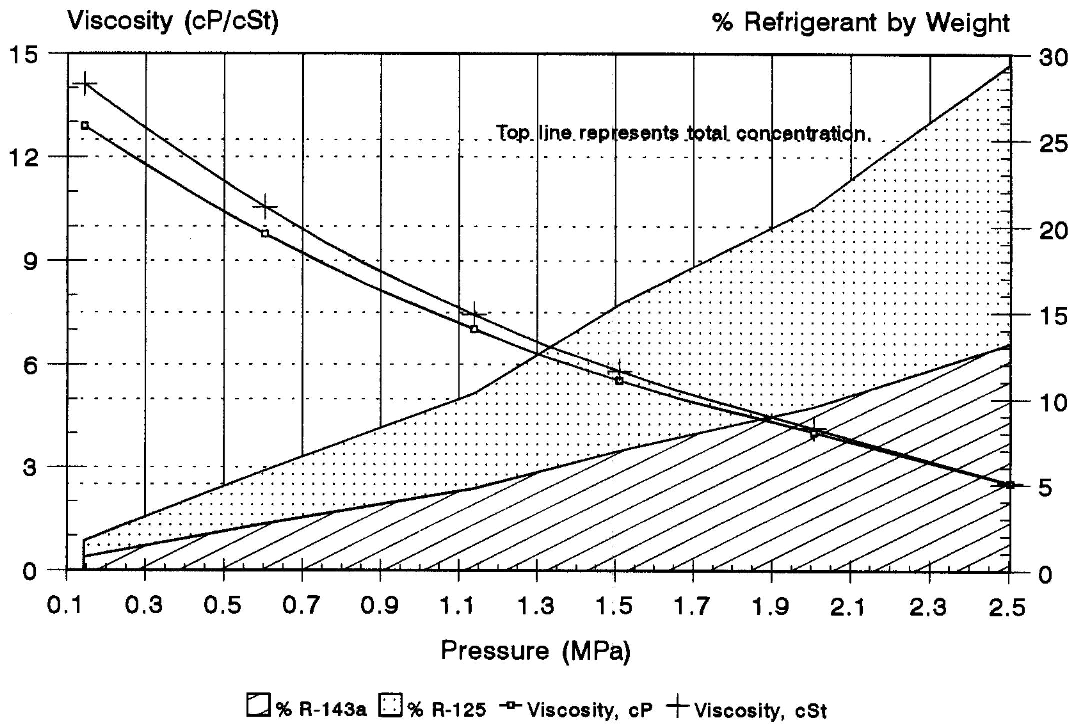


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

EMKARATE RL32S with R-507 at 60°C

Figure N.3

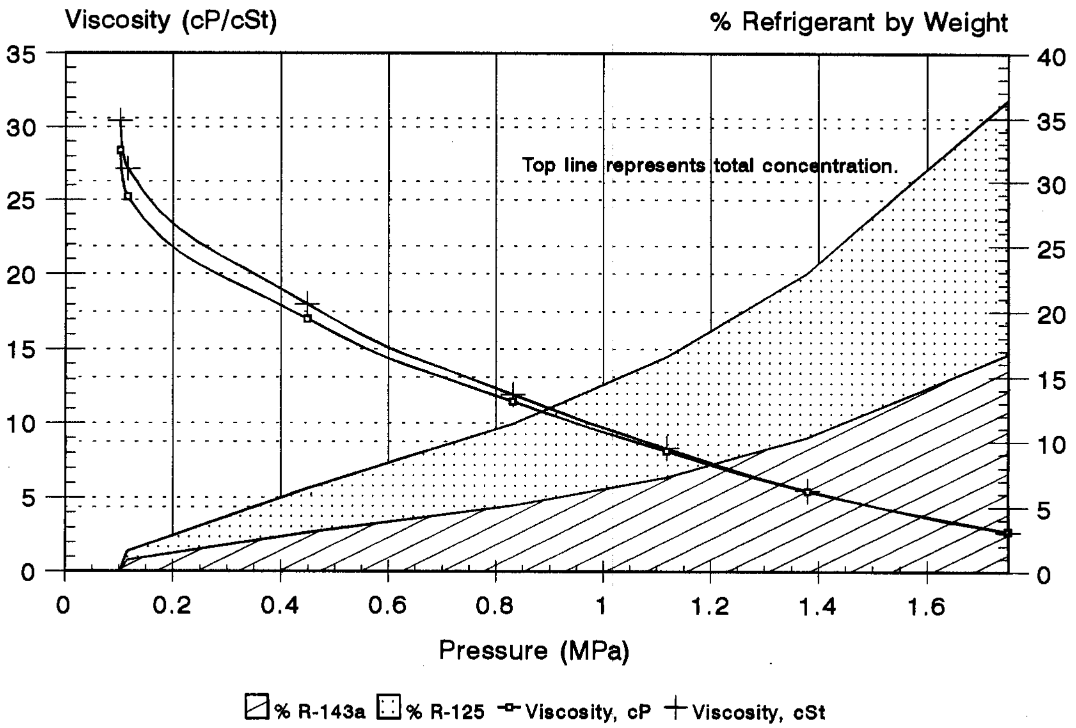


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

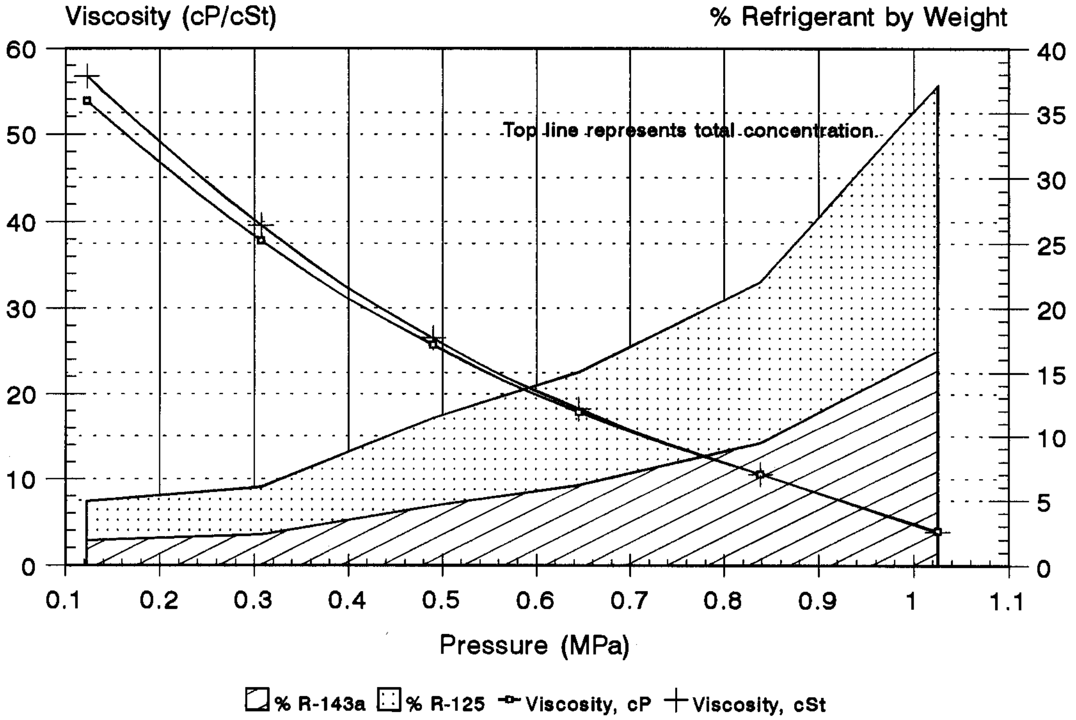
EMKARATE RL32S with R-507 at 40°C

Figure N.4



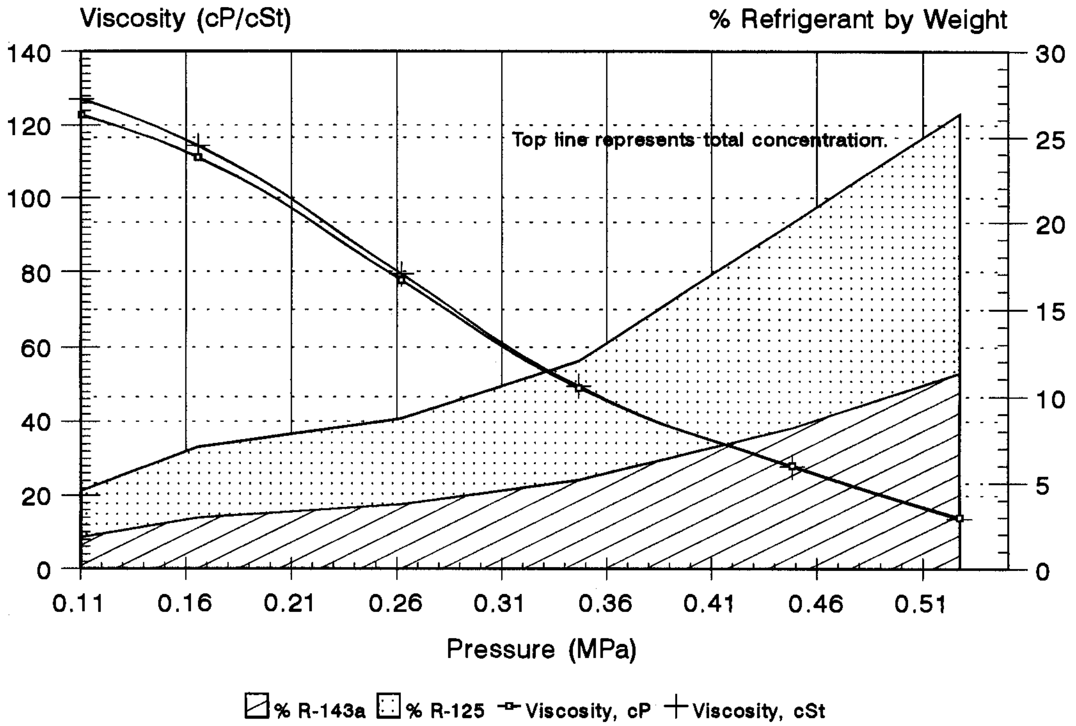
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-507 at 20°C
Figure N.5



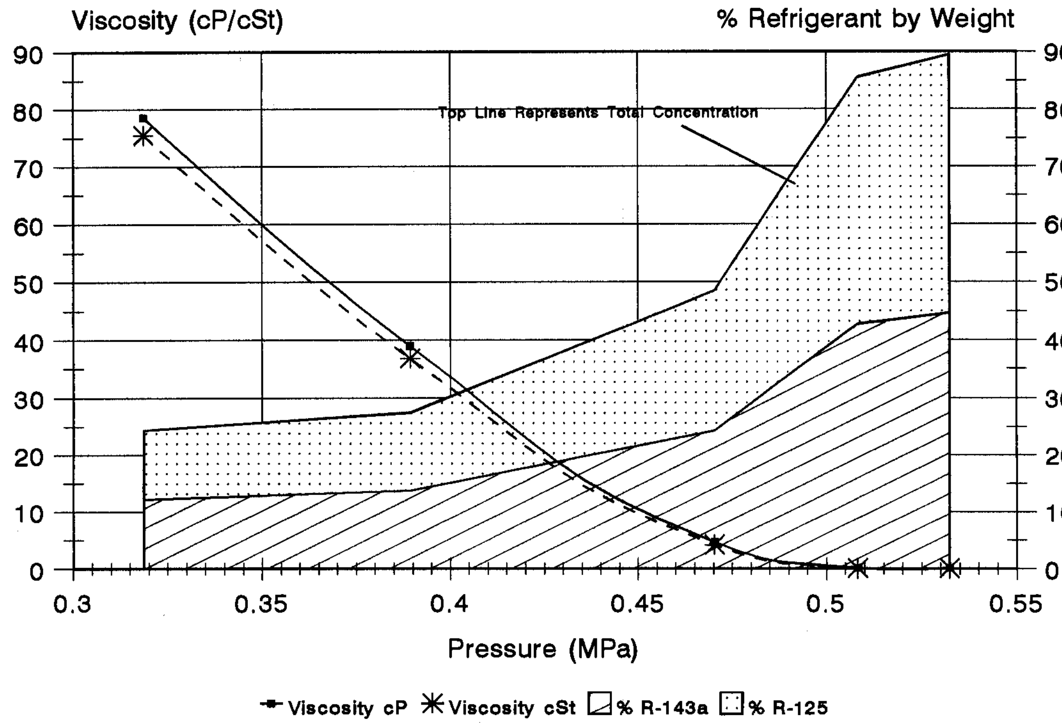
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-507 at 0°C
Figure N.6



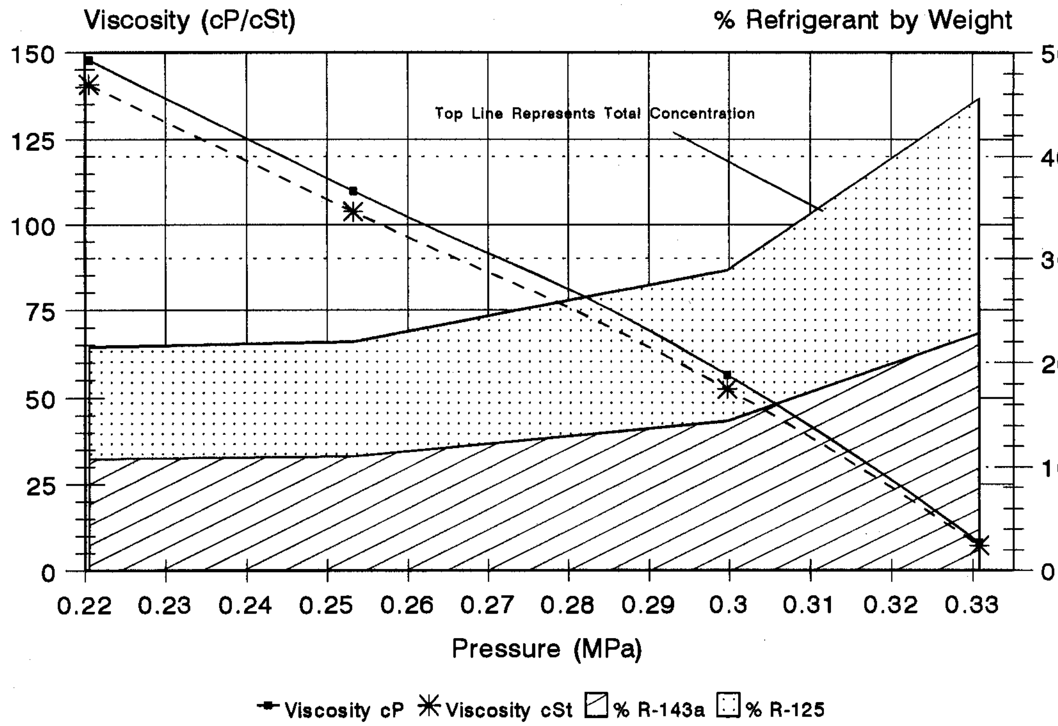
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity Solubility, and Gas Fractionation
EMKARATE RL32S with R-507 at -5°C
Figure N.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-507 at -19°C
Figure N.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
EMKARATE RL32S with R−507
Table N.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.894	345.00	2.38	9.3 (50/50)	2.2	2.4
0.887	275.75	1.90	7.4 (52/48)	2.4	2.7
0.876	218.50	1.51	5.4 (53/47)	2.6	2.9
0.870	168.00	1.16	4.4 (53/47)	2.8	3.3
0.863	100.50	0.69	2.6 (54/46)	3.1	3.6
0.851	23.00	0.16	0.8 (55/45)	3.6	4.3

