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

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ABSTRACT

The lubricants tested in this project were chosen based on the results of liquid/liquid miscibility tests. A 32 ISO VG mixed acid polyolester and a 32 ISO VG branched acid polyolester were selected. Their vapor liquid equilibrium (VLE) viscosity reduction was measured with two different refrigerant blends: HFC-125/143a/134a (44/52/4% w/w), and HFC-125/143a (50/50% w/w). In addition. measurements were made with HFC-134a and HFC-143a, two of the single refrigerants that make up the tested blends.

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1. SCOPE

This study will measure the viscosity, solubility, and density of lubricant/blended refrigerant mixtures, and of mixtures of lubricants with the individual refrigerants that make up the tested blends. The two lubricants that will be used in these mixtures are a 32 ISO VG branched acid polyolester and a mixed branched acid 32 ISO VG polyolester. The refrigerant blends that will be tested are blends D, E, and F on the table below.

Miscibility evaluations of five different lubricants and six refrigerant blends were used to select materials for testing (see appendix A).

Table 1. Blends with Refrigerant Proportions in Percentages by Weight

Blend	HFC-32 %	HFC-125 %	HFC-134a %	HFC-143a %
A	60	40		
B	30		70	
C	30	10	60	
D*		44	4	52
E†	23	25	52	
F‡		50		50

*The manufacturer of this blend has changed its composition. The original composition, used in the miscibility evaluations, was 44% HFC-125 : 2% HFC-134a : 54% HFC-143a.

†The manufacturer of this blend has changed its composition. The original composition, used in the miscibility evaluations, was 20% HFC-32 : 55% HFC-125 : 20% HFC-134a : 5% HFC-290.

‡The manufacturer of this blend has changed its composition. The original composition, used in miscibility evaluations, was 45% HFC-125 : 55% HFC-143a.

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

1.1 Statement and Chemical Properties of Lubricants

The viscosity and liquid/liquid miscibility of lubricants with refrigerants depend on the composition of the lubricants. However, because the lubricants and pentarerythritol poloylesters used in this study are proprietary formulations, information about their specific structural properties, including alcohol type and the stoichiometry of the carboxylic acids used in synthesis, remains with the manufacturer. As a result, only the miscibility and viscosity differences between the polyolesters are reported.

2. METHODS

2.1 Viscosity Determinations

The viscosity determination method used in this study is similar to that described by Albright (1956-59), Little (1956) and Parmelee (1964). These authors use the gas equilibrium concept -- the saturation of the liquid with vapor -- 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 (Figure 1), which was taken from a report by Nissen (1981). This viscometer system consists of an oscillating body device enclosed in a low volume pressure tube. The active part of this system is a solid oscillating cylinder made of highly polished stainless steel; this is connected to a precisely thermostatted spring inside a stainless steel pipe. An external electromagnet causes the cylindrical bob to oscillate.

The bob gradually slows and stops. The sinusoidal decay of its motion is called the *decrement*. A quick decay represents a high viscosity; a slow decay, a low one. The viscosity of the solution can be determined from the decrement and density.

The viscosity of both tested polyolesters, as well as 32 ISO VG mineral oil were measured; the standards used were water and certified standard test fluids (NIST traceable). These standards are calibrated from -25°C to 125°C and are reported in both cP and cSt values. This information is presented in the raw data tables under the heading "Neat Viscosity Check." (Table B.1 for mineral oil, D.1 for branched acid polyolester, and E.1 for mixed acid polyolester.) The density of these lubricants is also reported.

The readability of the viscometer is 0.06 cP. The wide temperature range of various calibration oils results in a significant overlap that serves as an internal standard and self check. For low viscosity solutions, the difference between standards is ±0.1%; this increases to ±1.5% for high viscosity solutions.

This viscometer allows a wide range of viscosity determinations (.10 to 1800 cP) to be made with a single oscillating bob. In addition, the bob can also be used to determine density. By observing the position changes of the bob, density can be determined to within 0.0005 g/ml. Determining consistent density at constant temperature and constant pressure is a very accurate method of measuring fluid consistency. Accurate density measurements allow the calculation of centistokes (cSt) from centipoise (cP). The density range of the instrument is calibrated with known, readily available pure fluids that are dried over a 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 fluid refrigerant mixture is pumped from the bottom of the viscometer and sprayed into the refrigerant vapor space at specific pressures and temperatures. Consequently, density may be monitored for equilibrium conditions, the decrement may be measured, and the viscosity may be calculated. Before the fluid is sampled, it is visually examined several times to determine that true solution conditions are present. 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 is retained. The ratio of gas to liquid oil (percentage by weight) may then be calculated. The concentration measurement is reproducible within ±0.5% by weight at a given isothermal pressure test point. Directly sampling the refrigerant lubricant mixture at each isothermal pressure test point is essential to the measurement technique used in this study.

The solubility ranges of refrigerant/lubricant combinations may be inconsistent. For example, the viscometer does not allow the kind of immiscibility conditions that could occur in a low temperature pressure cell containing liquid refrigerant and a partially immiscible lubricant. According to the principles of gas equilibrium, forced saturation with liquefied gas is required to produce immiscible layers. Oil may be kept saturated with gas at a specific pressure and temperature by accurately monitoring the gas pressure and keeping it at or below the saturation pressure. For oils that are nearly infinitely miscible, liquid refrigerant can be added to the viscometer under pressure, and fluid properties can be measured for viscosity, density, pressure and refrigerant concentration. Measurements are taken when the oil is saturated with refrigerant gas.

If there is any void space in a pressurized viscometer cell, the refrigerant-oil pair combinations will change. For example, a fluid with 6.6% refrigerant by weight at

100°C (212°F) will have a refrigerant concentration almost three times greater (22.0%) when it is cooled to 10°C(50°F) inside a closed system (like a viscometer) which has available gas space. When refrigerant blends are used, the composition of the gas in the vapor space of the viscometer is maintained equal to that of the pure refrigerant blend. The fractionation of the mixed gases is determined at every temperature and pressure. Samples of the fluid/refrigerant mixture are collected to determine the percent refrigerant by weight in the fluid. The ratio of gases is determined by gas chromatography, as stated in Section 2.2.

The fluid measurement portion of the viscometer is equipped with two high temperature and pressure sight glasses directly adjacent to the suspended stainless steel solid cylinder. Through the upper sight glass, the solution is continually monitored for the formation of any immiscible particulate or haze of the fluid and refrigerant. The observer can ensure that the viscometer is charged with enough fluid to completely cover the bob. The lower sight glass is adjacent to the gas introduction port and to the oil sampling port. The third sight glass, located at the top of the vapor space directly adjacent to the pump exit, allows observation of the foaming qualities of the lubricant and lets the observer guarantee that the mixed system is always at the stated measurement temperature.

Pressure is measured with a Bourdon tube gauge; the double helix design of this gauge allows the needle to rotate through almost two complete circles (660 degrees). This temperature-compensated gauge is calibrated with both gas and liquid, is accurate to ± 0.2 psia, and is traceable to NIST standards. Vapor pressure is measured at equilibrium, when the soluble gases are responsible for the fluid properties. Since the gas content of the fluid is measured, the amount of gas contained in the Bourdon tube is irrelevant.

Density, viscosity, and vapor pressure are always measured under isothermal conditions. The viscometer temperature is maintained by a circulating constant temperature glycol bath controlled by a Platinum RTD (±0.1°C) 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) with type "J" thermocouples.

Oil is pumped into the viscometer by a magnetically coupled impeller located in the pump body and sprayed into a soluble gas vapor space at the top of the viscometer. The pressure and temperature in the instrument can be varied to simulate the lubricant/refrigerant pair conditions that exist in operating compressor systems. Test fluids are degassed at 60°C (140°F) to 20 millitorr for 24 hours and are generally dried to 50 ppm. Similarly, the viscometer is evacuated to 20 millitorr for several hours, purged with the refrigerant gas several times, and evacuated. The test oil is then drawn through the oil charging valve and re-evacuated to 20 millitorr. The oil is purged with refrigerant gas and evacuated again. Non-condensable gas content is not allowed to exceed 10 ppm or equivalent to the refrigerant used.

2.2 Refrigerant Blend Sampling

After refrigerant/lubricant samples are obtained from the viscometer, the glass container and its rubber stopper are weighed. The glass 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 lower pressure in the gas chamber pulls the refrigerant out of the sample in the glass bulb. To separate the refrigerant from the lubricant, the glass bulb is heated carefully with a propane torch. The lower stopcock is closed within 30 seconds after heating. One minute after the lower stopcock is closed, equilibrium is established.

The ratio of the gases can be determined from the sample of gases drawn off the top oil. A second gas sample is obtained to determine if equilibrium has been established and whether the ratio of gases has changed. Gas chromatography is used to analyze the refrigerant sample. Separate measurement studies indicate 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. This was then used for the final measurements of net percentage by weight.

Figure 1. Oscillating Body Viscometer

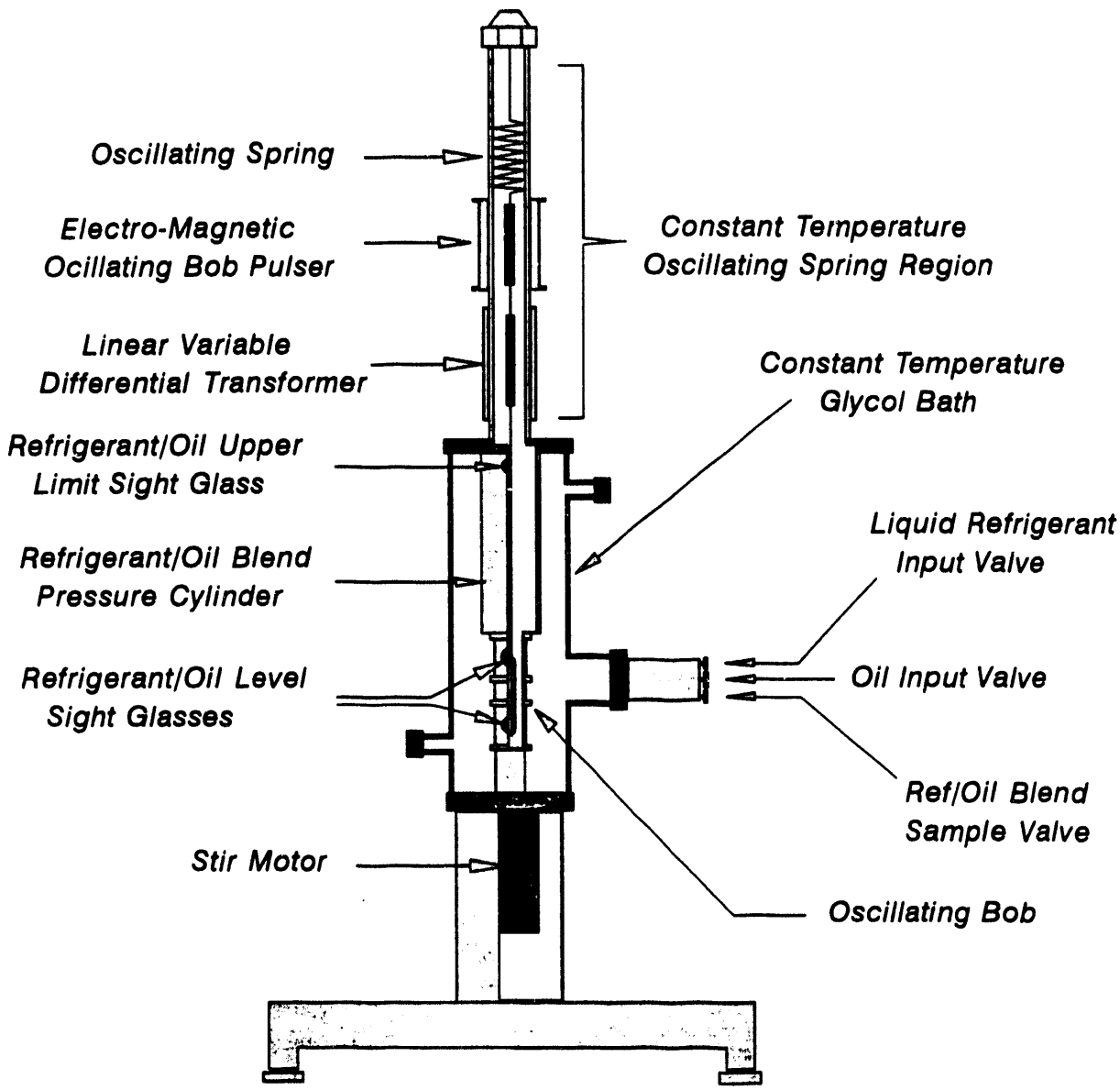
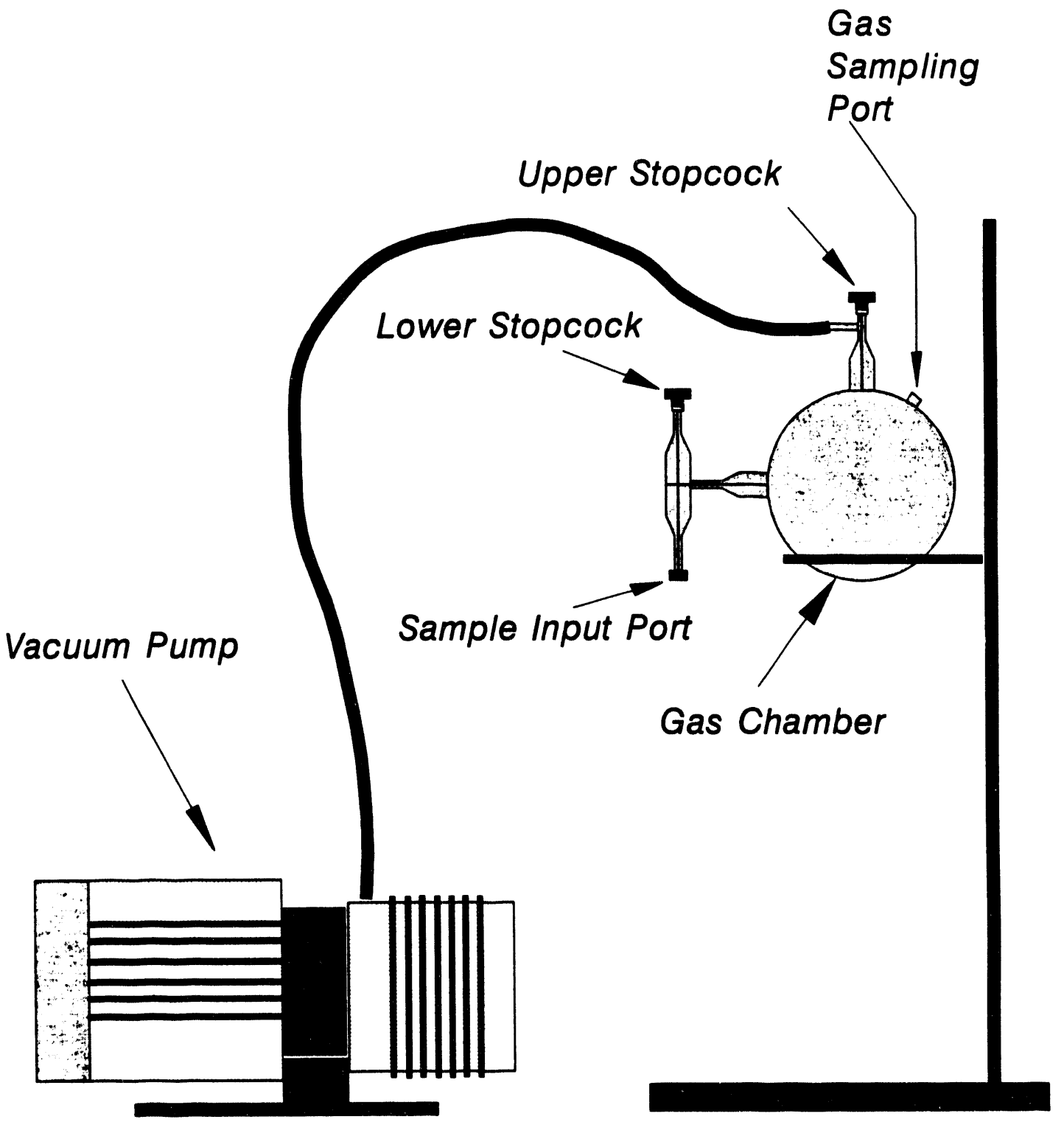


Figure 2. Refrigerant Blend Sampling Apparatus



3. RESULTS OF MEASUREMENTS WITH SINGLE REFRIGERANTS

3.1 Viscosity of 32 ISO VG Mixed Acid Polyester with HFC-134a

Appendix D presents, in Table D.1, the isothermal viscosity, density, and solubility of gaseous HFC-134a in a 32 ISO VG mixed acid polyolester 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. Figure 3 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 4 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 5 shows density as a function of temperature at constant concentrations.

3.2 Viscosity of 32 ISO VG Branched Acid Polyester with HFC-134a

Appendix E presents, in Table E.1, the isothermal viscosity, density, and solubility of gaseous HFC-134a in a 32 ISO VG branched acid polyolester with good miscibility characteristics. Figure 6 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 7 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 8 shows density as a function of temperature at constant concentrations.

3.3 Viscosity of 32 ISO VG Branched Acid Polyester with HFC-143a

Appendix F presents, in Table F.1, the isothermal viscosity, density, and solubility of gaseous HFC-143a in a 32 ISO VG branched acid polyolester. Five viscosity data points were taken for each temperature. Figure 9 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 10 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 11 shows density as a function of temperature at constant concentrations.

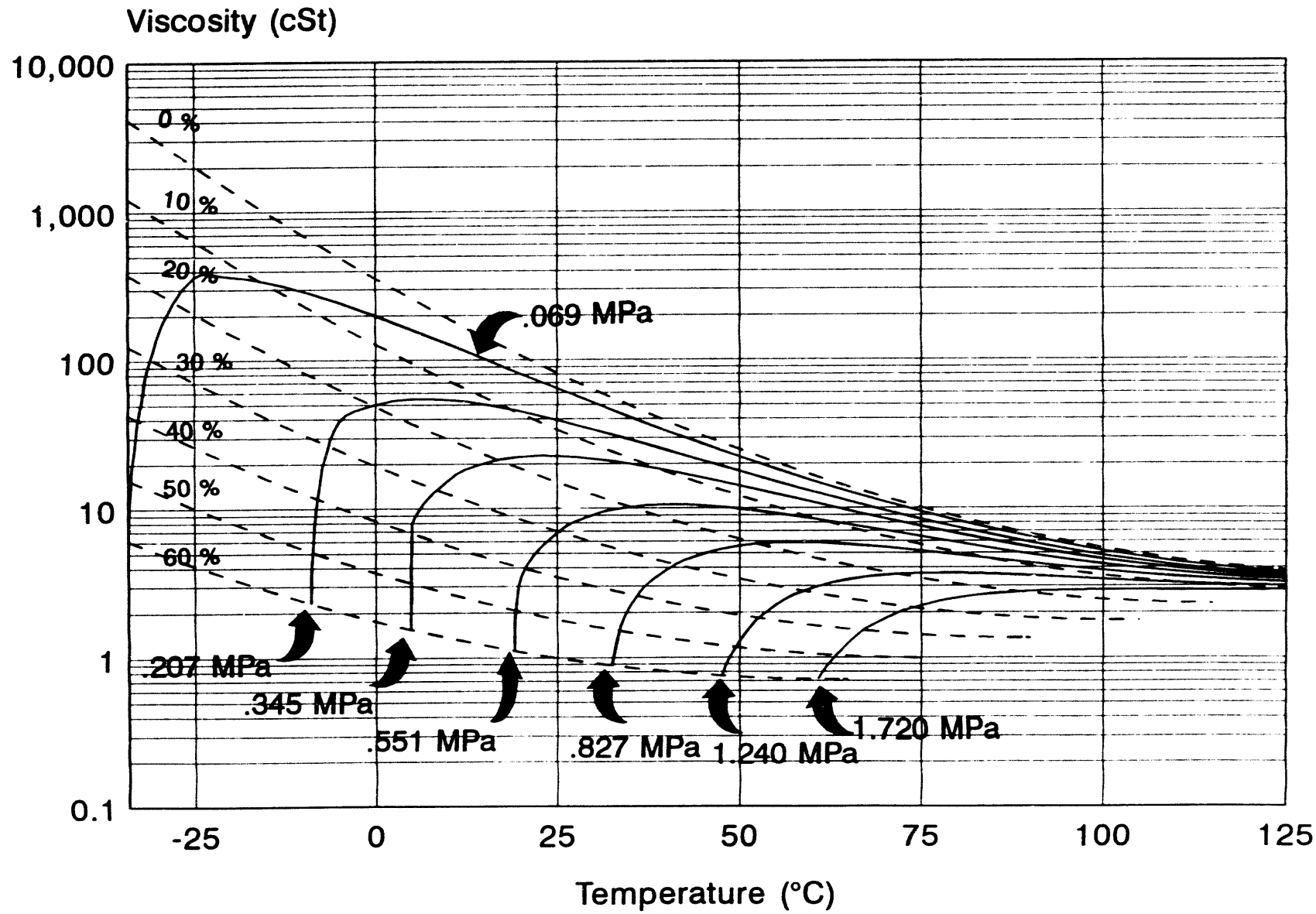
3.4 Viscosity of 32 ISO VG Mixed Acid Polyester with HFC-143a

Appendix G presents, in Table G.1, the isothermal viscosity, density, and solubility of gaseous HFC-143a in a 32 ISO VG mixed acid polyolester with good miscibility characteristics. Five viscosity data points were taken for each temperature. Figure 12 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 13 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 14 shows density as a function of temperature at constant concentrations.