* Ratio of components (143a/125) as wt%

90°C (194°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.881	23.25	0.16	1.6 (47/53)	6.5	7.4
0.888	81.00	0.56	3.3 (49/51)	5.7	6.4
0.904	158.50	1.09	6.2 (49/51)	4.9	5.4
0.912	225.00	1.55	9.1 (49/51)	4.3	4.7
0.922	291.50	2.01	11.8 (49/51)	3.8	4.2
0.935	352.75	2.43	14.7 (50/50)	3.4	3.6

* Ratio of components (143a/125) as wt%

60°C (140°F) Temperature
433.4 psia Saturation Pressure
2.986 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.994	363.00	2.50	29.4 (45/55)	2.5	2.5
0.972	291.00	2.01	21.1 (45/55)	4.0	4.1
0.953	219.00	1.51	15.5 (45/55)	5.5	5.8
0.944	165.00	1.14	10.3 (46/54)	7.0	7.4
0.926	87.50	0.60	5.8 (46/54)	9.8	10.6
0.913	20.75	0.14	1.7 (46/54)	12.9	14.1

* Ratio of components (143a/125) as wt%

40°C (104°F) Temperature
274.46 psia Saturation Pressure
1.891 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.934	14.70	0.10	0.0 (0/0)	28.4	30.4
0.929	16.75	0.12	1.6 (55/45)	25.2	27.1
0.945	65.00	0.45	6.4 (47/52)	17.0	18.0
0.960	120.50	0.83	11.4 (45/55)	11.5	11.9
0.976	162.00	1.12	16.5 (44/56)	8.1	8.3
0.991	200.00	1.38	23.0 (45/55)	5.4	5.5
1.019	253.50	1.75	36.4 (46/54)	2.7	2.7

* Ratio of components (143a/125) as wt%

20°C (68°F) Temperature
163.3 psia Saturation Pressure
1.125 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.032	148.60	1.03	37.1 (45/55)	4.0	3.8
1.000	121.50	0.84	22.0 (43/57)	10.5	10.5
0.981	93.50	0.65	15.0 (41/59)	17.8	18.2
0.970	71.00	0.49	11.4 (40/60)	25.7	26.5
0.956	44.50	0.31	6.2 (39/61)	37.8	39.6
0.948	17.75	0.12	4.9 (39/61)	53.8	56.8

* Ratio of components (143a/125) as wt%

0°C (32°F) Temperature
90.04 psia Saturation Pressure
.6203 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.966	16.00	0.11	4.6 (40/60)	122.8	127.1
0.972	24.00	0.17	7.1 (42/58)	111.1	114.3
0.979	36.00	0.26	8.7 (43/57)	77.7	79.4
0.989	50.25	0.35	12.0 (43/57)	49.0	49.5
1.006	65.00	0.45	20.0 (41/59)	26.1	27.6
1.029	76.40	0.53	26.4 (43/57)	14.0	13.6

* Ratio of components (143a/125) as wt%

−5°C (23°F) Temperature
77.25 psia Saturation Pressure
.5322 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.2007	77.25	0.53	69.5 (50/50)	0.1	0.1
1.1964	73.75	0.51	85.6 (50/50)	0.1	0.1
1.1106	68.25	0.47	48.5 (50/50)	4.6	4.2
1.0586	56.5	0.39	27.4 (50/50)	39.0	36.8
1.0417	46.25	0.32	24.3 (50/50)	78.6	75.5

* Ratio of components (143a/125) as wt%

−19°C (−2.2°F) Temperature
48.0 psia Saturation Pressure
.3307 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity (cP)	Viscosity (cSt)
1.1175	48	0.33	45.6 (50/50)	8.1	7.2
1.0769	43.5	0.30	28.8 (50/50)	56.5	52.4
1.0588	36.75	0.25	20.0 (50/50)	109.9	103.8
1.0496	32	0.22	21.5 (50/50)	147.7	140.7

* Ratio of components (143a/125) as wt%

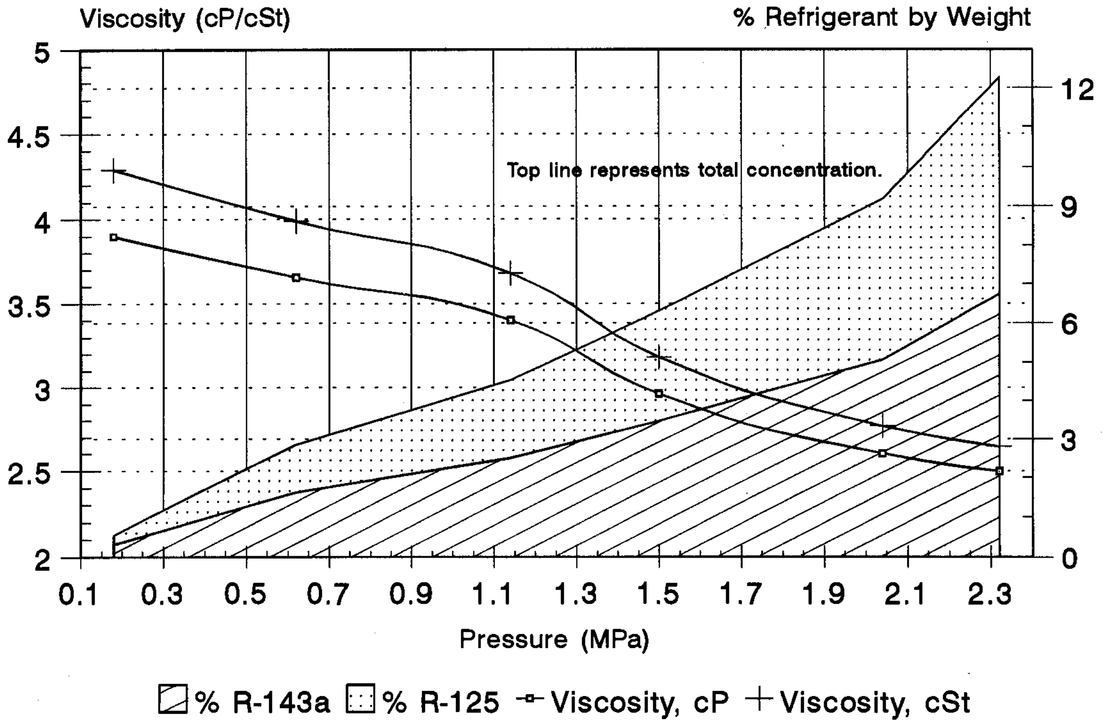
APPENDIX O
Viscosity, Density, Solubility, and Gas Fractionation of Emery 2968A at Various Temperatures with R-507

In the following graphs, the shaded areas indicate the concentrations of the blend components. These areas are cumulative, not overlapped. For example, in Figure O.1**,** the concentration of HFC-143a alone is slightly more than six percent. The concentration of HFC-125 is also about six percent. These areas are stacked on top of one another. The top line represents the total concentration of R-507, slightly more than twelve percent.

Viscosity, Solubility, and Gas Fractionation

EMERY 2968A with R-507 at 125°C

Figure O.1

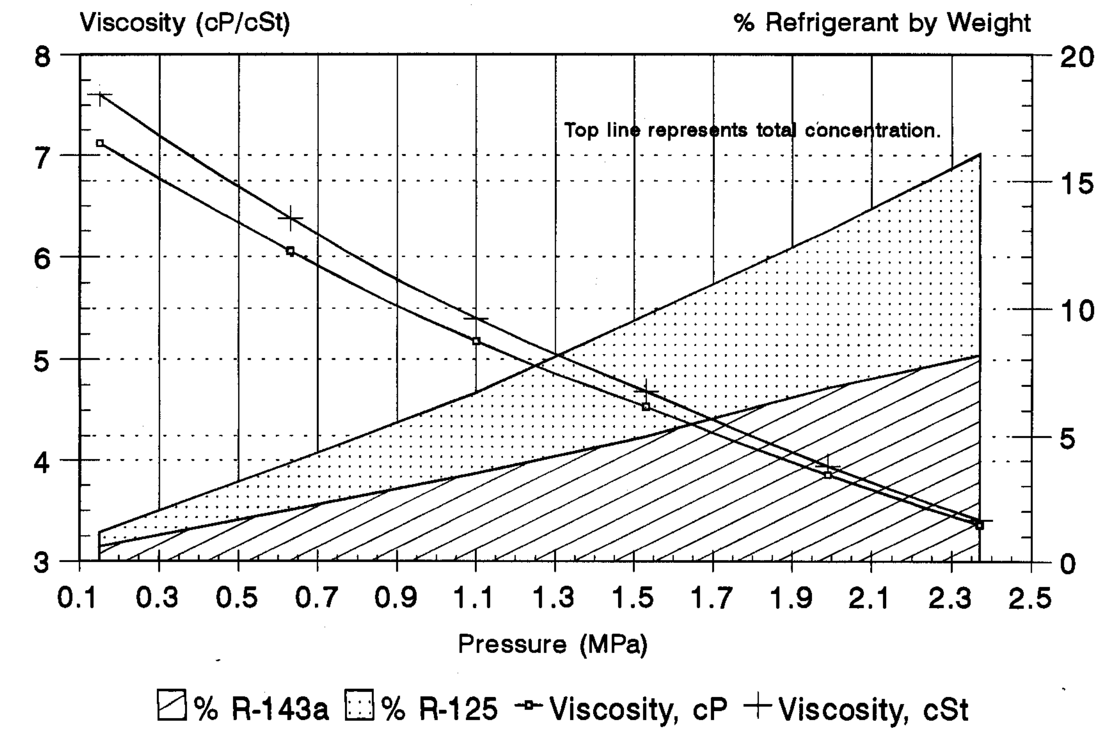


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

EMERY 2968A with R-507 at 90°C

Figure O.2

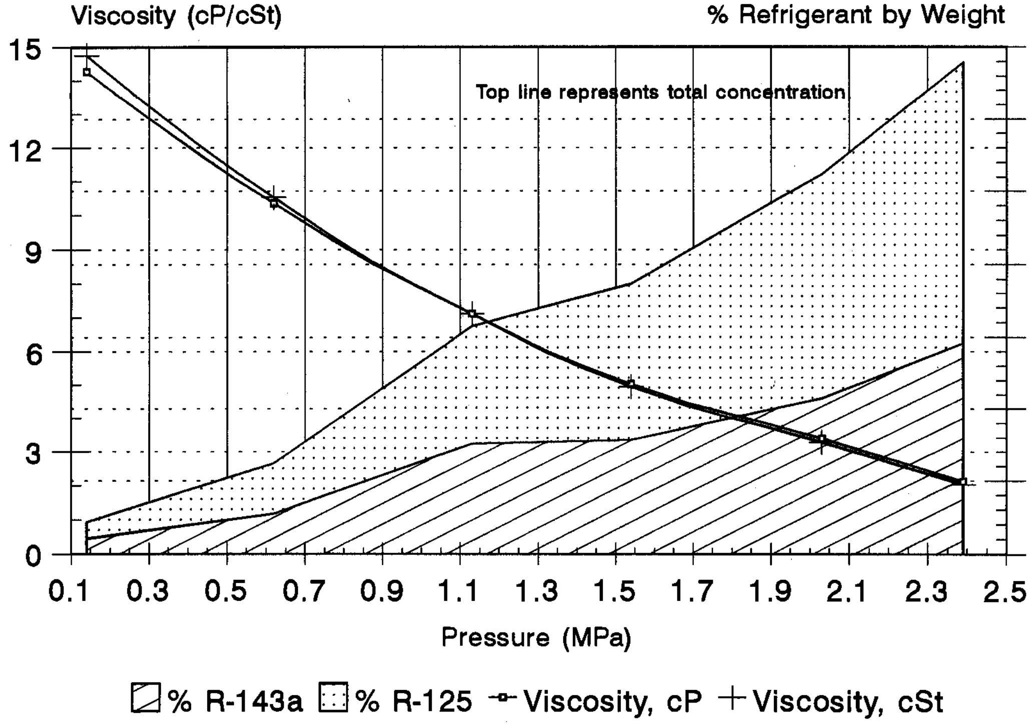


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

EMERY 2968A with R-507 at 60°C

Figure O.3

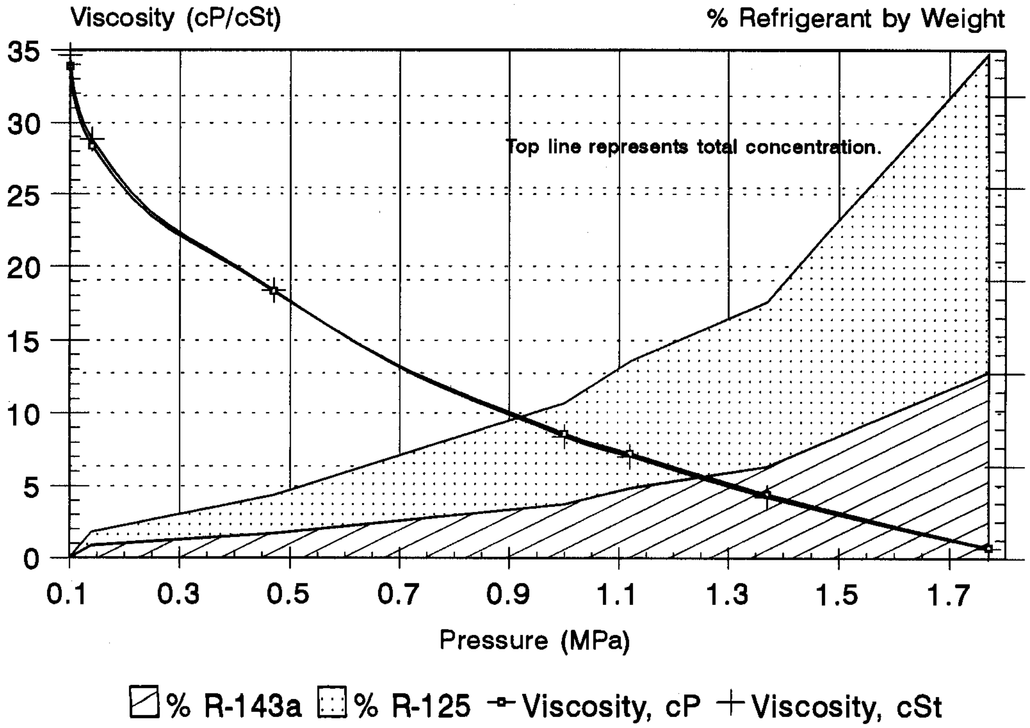


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

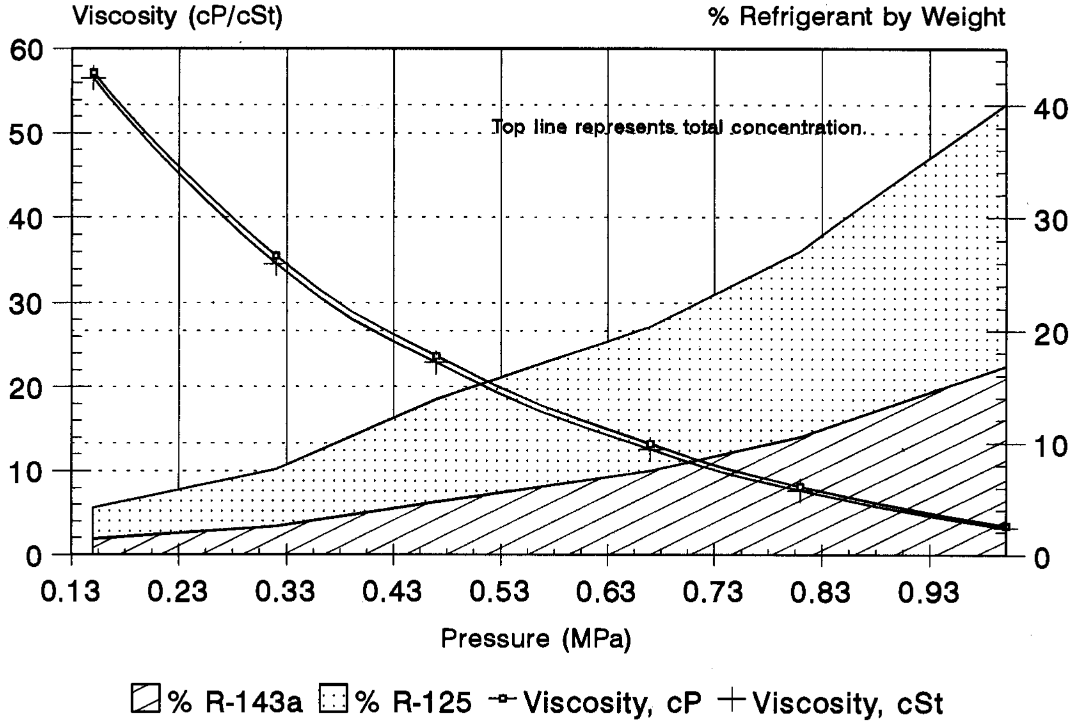
EMERY 2968A with R-507 at 40°C

Figure O.4



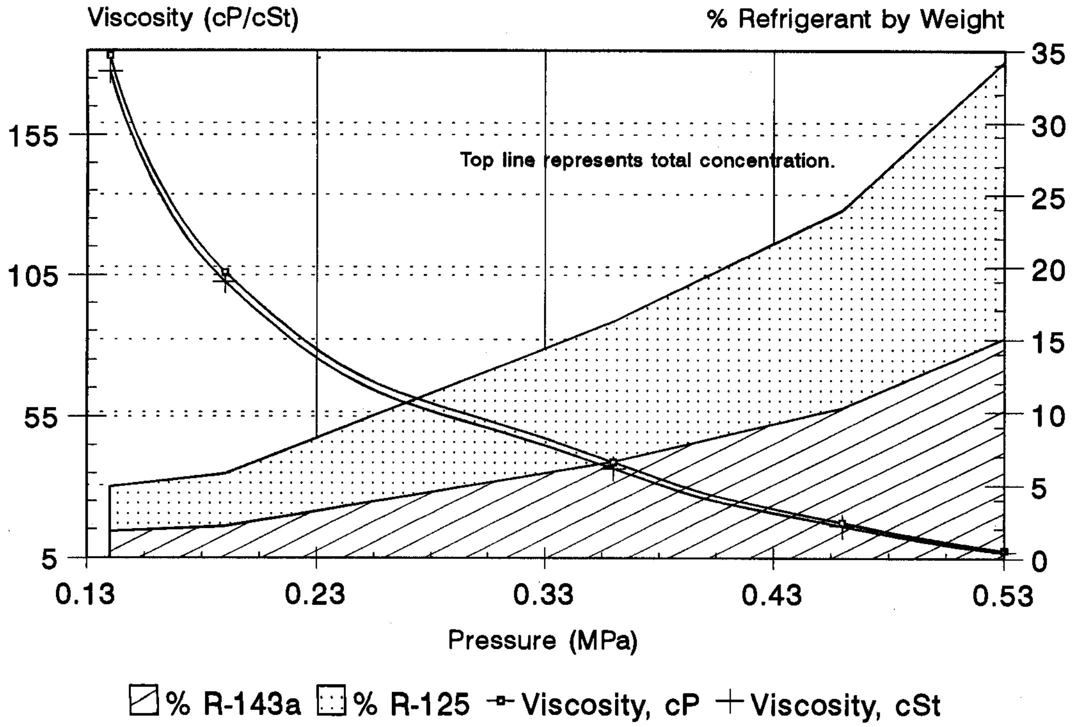
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-507 at 20°C
Figure O.5



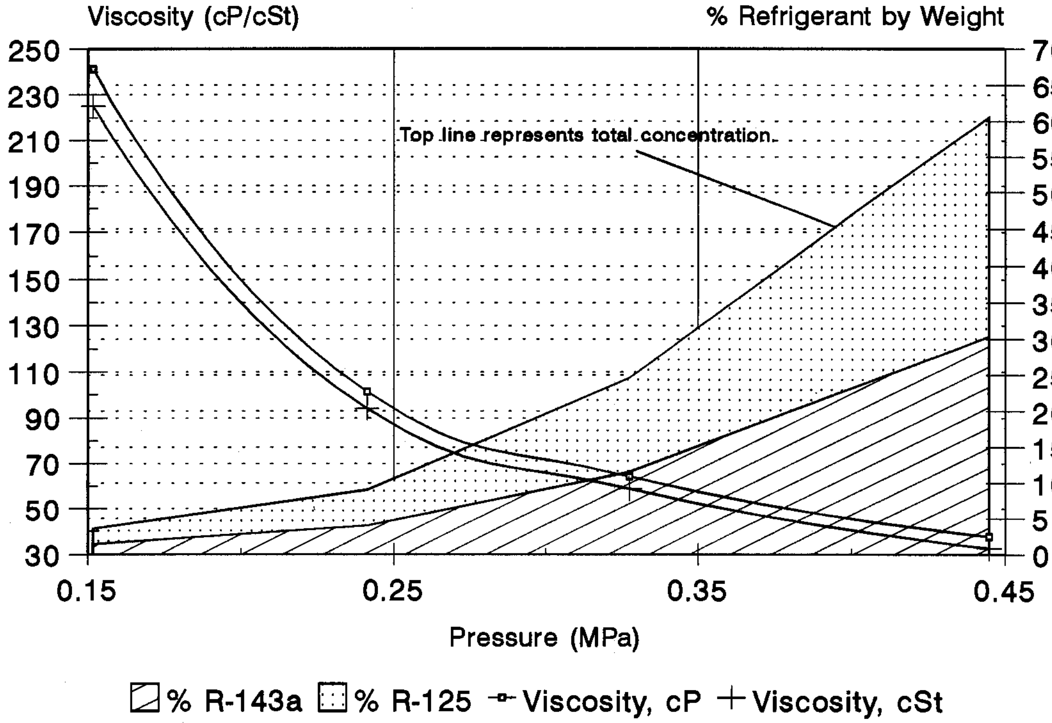
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-507 at 0°C
Figure O.6



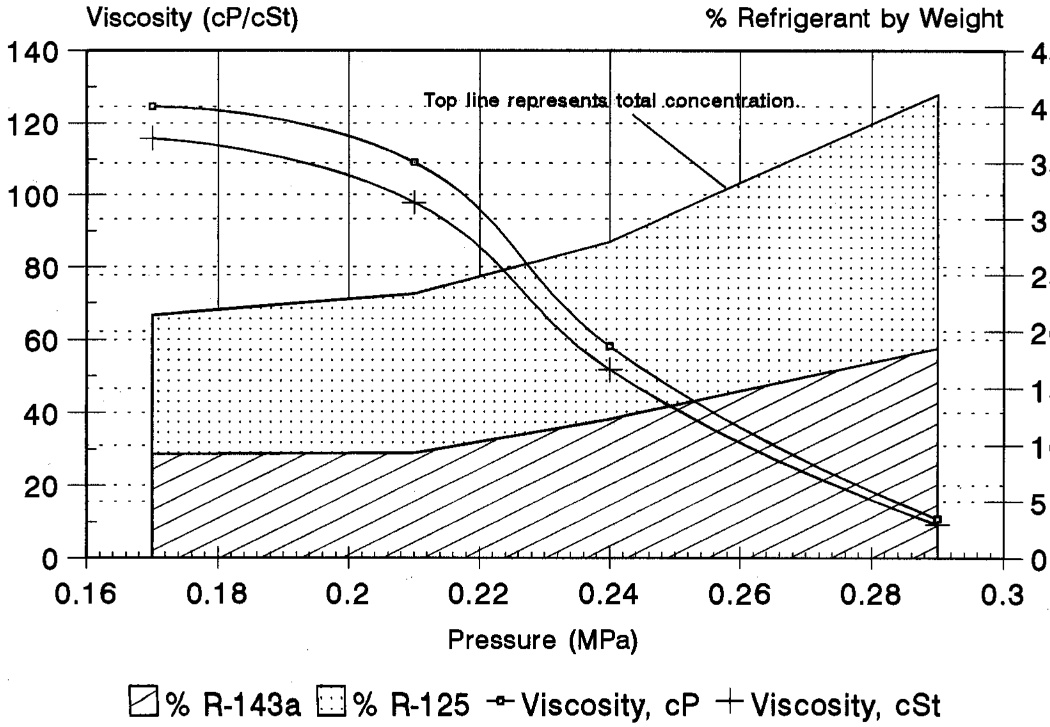
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-507 at -10°C
Figure O.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-507 at -20°C
Figure O.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
Emery 2968A with R-507
Table O.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.944	336.50	2.32	12.3 (55/45)	2.5	2.6
0.939	296.50	2.04	9.2 (55/45)	2.6	2.8
0.931	218.00	1.50	6.3 (55/45)	3.0	3.2
0.925	165.50	1.14	4.5 (55/45)	3.4	3.7
0.916	90.50	0.62	2.6 (57/43)	3.7	4.0
0.909	26.50	0.18	0.5 (57/43)	3.9	4.3

*Wt.% refrigerant is given in parentheses in the order HFC-143a/125

90°C (194°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.937	21.75	0.15	1.1 (51/49)	7.1	7.6
0.950	90.75	0.63	3.9 (52/48)	6.1	6.4
0.959	159.25	1.10	6.7 (52/48)	5.2	5.4
0.967	222.00	1.53	9.7 (51/49)	4.5	4.7
0.978	288.00	1.99	13.0 (53/47)	3.9	3.9
0.986	343.75	2.37	16.1 (51/49)	3.4	3.4

*Wt.% refrigerant is given in parentheses in the order HFC-143a/125

60°C (140°F) Temperature
418.7 psia Saturation Pressure
2.885 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.047	346.75	2.39	33.9 (43/57)	2.1	2.0
1.032	294.00	2.03	26.2 (41/59)	3.4	3.3
1.016	223.00	1.54	18.7 (42/58)	5.0	5.0
1.001	164.25	1.13	15.7 (48/52)	7.1	7.1
0.984	90.00	0.62	6.2 (44/56)	10.4	10.5
0.967	21.00	0.14	2.2 (48/52)	14.3	14.8

*Wt.% refrigerant is given in parentheses in the order HFC-143a/125

40°C (104°F) Temperature
257.9 psia Saturation Pressure
1.777 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.978	14.70	0.10	0.0 (0/0)	33.9	34.6
0.984	20.00	0.14	2.8 (48/52)	28.4	28.8
0.997	67.50	0.47	6.9 (39/61)	16.3	16.4
1.025	145.00	1.00	16.8 (35/65)	6.6	6.4
1.029	162.00	1.12	21.3 (36/64)	7.2	7.0
1.047	198.00	1.37	27.7 (36/64)	4.5	4.3
1.070	256.50	1.77	54.5 (37/63)	0.8	0.7

*Wt.% refrigerant is given in parentheses in the order HFC-143a/125

20°C (68°F) Temperature
148.6 psia Saturation Pressure
1.024 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.083	145.00	1.00	40.1 (42/58)	3.5	3.2
1.063	117.50	0.81	27.1 (39/61)	8.2	7.7
1.051	97.75	0.67	20.4 (37/63)	13.2	12.6
1.035	68.25	0.47	13.9 (34/66)	23.7	22.9
1.026	46.00	0.32	7.6 (33/67)	35.5	34.6
1.011	21.75	0.15	4.2 (33/67)	57.2	56.5

*Wt.% refrigerant is given in parentheses in the order HFC-143a/125

0°C (32°F) Temperature
76.4 psia Saturation Pressure
.5264 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.032	20.50	0.14	4.9 (37/63)	183.2	177.5
1.033	27.50	0.19	5.8 (37/63)	105.9	102.4
1.039	42.00	0.29	6.2 (38/62)	88.4	85.1
1.061	51.75	0.36	16.2 (41/59)	38.9	36.7
1.076	67.00	0.46	23.9 (43/57)	17.4	16.2
1.098	76.40	0.53	34.3 (44/56)	7.8	7.1

*Wt.% refrigerant is given in parentheses in the order HFC-143a/125

-10°C (14°F) Temperature
65.7 psia Saturation Pressure
.4526 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.158	64.50	0.44	60.6 (50/50)	37.6	32.6
1.092	47.50	0.33	24.7 (47/53)	64.3	58.9
1.078	35.00	0.24	9.0 (44/56)	101.4	94.1
1.072	22.00	0.15	3.6 (40/60)	241.3	225.1

*Wt.% refrigerant is given in parentheses in the order HFC-143a/125

-20°C (-13°F) Temperature
46.0 psia Saturation Pressure
.3169 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.076	25.00	0.17	21.4 (43/57)	124.5	115.7
1.114	30.00	0.21	23.3 (40/60)	109.0	97.9
1.122	35.00	0.24	28.0 (44/56)	58.1	51.8
1.163	42.00	0.29	41.1 (45/55)	10.8	9.3

*Wt.% refrigerant is given in parentheses in the order HFC-143a/125

Raw Data: Unpurged Viscosity, Density, and Solubility
Emery 2968A with R−507
Table O.2