Viscosity vs. Temperature

HFC-134a in 32 ISO VG Mixed Acid Polyolester

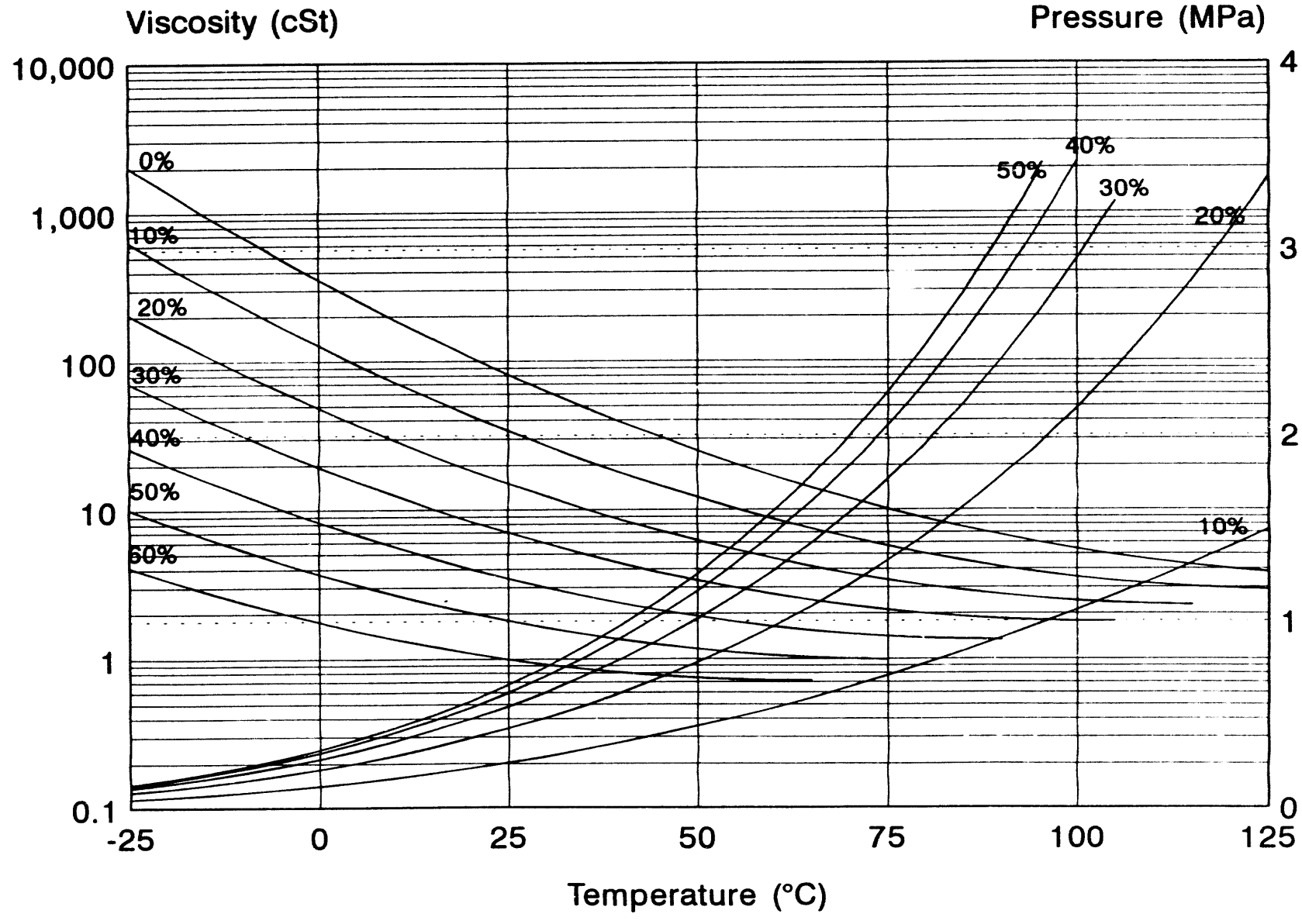
Figure 3



Viscosity and Pressure at Constant Concentrations

HFC-134a in 32 ISO VG Mixed Acid Polyolester

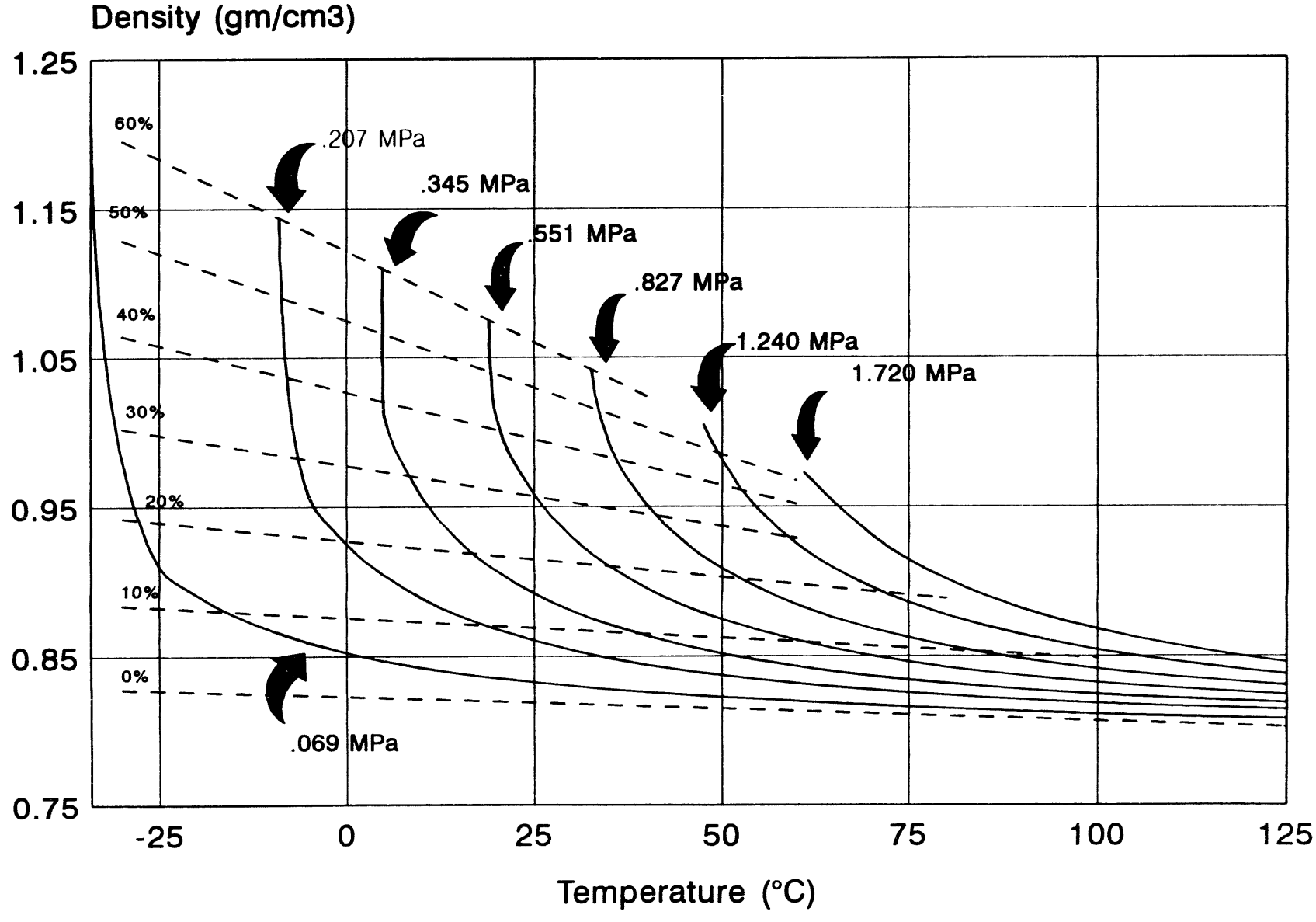
Figure 4



Density vs. Temperature

HFC-134a in 32 ISO VG Mixed Acid Polyolester

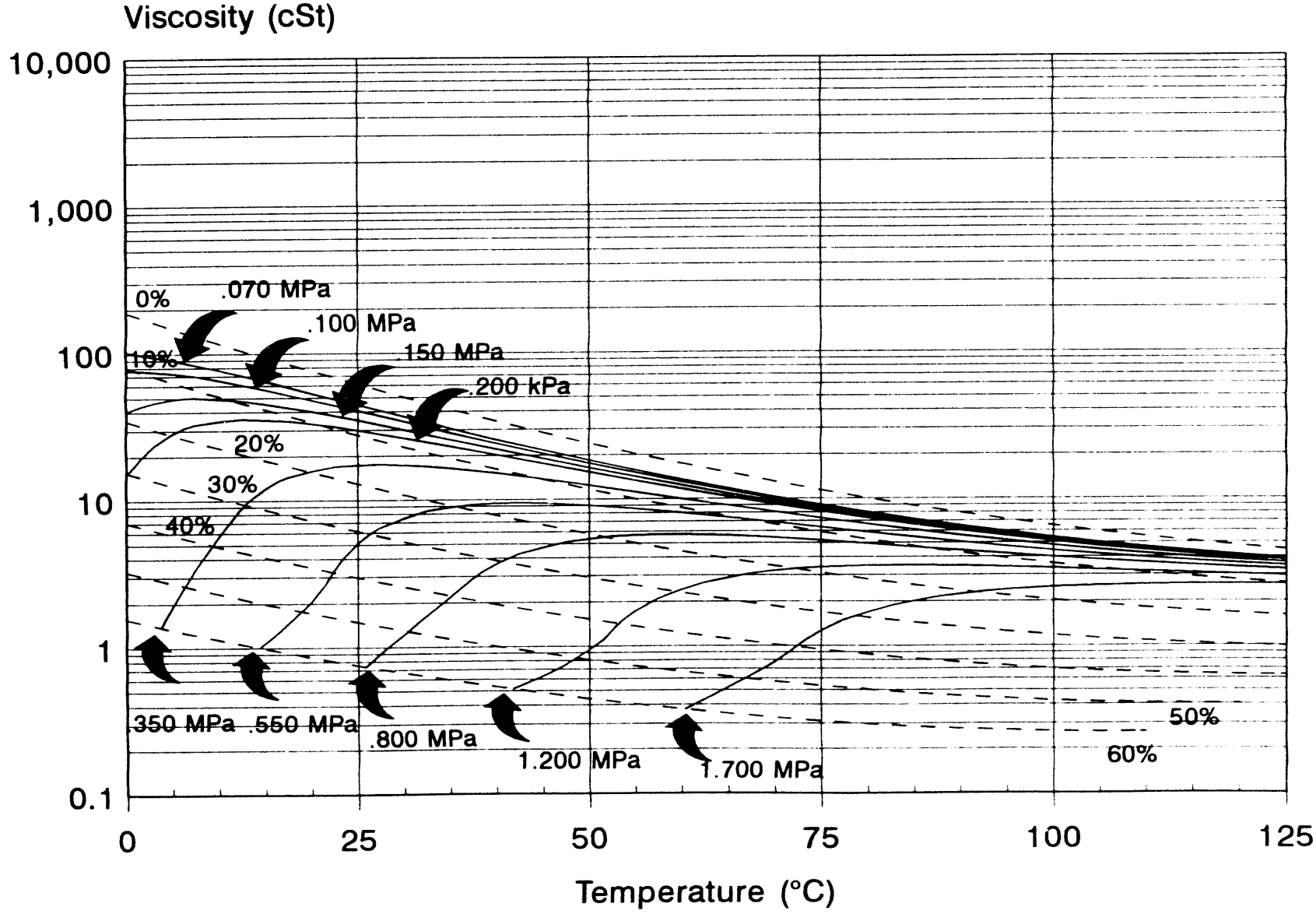
Figure 5



Viscosity vs. Temperature

HFC-134a in 32 ISO VG Branched Acid Polyolester

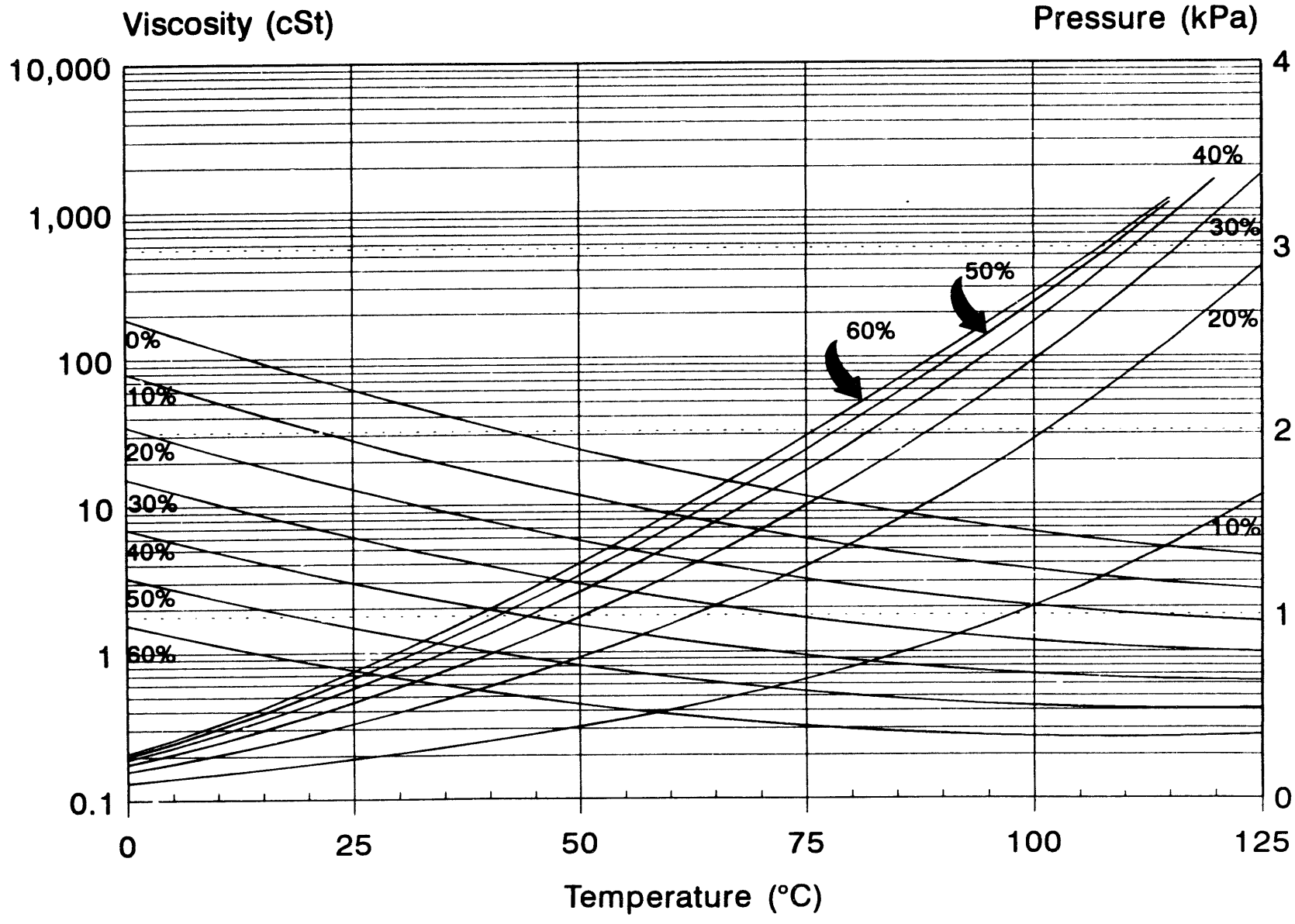
Figure 6



Viscosity and Pressure at Constant Concentrations

HFC-134a in 32 ISO VG Branched Acid Polyolester

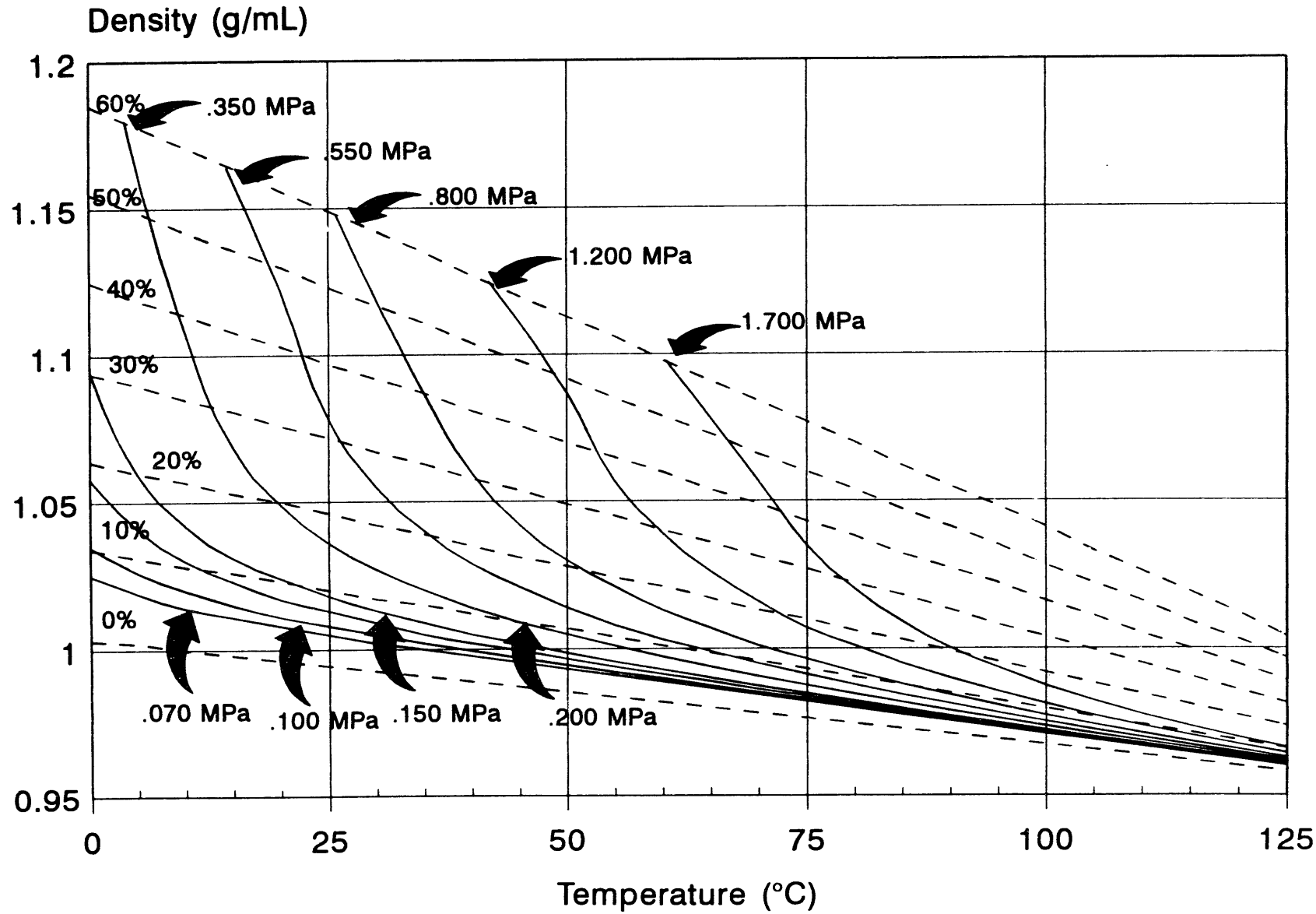
Figure 7



Density vs. Temperature

HFC-134a in 32 ISO VG Branched Acid Polyolester

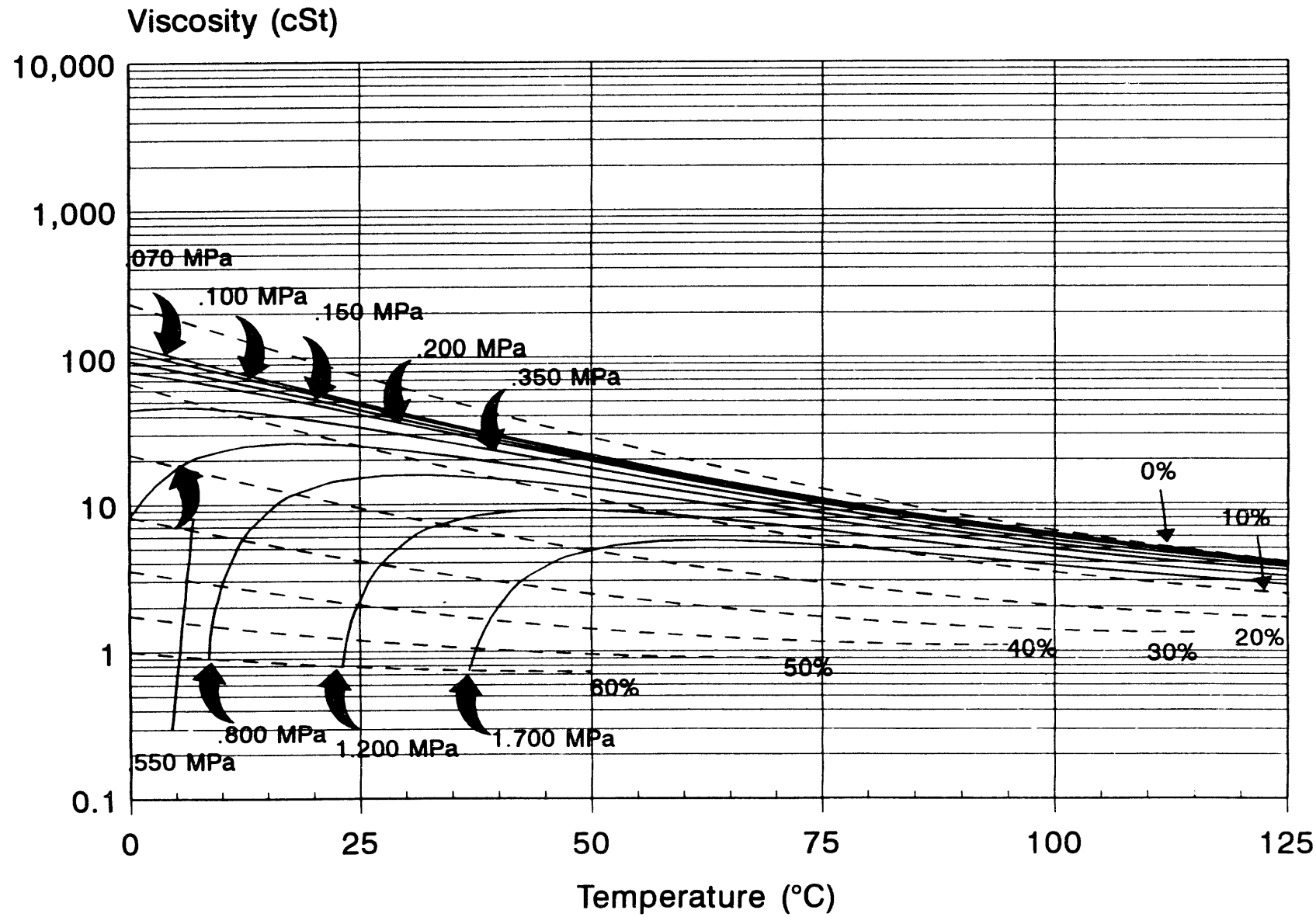
Figure 8



Viscosity vs. Temperature

HFC-143a in 32 ISO Branched Acid Polyolester

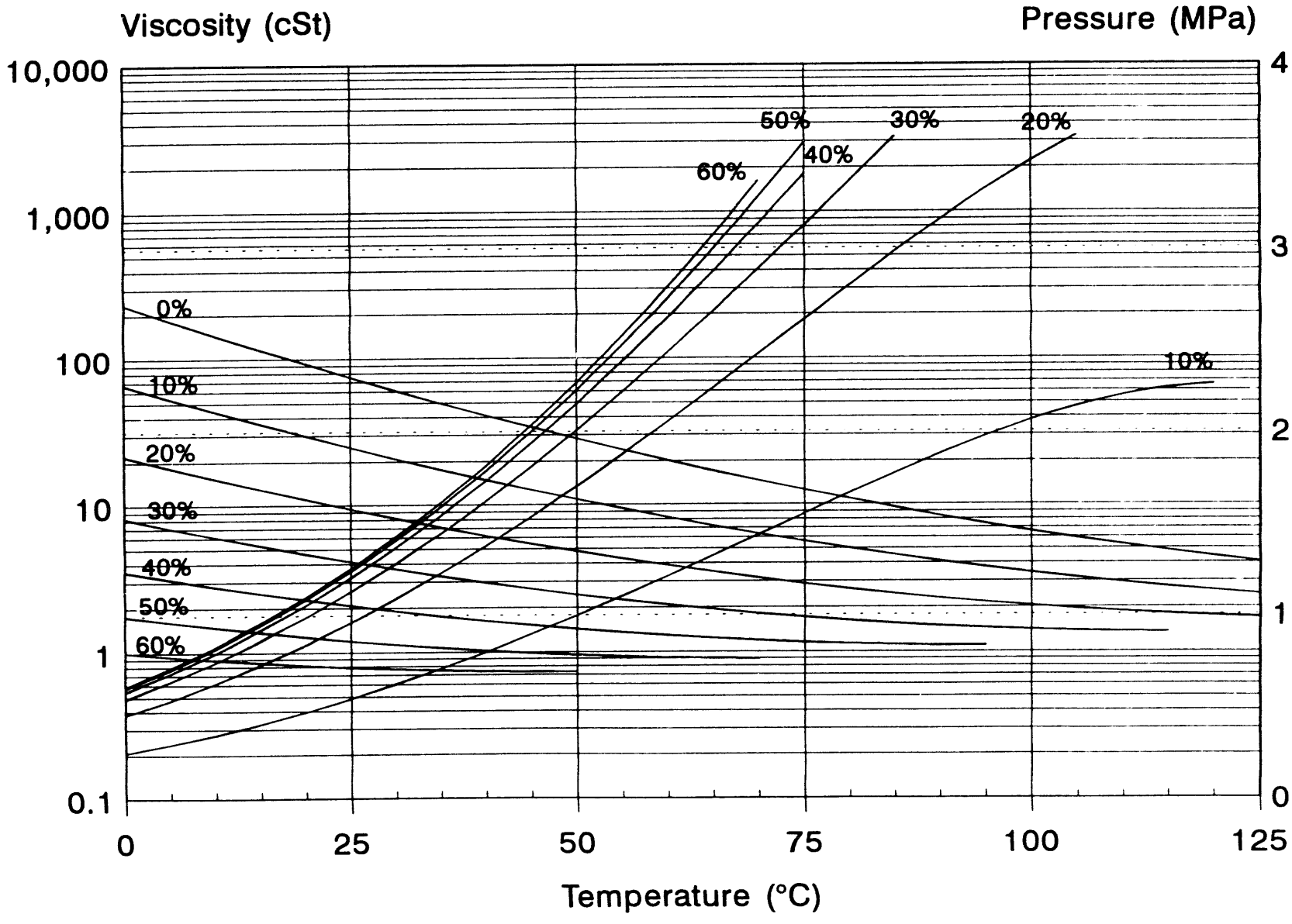
Figure 9



Viscosity and Pressure at Constant Concentrations

HFC-143a in 32 ISO VG Branched Acid Polyolester

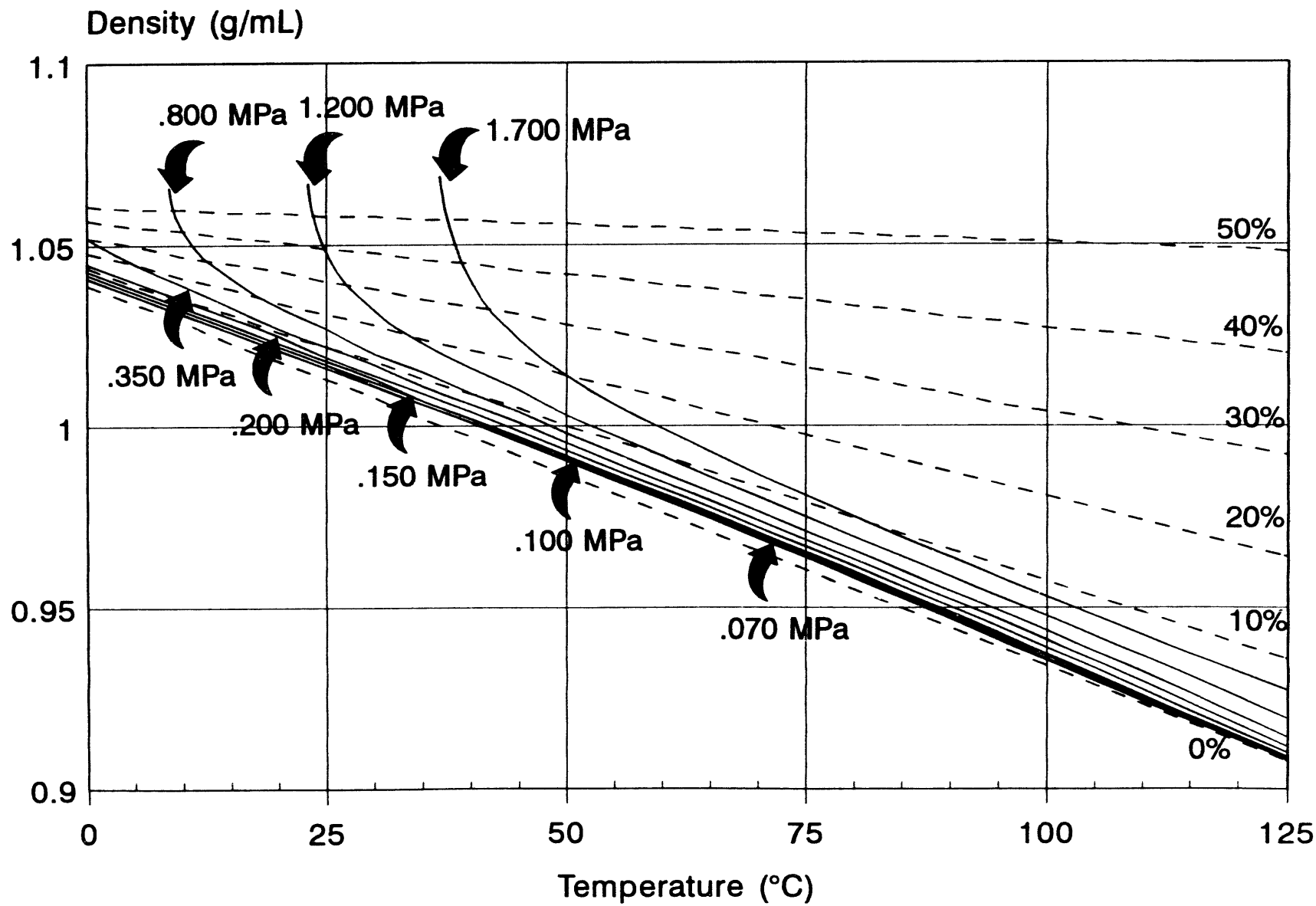
Figure 10



Density vs. Temperature for Constant Concentrations

HFC-143a with 32 ISO VG Branched Acid Polyolester

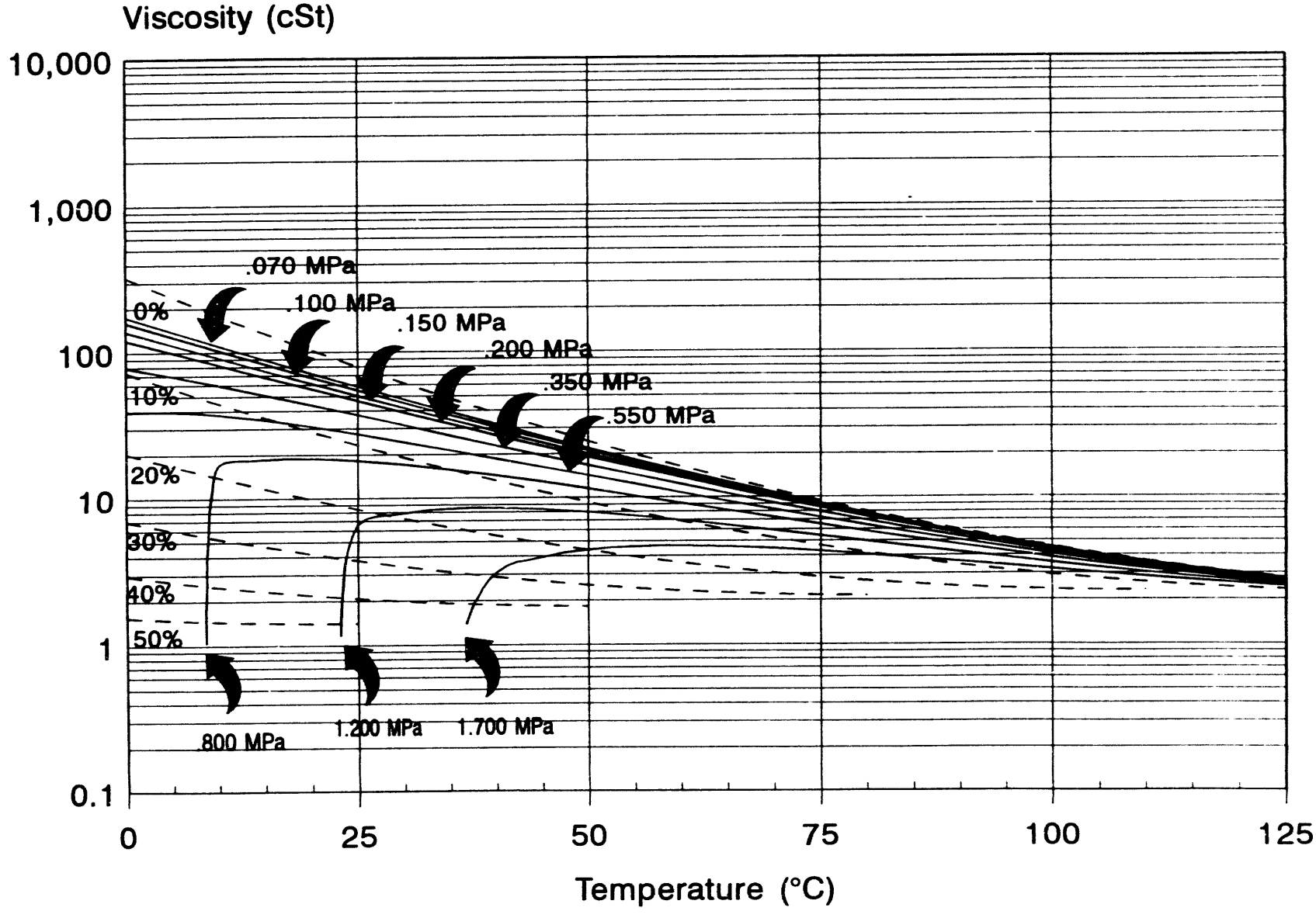
Figure 11



Viscosity vs. Temperature

HFC-143a in 32 ISO Mixed Acid Polyolester

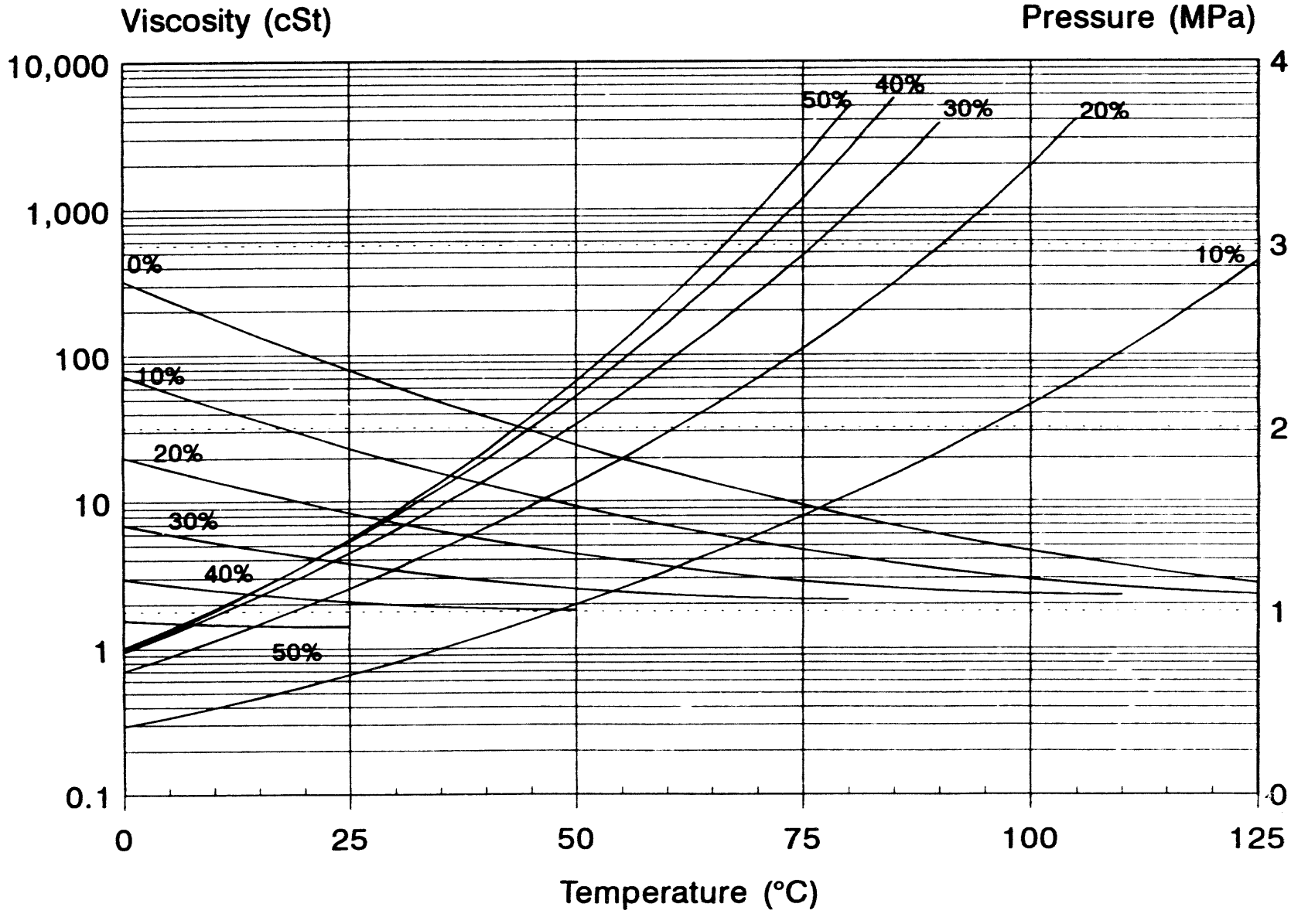
Figure 12



Viscosity and Pressure at Constant Concentrations

HFC-143a in 32 ISO VG Mixed Acid Polyolester

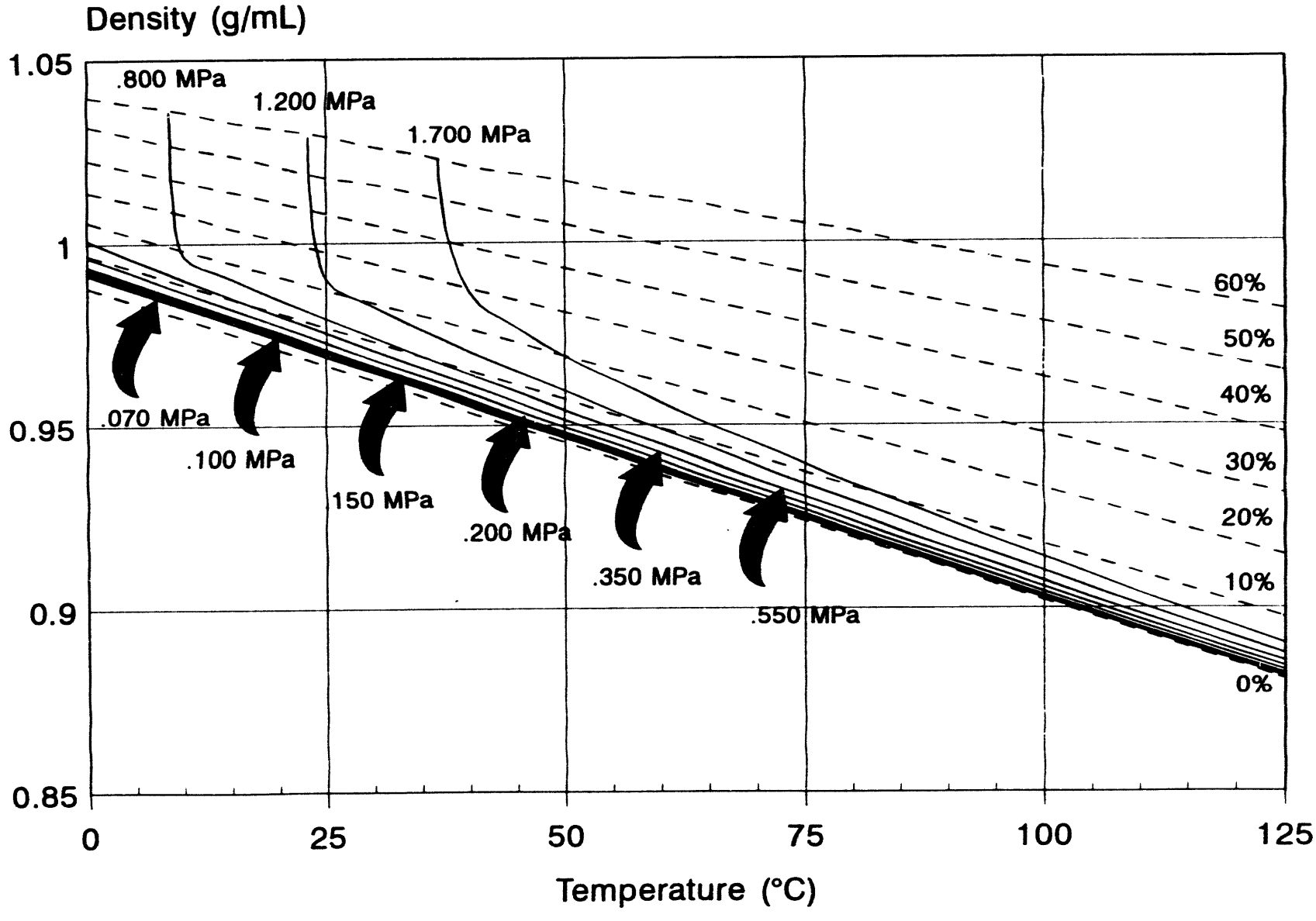
Figure 13



Density vs. Temperature

HFC-143a in 32 ISO VG Mixed Acid Polyolester

Figure 14



4. RESULTS OF MEASUREMENTS WITH REFRIGERANT BLENDS

4.1 Viscosity of 32 ISO VG Branched Acid Polyester with HFC-125/143a/134a (44/52/4% w/w)

Appendix H presents, in Table H.1, the isothermal viscosity, density, and solubility of the gaseous blend HFC-125/143a/134a (44/52/4% w/w) in a 32 ISO VG branched acid polyolester. 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 15 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 16 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 17 shows density as a function of temperature at constant concentrations.

4.2 Viscosity of 32 ISO VG Mixed Acid Polyester with HFC-125/143a/134a (44/52/4% w/w)

Appendix I presents, in Table I.1, the isothermal viscosity, density, and solubility of the gaseous blend HFC-125/143a/134a (44/52/4% w/w) in a 32 ISO VG mixed acid polyolester. 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 18 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 19 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 20 shows density as a function of temperature at constant concentrations.

4.3 Viscosity of 32 ISO VG Mixed Acid Polyester with HFC-125/143a (50/50 % w/w)

Appendix J presents, in Table J.1, the isothermal viscosity, density, and solubility of the gaseous blend HFC-125/143a (50/50 % w/w) in a 32 ISO VG mixed acid polyolester. 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 21 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 22 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 23 shows density as a function of temperature at constant concentrations.

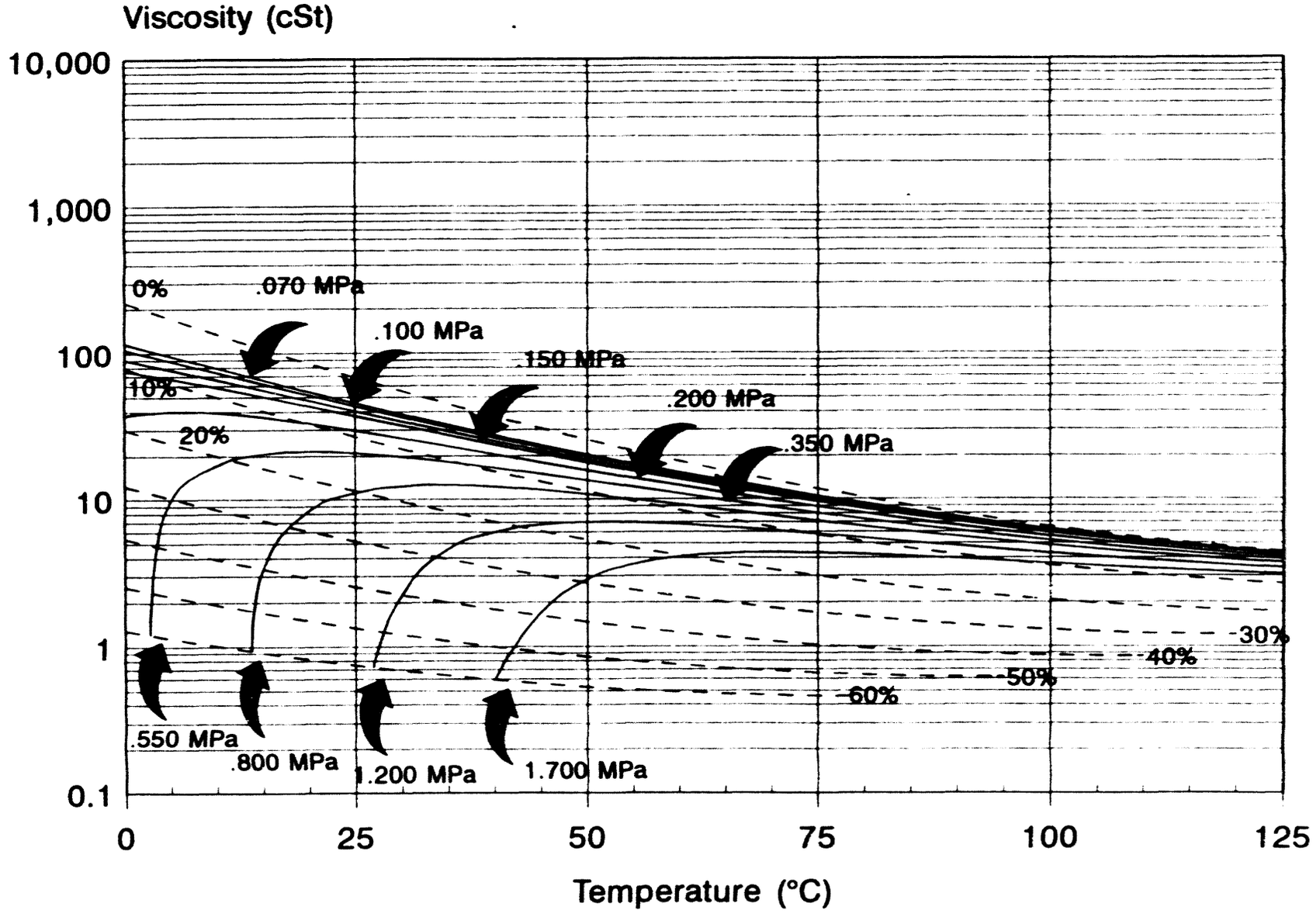
4.4 Viscosity of 32 ISO VG Branched Acid Polyester with HFC-125/143a (50/50 % w/w)

Appendix K presents, in Table K.1, the isothermal viscosity, density, and solubility of the gaseous blend HFC-125/143a (50/50 % w/w) in a 32 ISO VG branched acid polyolester. 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 24 presents viscosity as a function of temperature and includes isobaric pressure lines. Figure 25 presents a modified "Daniel plot" showing viscosity and pressure at constant concentrations as a function of temperature. Figure 26 shows density as a function of temperature at constant concentrations.