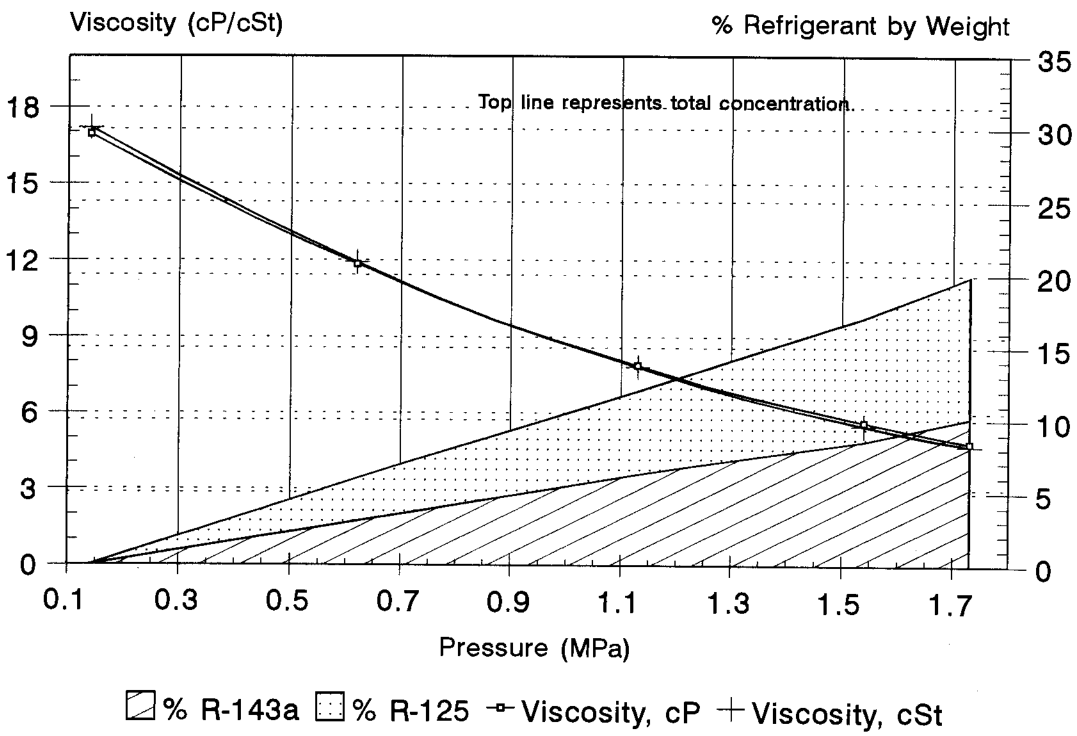
60°C (140°F) Temperature 433.4 psia Saturation Pressure 2.986 MPa			Obtained October and November 1994			
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.* Viscometer headspace	% Refrig. Conc.* solubilized gas in lube	Viscosity cP	Viscosity cSt
0.985	21.00	0.14	3.1		16.9	17.2
			no data	no data		
0.993	90.00	0.62	6.0		11.8	11.9
			(49/51)	(49/51)		
1.008	164.25	1.13	12		7.9	7.8
			(46/54)	(48/52)		
1.025	223.00	1.54	17.1		5.6	5.5
			(47/53)	(50/50)		
1.026	250.00	1.72	19.9		4.8	4.7
			(47/53)	(49/51)		

* Data indicates ratio of wt.% conc. in the order 125/143a

Viscosity, Solubility, and Gas Fractionation, UNPURGED

EMERY 2968A with R-507 at 60°C

Figure O.9



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

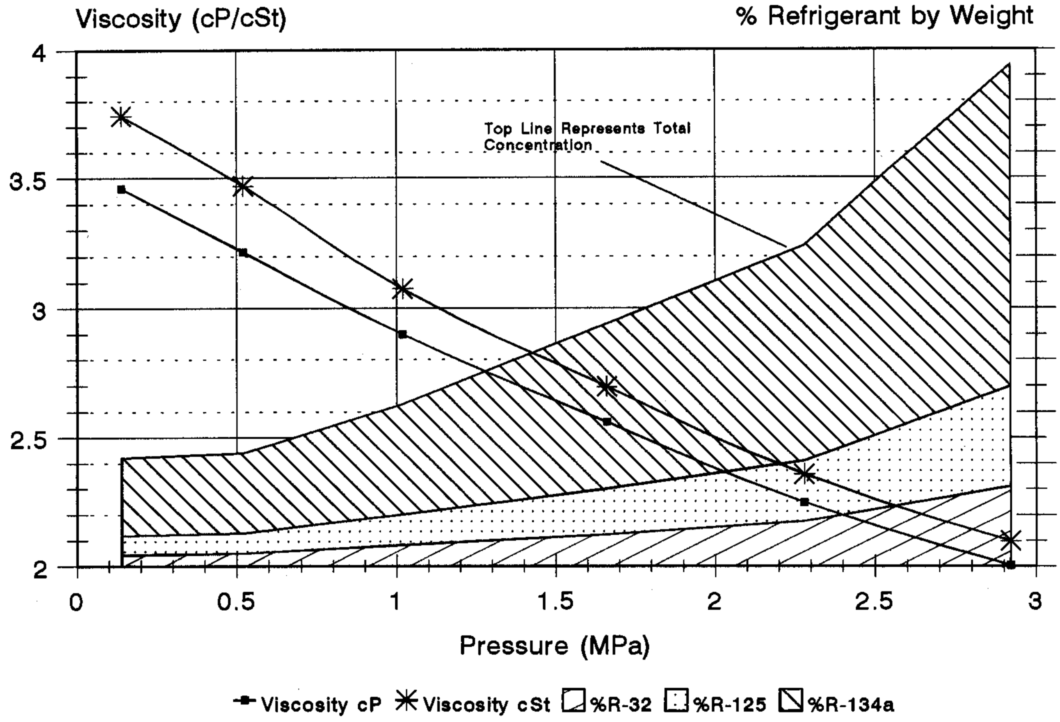
APPENDIX P
Viscosity, Density, Solubility, and Gas Fractionation of Emery 2968A at Various Temperatures with R-407C

In the following graphs, the shaded areas indicate the concentrations of the blend components. These areas are cumulative, not overlapped. For example, in Figure P.1, the concentration in the lubricant of HFC-134 at 1 MPa is sixty-eight percent. The concentration of HFC-125 is nineteen percent. These areas are stacked on top of one another. The top line represents the total concentration of R-407C, at slightly more than nine percent.

Viscosity, Solubility, and Gas Fractionation

EMERY 2968A with R-407C at 125°C

Figure P.1

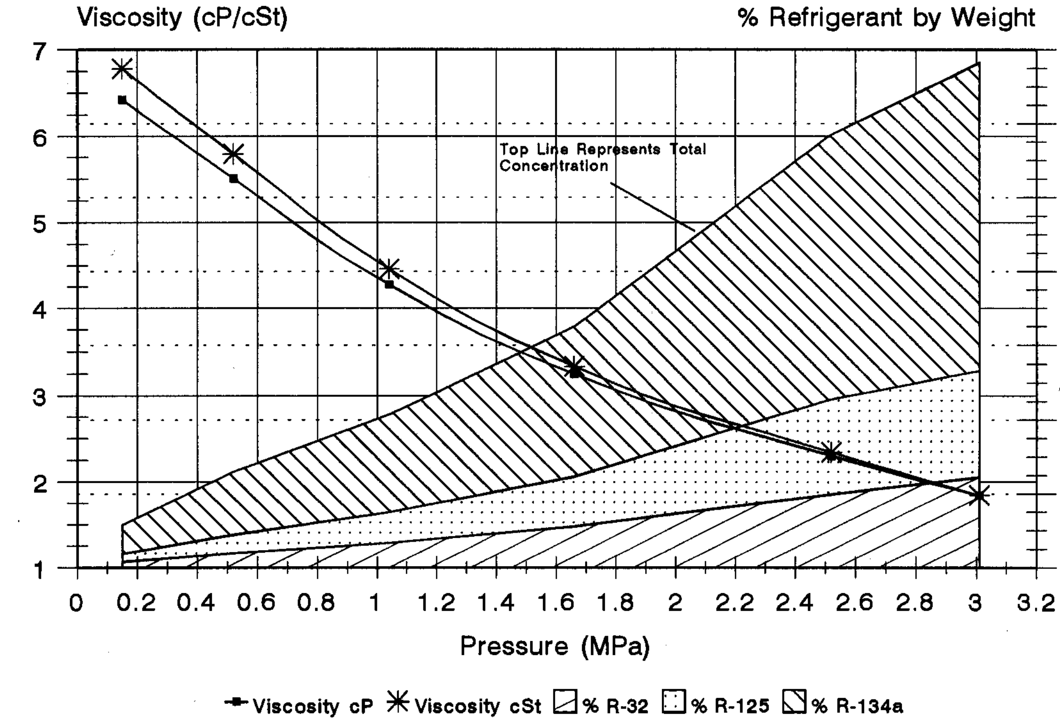


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

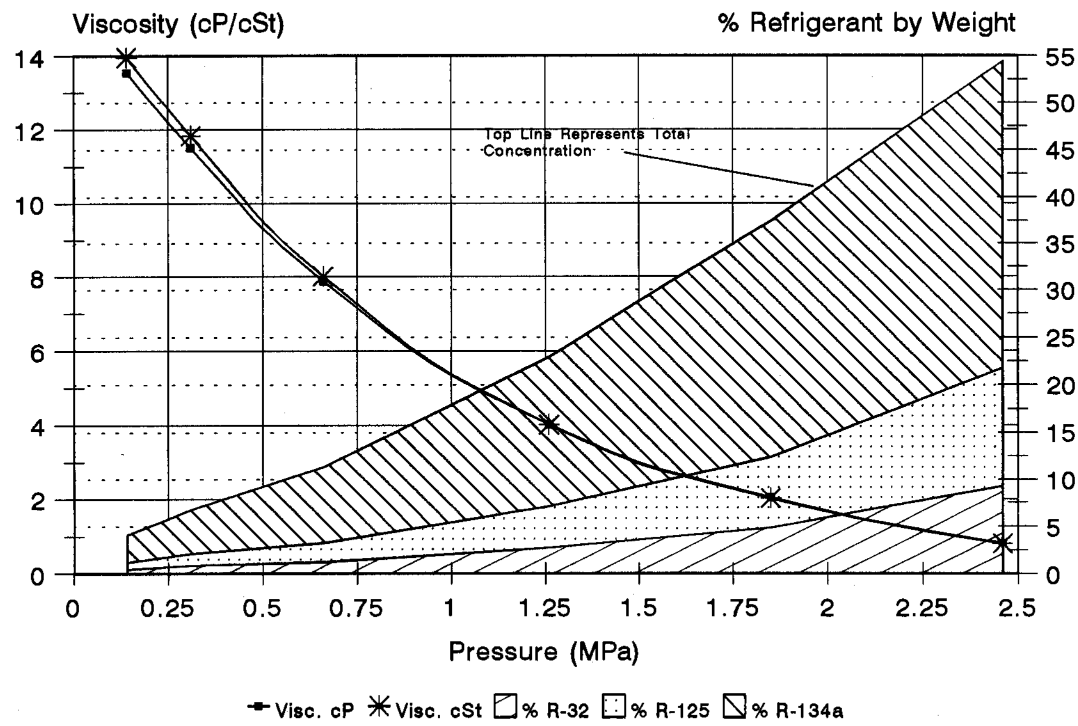
EMERY 2968A with R-407C at 90°C

Figure P.2



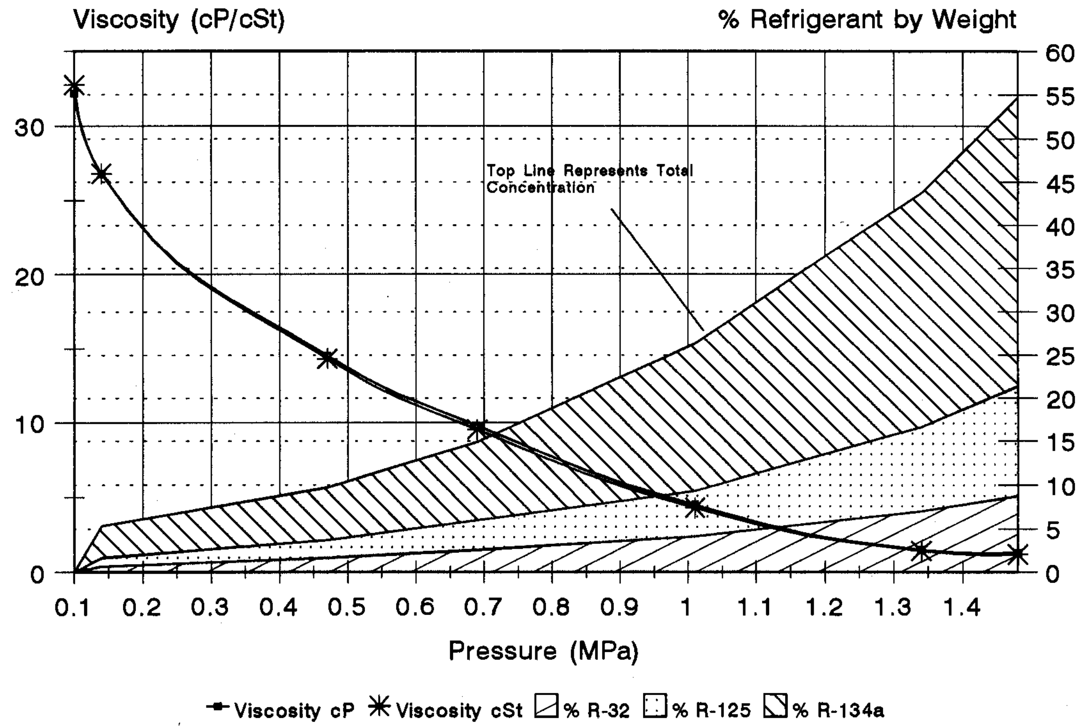
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-407C at 60°C
Figure P.3



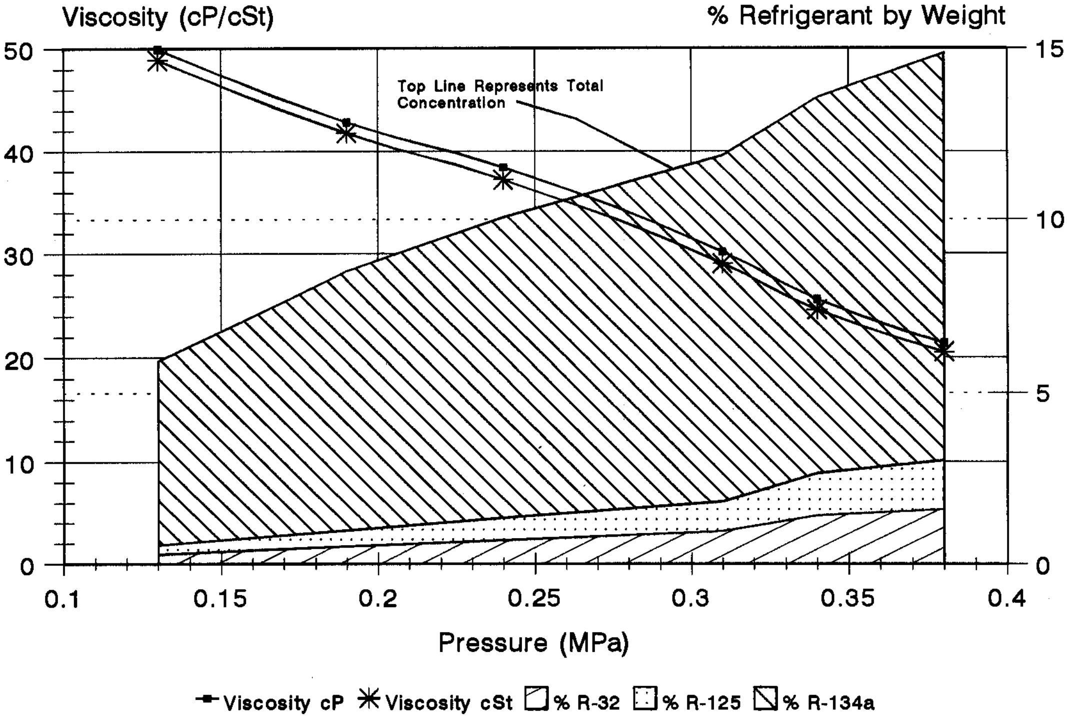
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-407C at 40°C
Figure P.4