Viscosity vs. Temperature

Blend 125/143a/134a (44/52/4% w/w) in 32 ISO VG Branched Acid Polyolester

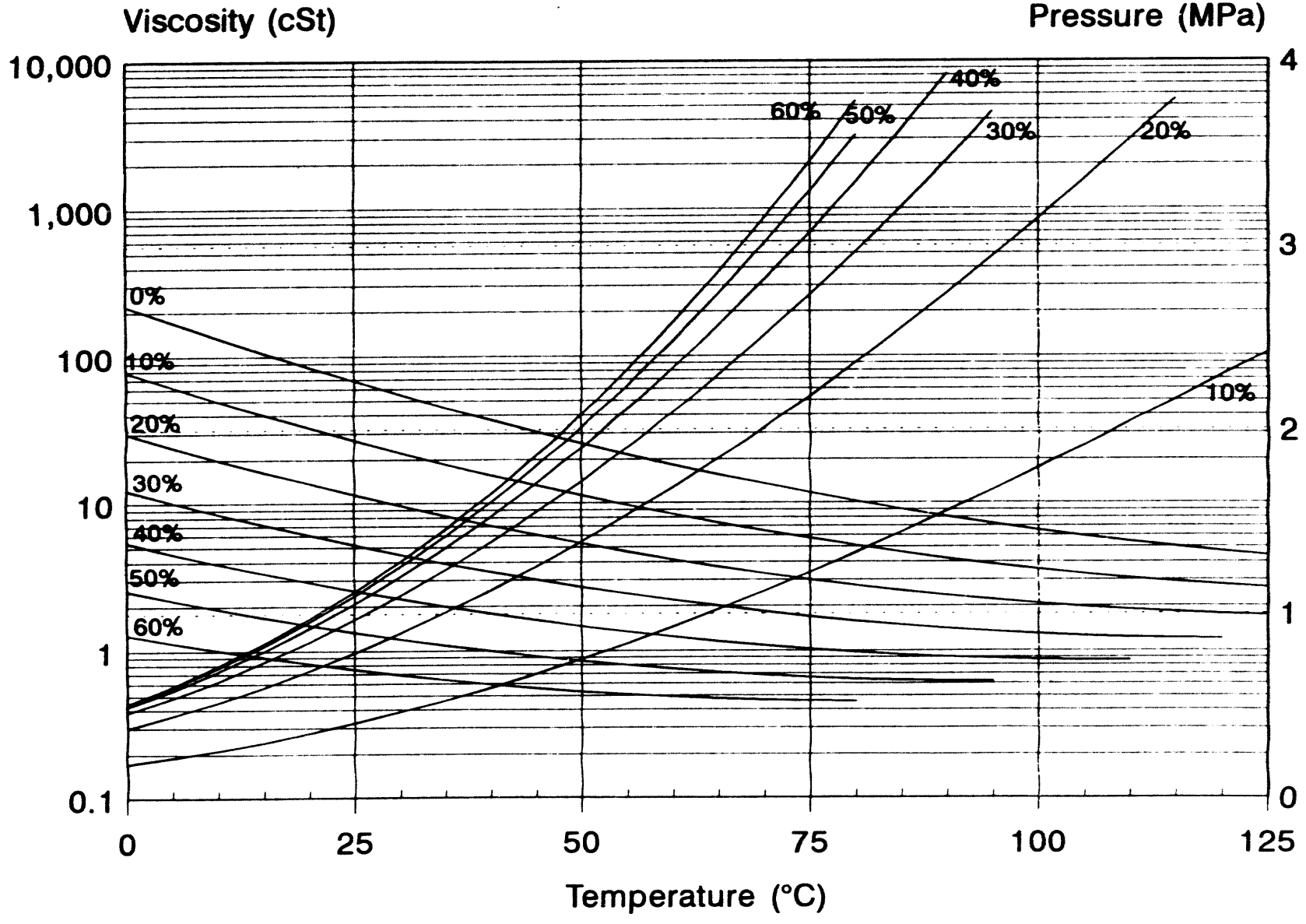
Figure 15



Viscosity and Pressure at Constant Concentrations

Blend 125/143a/134a (44/52/4% w/w) in 32 ISO VG Branched Acid Polyolester

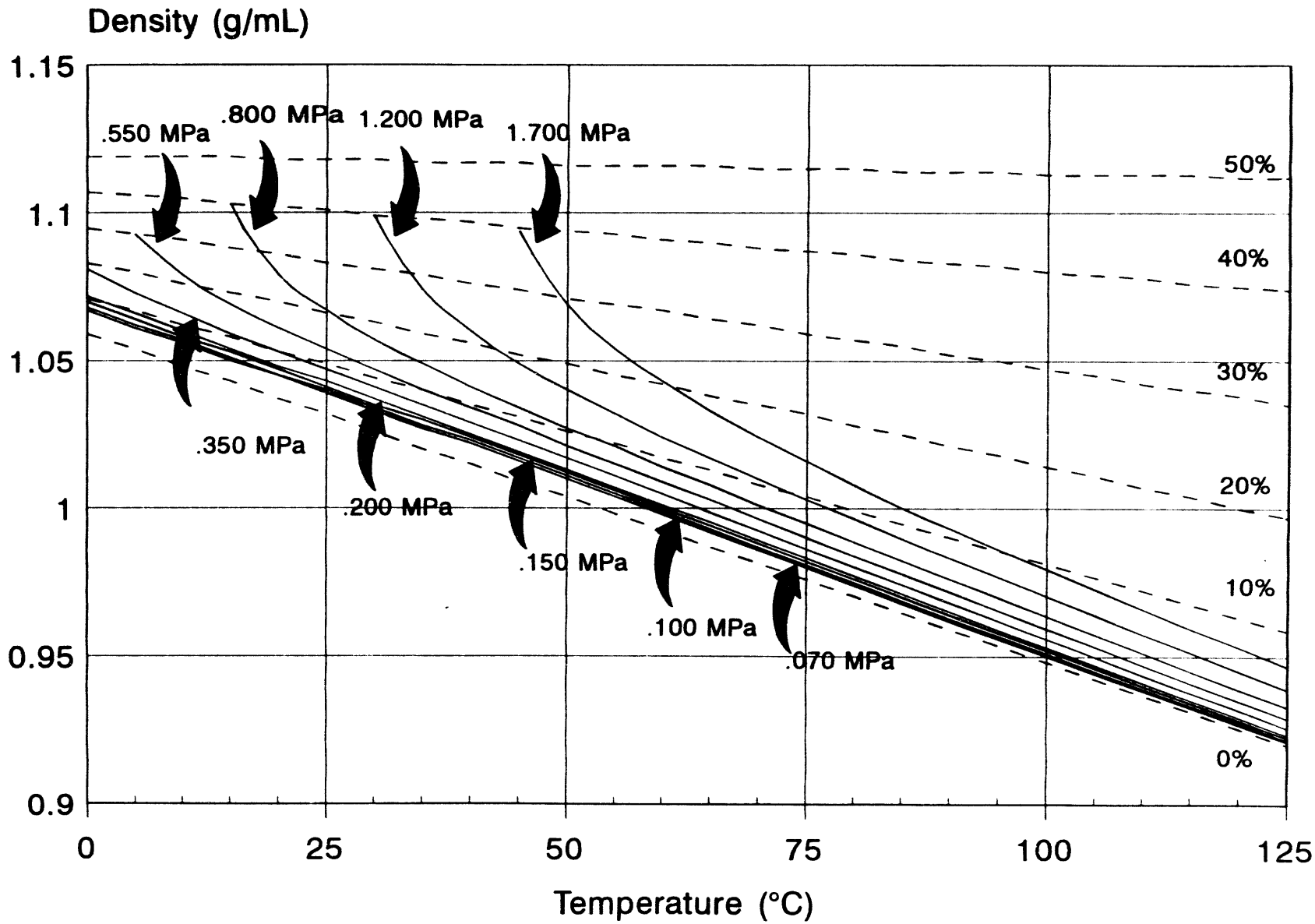
Figure 16



Density vs. Temperature

Blend 125/143a/134a (44/52/4% w/w) in 32 ISO VG Branched Acid Polyolester

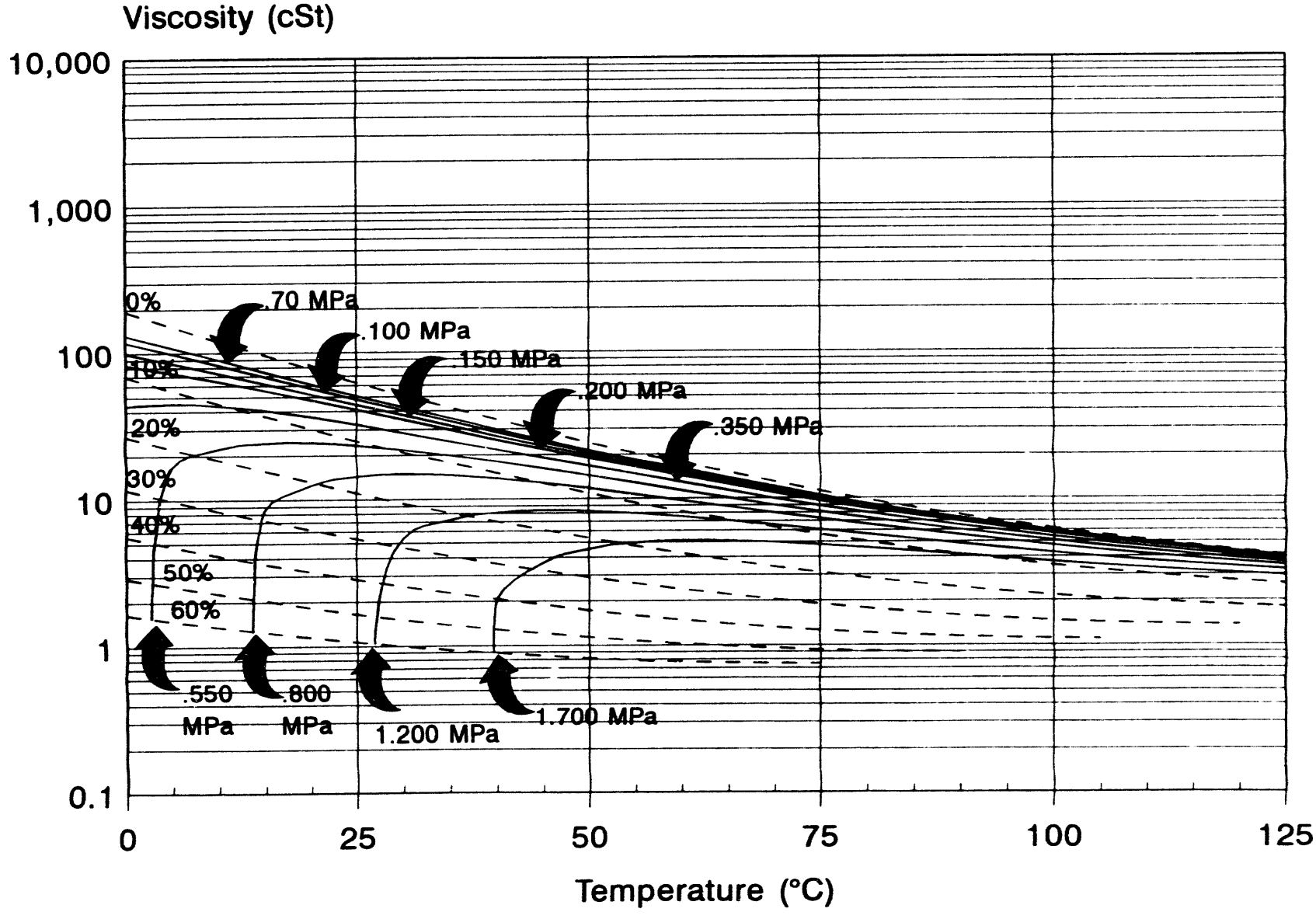
Figure 17



Viscosity vs. Temperature

Blend 125/143a/134a (44/52/4% w/w) in 32 ISO VG Mixed Acid Polyolester

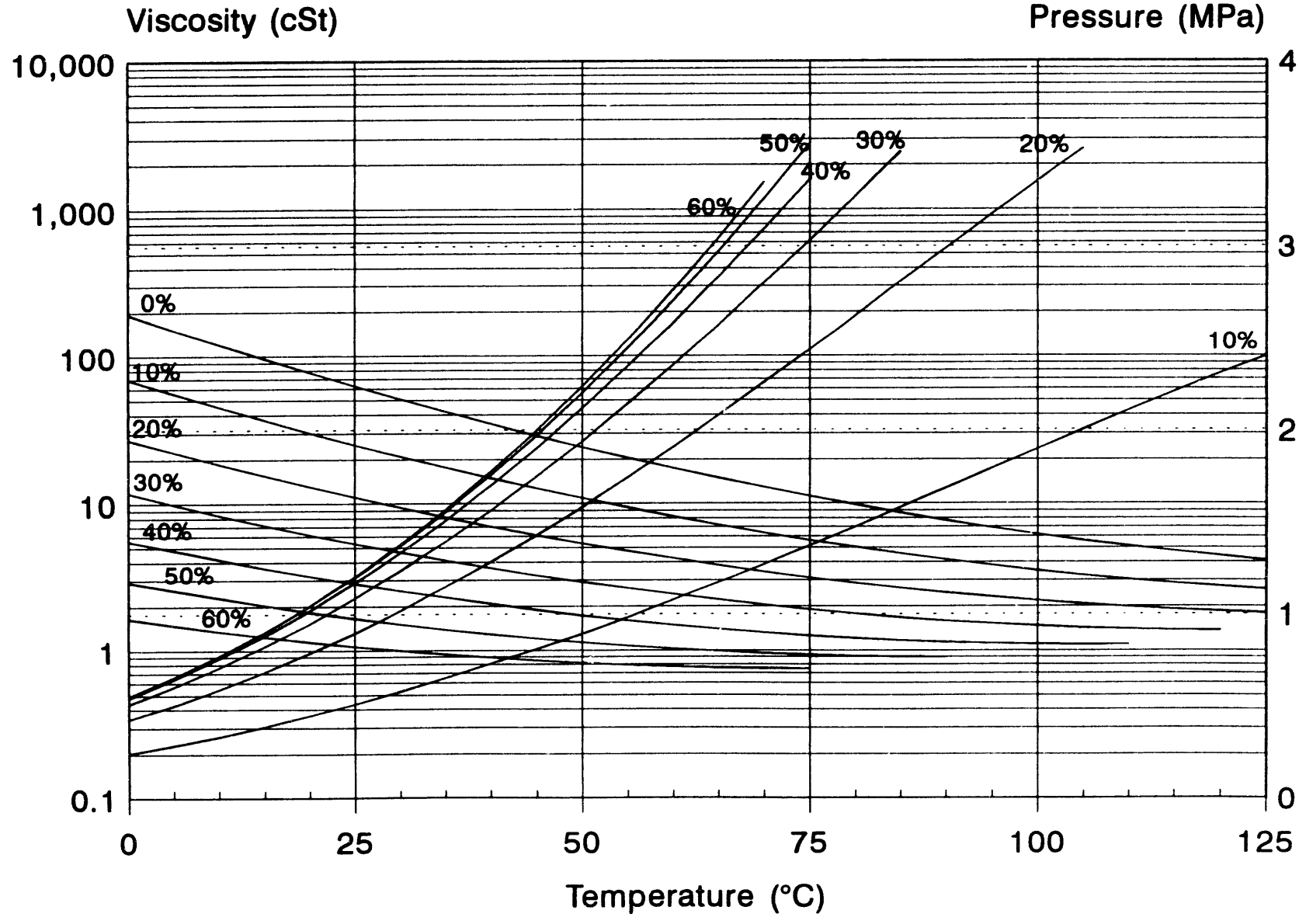
Figure 18



Viscosity and Pressure at Constant Concentrations

Blend 125/143a/134a (44/52/4% w/w) in 32 ISO VG Mixed Acid Polyolester

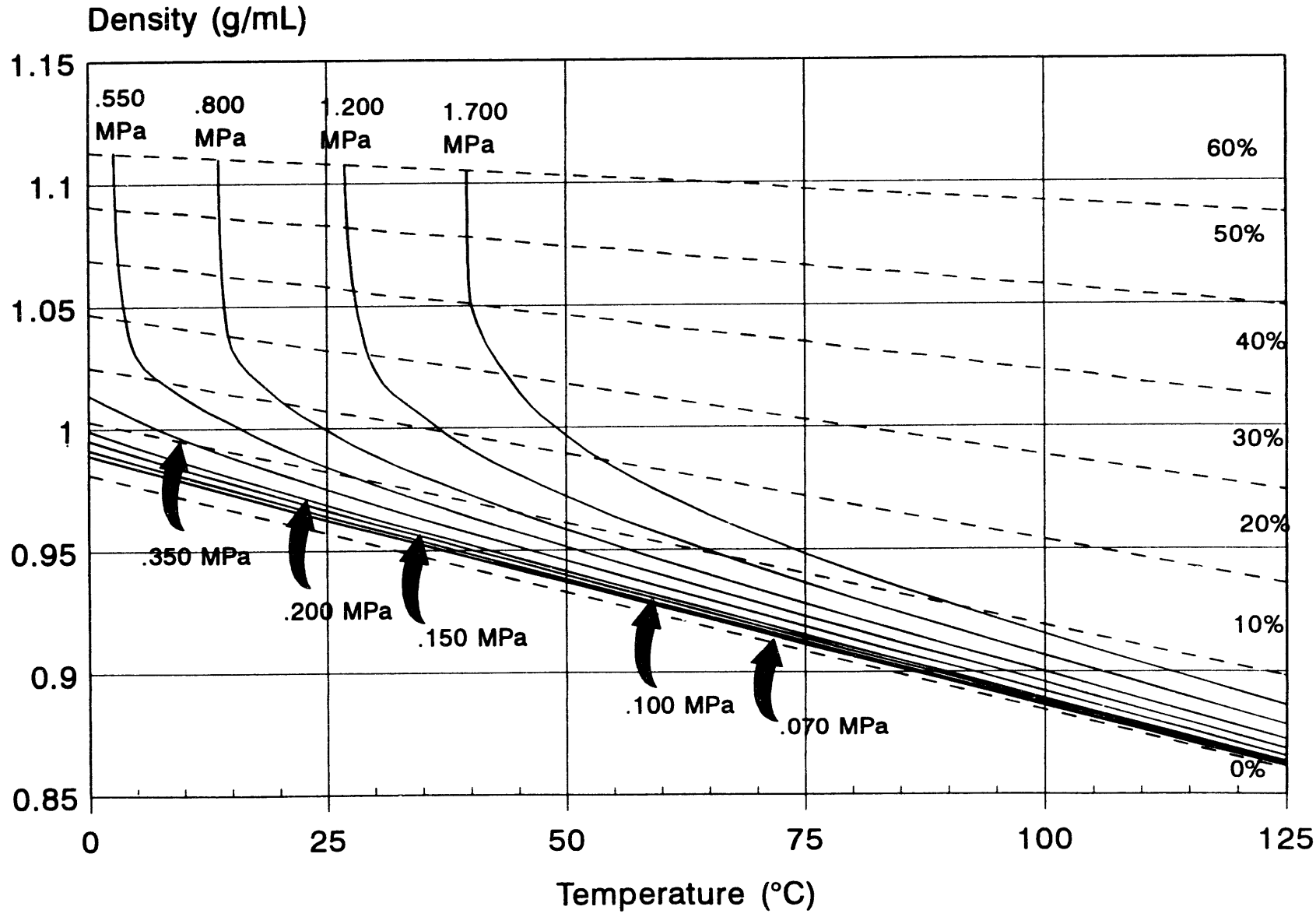
Figure 19



Density vs. Temperature

Blend 125/143a/134a (44/52/4% w/w) in 32 ISO VG Mixed Acid Polyolester

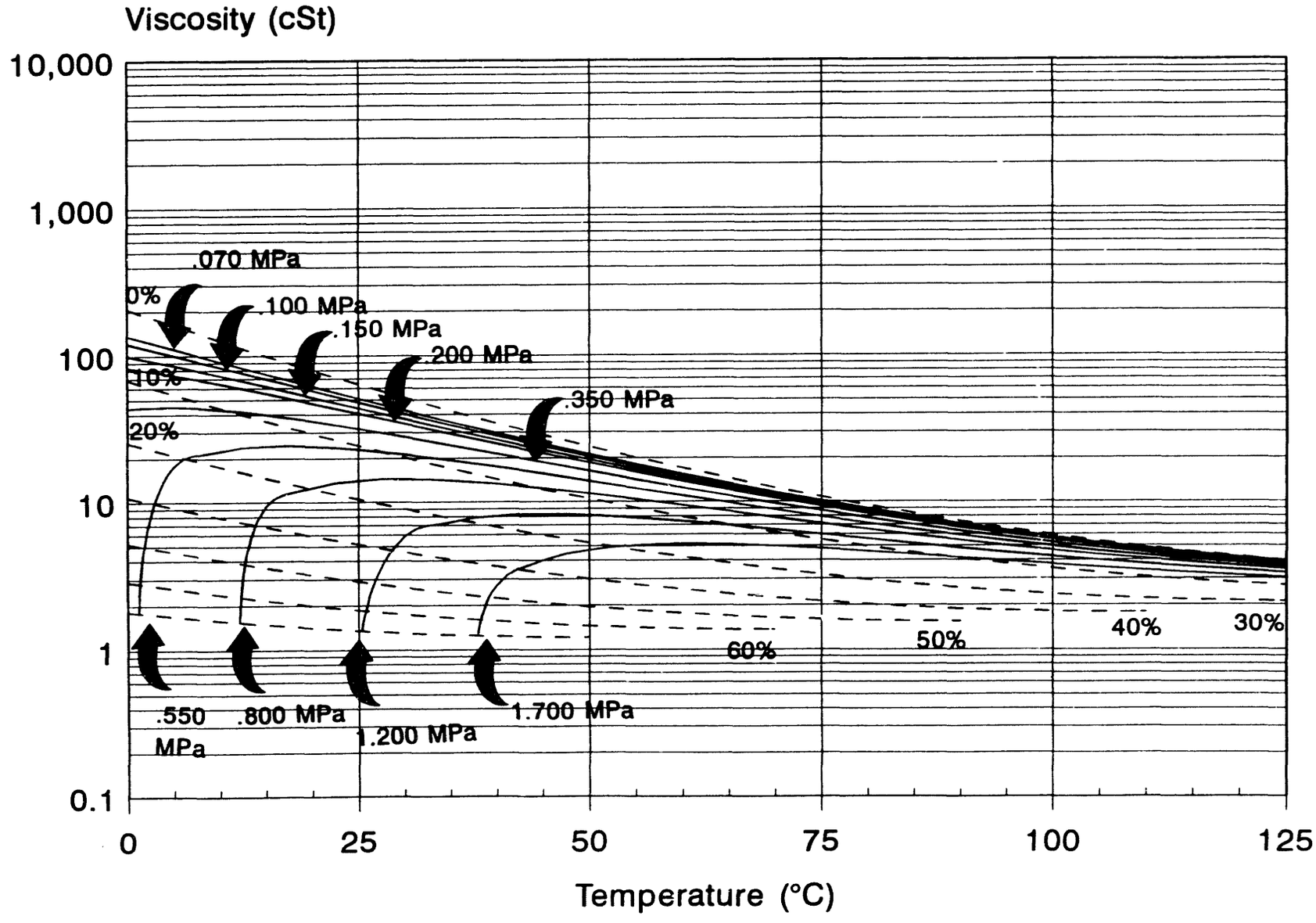
Figure 20



Viscosity vs. Temperature

Blend 125/143a (50/50% w/w) in 32 ISO VG Mixed Acid Polyolester

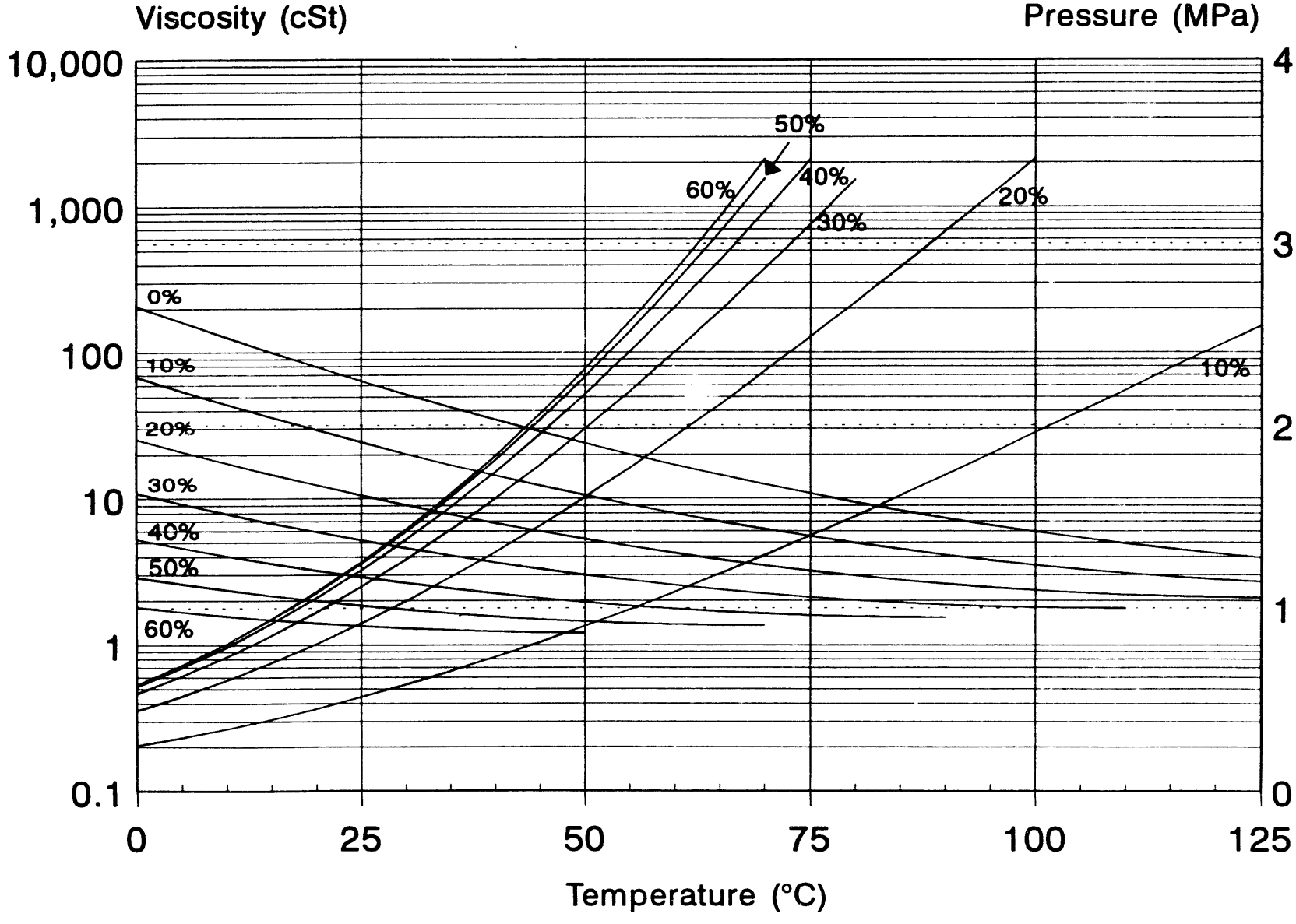
Figure 21



Viscosity and Pressure at Constant Concentrations

Blend 125/143a (50/50% w/w) in 32 ISO VG Mixed Acid Polyolester

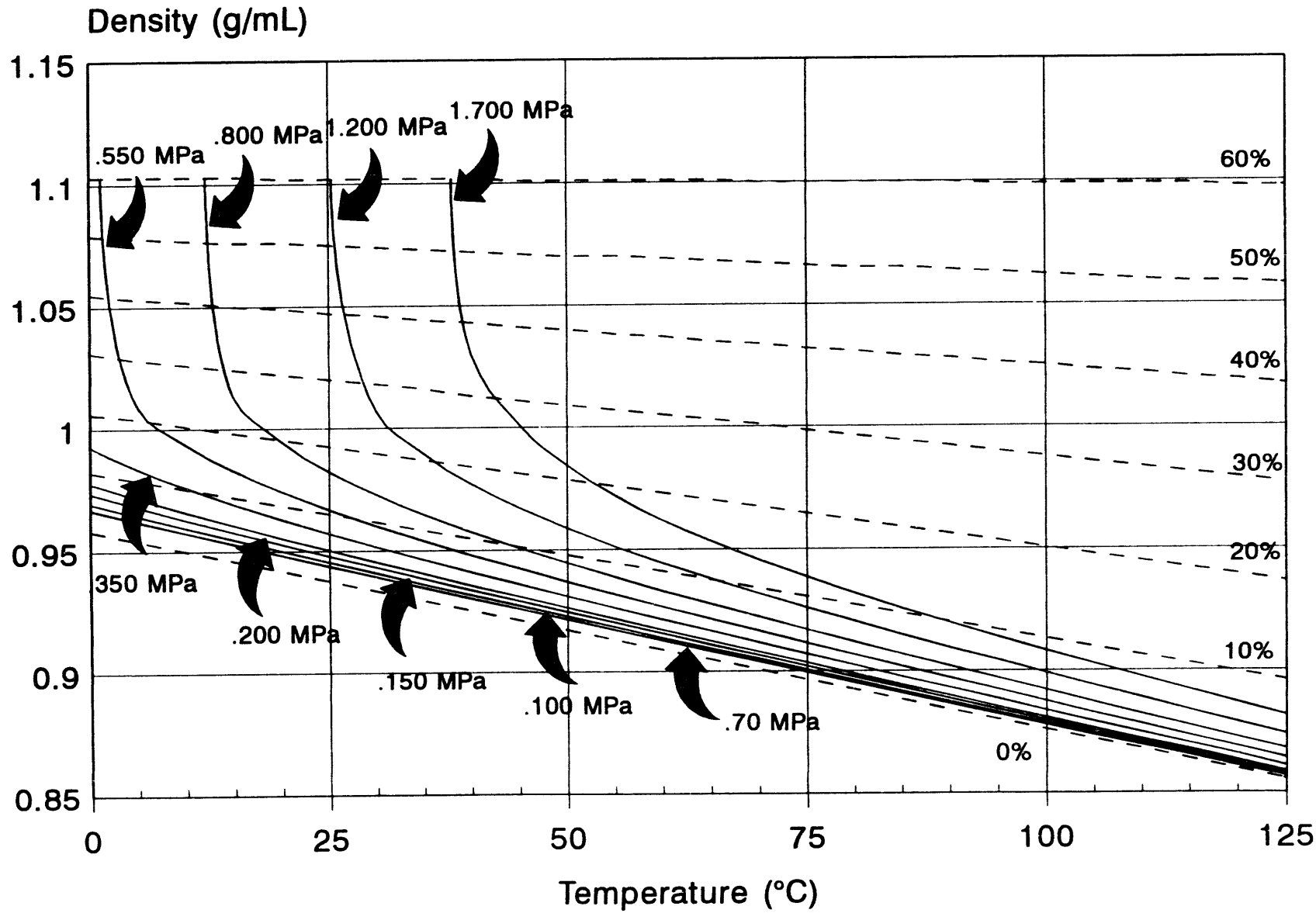
Figure 22



Density vs. Temperature

Blend 125/143a (50/50% w/w) in 32 ISO VG Mixed Acid Polyolester

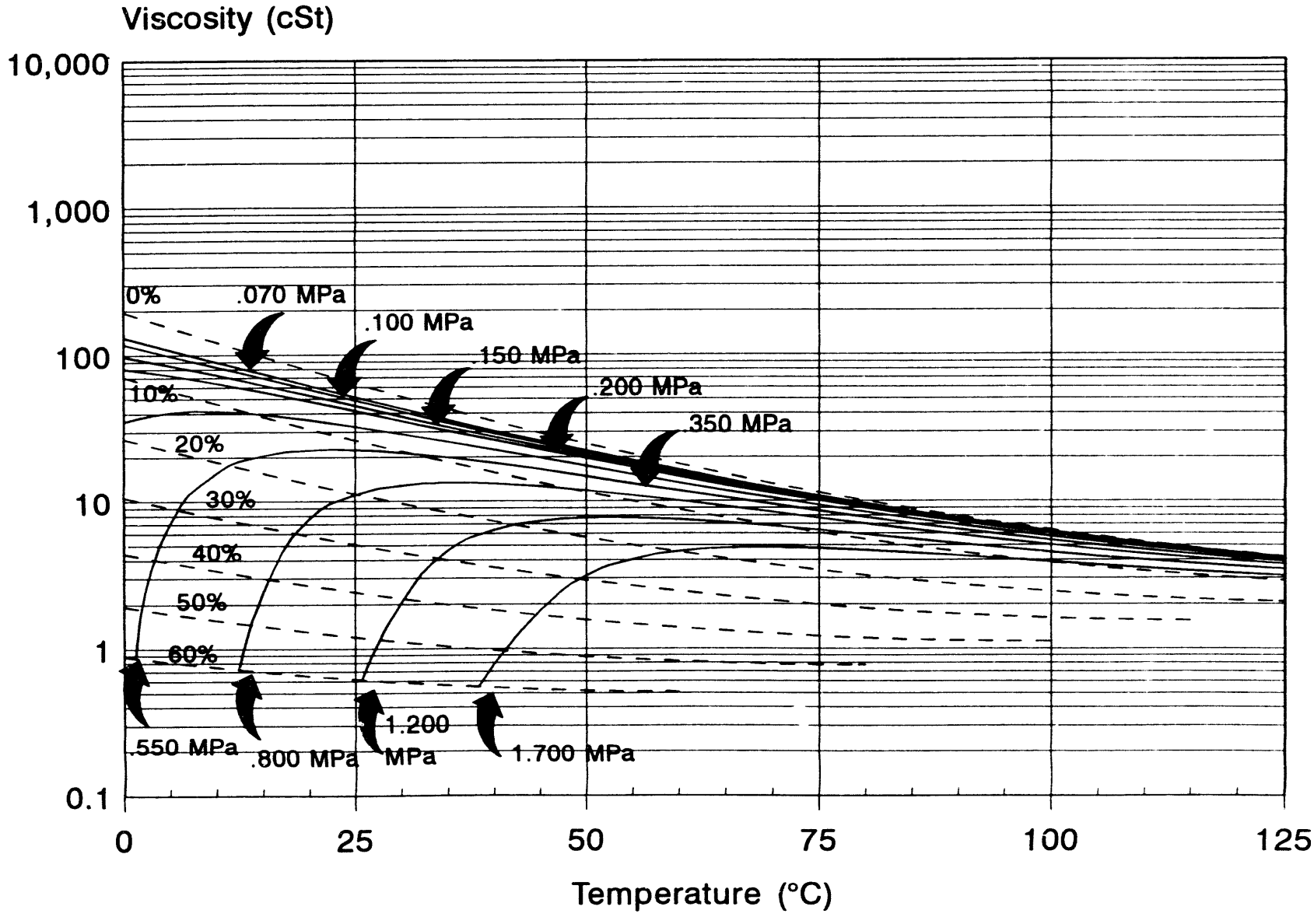
Figure 23



Viscosity vs. Temperature

Blend 125/143a (50/50% w/w) in 32 ISO VG Branched Acid Polyolester

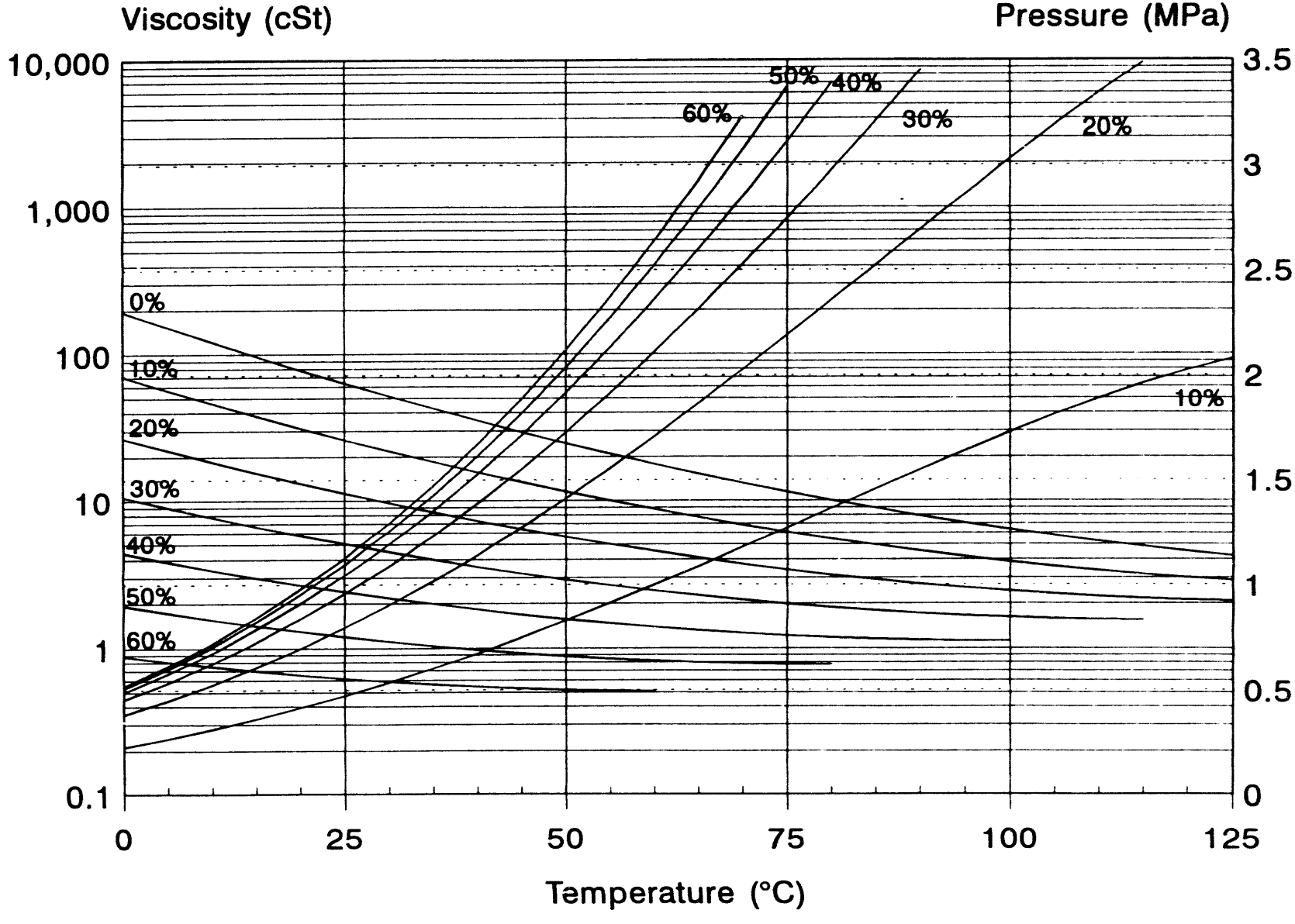
Figure 24



Viscosity and Pressure at Constant Concentrations

Blend 125/143a (50/50% w/w) in 32 ISO VG Branched Acid Polyolester

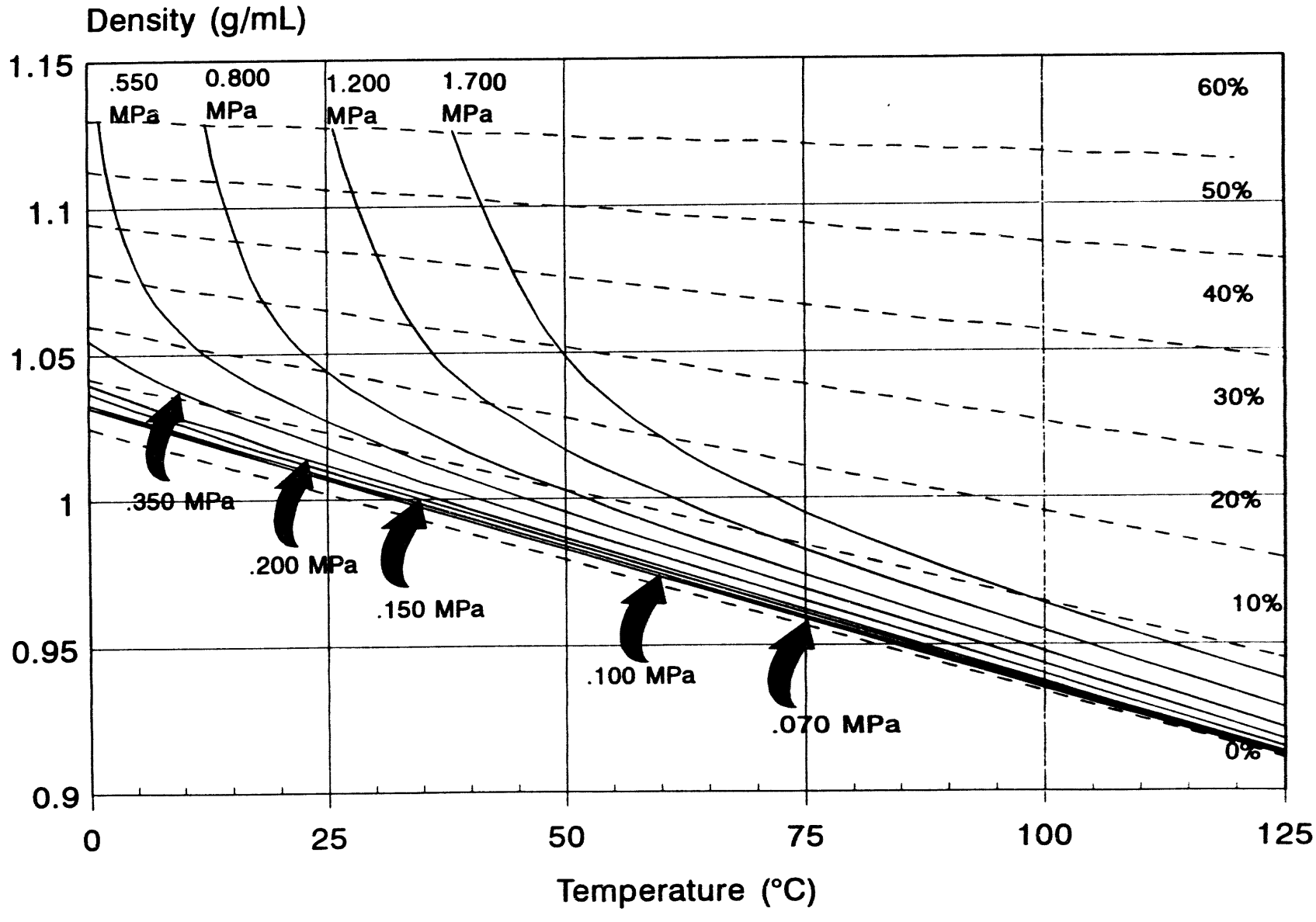
Figure 25



Density vs. Temperature

Blend 125/143a (50/50% w/w) in 32 ISO VG Branched Acid Polyolester

Figure 26



5. COMPLIANCE WITH AGREEMENT

Imagination Resources, Inc. is in compliance with the contract agreement.

6. PRINCIPAL INVESTIGATOR EFFORT

The principal investigators have devoted 1750 hours toward the completion of this contract. Activities include reporting early refrigerant miscibility information to the Technical Oversight Group, and measuring viscosity, density, and solubility.

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APPENDICES

APPENDIX A
Miscibilities of Refrigerant Blends A-F

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

Alkylbenzene (Lubricant 5) was used to determine the miscibility of aromatics. Surprisingly, it appeared partially miscible with refrigerant blend D (HFC-125/143a/134a 44/52/4% w/w). This miscibility might result from lower temperatures; this suggests a possibility for good oil return and inverse miscibility at higher temperatures.

Levels of immiscibility may significantly effect the fractionation of individual gases at different temperatures and pressures. For example, Lubricant 2 is a 32 ISO VG branched acid polyolester, believed to be the most miscible type; 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 3 has been determined to be the least miscible lubricant tested, although its viscosity is close to that of Lubricant 2. Consequently, Lubricant 3 was used in this study to verify the impact of partial liquid miscibility on the gas solubility of various gases in refrigerant blends. Lubricants 1 and 4 are in the intermediate range of miscibility. Lubricant 6, a mineral oil, was included in order to provide a basis for comparison.