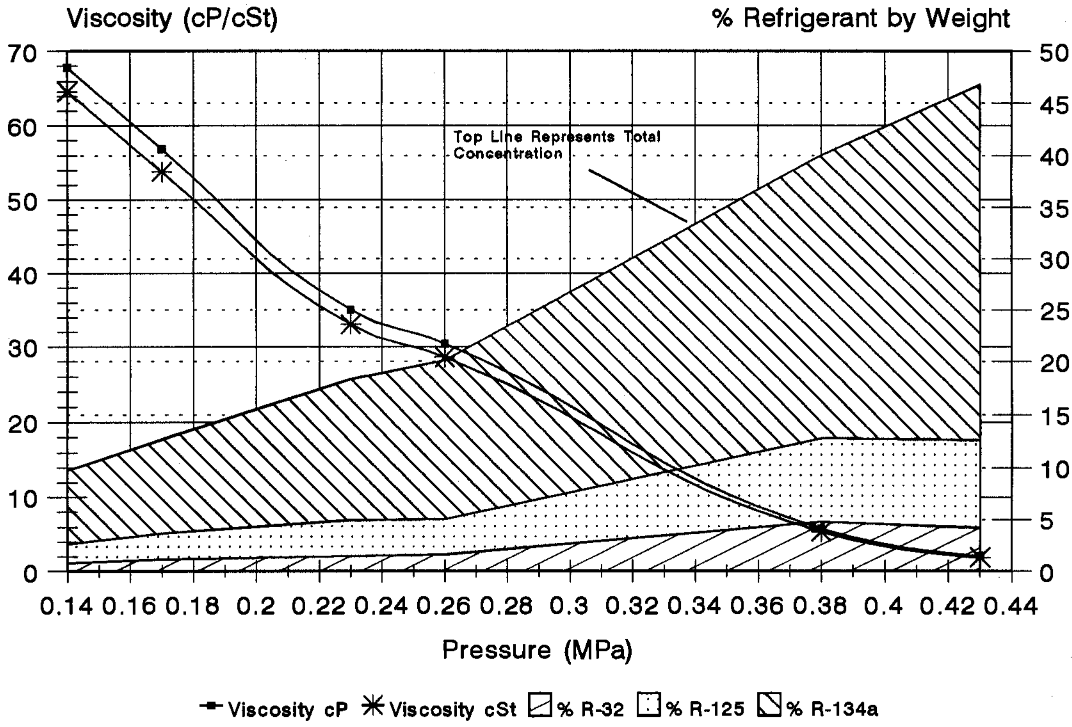
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-407C at 20°C
Figure P.5



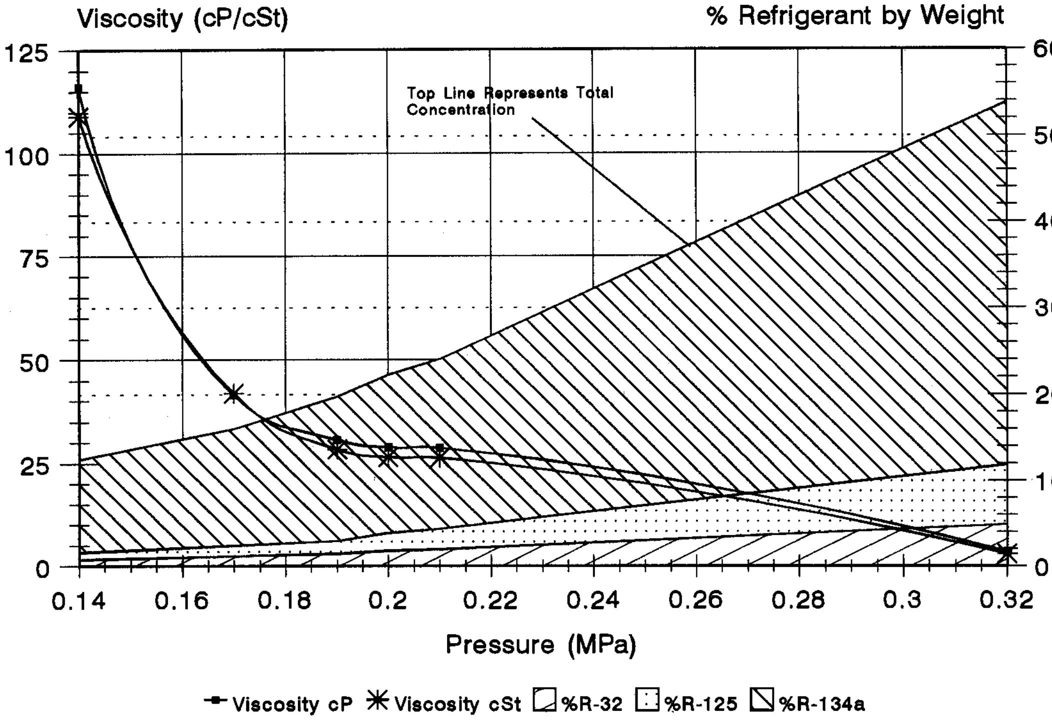
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A in R-407C at 0°C
Figure P.6



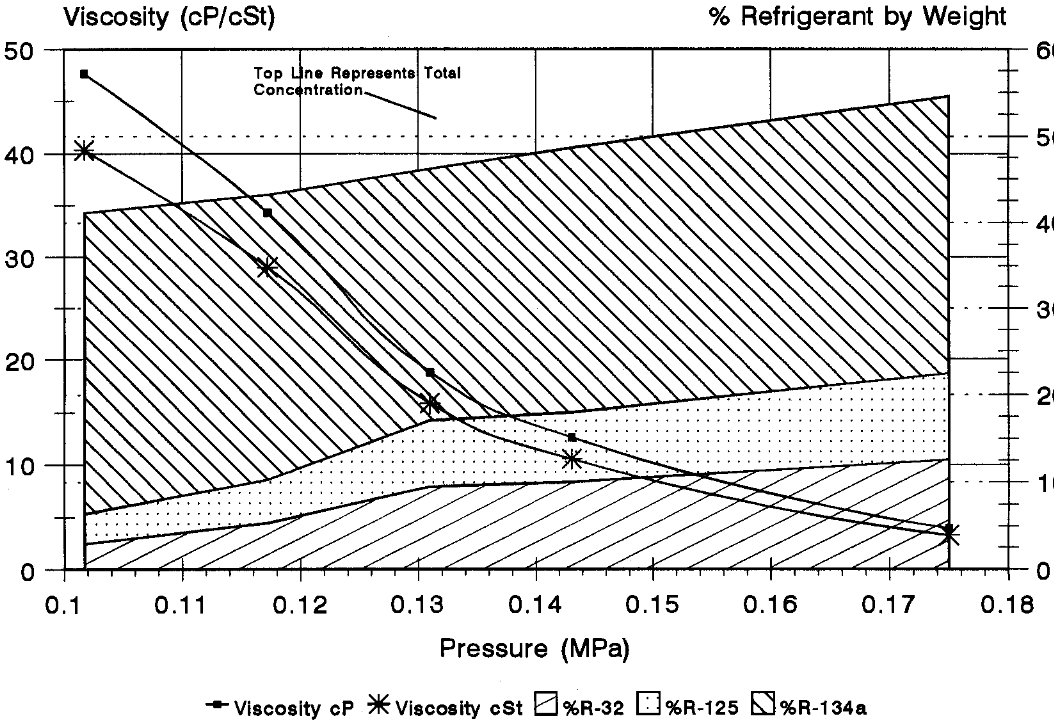
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-407C at -10°C
Figure P.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-407C at -25°C
Figure P.8