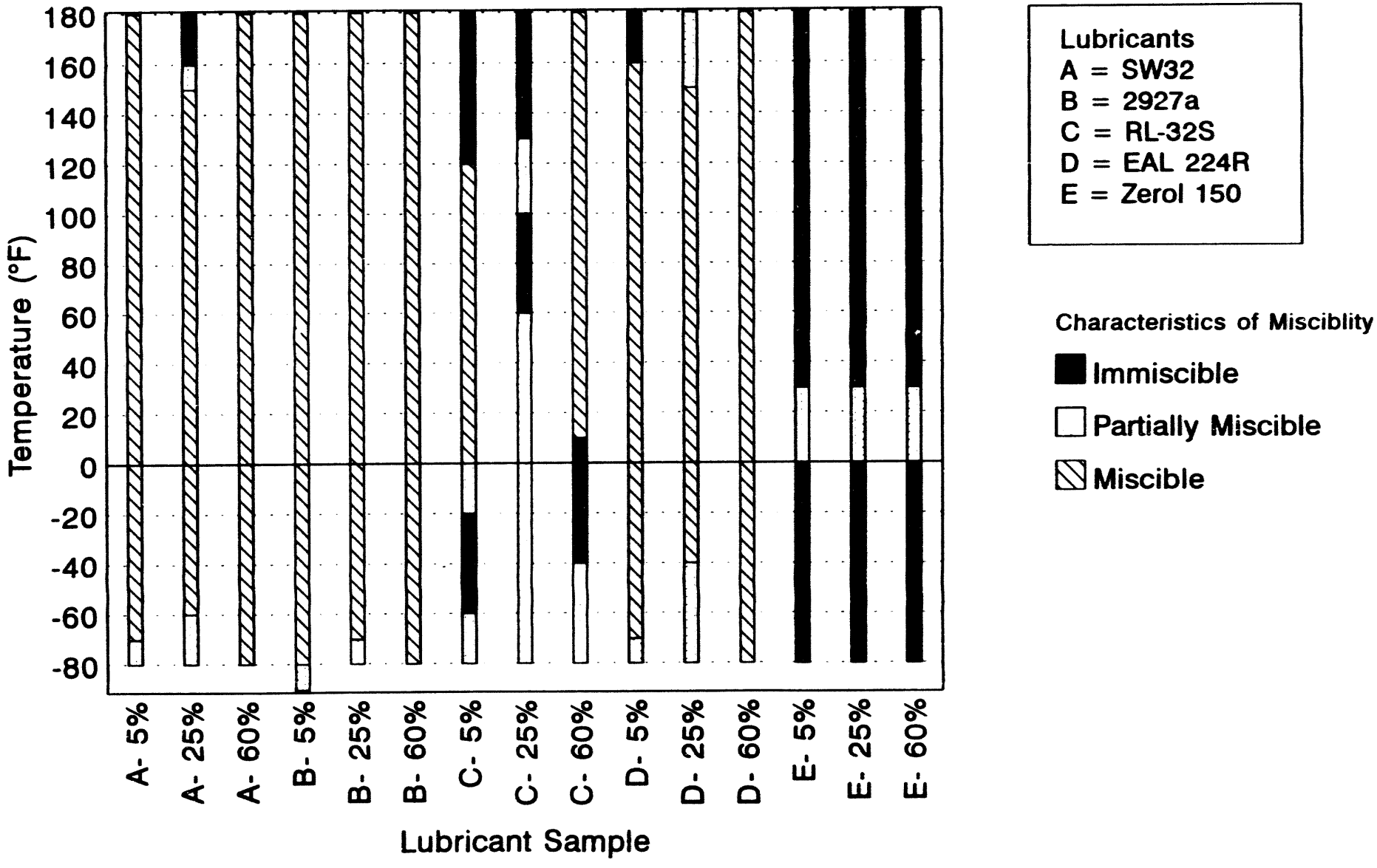
Table A.1. Lubricants Used in Miscibility Tests

Fluid	Name	Manufacturer	Type	Trademark?
1	Icematic SW32	Castrol	Branched Acid Polyolester	Registered Trademark
2	Emery 2968a	Henkel, Emery Group	Branched Acid Polyolester	Registered Trademark
3	RL-32S	ICI Chemicals and Polymers, Ltd.	Mixed Acid Polyolester	Registered Trademark
4	Arctic EAL 224R	Mobil	Mixed Acid Polyolester	Registered Trademark
5	Shrieve Zerol 150	Shrieve Chemical Company	Alkylbenzene	Registered Trademark
6	Suniso 3GS	Witco Corporation	Naphthenic Mineral Oil	Registered Trademark

Miscibility of Refrigerant Blend A

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

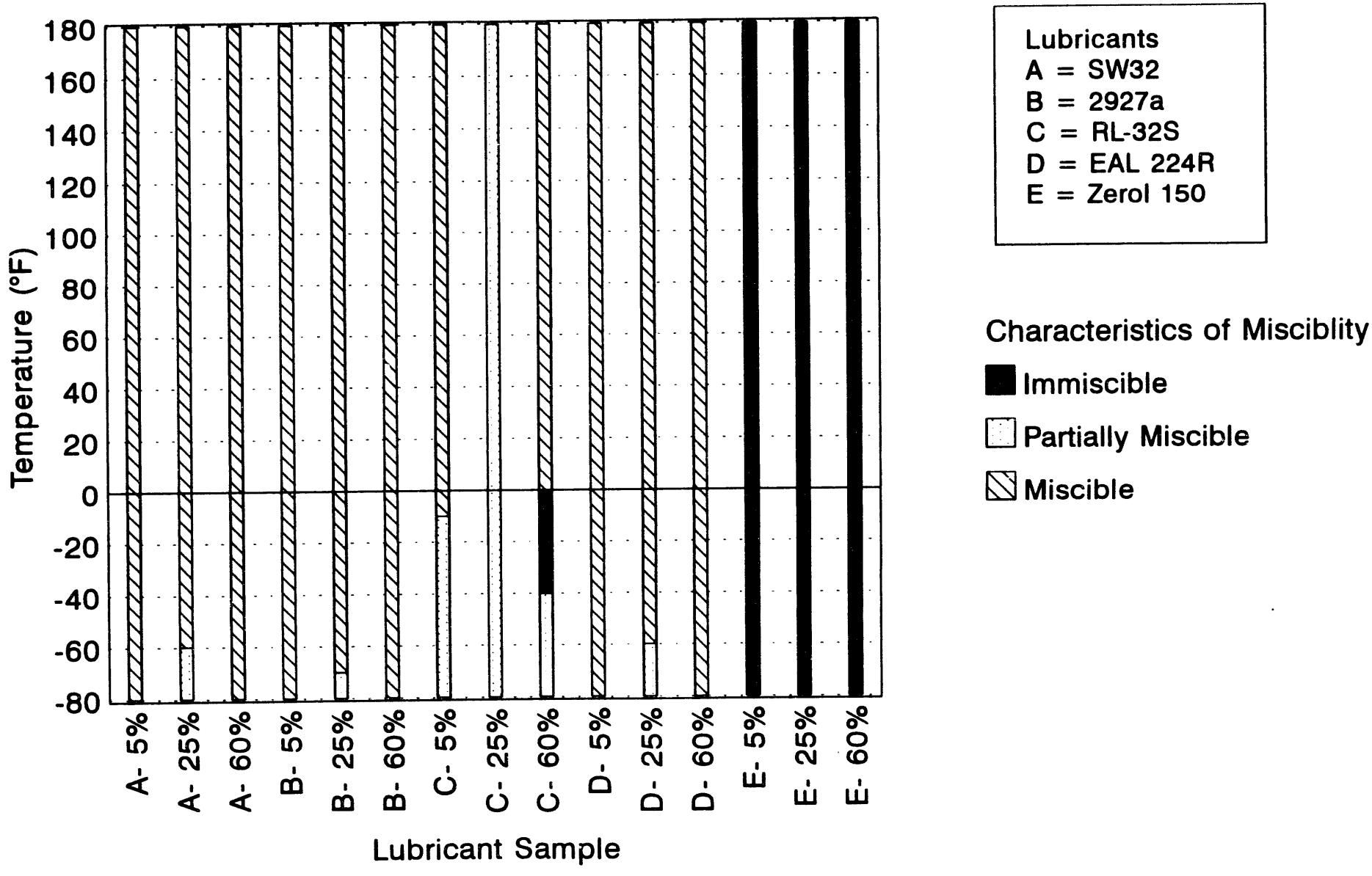
Figure A.1



Miscibility of Refrigerant Blend B

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

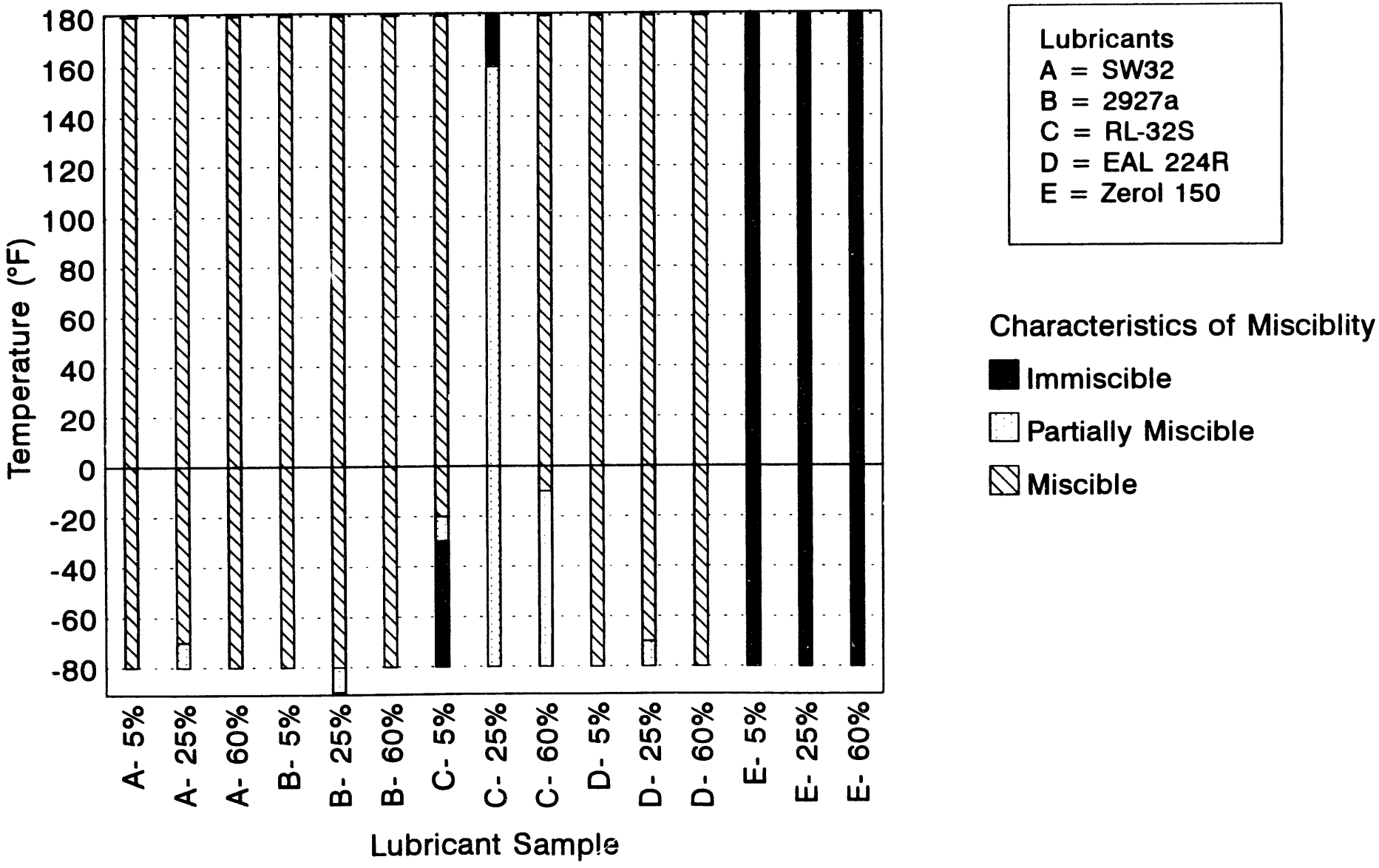
Figure A.2



Miscibility of Refrigerant Blend C

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

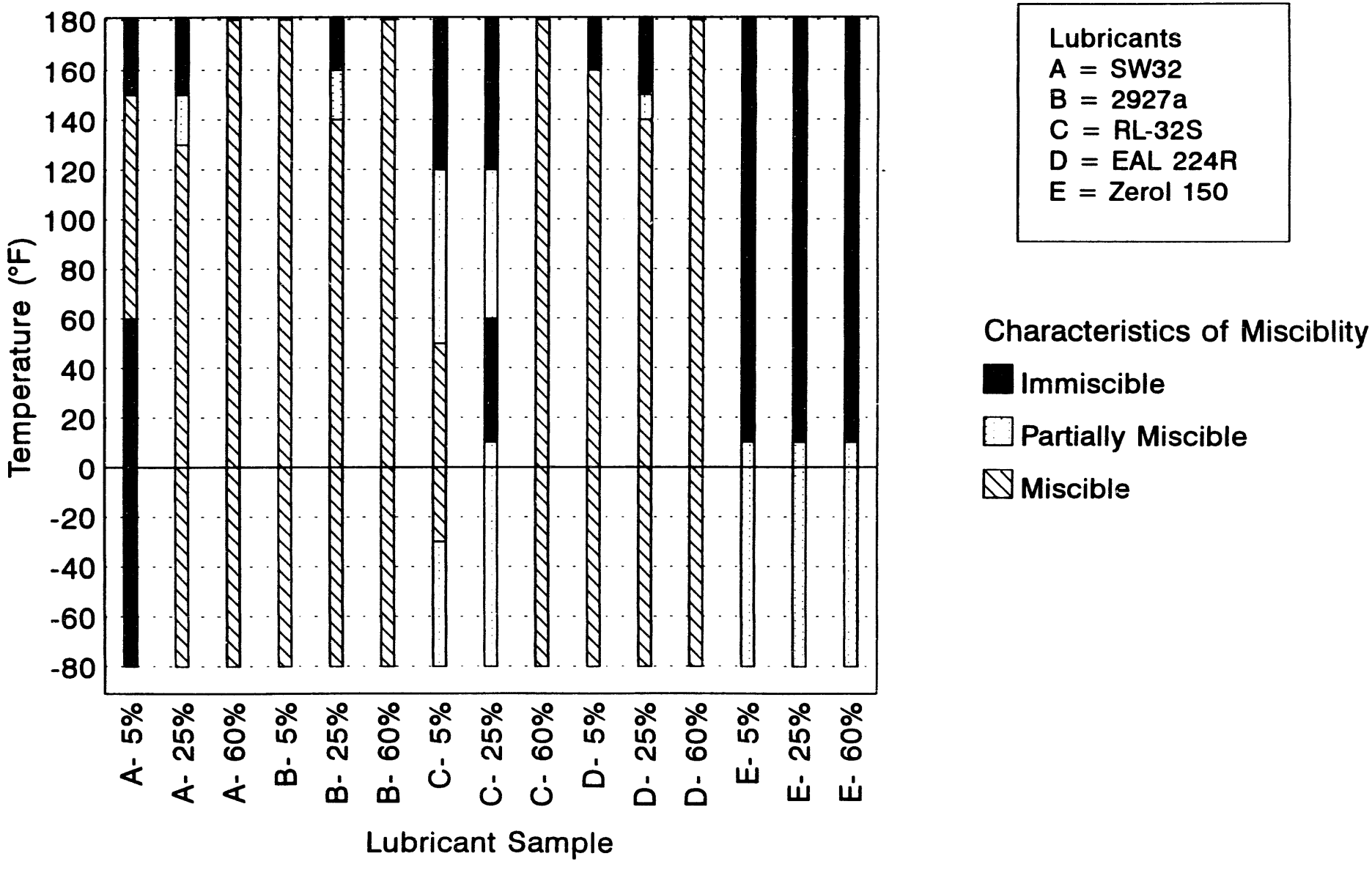
Figure A.3



Miscibility of Refrigerant Blend D

HFC-125 (44%), HFC-143a (52%) and HFC-134a (4%)

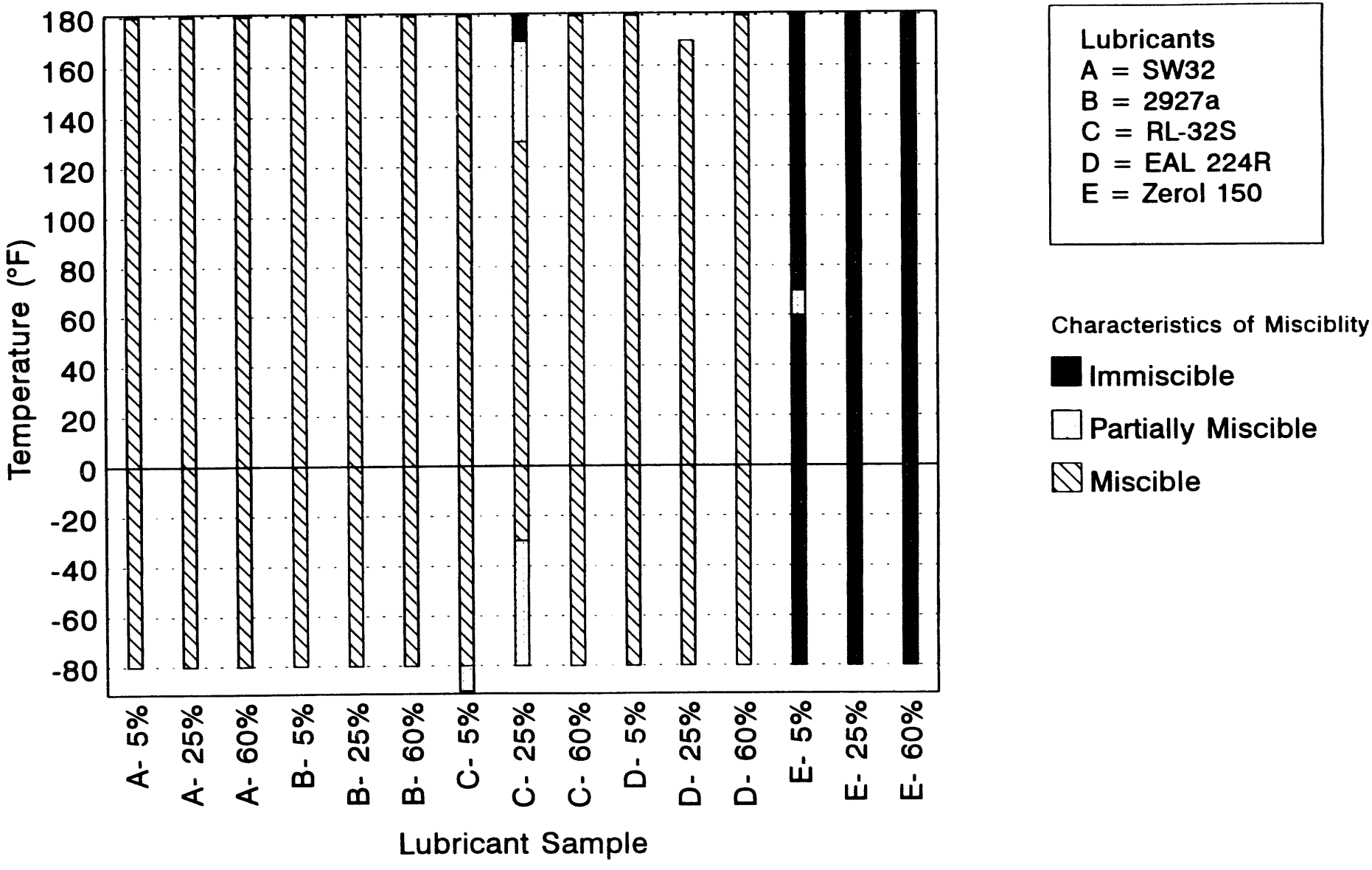
Figure A.4



Miscibility of Refrigerant Blend E

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

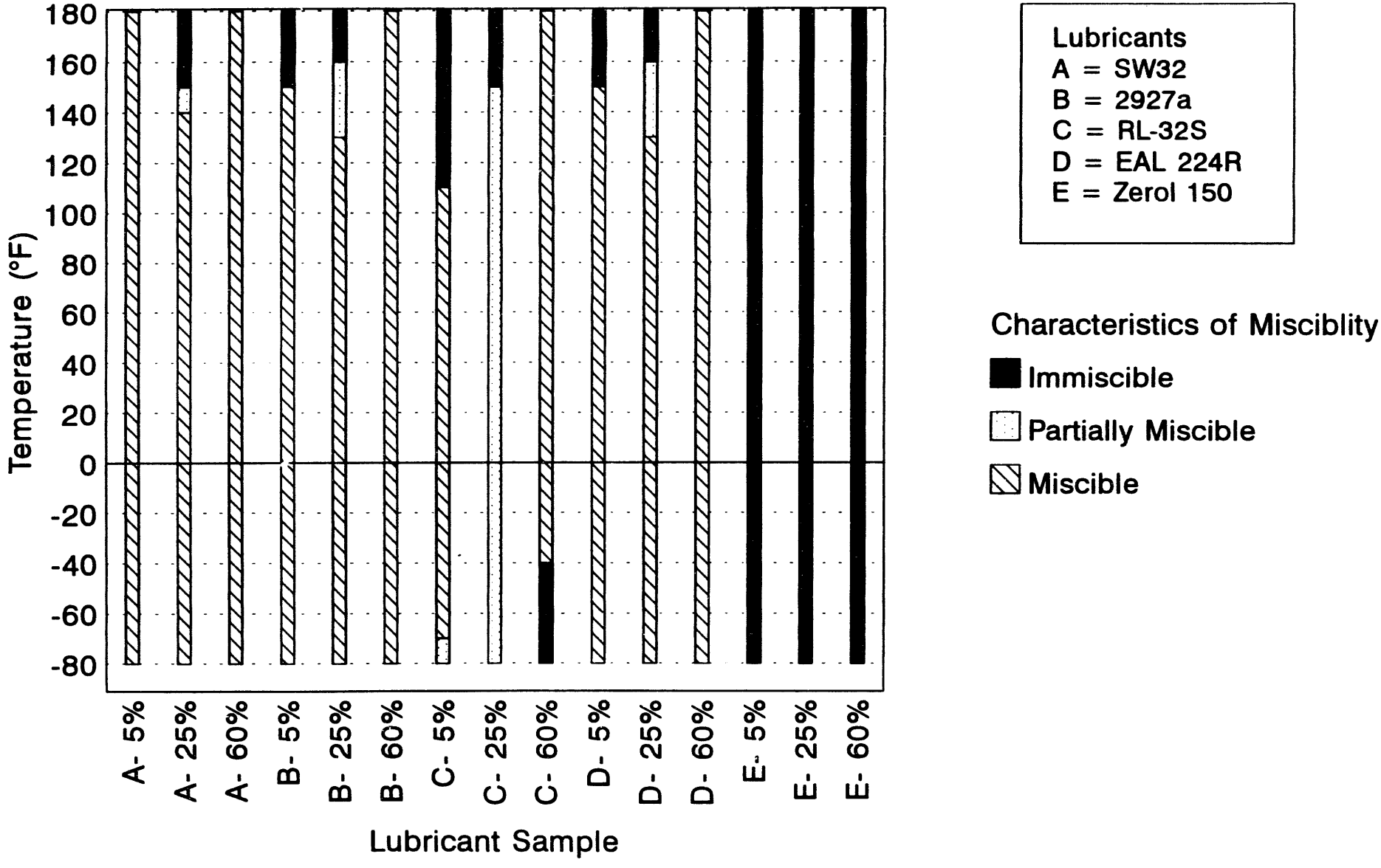
Figure A.5



Miscibility of Refrigerant Blend F

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

Figure A.6



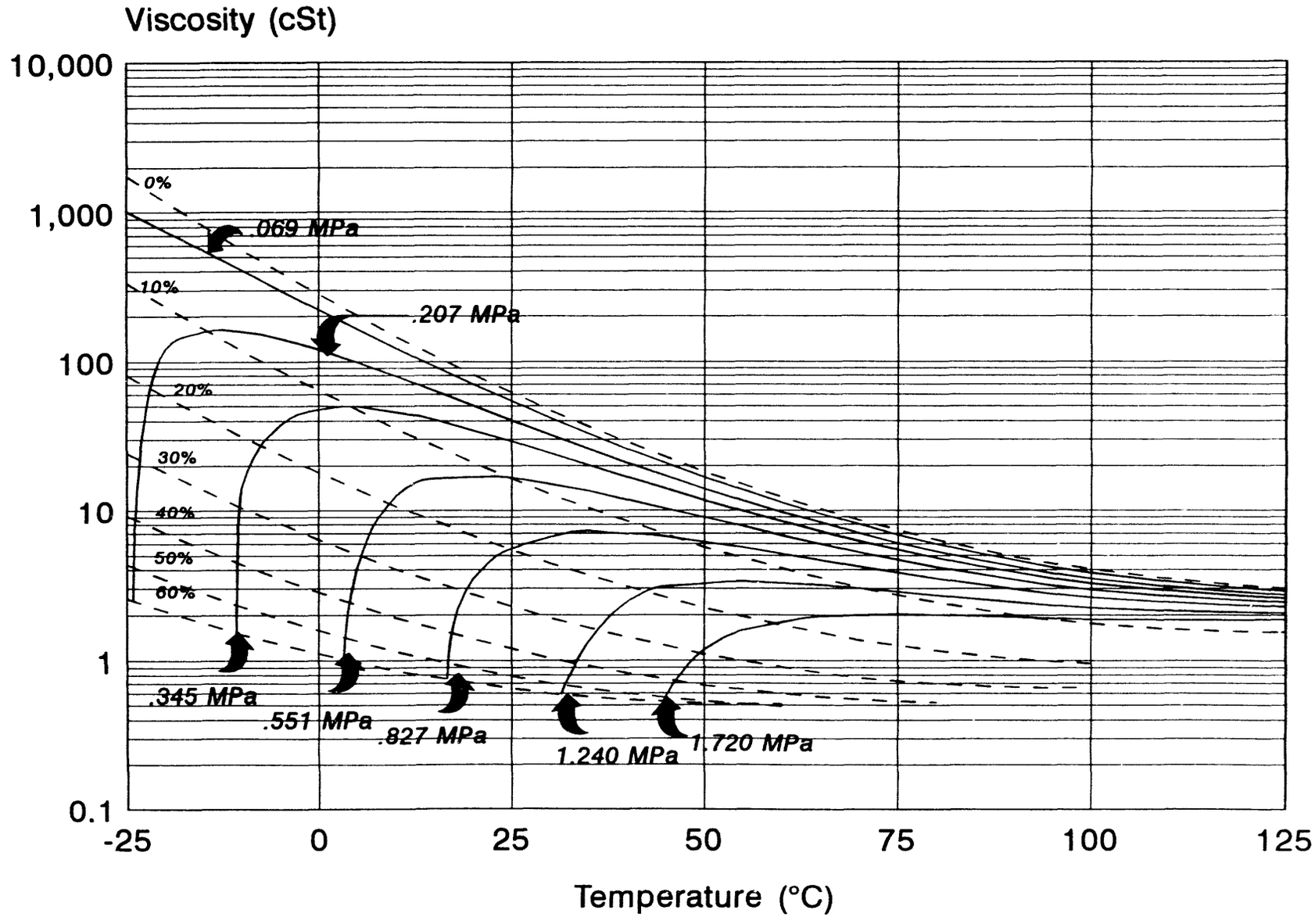
APPENDIX B:
Viscosity and Gas Solubility of 32 ISO VG Mineral Oil with HCFC-22

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

The oil used was purchased locally at Grainger Industrial Supply. Isothermal determination provides a snapshot view of refrigerant/lubricant solubility knees, which are unique to each refrigerant/lubricant combination. Solubility knees become apparent as the concentration of refrigerants approaches the critical phase of refrigerant/refrigerant gas solutions. The lowest temperature for which viscosities were determined is -20°C. Viscosity measurements at -40°C 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.

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

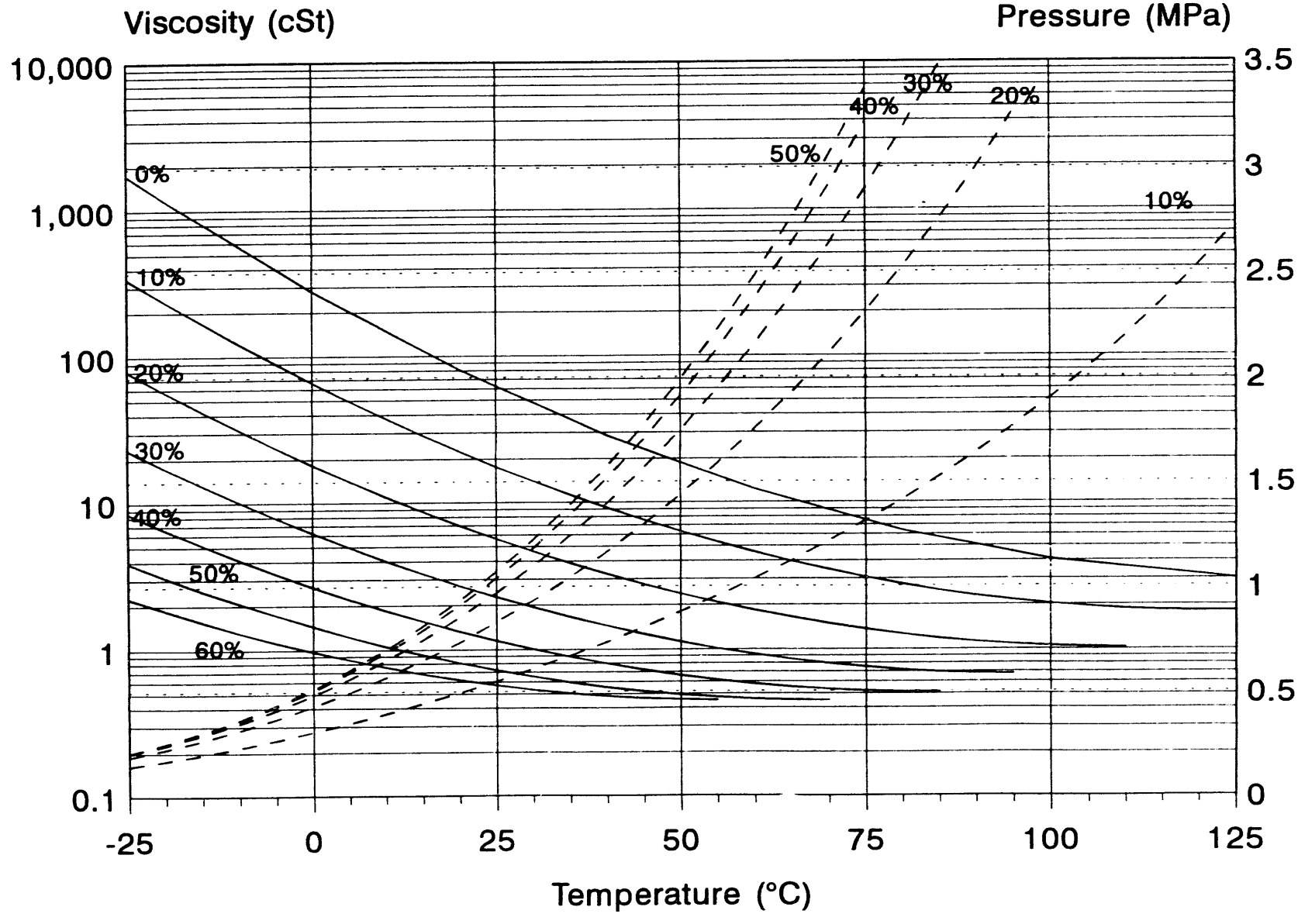
Viscosity vs. Temperature
HCFC-22 in 32 ISO VG Mineral Oil
Figure B.1