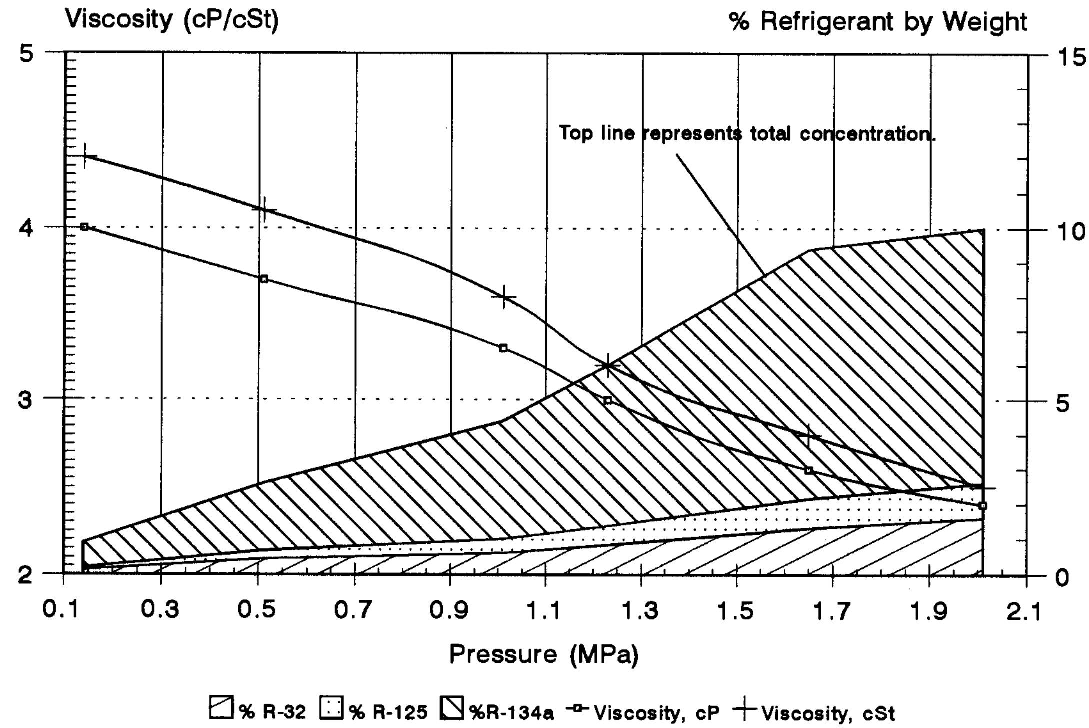


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

EMERY 2968A with R-407C at 125°C

Figure P.1a

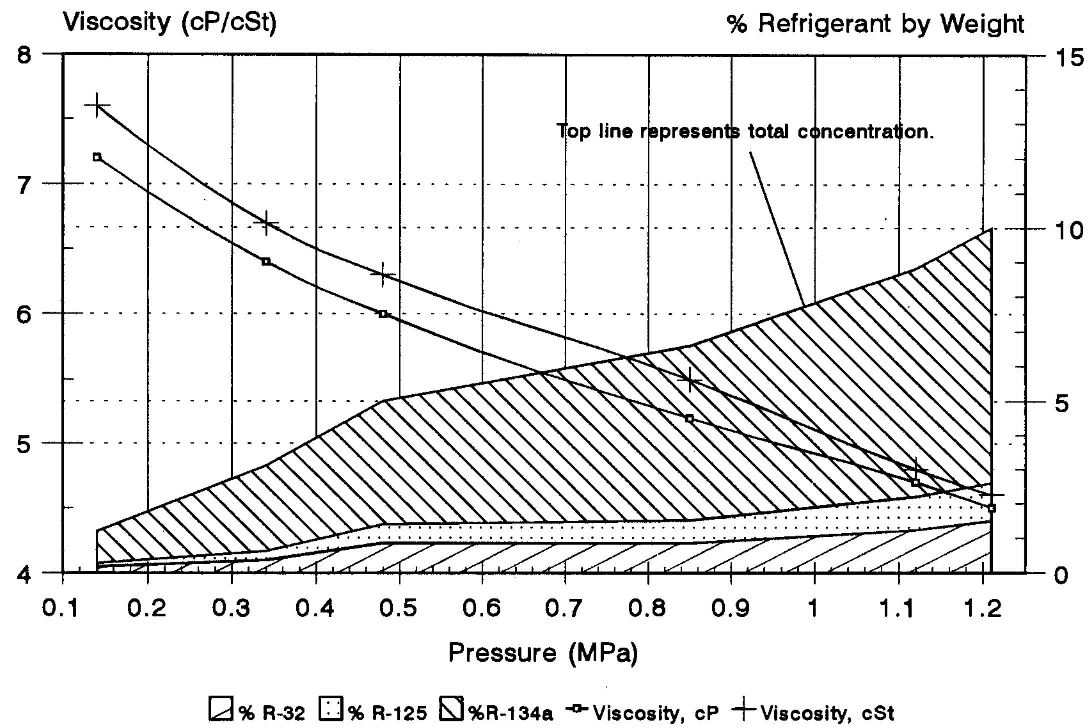


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

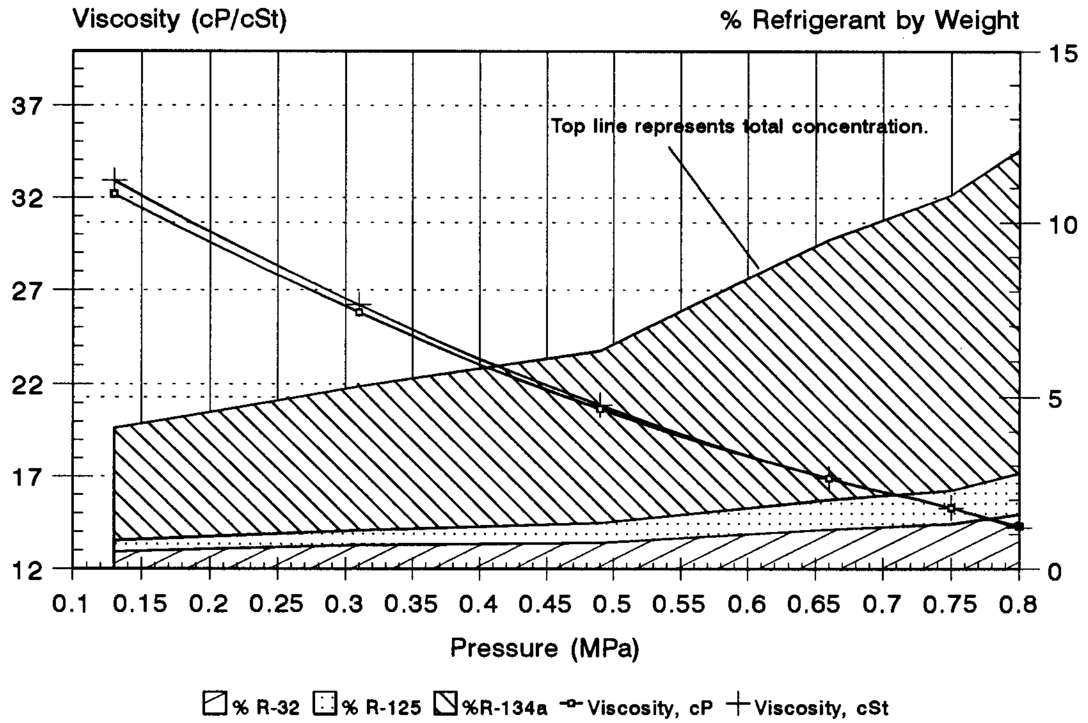
EMERY 2968A with R-407C at 90°C

Figure P.2a



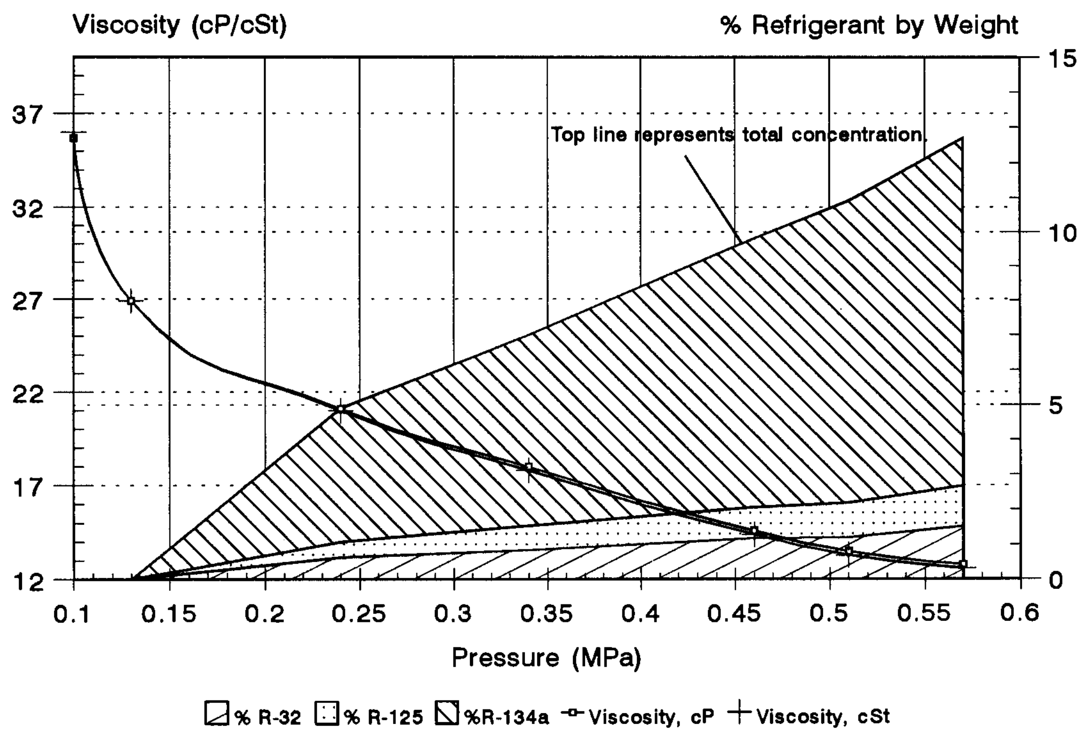
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-407C at 60°C
Figure P.3a



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMERY 2968A with R-407C at 40°C
Figure P.4a



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
Emery 2968A with R-407C
Table P.1

125°C (257°F) Temperature >500 psia Saturation Pressure >3.445 MPa			Acquired 12/94 with vented hydraulic cylinder. See Fig. P.1		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.956	422.50	2.92	19.4 (16/20/64)	2.0	2.1
0.954	330.00	2.26	12.4 (14/19/67)	2.2	2.4
0.949	240.00	1.66	9.4 (13/19/68)	2.6	2.7
0.942	148.00	1.02	6.3 (13/19/68)	2.9	3.1
0.927	76.00	0.52	4.4 (11/18/71)	3.2	3.5
0.924	20.00	0.14	4.2 (10/18/72)	3.5	3.7

* Ratio of components (32/125/134a) in wt.% in parentheses

125°C (257°F) Temperature >500 psia Saturation Pressure >3.445 MPa			Acquired 6/94 See Fig. P.1a		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.945	291.00	2.01	10.0 (16/20/64)	2.4	2.5
0.939	240.00	1.65	9.4 (14/19/67)	2.6	2.8
0.931	179.00	1.23	6.0 (13/19/68)	3.0	3.2
0.928	146.00	1.01	4.4 (13/19/68)	3.3	3.6
0.920	74.00	0.51	2.6 (11/18/71)	3.7	4.1
0.913	20.50	0.14	0.9 (10/18/72)	4.0	4.4

* Ratio of components (32/125/134a) in wt.% in parentheses

90°C (194°F) Temperature >500 psia Saturation Pressure >3.445 MPa			Acquired 12/94 with vented hydraulic cylinder. See Fig. P.2		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.947	22.00	0.15	2.3 (14/19/67)	6.4	6.8
0.951	75.00	0.52	5.2 (15/19/66)	5.5	5.8
0.959	150.00	1.04	8.3 (16/20/64)	4.3	4.5
0.974	240.00	1.66	13.0 (17/21/62)	3.2	3.3
0.983	365.00	2.52	23.4 (17/22/61)	2.3	2.3
1.000	436.00	3.01	27.3 (18/21/61)	1.8	1.8

* Ratio of components (32/125/134a) in wt.% in parentheses

90°C (194°F) Temperature >500 psia Saturation Pressure >3.445 MPa			Acquired 6/94 See Fig. P.2a		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.969	175.00	1.21	10.0 (14/19/67)	4.5	4.6
0.966	162.00	1.12	8.8 (15/19/66)	4.7	4.8
0.959	123.50	0.85	6.6 (16/20/64)	5.2	5.5
0.951	70.00	0.48	5.0 (17/21/62)	6.0	6.3
0.950	50.00	0.34	3.1 (17/22/61)	6.4	6.7
0.945	20.00	0.14	1.2 (18/21/61)	7.2	7.6

* Ratio of components (32/125/134a) in wt.% in parentheses

60°C (140°F) Temperature 361.78 psia Saturation Pressure 2.492 MPa			Acquired 12/94 with vented hydraulic cylinder. See Fig. P.3		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.019	356.50	2.46	54.4 (17/23/60)	0.8	0.8
1.009	268.00	1.85	37.4 (13/20/67)	2.0	2.0
1.002	182.00	1.26	22.9 (12/19/69)	4.0	4.0
0.984	95.00	0.66	11.3 (11/18/71)	7.9	8.0
0.973	45.00	0.31	6.7 (13/19/69)	11.5	11.8
0.971	20.00	0.14	4.1 (11/18/71)	13.5	14.0

* Ratio of components (32/125/134a) in wt.% in parentheses

60°C (140°F) Temperature 361.78 psia Saturation Pressure 2.492 MPa			Acquired 6/94 See Fig. P.3a		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.004	115.50	0.80	12.1 (17/23/60)	14.3	14.2
1.003	109.00	0.75	10.8 (13/20/67)	15.3	15.3
0.997	95.00	0.66	9.5 (12/19/69)	16.9	17.0
0.992	71.00	0.49	6.3 (11/18/71)	20.7	20.9
0.986	45.00	0.31	5.3 (13/19/69)	25.8	26.2
0.976	19.00	0.13	4.1 (11/18/71)	32.2	33.0

* Ratio of components (32/125/134a) in wt.% in parentheses

40°C (104°F) Temperature 220.03 psia Saturation Pressure 1.516 MPa			Acquired 12/94 with vented hydraulic cylinder. See Fig. P.4		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.983	14.70	0.10	0.0	32.2	32.7
1.000	20.00	0.14	5.3 (12/19/69)	26.8	26.8
1.014	67.50	0.47	9.7 (17/21/62)	14.5	14.3
1.028	100.00	0.69	14.9 (17/23/60)	9.8	9.5
1.043	146.00	1.01	25.8 (14/20/66)	4.5	4.3
1.050	194.00	1.34	43.7 (16/22/62)	1.5	1.4
1.056	214.50	1.48	54.7 (16/23/61)	1.3	1.2

* Ratio of components (32/125/134a) in wt.% in parentheses

40°C (104°F) Temperature 220.03 psia Saturation Pressure 1.516 MPa			Acquired 6/94 See Fig. P.4a		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.989	14.70	0.10	0.0	35.7	36.1
1.000	19.50	0.13	1.8 (12/19/69)	26.9	26.9
1.006	34.50	0.24	4.9 (17/21/62)	21.1	21.0
1.010	49.00	0.34	7.0 (17/23/60)	18.0	17.8
1.014	66.50	0.46	9.8 (14/20/66)	14.6	14.4
1.017	74.50	0.51	10.9 (16/22/62)	13.5	13.3
1.020	82.50	0.57	12.7 (16/23/61)	12.8	12.5

* Ratio of components (32/125/134a) in wt.% in parentheses

Raw Data: Viscosity, Solubility, and Density
Emery 2968A with R–407C
Table P.1 (cont.)

20°C (68°F) Temperature 125.37 psia Saturation Pressure .8638 MPa			Acquired 6/94 See Fig. P.5		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.042	55.50	0.38	14.9 (11/10/79)	21.4	20.5
1.041	50.00	0.34	13.6 (11/9/80)	25.7	24.6
1.038	45.00	0.31	11.9 (8/7/85)	30.1	29.0
1.032	35.00	0.24	10.1 (7/7/86)	38.4	37.2
1.028	28.00	0.19	8.5 (6/6/88)	42.8	41.8
1.022	18.50	0.13	5.9 (5/5/90)	49.9	48.9

* Ratio of components (32/125/134a) in wt.% in parentheses

0°C (32°F) Temperature 65.56 psia Saturation Pressure .4517 MPa			Acquired 6/94 See Fig. P.6		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.105	62.50	0.43	46.8 (9/18/73)	2.1	1.9
1.081	55.00	0.38	40.0 (12/20/68)	5.8	5.3
1.064	37.00	0.26	20.1 (8/17/75)	30.4	28.6
1.060	34.00	0.23	18.3 (8/19/73)	35.0	33.0
1.057	25.00	0.17	12.7 (9/20/71)	56.9	53.8
1.050	20.00	0.14	9.7 (8/19/73)	67.8	64.6

* Ratio of components (32/125/134a) in wt.% in parentheses

–10°C (14°F) Temperature 45.53 psia Saturation Pressure .3137 MPa			Acquired 6/94 See Fig. P.7		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.064	20.00	0.14	12.4 (6/6/88)	116.0	109.0
1.075	25.00	0.17	16.0 (7/8/85)	38.3	35.6
1.080	27.00	0.19	19.7 (7/8/85)	30.6	28.4
1.089	29.00	0.20	22.3 (8/9/83)	28.9	26.5
1.092	31.00	0.21	24.1 (8/10/82)	28.8	26.3
1.204	45.82	0.32	53.8 (9/13/78)	3.5	2.9

* Ratio of components (32/125/134a) as wt.% in parentheses

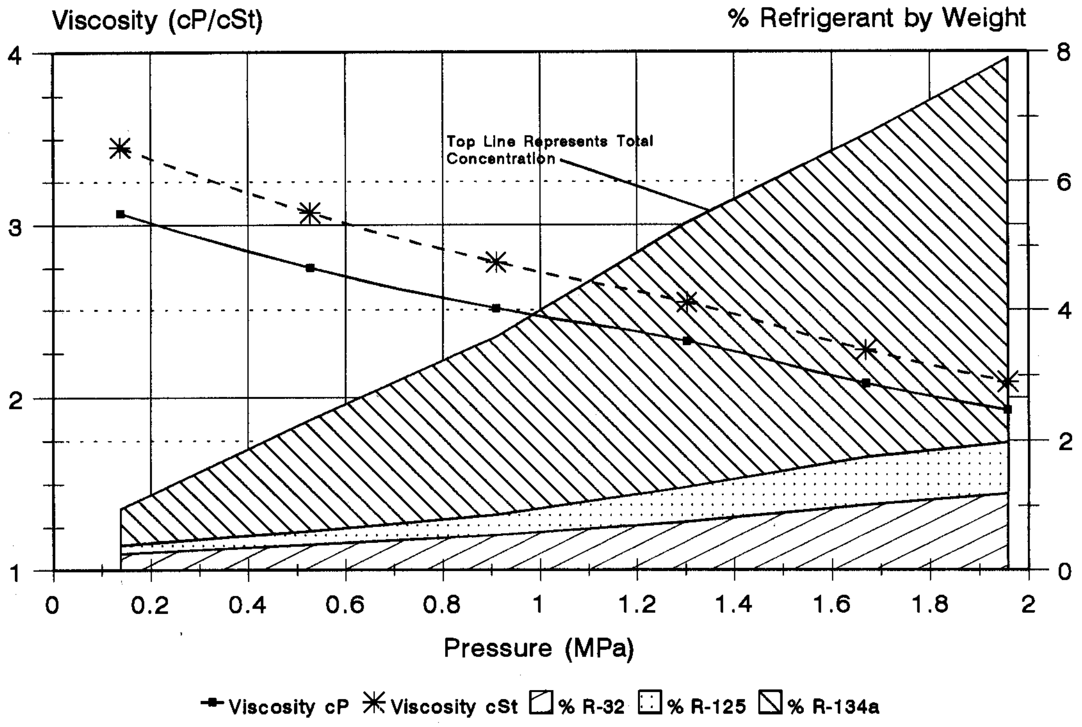
–25°C (–13°F) Temperature 25.29 psia Saturation Pressure .1742 MPa			Acquired 6/94 See Fig. P.8		
Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity (cP)	Viscosity (cSt)
1.21	25.29	0.175	54.5 (21/17/62)	3.9	3.3
1.20	20.75	0.14	48.6 (21/16/63)	12.6	10.5
1.18	19	0.13	46.2 (17/13/70)	18.8	15.8
1.18	17	0.12	43.2 (12/11/77)	34.3	29.0
1.18	14.75	0.10	39.2 (8/9/83)	47.6	40.3

* Ratio of components (32/125/134a) as wt.% in parentheses

APPENDIX Q
Viscosity, Density, Solubility, and Gas Fractionation of EMKARATE RL32S at Various Temperatures with R-407C