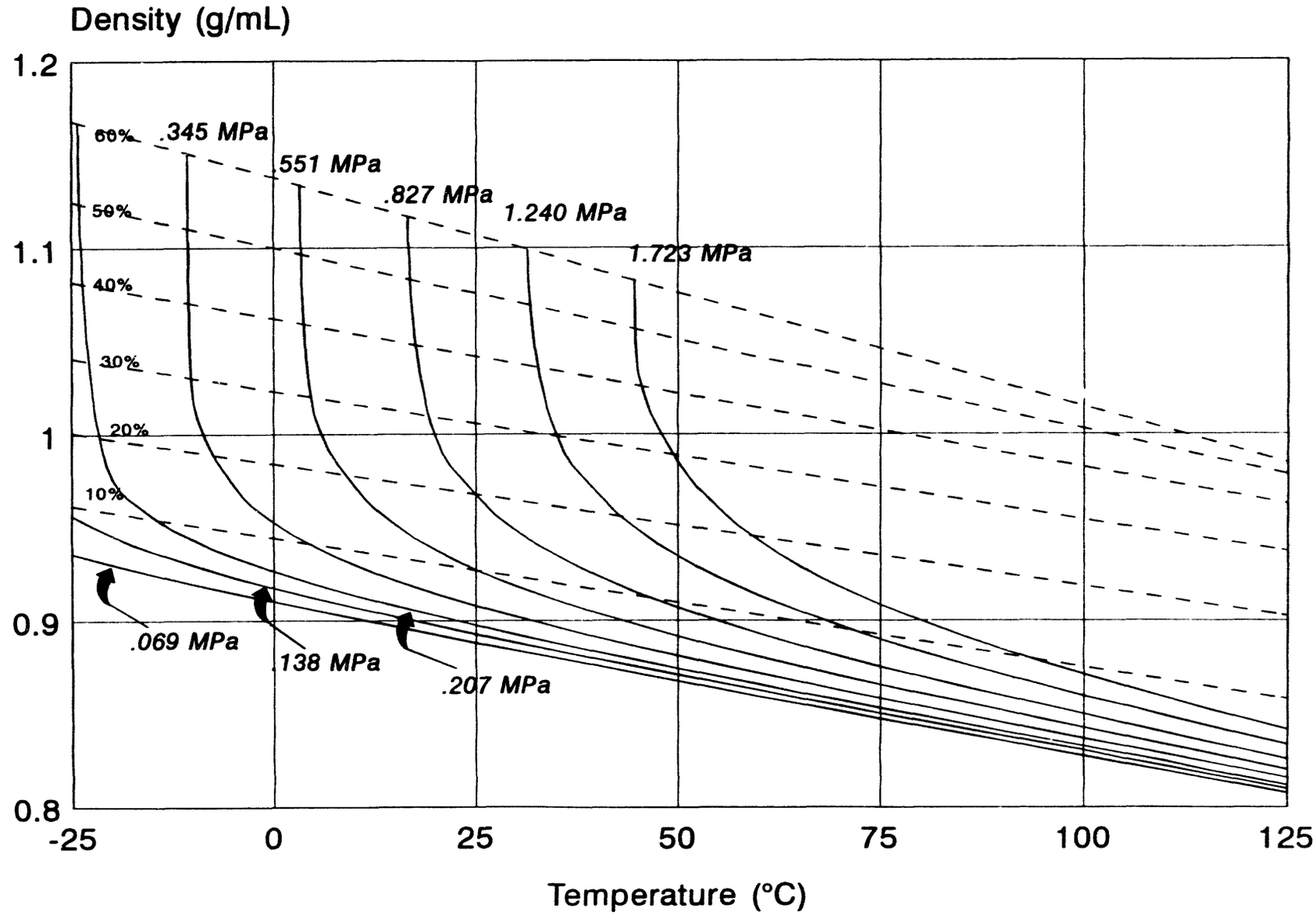
Viscosity and Pressure at Constant Concentrations

HCFC-22 in 32 ISO VG Mineral Oil

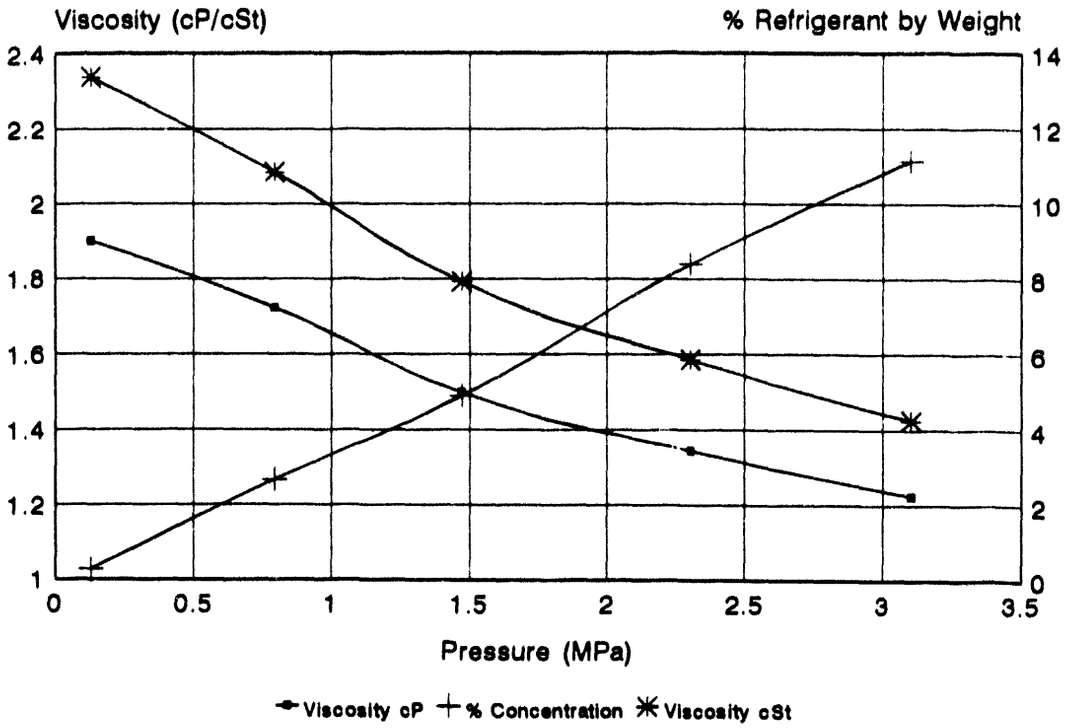
Figure B.2



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

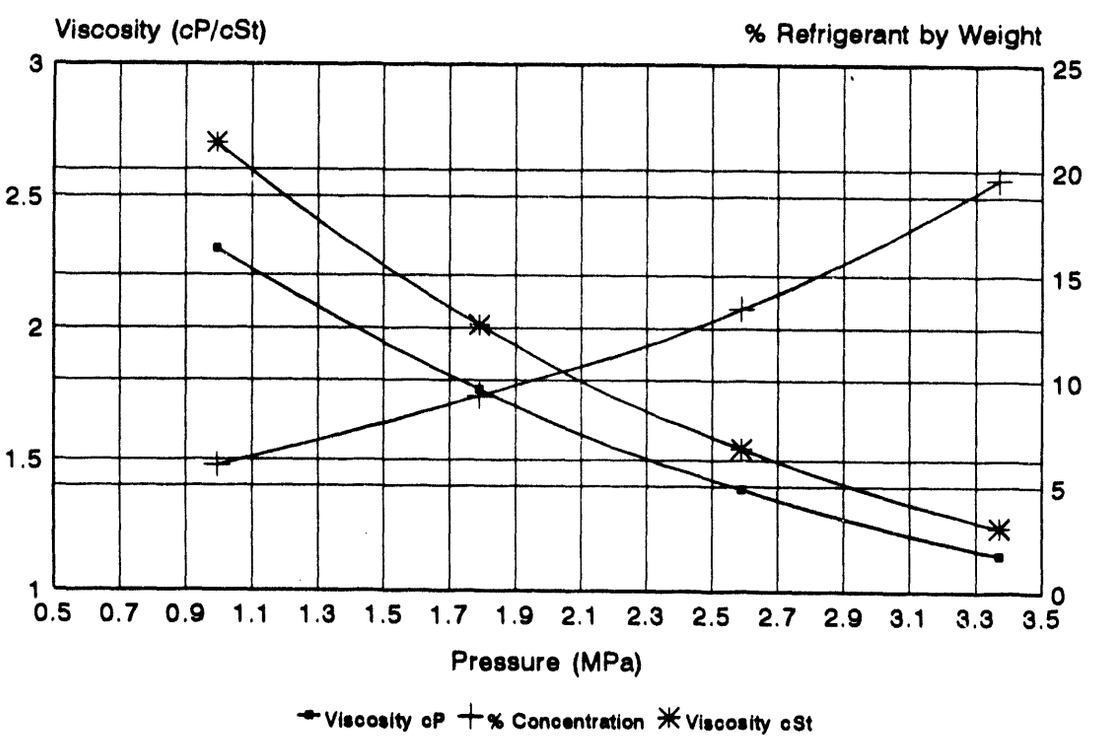


Viscosity and Gas Solubility
32 ISO VG Mineral Oil with HCFC-22 at 125°C
Figure B.4



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

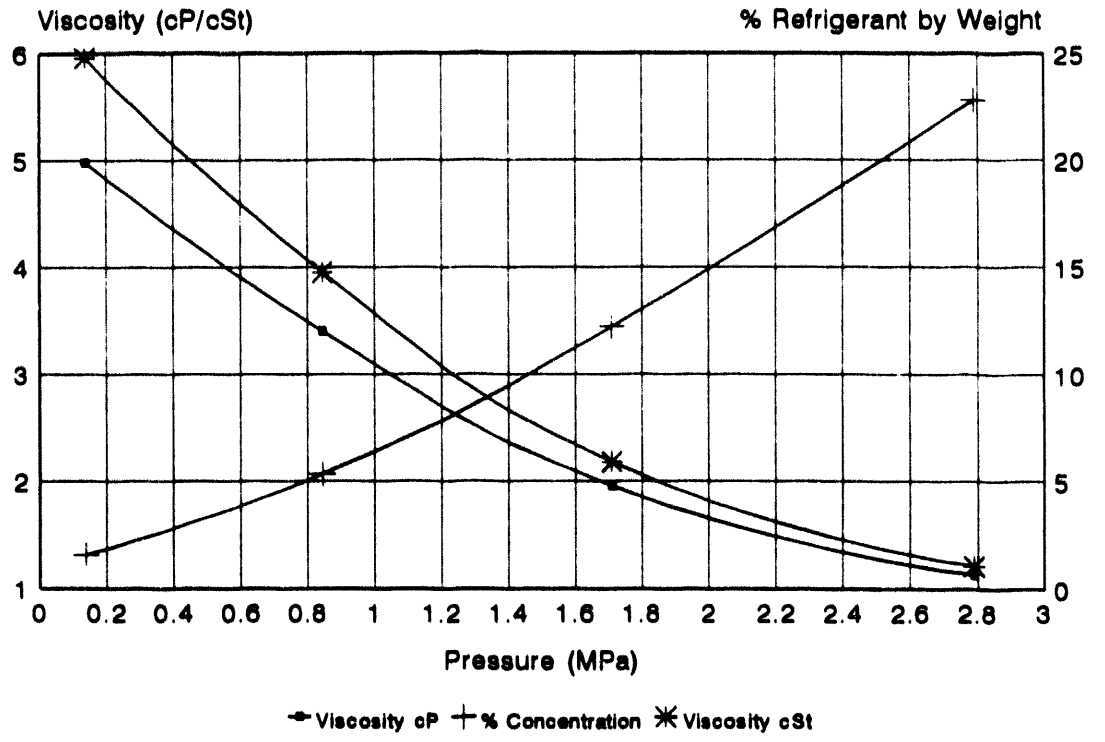


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mineral Oil with HCFC-22 at 80°C

Figure B.6

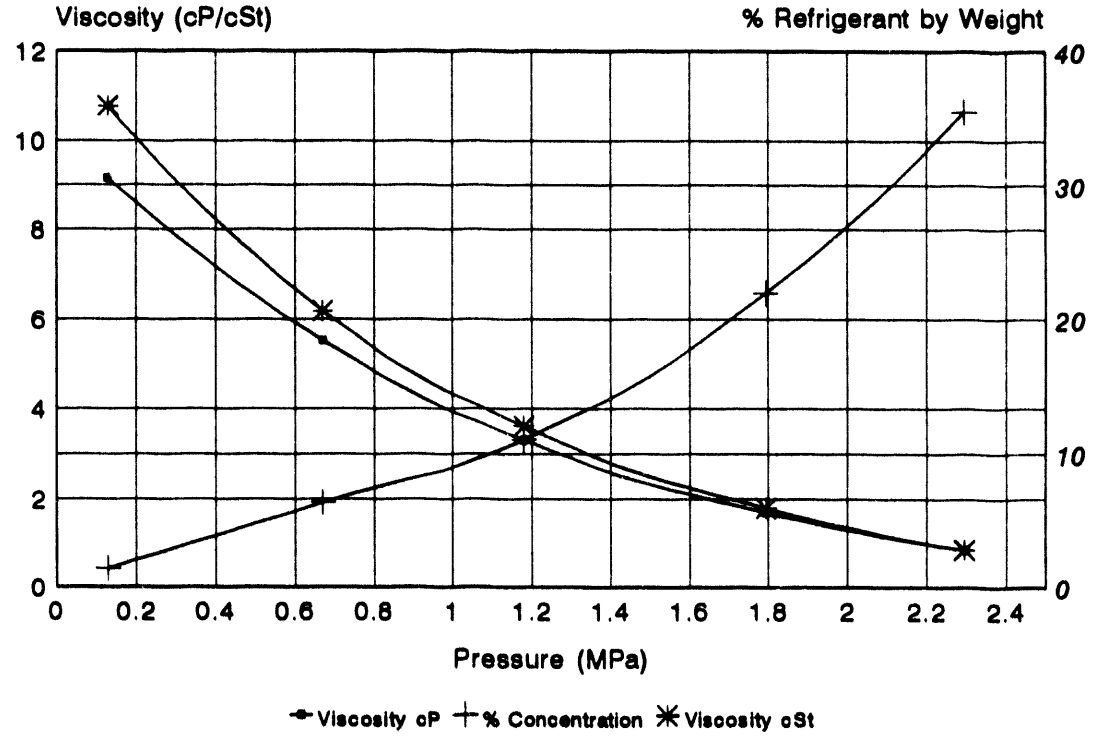


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

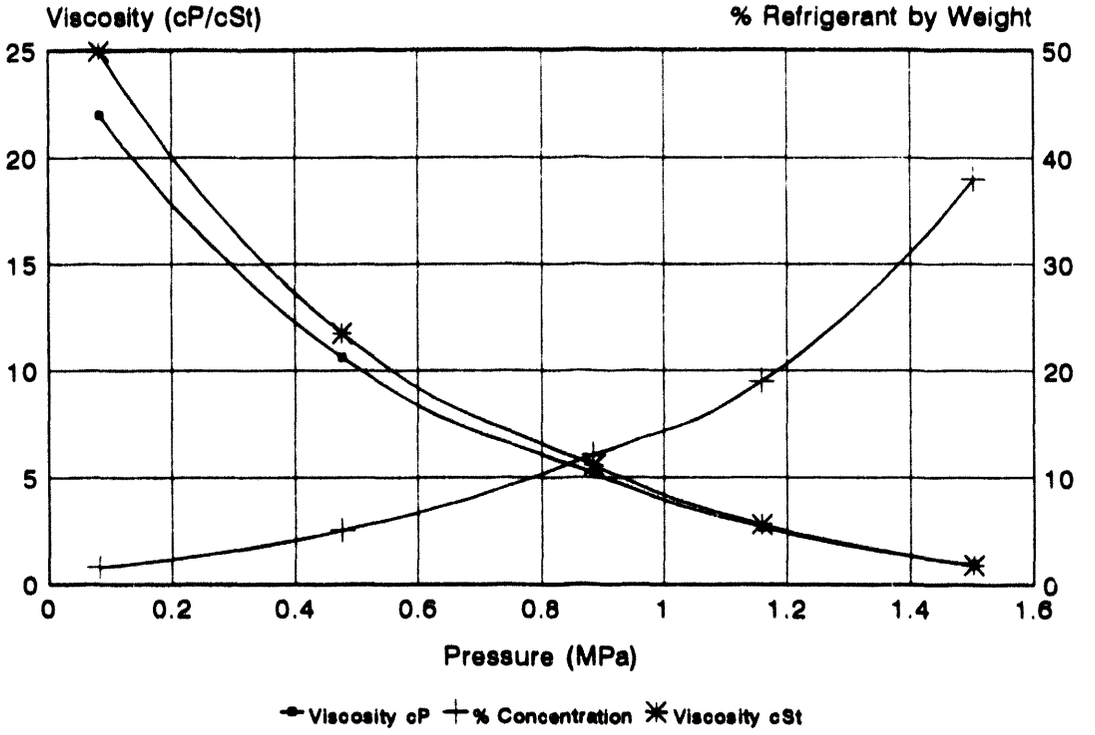
32 ISO VG Mineral Oil with HCFC-22 at 60°C

Figure B.7



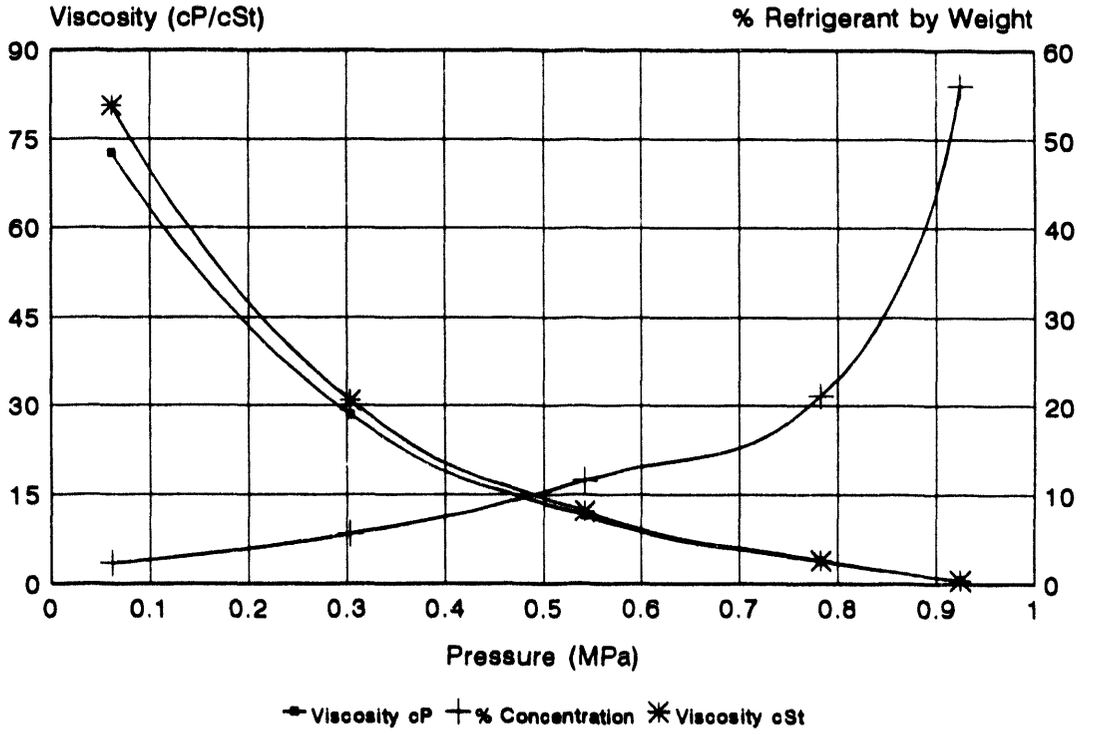
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

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



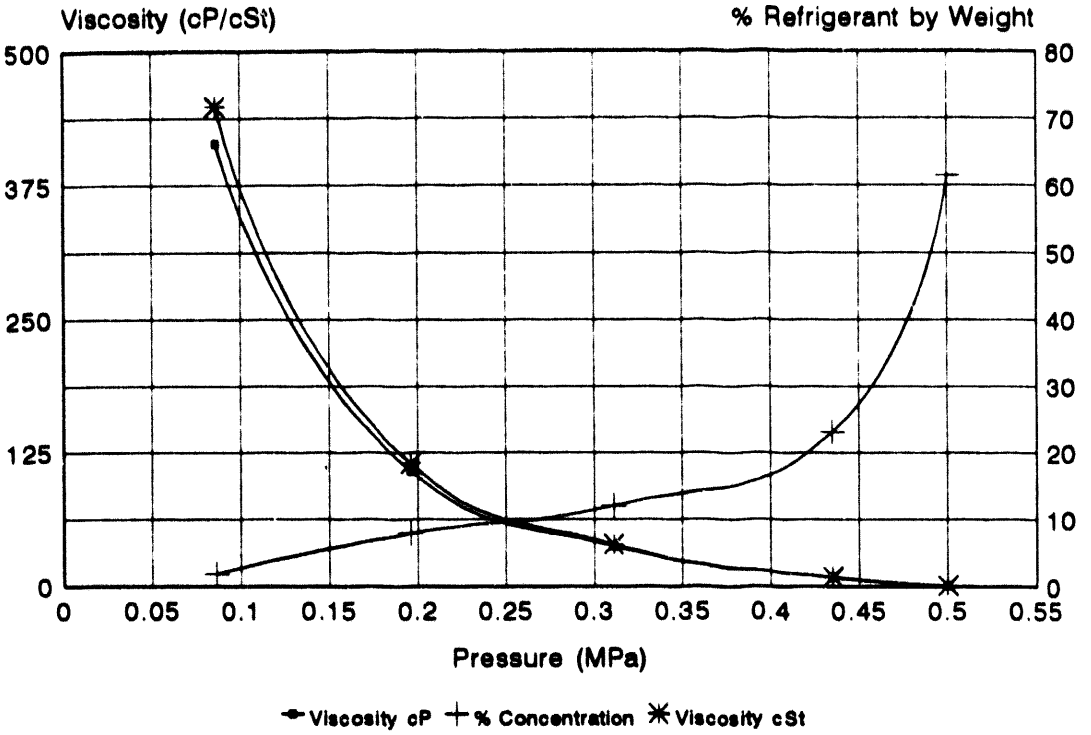
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

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



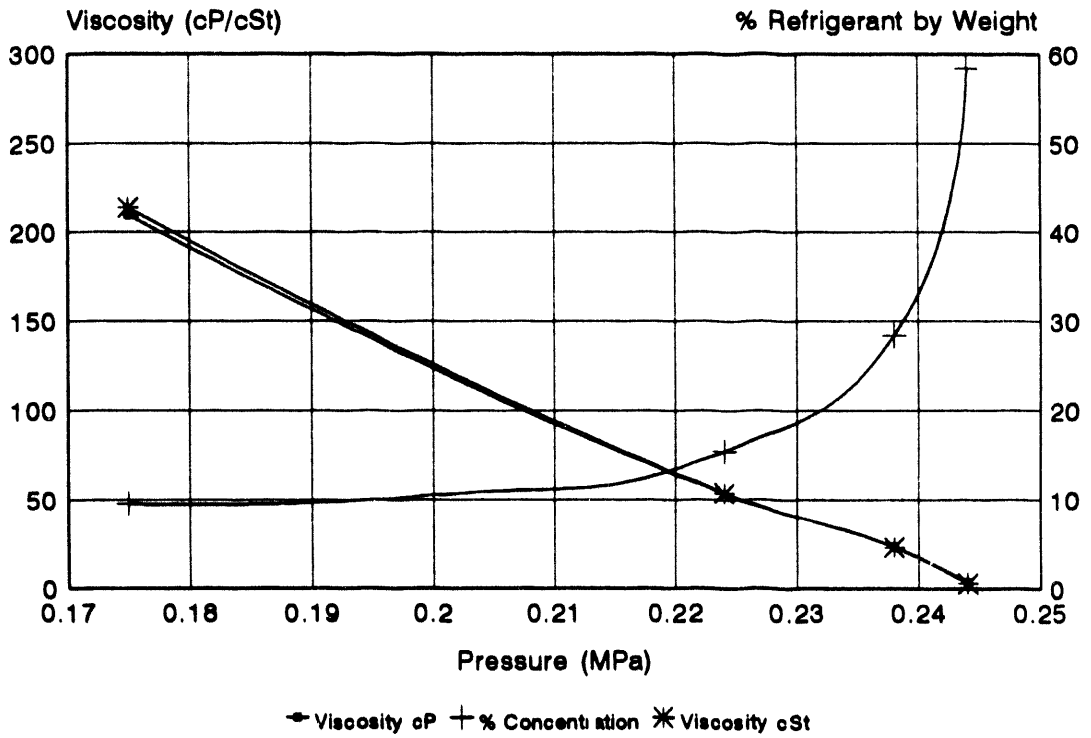
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

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

125.0°C Temperature
>500.0 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.8129	16.50	0.128	0.271	1.900	2.338
0.8271	118.00	0.794	2.669	1.725	2.084
0.8388	213.00	1.470	4.906	1.500	1.792
0.8480	334.00	2.305	8.379	1.348	1.588
0.8592	450.00	3.105	11.134	1.225	1.426

100 °C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.8260	10.00	0.069	1.732	3.231	3.908
0.8530	144.00	0.994	5.668	2.301	2.696
0.8779	259.00	1.787	9.261	1.765	2.010
0.8996	375.00	2.586	13.416	1.388	1.543
0.9168	489.00	3.374	19.272	1.140	1.244

80 °C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.8360	20.00	0.138	1.590	4.982	5.959
0.8610	155.20	1.071	5.336	3.403	3.954
0.8860	248.00	1.711	12.237	1.986	1.279
0.9330	405.00	2.795	22.825	1.133	1.215

60 °C Temperature
500 psia Saturation Pressure

Density	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	1.669	1.791
0.9678	332.50	2.294	35.500	0.849	0.880

Neat Viscosity Check
Oil alone
40°C. 14.7 psia.

Density	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

40 °C Temperature
222.4 psia Saturation Pressure

Density	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	5.165	5.574
0.9565	168.00	1.159	18.977	2.690	2.813
1.0266	27.75	0.191	38.002	0.938	0.918

20 °C Temperature
132.0 psia Saturation Pressure

Density	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	79.00	0.538	11.573	11.495	12.171
0.9811	113.00	0.780	21.107	3.839	3.913
1.1080	132.00	0.911	55.534	0.609	0.560

0 °C Temperature
72.2 psia Saturation Pressure

Density	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
0.9680	45.00	0.311	12.073	37.507	39.154
1.0085	63.00	0.435	23.106	8.634	8.579
1.1531	72.50	0.500	61.534	0.690	0.772

-20 °C Temperature
40.3 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.9611	25.50	0.176	9.542	209.777	213.815
0.9808	32.50	0.224	15.426	52.501	53.491
1.0177	34.50	0.238	33.365	23.486	23.077
1.1668	35.50	0.245	58.439	3.368	2.874

APPENDIX C:

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

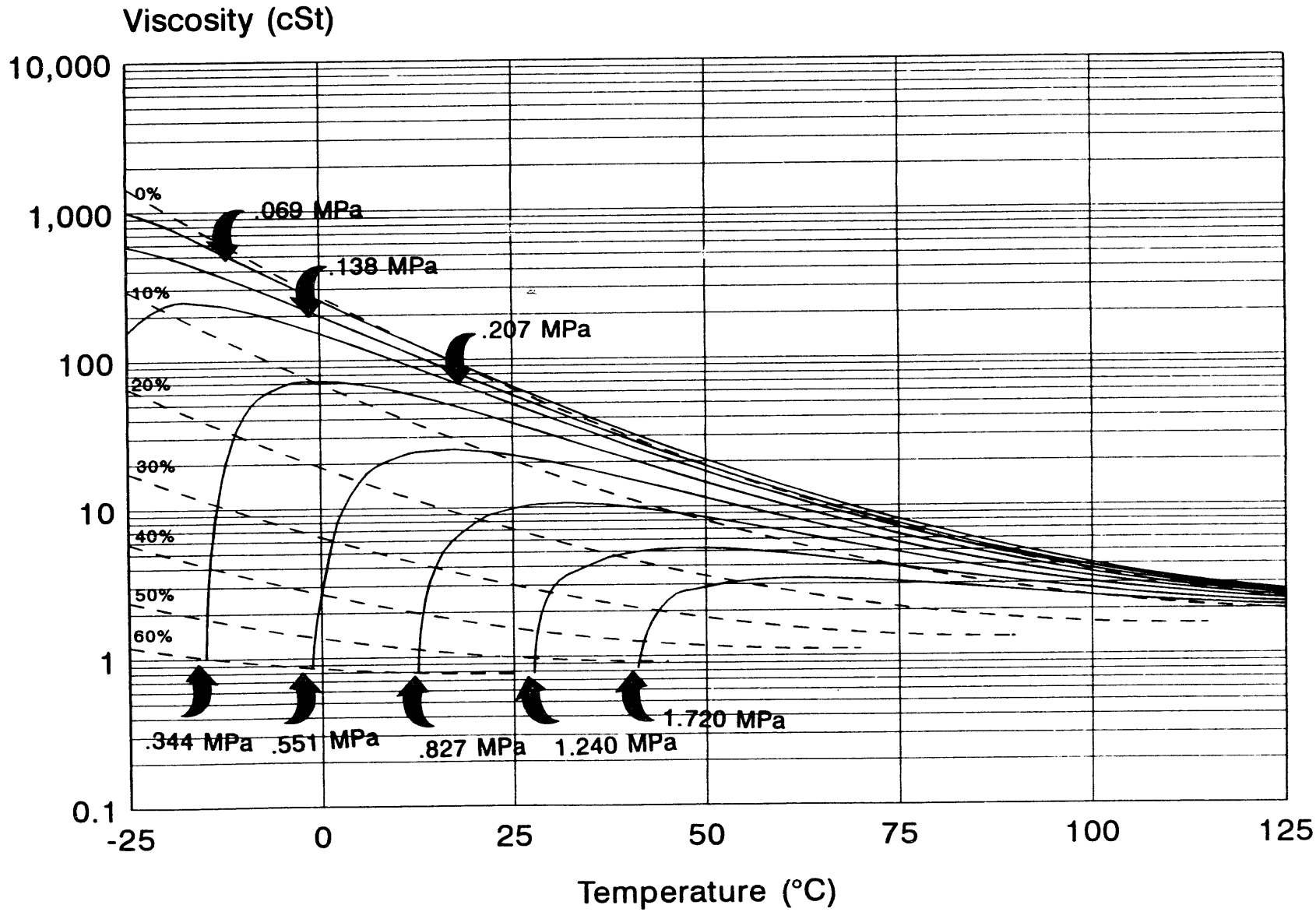
Appendix C shows the isothermal viscosity, density, and solubility of R-502 in 32 ISO VG mineral oil. Each isothermal plot shows the fractionation of R-502 as percentage R-22 of the total gas in solution. The lowest temperature at which viscosity was determined is -10°C: the highest is 125°C and 500 psia. At each test temperature and pressure, mixed refrigerant gas is purged through the lubricant until the fractionated components reach equilibrium. The equilibrium is maintained by making the refrigerant gas above the lubricant equal to the proportion of the mixed lubricant and 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.

As ARTI recommended, the purity of the test oil was verified and additional tests were conducted with samples much larger than the 1 g samples used previously. 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.

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

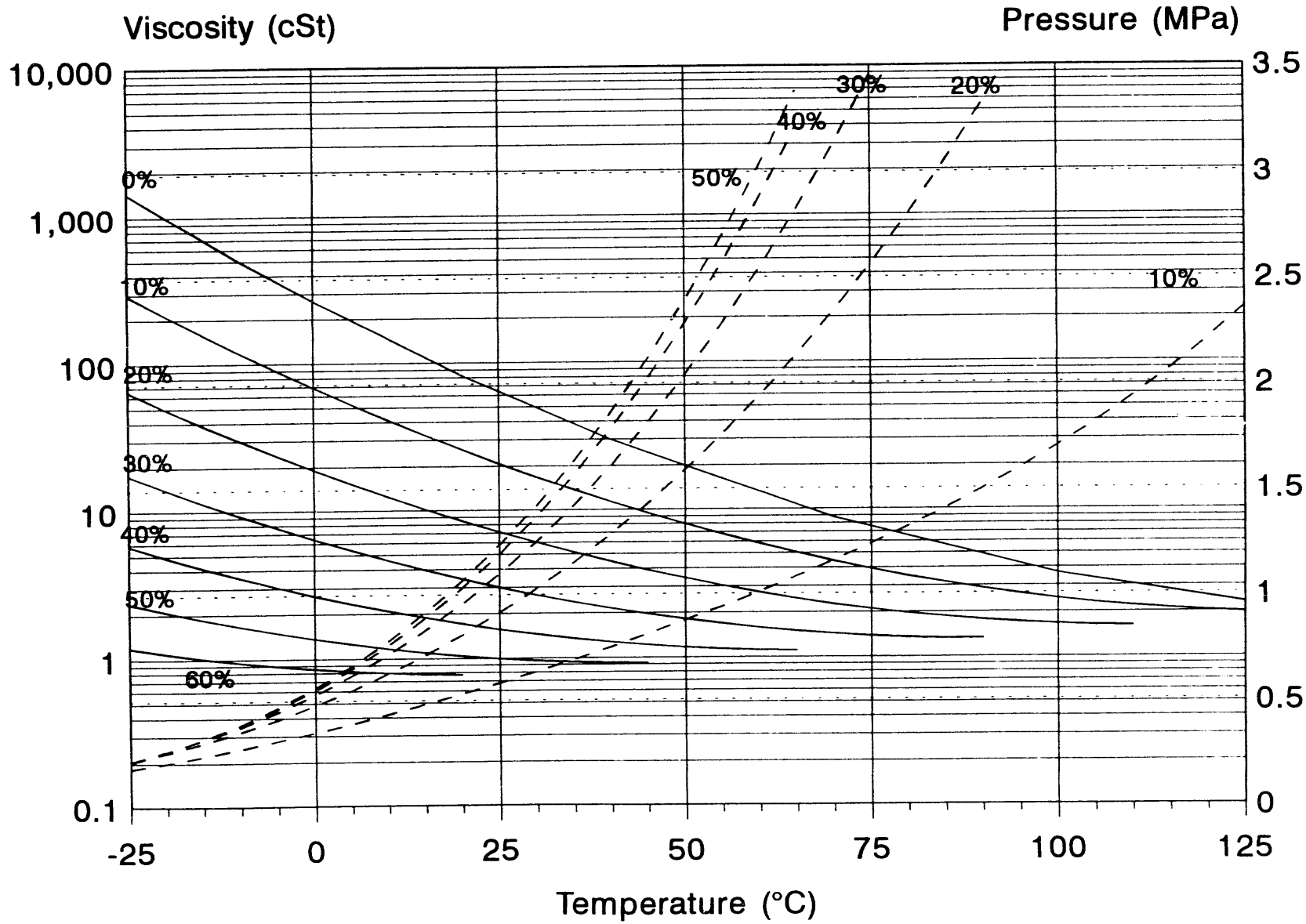
Viscosity vs. Temperature
R-502 in 32 ISO VG Mineral Oil
Figure C.1



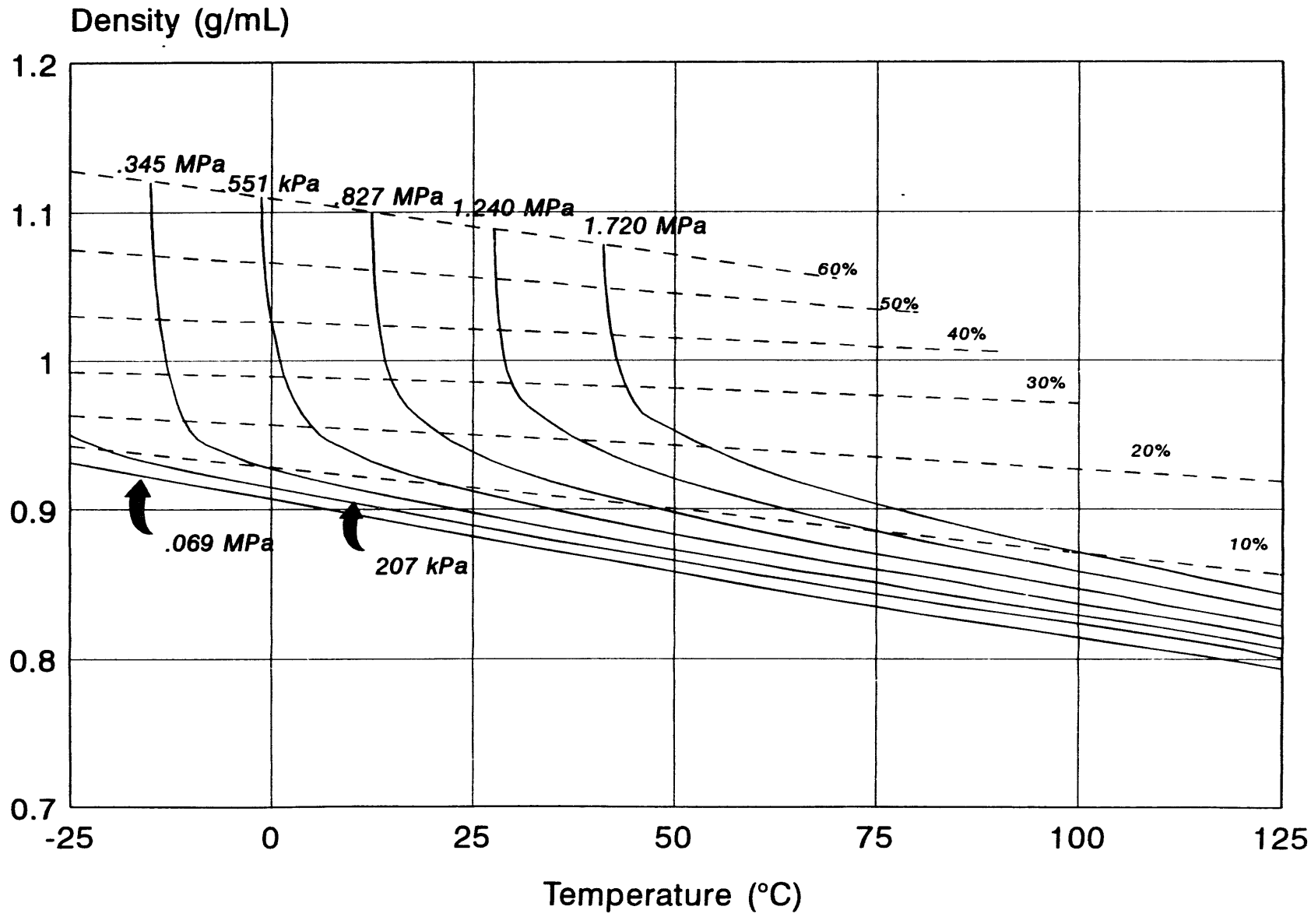
Viscosity and Pressure at Constant Concentrations

R-502 in 32 ISO VG Mineral Oil

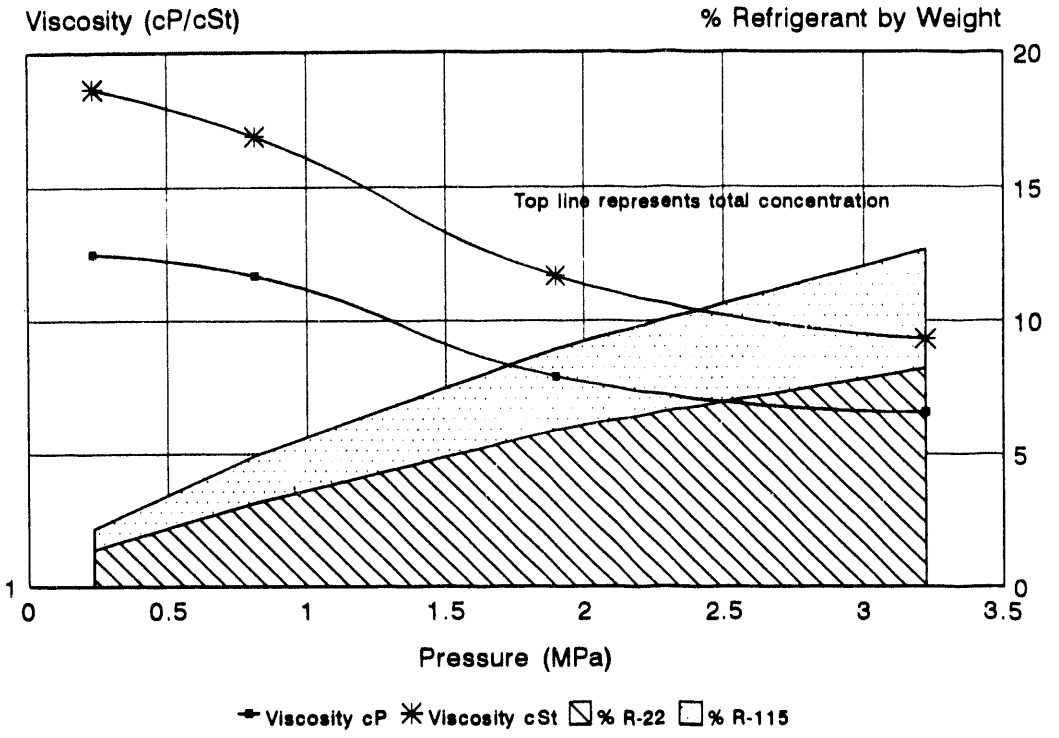
Figure C.2



Density vs. Temperature
R-502 in 32 ISO VG Mineral Oil
Figure C.3

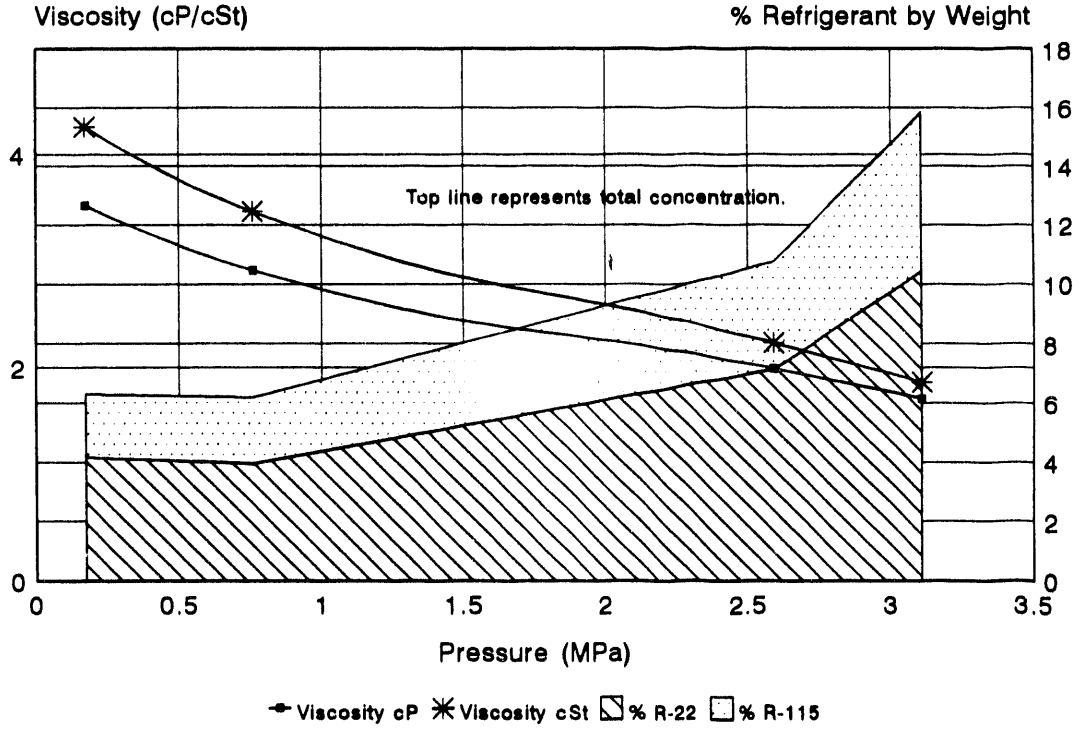


Viscosity, Solubility, and Gas Fractionation
32 ISO VG Mineral Oil with R-502 at 125°C
Figure C.4



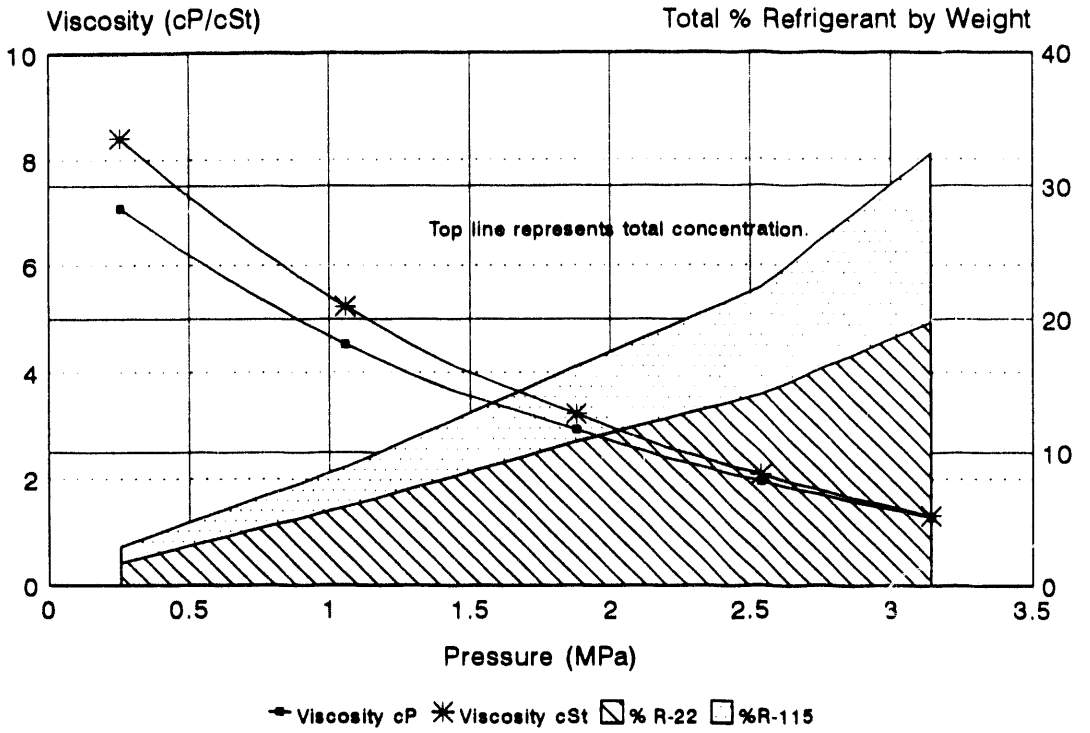
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
32 ISO VG Mineral Oil with R-502 at 100°C
Figure C.5



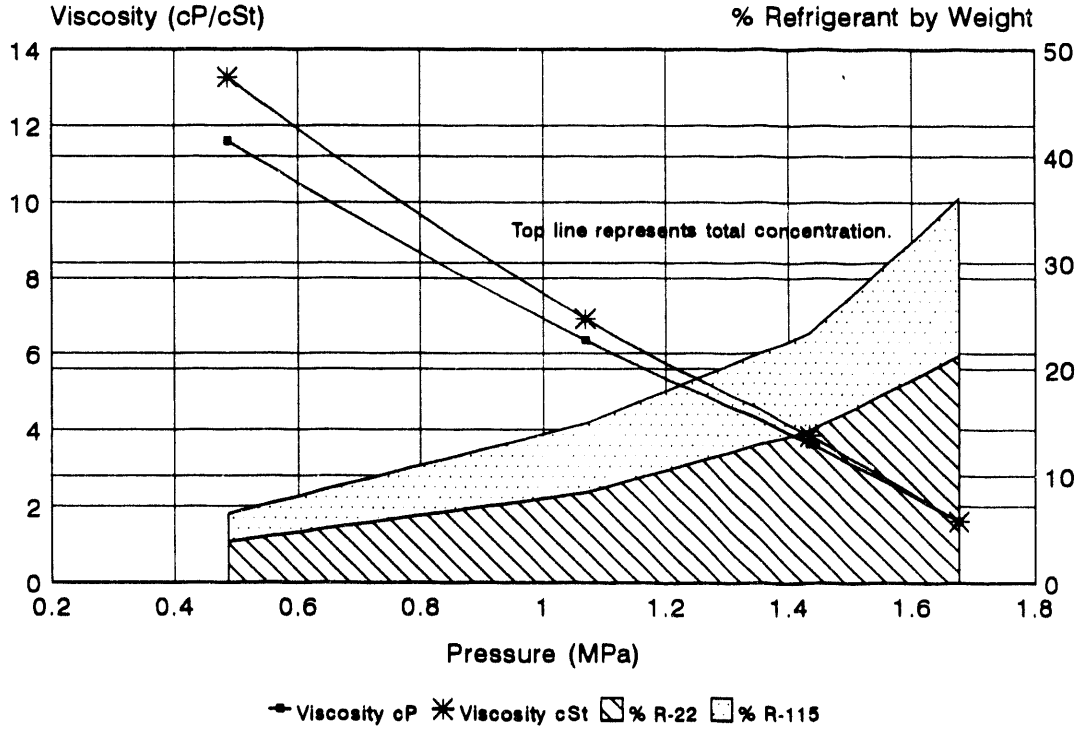
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
32 ISO VG Mineral Oil with R-502 at 70°C
Figure C.6



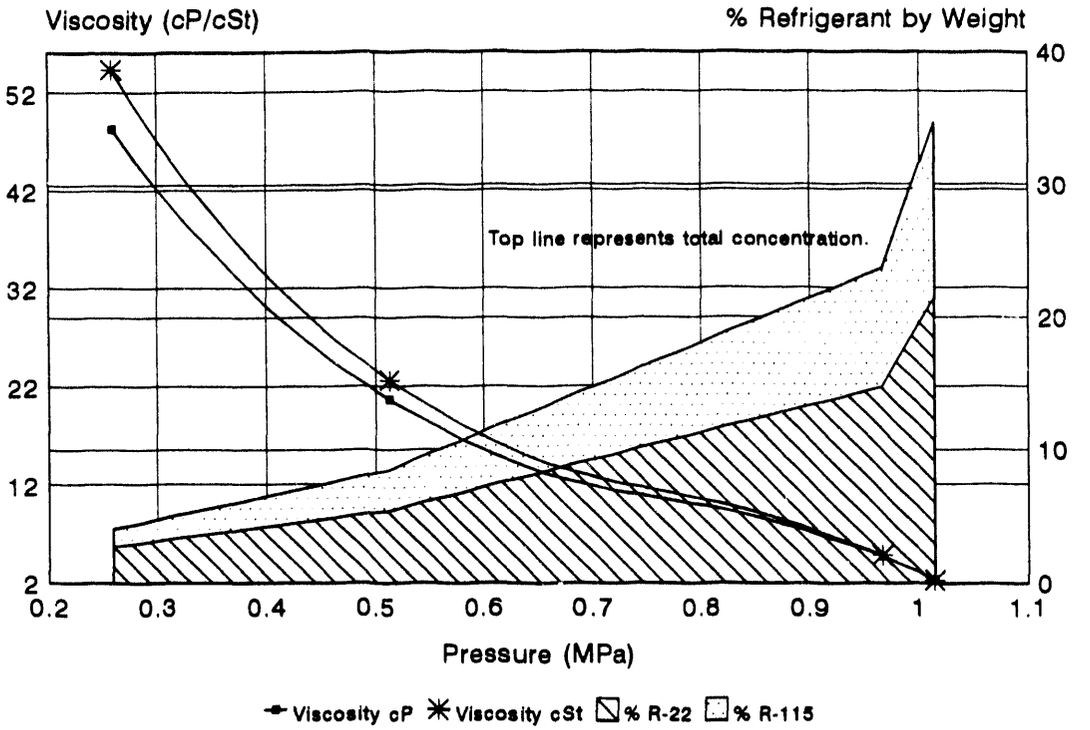
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation
32 ISO VG Mineral Oil with R-502 at 40°C
Figure C.7



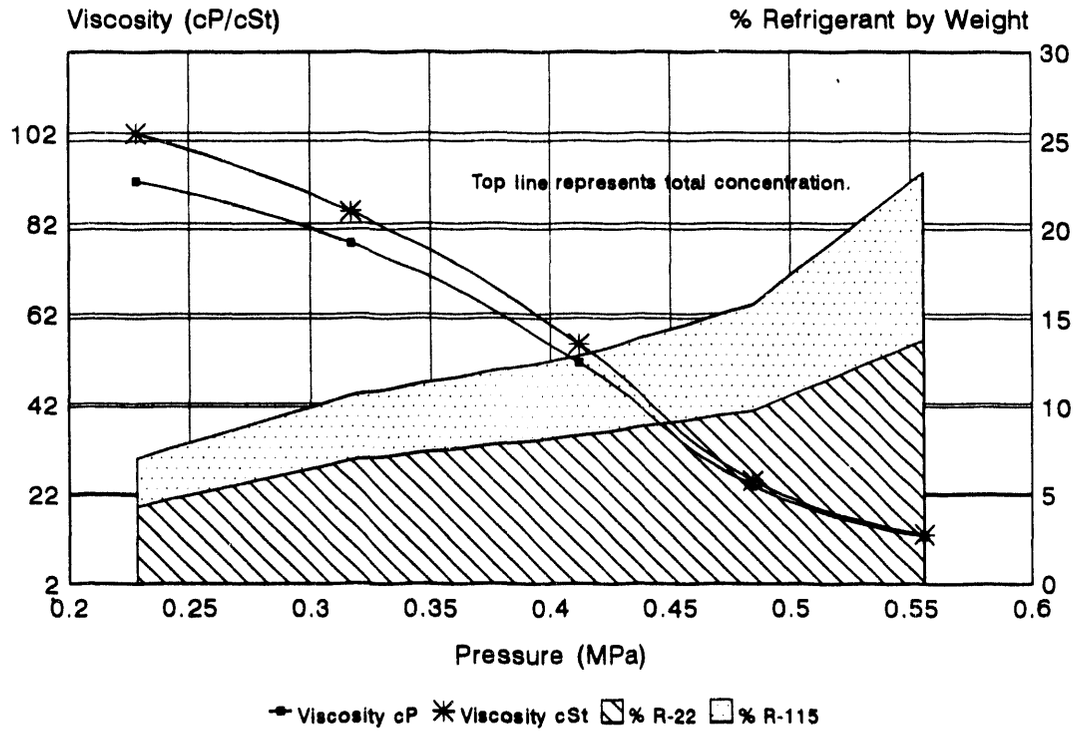
Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

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

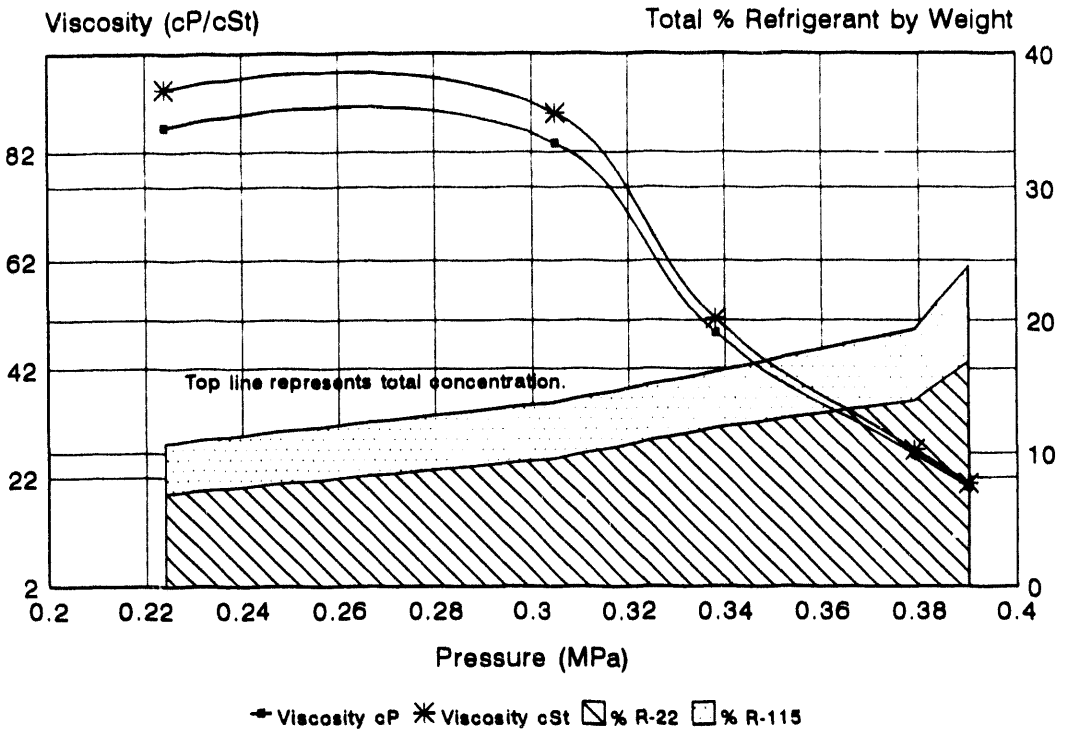


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mineral Oil with R-502 at -10°C

Table 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

125.0°C Temperature
>500.0 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% R-22
0.8073	34.75	0.239775	2.175	1.938	2.400	66.100
0.8273	118.00	0.8142	4.930	1.677	2.269	63.900
0.8488	274.50	1.89405	8.926	1.593	1.876	66.400
0.8785	466.75	3.220575	12.671	1.492	1.733	65.900

80 °C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% R-22
0.8259	25.00	0.1725	6.295	4.263	4.263	66.100
0.8399	110.00	0.759	8.169	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 Temperature
467.67 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% R-22
0.8414	37.00	0.2553	2.864	7.080	8.409	57.600
0.8653	153.00	1.0557	6.686	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	1.264	1.305	60.850

40 °C Temperature
243.2 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% R-22
0.8747	70.50	0.48645	6.432	11.599	13.260	59.550
0.9183	155.00	1.0695	14.669	6.346	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, 14.7 psia.