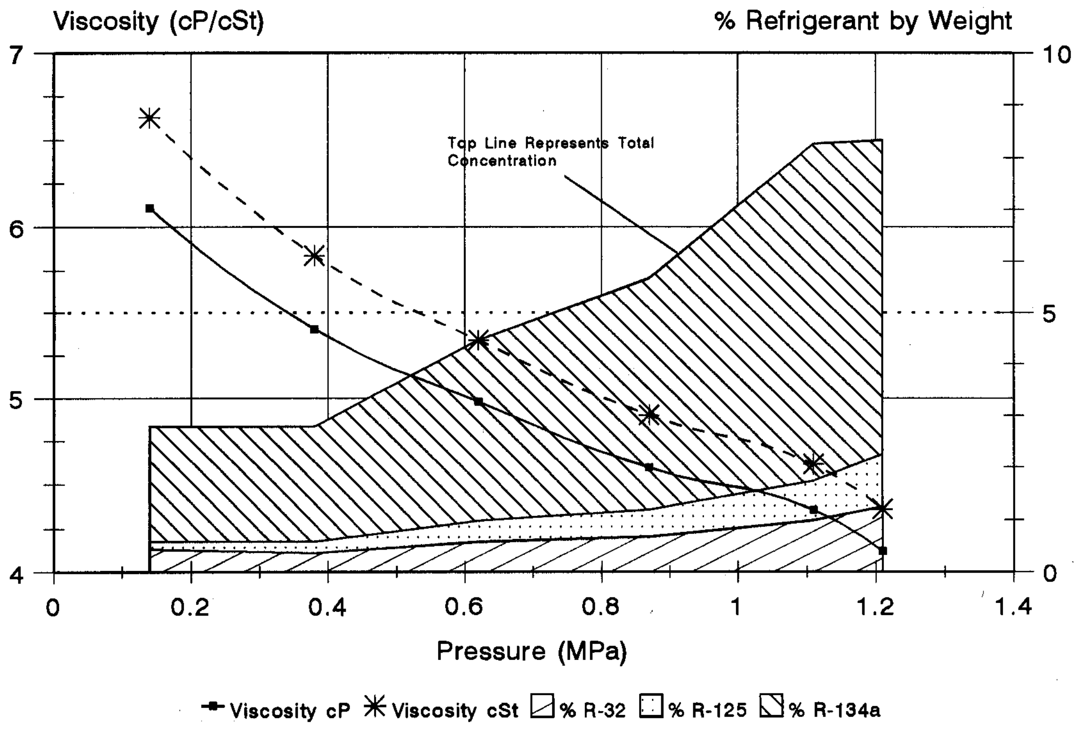
In the following graphs, the shaded areas indicate the concentrations of the blend components. These areas are cumulative, not overlapped. For example, in Figure Q.1, the concentration in the lubricant of HFC-134a at 1 MPa is about seventy percent. The concentration of HFC-125 is about nine percent. These areas are stacked on top of one another. The top line represents the total concentration of R-407C, at slightly more than nine percent.

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-407C at 125°C
Figure Q.1



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-407C at 90°C
Figure Q.2

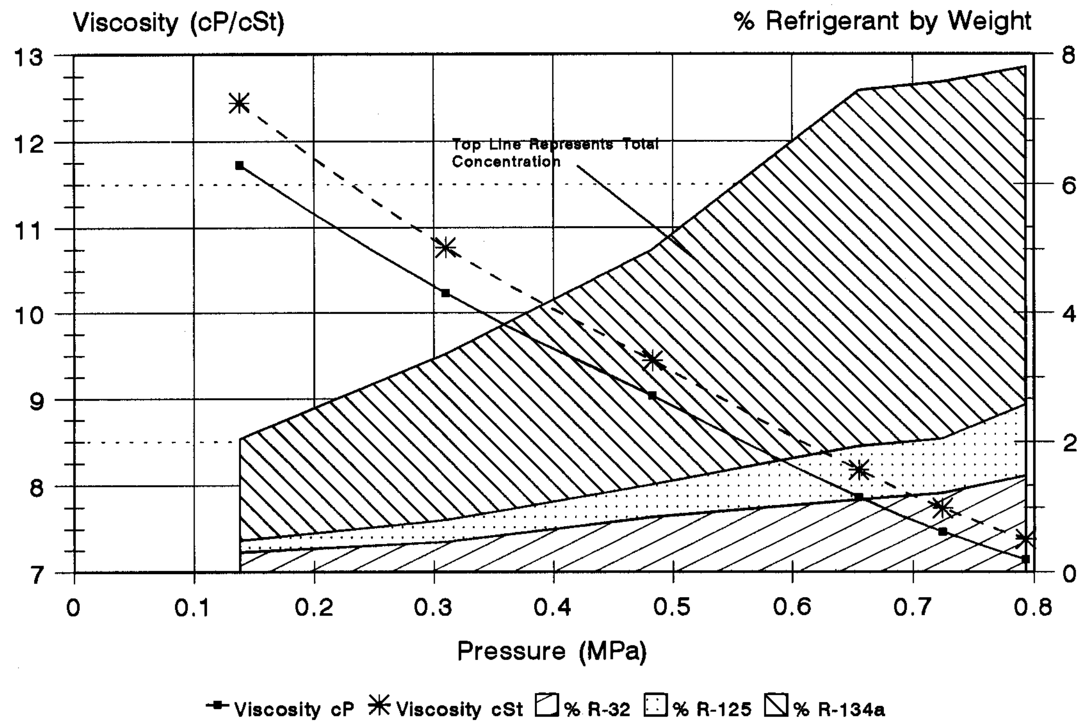


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

EMKARATE RL32S with R-407C at 60°C

Figure Q.3

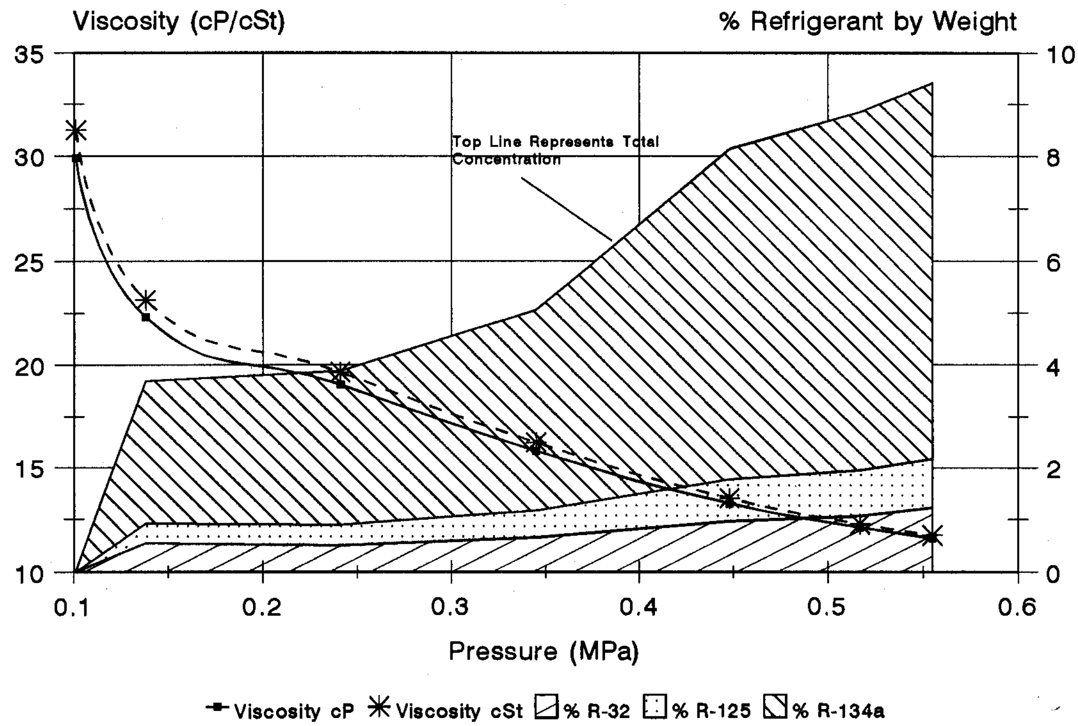


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

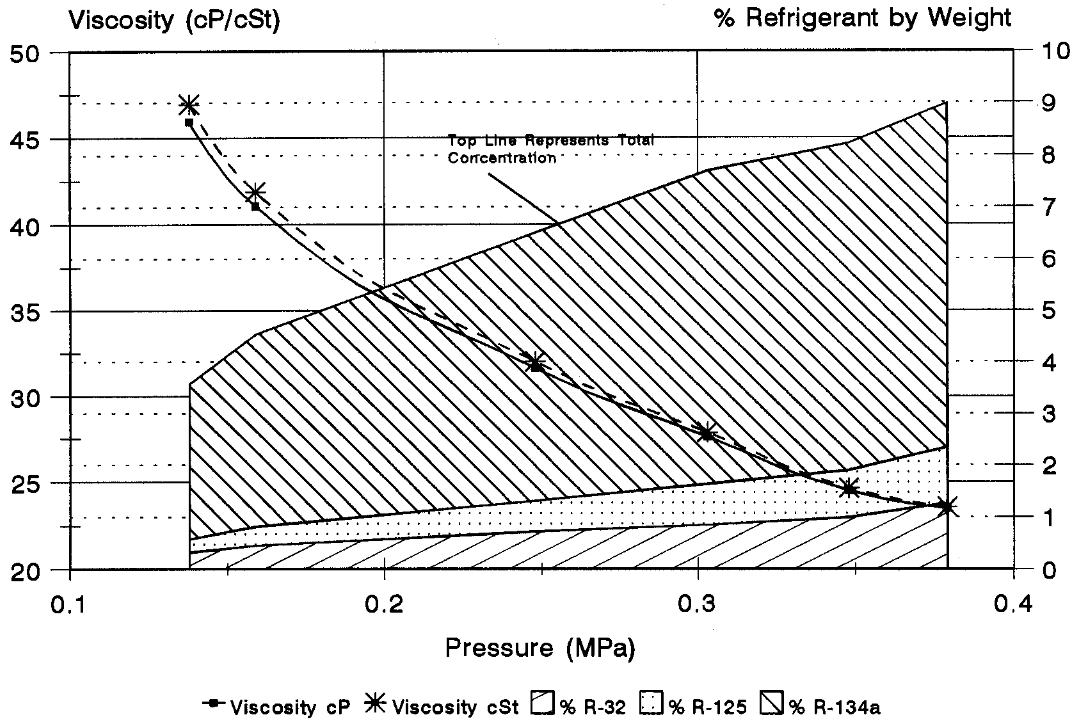
EMKARATE RL32S with R-407C at 40°C

Figure Q.4



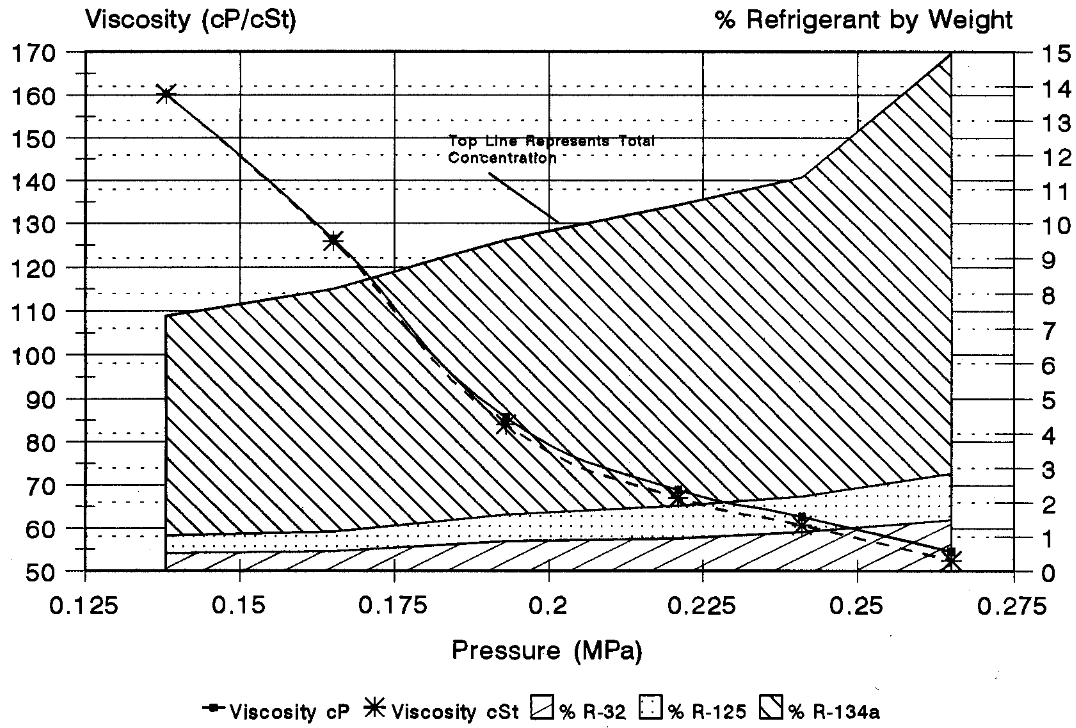
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-407C at 20°C
Figure Q.5



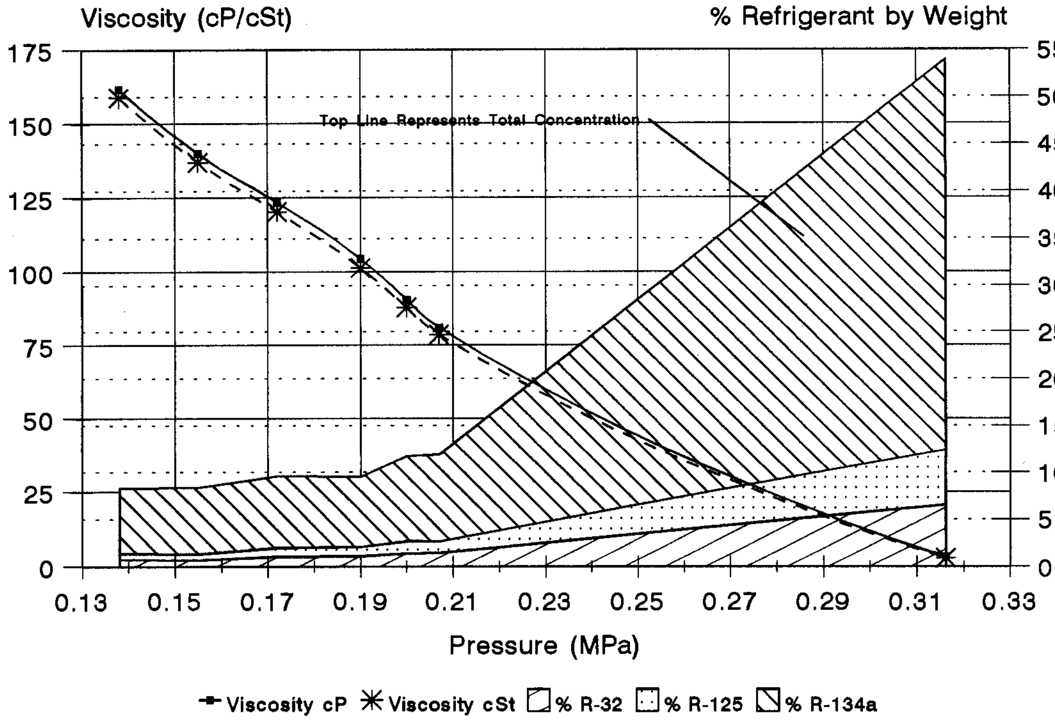
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-407C at 0°C
Figure Q.6



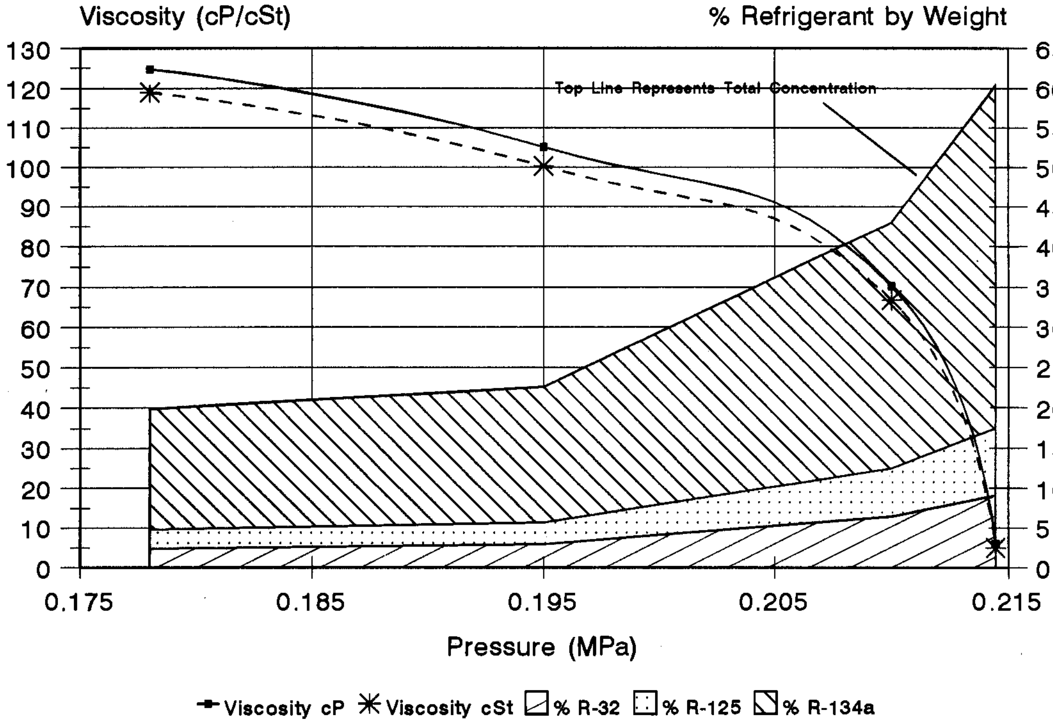
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-407C at -10°C
Figure Q.7



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
EMKARATE RL32S with R-407C at -20°C
Figure Q.8



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
EMKARATE RL32S with R-407C
Table Q.1

125°C (257°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.923	284.00	1.96	7.9 (15/10/75)	1.9	2.1
0.917	242.00	1.67	6.7 (15/11/74)	2.1	2.3
0.911	189.00	1.30	5.4 (14/9/77)	2.3	2.5
0.902	132.00	0.91	3.6 (15/9/76)	2.5	2.8
0.896	76.50	0.53	2.3 (17/9/74)	2.8	3.1
0.889	20.00	0.14	0.9 (27/14/59)	3.1	3.4

* Ratio of components (32/125/134a) in wt.% in parentheses

90°C (194°F) Temperature
>500 psia Saturation Pressure
>3.445 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.945	175.50	1.21	8.3 (15/12/73)	4.1	4.4
0.944	161.00	1.11	8.3 (12/9/79)	4.4	4.6
0.938	126.00	0.87	5.7 (12/9/79)	4.6	4.9
0.932	90.50	0.62	4.5 (13/9/78)	5.0	5.3
0.926	55.00	0.38	2.8 (13/8/79)	5.4	5.8
0.922	20.00	0.14	2.2 (19/8/73)	6.1	6.6

* Ratio of components (32/125/134a) in wt.% in parentheses

60°C (140°F) Temperature
361.76 psia Saturation Pressure
2.492 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.968	115.00	0.79	7.8 (19/14/67)	7.1	7.4
0.966	105.00	0.72	7.6 (16/11/73)	7.5	7.7
0.962	95.00	0.66	7.4 (15/11/74)	7.9	8.2
0.957	70.00	0.48	5.0 (17/10/73)	9.0	9.4
0.950	45.00	0.31	3.4 (14/10/76)	10.2	10.8
0.943	20.00	0.14	2.1 (15/9/76)	11.7	12.4

* Ratio of components (32/125/134a) in wt.% in parentheses

40°C (104°F) Temperature
220.03 psia Saturation Pressure
1.516 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.957	14.70	0.10	0.0 (0/0/0)	29.9	31.3
0.988	80.50	0.56	9.4 (13/10/77)	11.6	11.8
0.987	75.00	0.52	8.9 (12/10/78)	12.1	12.3
0.982	65.00	0.45	8.1 (12/10/78)	13.3	13.5
0.975	50.00	0.34	5.1 (13/10/77)	15.8	16.2
0.970	35.00	0.24	3.9 (13/10/77)	19.1	19.7
0.964	20.00	0.14	3.7 (15/10/75)	22.3	23.2

* Ratio of components (32/125/134a) in wt.% in parentheses

20°C (68°F) Temperature
125.37 psia Saturation Pressure
.8638 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.996	55.00	0.38	9.0 (14/12/74)	23.5	23.6
0.994	50.50	0.35	8.2 (12/11/77)	24.5	24.6
0.991	44.00	0.30	7.7 (11/10/79)	27.6	27.9
0.988	36.00	0.25	6.5 (11/9/80)	31.6	32.0
0.980	23.00	0.16	4.5 (10/8/82)	41.0	41.9
0.979	20.00	0.14	3.6 (9/7/84)	45.9	46.9

* Ratio of components (32/125/134a) in wt.% in parentheses

0°C (32°F) Temperature
65.56 psia Saturation Pressure
.4517 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.040	38.50	0.27	14.9 (10/9/81)	54.5	52.5
1.032	35.00	0.24	11.4 (9/9/82)	62.7	60.7
1.028	32.00	0.22	10.5 (9/8/83)	68.9	67.0
1.019	28.00	0.19	9.6 (8/8/84)	85.6	84.0
1.005	24.00	0.17	8.1 (7/7/86)	126.4	125.8
1.000	20.00	0.14	7.4 (7/7/86)	160.2	160.3

* Ratio of components (32/125/134a) in wt.% in parentheses

−10°C (14°F) Temperature
45.62 psia Saturation Pressure
.3157 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.1553	45.82	0.32	53.9 (12/12/76)	3.3	2.9
1.031	30.00	0.21	12.0 (12/11/77)	81.0	78.6
1.030	29.00	0.20	11.7 (12/11/77)	90.5	87.8
1.030	27.50	0.19	11.0 (12/10/77)	104.5	101.5
1.026	25.00	0.17	9.5 (11/10/79)	123.5	120.3
1.022	22.50	0.16	8.3 (9/9/83)	140.0	137.0
1.018	20.00	0.14	8.2 (9/8/83)	161.7	158.8

* Ratio of components (32/125/134a) in wt.% in parentheses

−20°C (−4°F) Temperature
31.06 psia Saturation Pressure
.2141 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
1.048	25.75	0.18	19.9 (11/12/77)	124.7	119.0
1.049	28.25	0.19	22.6 (13/12/75)	105.1	100.2
1.052	30.50	0.21	42.9 (15/14/71)	70.2	66.7
1.201	31.08	0.21	60.3 (17/15/68)	6.0	5.0

* Ratio of components (32/125/134a) in wt.% in parentheses

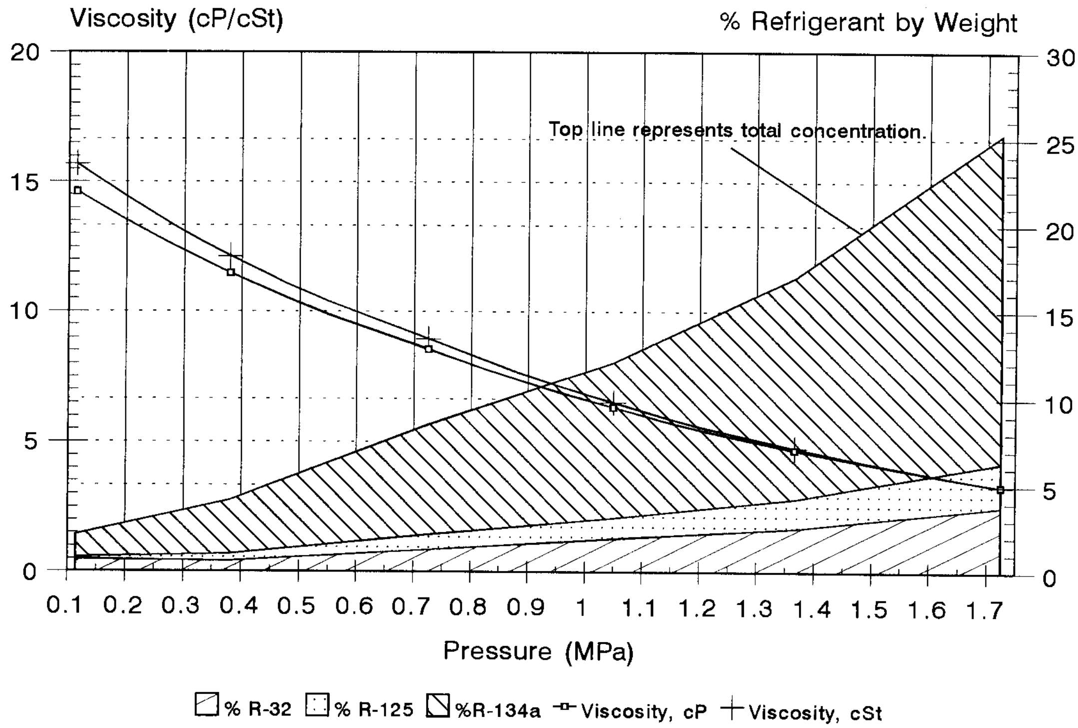
Raw Data: Unpurged Viscosity, Density, and Solubility
EMKARATE RL32S with R−407C
Table Q.2

60°C (140°F) Temperature
361.7 psia Saturation Pressure
2.492 MPa

Density g/ml	Pressure psia	Pressure MPa	% Refrig. Conc.* Viscometer headspace	% Refrig. Conc.* solubilized gas in lube	Viscosity cP	Viscosity cSt
0.931	16.50	0.11	2.1		14.6	15.7
			(22/14/66)	(33/11/56)		
0.946	55.00	0.38	4.1		11.5	12.1
			(21/15/64)	(15/10/75)		
0.955	105.00	0.72	8.6		8.5	9.0
			(21/14/65)	(16/10/74)		
0.972	152.00	1.05	12.1		6.3	6.53
			(20/14/66)	(16/10/74)		
0.984	198.00	1.37	17.0		4.7	4.79
			(21/14/65)	(15/10/75)		
1.007	250	1.72	25.3		3.32	3.30
			(21/14/65)	(15/10/75)		

* Data indicates ratio of %wt. conc. in the order 32/125/134a

Viscosity, Solubility, and Gas Fractionation, UNPURGED
EMKARATE RL32S with R-407C at 60°C
Figure Q.9



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

APPENDIX R
Fitting Empirical Equations to Experimental Data

Once viscosity, density, pressure, and concentration measurements have been experimentally determined over a range of temperatures for a lubricant/refrigerant mixture, several empirical equations are fit to the collected data. These equations allow one to interpolate viscosity, pressure, or density values at any temperature and refrigerant concentration within the range that was measured.

A saturation pressure equation is first determined. The saturation pressure of the refrigerant at any temperature is given by a formula of the form

$$P_{sat}(T) = A \exp\left(-\frac{B}{T + 273}\right) \qquad (1)$$

where T is the temperature in degrees Celsius. Once the saturation pressure is known at two temperatures, the coefficients A and B can be determined through elementary mathematical methods. The minimum temperature at which the refrigerant can exist as a gas for a given pressure can be determined by solving equation (1) for T.

After the saturation pressure relationship has been determined, a pressure equation is fit to the data. This equation gives pressure as a function of temperature and mole fraction of refrigerant. The equation used is the following extension of Raoult's law:

$$P(x, T) = xP_{sat}(T) + x(1 - x)(a + bT + cT^2 + dx + exT + fxT^2)P_{sat}(T) \qquad (2)$$

Here x is the mole fraction of refrigerant and T is the temperature. The coefficients a through f are calculated by means of a least squares regression. It is useful to be able to determine a mole fraction at a given pressure and temperature (e.g. to compute isobaric viscosity and isobaric density curves.) To accomplish this, it is necessary to write (2) as a polynomial in x and find its roots. Equation (2) can be rewritten as

$$x^3 + px^2 + qx + r = 0 \qquad (3)$$

where the coefficients p, q, and r are given by

$$p = -\frac{(d - a) + (e - b)T + (c - f)T^2}{d + eT + fT^2} \tag{4}$$

$$q = -\frac{1 + a + bT + cT^2}{d + eT + fT^2} \tag{5}$$

$$r = \frac{P}{P_{sat}(T)(d + eT + fT^2)}. \tag{6}$$

The roots of equation (3) are found by using the analytic solution for cubic polynomials. Although there are three roots, only the one that is real and falls within the interval [0, 1] is used. Once the mole fraction x has been determined, the concentration by weight can be determined if the average molecular masses of the lubricant and refrigerant are known. If the refrigerant is a blend, then its average molecular mass is calculated by taking the weighted average of the molecular masses of each of its components with respect to its molar concentration. The following formula gives concentration by weight z in terms of mole fraction x where m_{LUB} and m_{REF} are the molecular masses of the lubricant and refrigerant respectively.

$$z = \frac{x m_{REF}}{x(m_{REF} - m_{LUB}) + m_{LUB}} \tag{7}$$

Once the concentration by weight has been calculated, it may be used in the viscosity and density equations described below.

The equation which is fit to the viscosity data is a function of refrigerant concentration and temperature and is given by

$$\log \mu(z, T) = a + bT + cT^2 + dz + ez^2 + fzT \tag{8}$$

where μ is dynamic viscosity, z is refrigerant concentration by weight and T is temperature. As before, the coefficients a through f are determined by a least squares regression. To determine viscosity at a given pressure and temperature, the corresponding mole fraction is calculated from equation (3), converted to concentration, and used as the value of z in equation (8).

The equation which is fit to the density data is a linear function of concentration and temperature and is given by

$$\rho(z, T) = a + bT + cz + dzT \tag{9}$$

where ρ is the density, z is refrigerant concentration, and T is temperature. The coefficients a through d are determined by a least squares regression. To calculate density for a given pressure and temperature, the same procedure that is described above for viscosity is used.