Density	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 Temperature
147.9 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% R-22
0.8869	37.50	0.259	4.083	46.295	54.331	67.50
0.9124	74.50	0.514	8.436	20.602	22.579	64.25
0.9627	140.00	0.966	23.638	4.706	4.789	62.00
1.0266	147.00	1.014	34.676	2.536	2.293	61.6

0 °C Temperature
83.1 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% R-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	24.674	55.261	61.95
0.9728	80.50	0.555	23.191	12.905	24.674	59.30

-10 °C Temperature
60.1 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	% R-22
0.9255	32.50	0.224	10.708	66.521	93.536	64.60
0.9265	40.75	0.281	10.544	123.132	132.903	62.65
0.9384	44.25	0.305	13.822	83.596	89.091	69.9
0.9494	49.00	0.338	16.106	46.671	51.264	73.65
0.9687	55.00	0.380	19.303	26.584	27.021	72.30
0.9708	57.50	0.397	20.266	20.266	20.895	70.20

APPENDIX D:

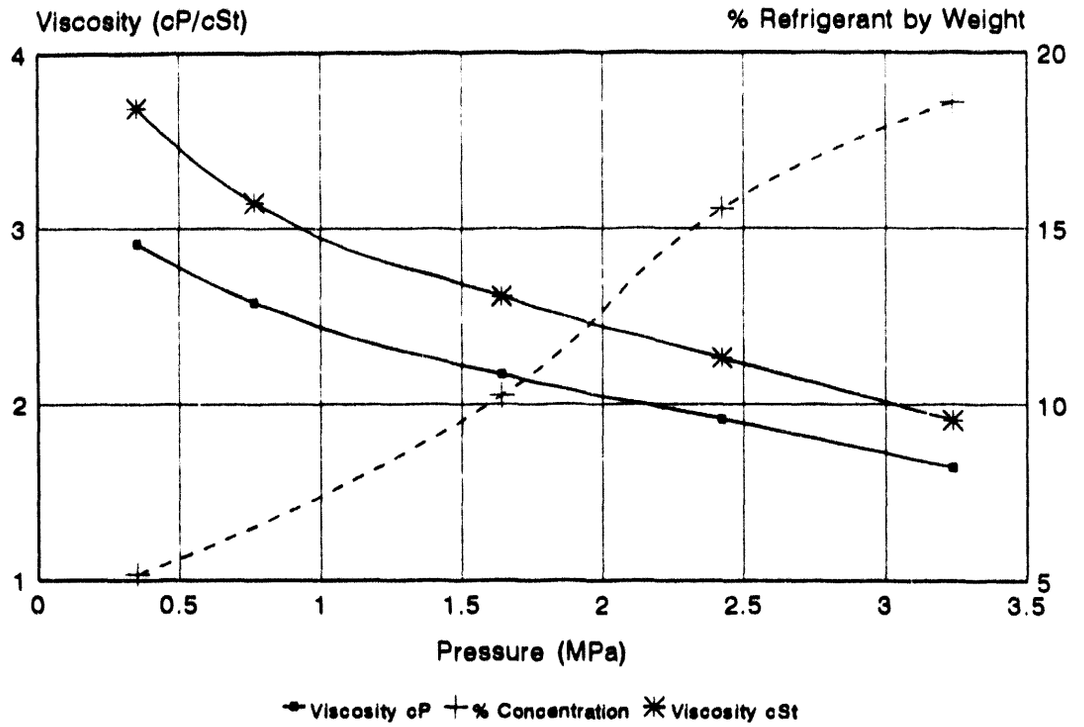
Viscosity, Density and Gas Solubility of 32 ISO VG Mixed Acid Polyolester at Various Temperatures with HFC-134a

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester With HFC-134a at 125°C

Figure D.1

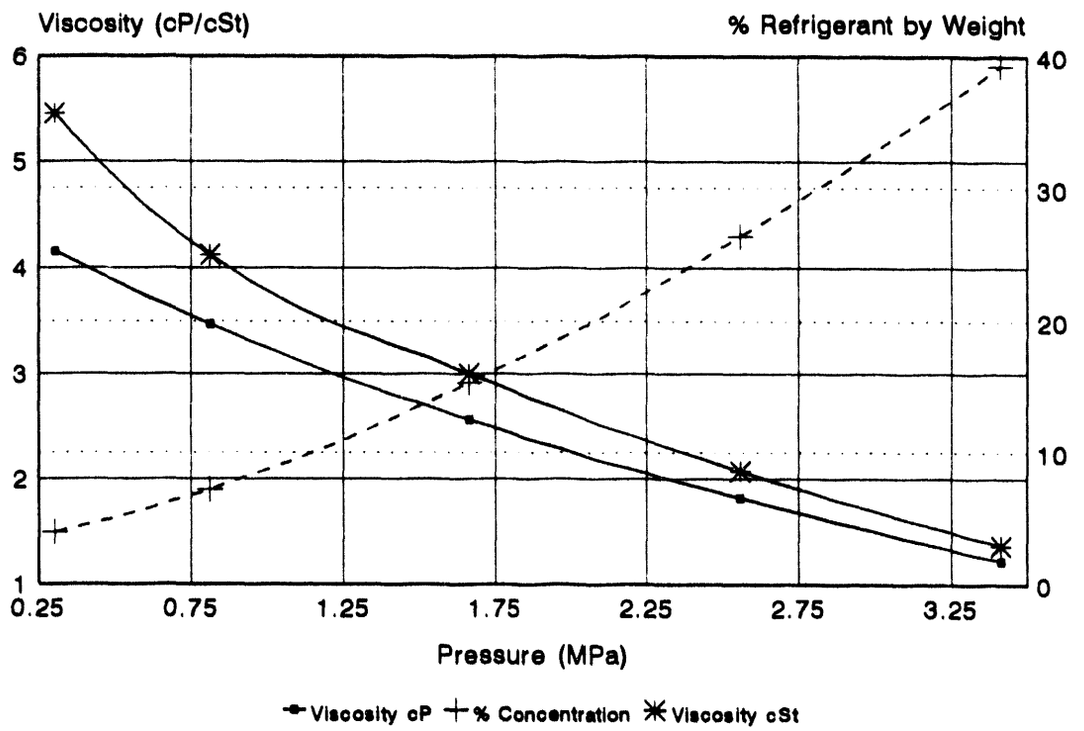


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-134a at 100°C

Figure D.2

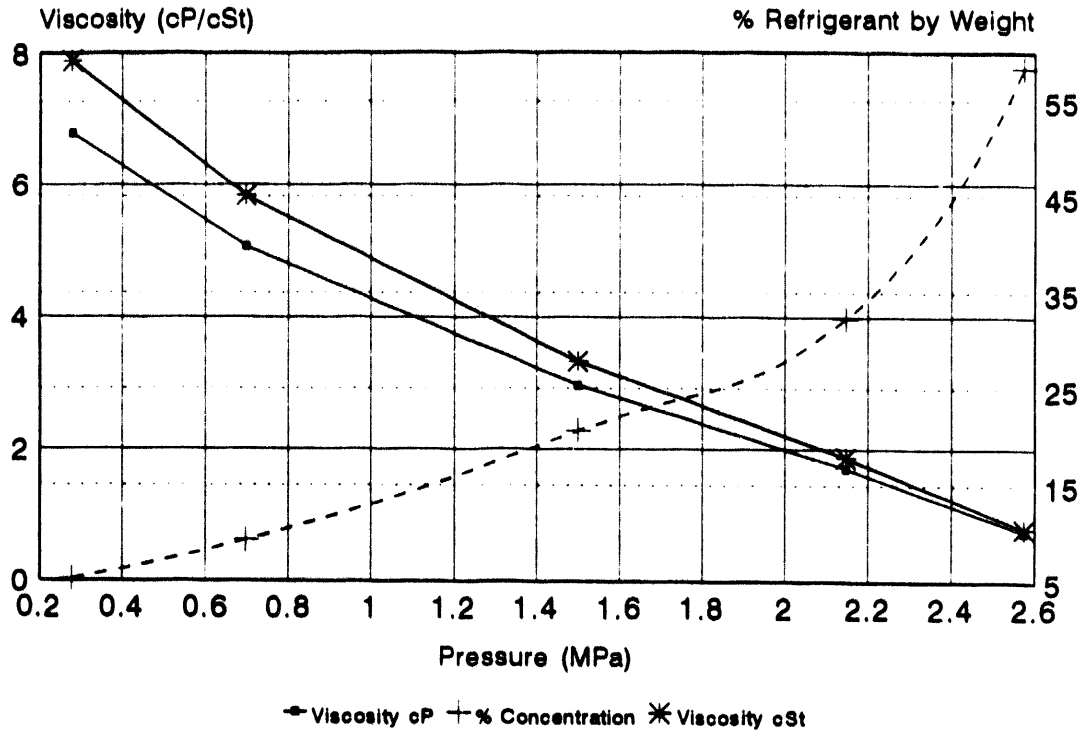


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-134a at 80°C

Figure D.3

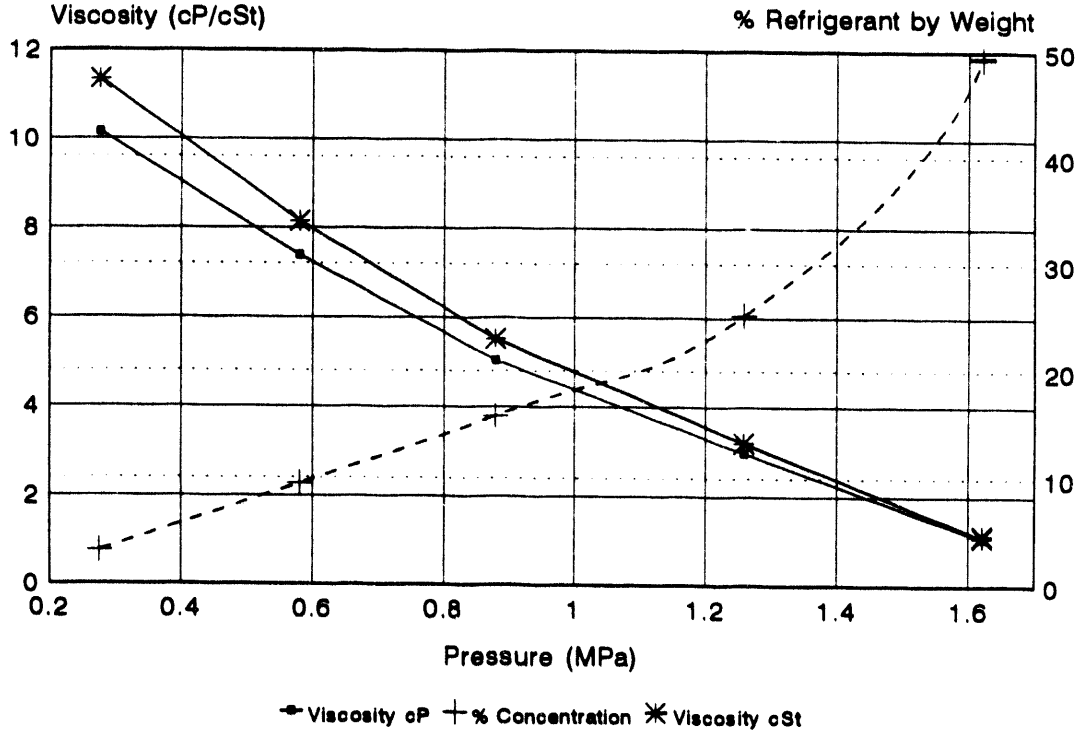


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-134a at 60°C

Figure D.4

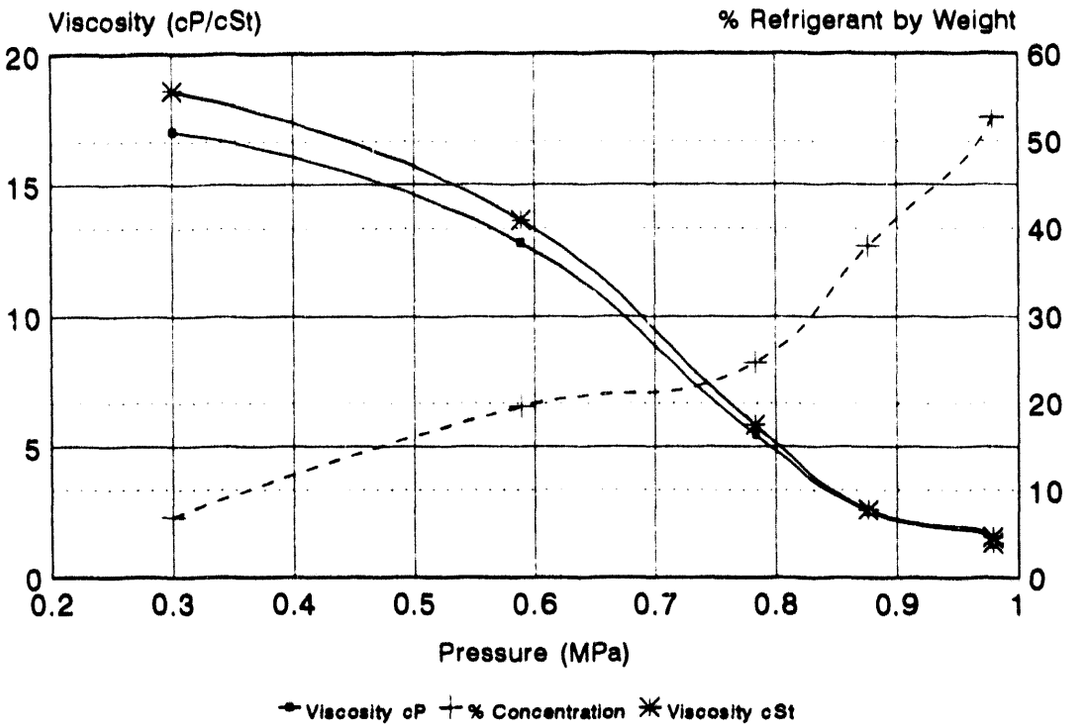


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Solubility

32 ISO VG Mixed Acid Polyolester with HFC-134a at 40°C

Figure D.5

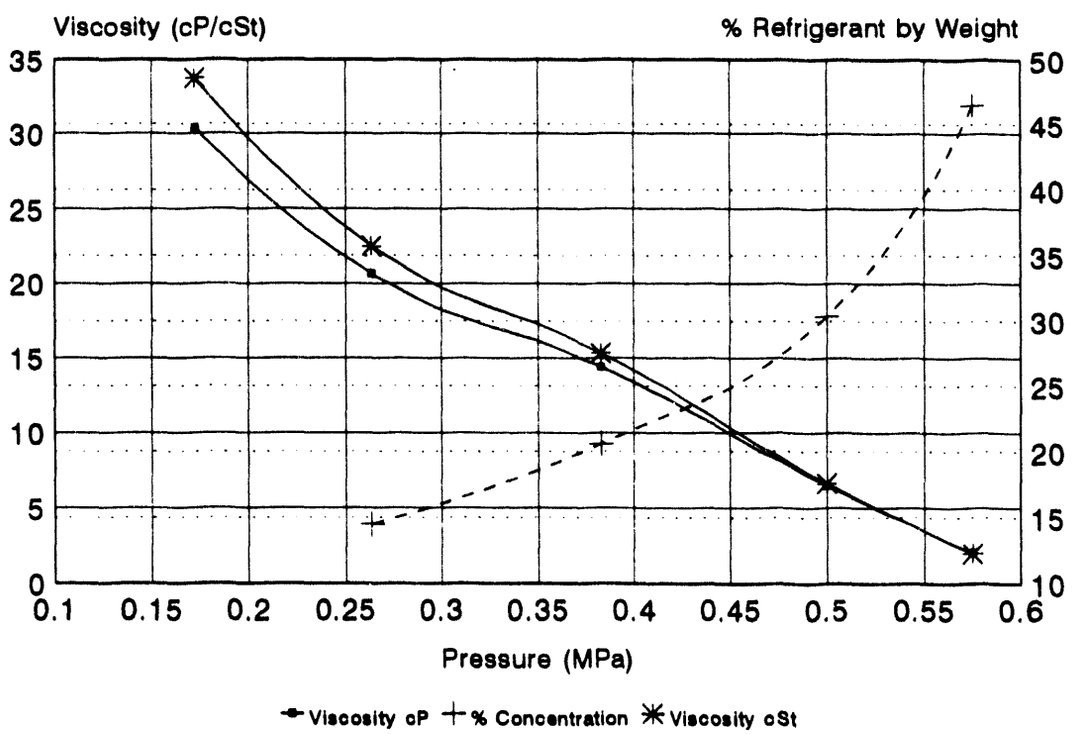


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-134a at 20°C

Figure D.6

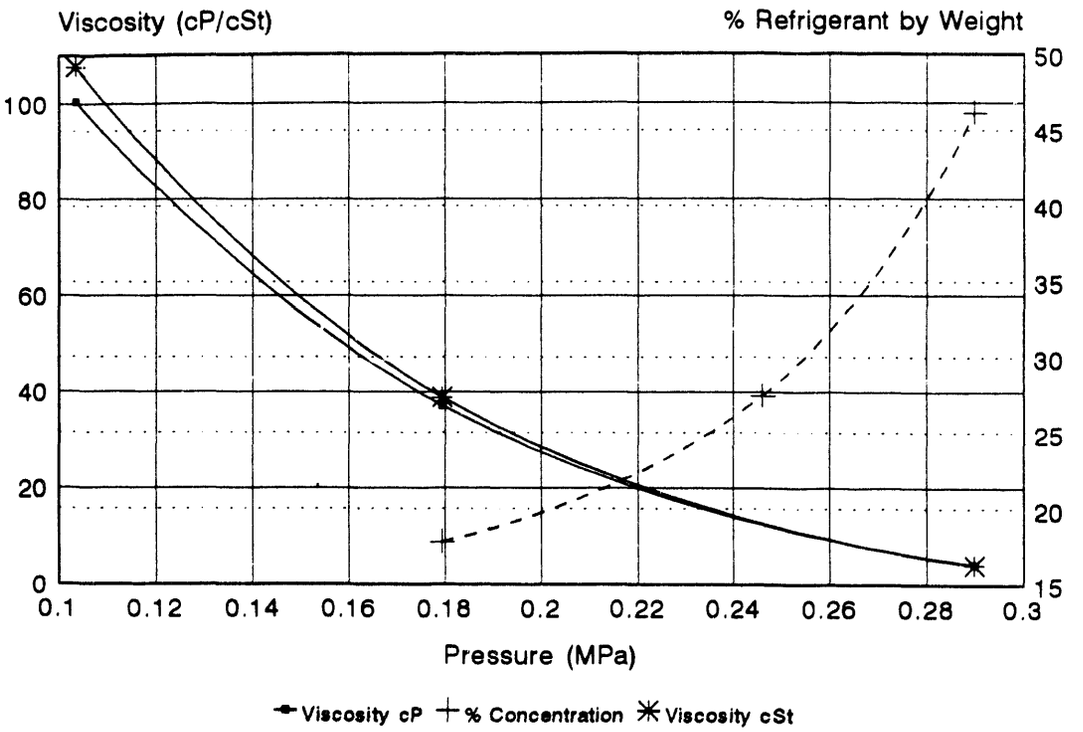


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-134a at 0°C

Figure D.7

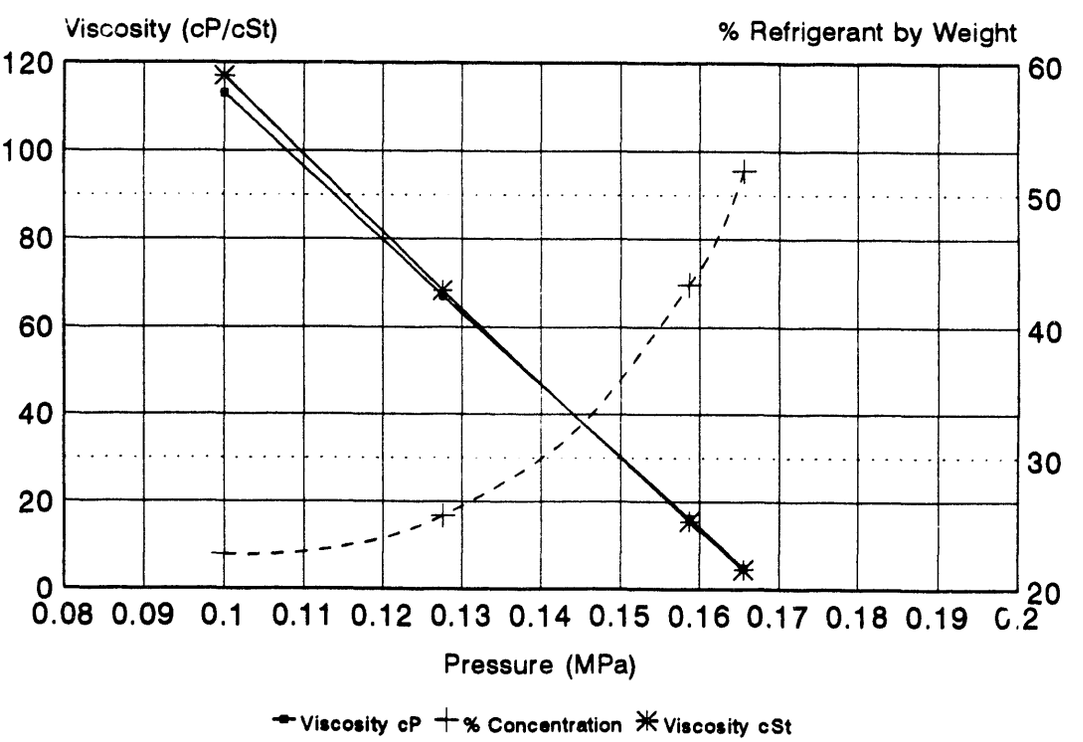


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-134a at -15.0°C

Figure D.8

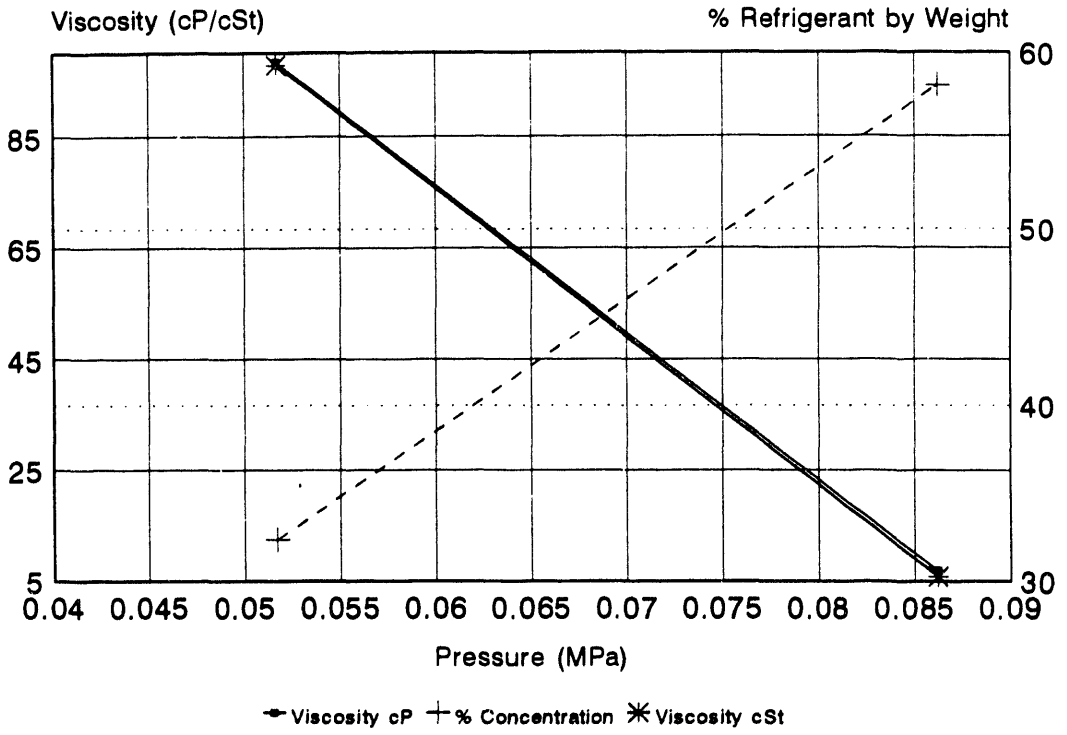


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-134a at -30.0°C

Figure D.9



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Solubility, and Density
32 ISO VG Mixed Acid Polyolester with HFC−134a
Table D.1

125°C Temperature
>500.0 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.7906	51.00	0.352	5.16	2.91	3.69
0.8198	111.25	0.766	5.40	2.58	3.15
0.8296	238.00	1.642	10.25	2.17	2.62
0.8455	351.25	2.424	15.57	1.92	2.27
0.8598	469.00	3.236	18.02	1.64	1.91

100.0°C Temperature
>500.0 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.782	44.00	0.304	3.92	4.16	5.46
0.8426	117.50	0.811	7.20	3.47	4.12
0.8533	241.38	1.665	15.35	2.56	3.00
0.8769	371.00	2.560	26.38	1.82	2.07
0.894	495.00	3.416	39.29	1.22	1.37

80.0°C Temperature
382.61 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.8605	40.50	0.279	5.20	6.78	7.88
0.8883	101.00	0.697	9.28	5.06	5.83
0.8911	217.50	1.501	21.19	2.96	3.32
0.9125	311.00	2.146	32.32	1.71	1.88
0.9404	373.00	2.574	29.21	0.76	0.81

60.0°C Temperature
245.24 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.8954	40.25	0.278	3.15	10.15	11.34
0.9054	84.00	0.580	9.46	7.38	8.15
0.914	127.50	0.880	15.85	5.04	5.51
0.9297	182.50	1.259	25.21	2.96	3.20
0.9546	235.00	1.622	49.42	1.08	1.12

40.0°C Temperature
146.47 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.9168	43.50	0.300	6.89	17.06	18.61
0.9368	85.50	0.590	19.60	12.76	13.64
0.9382	107.50	0.742	24.69	5.47	5.83
0.9775	127.50	0.880	38.00	2.53	2.59
0.9883	142.00	0.980	52.71	1.36	1.42

20.0°C Temperature
83.36 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.8997	25.00	0.173	19.82	30.36	33.75
0.9183	38.25	0.264	14.47	20.65	22.49
0.9397	55.50	0.383	20.61	14.41	15.33
0.961	72.50	0.500	30.36	6.52	6.64
1.0261	83.36	0.575	46.50	2.06	2.00

0.0°C Temperature
41.96 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.9325	15.00	0.104	none	100.42	107.69
0.9566	26.00	0.179	17.81	37.17	38.85
0.9753	35.75	0.247	27.49	19.17	19.66
1.0368	42.00	0.290	46.15	4.27	4.11

−15.0° C Temperature
23.51 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.9656	14.50	0.100	22.64	113.07	116.95
0.9825	18.50	0.128	25.61	67.08	68.27
1.0402	23.00	0.159	43.20	16.19	15.56
1.0802	23.70	0.164	51.86	4.83	4.47

−30° C Temperature
12.20 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.0053	7.50	0.052	32.33	98.36	97.84
1.1779	12.50	0.086	58.15	6.83	5.80

Neat Viscosity Check
Polyolester alone
40°C, 14.7 psia

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
0.945	14.7	0.101	0.00	29.79	31.51	Oscillating Bob Viscometer
0.957	14.7	0.101	0.00	29.90	31.24	Cannon Viscometer #300 645T

APPENDIX E:

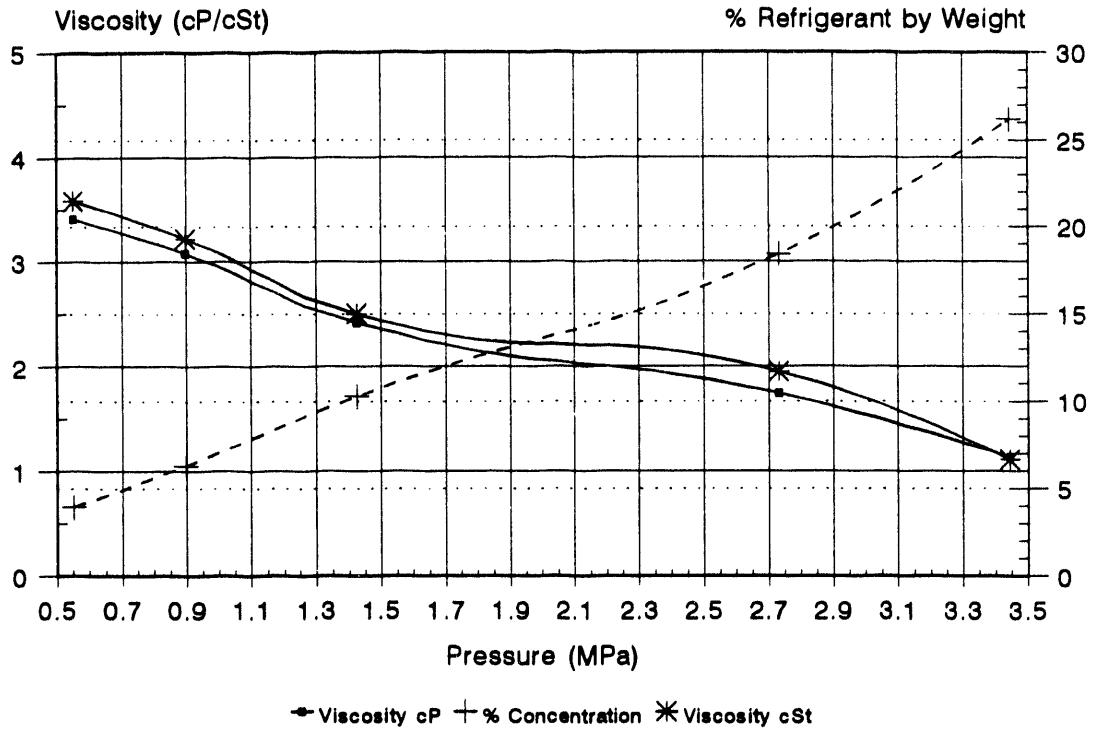
Viscosity, Density and Gas Solubility of 32 ISO VG Branched Acid Polyolester at Various Temperatures with HFC-134a

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

Viscosity and Gas Solubility

32 ISO VG Branched Acid Polyolester With HFC-134a at 125°C

Figure E.1

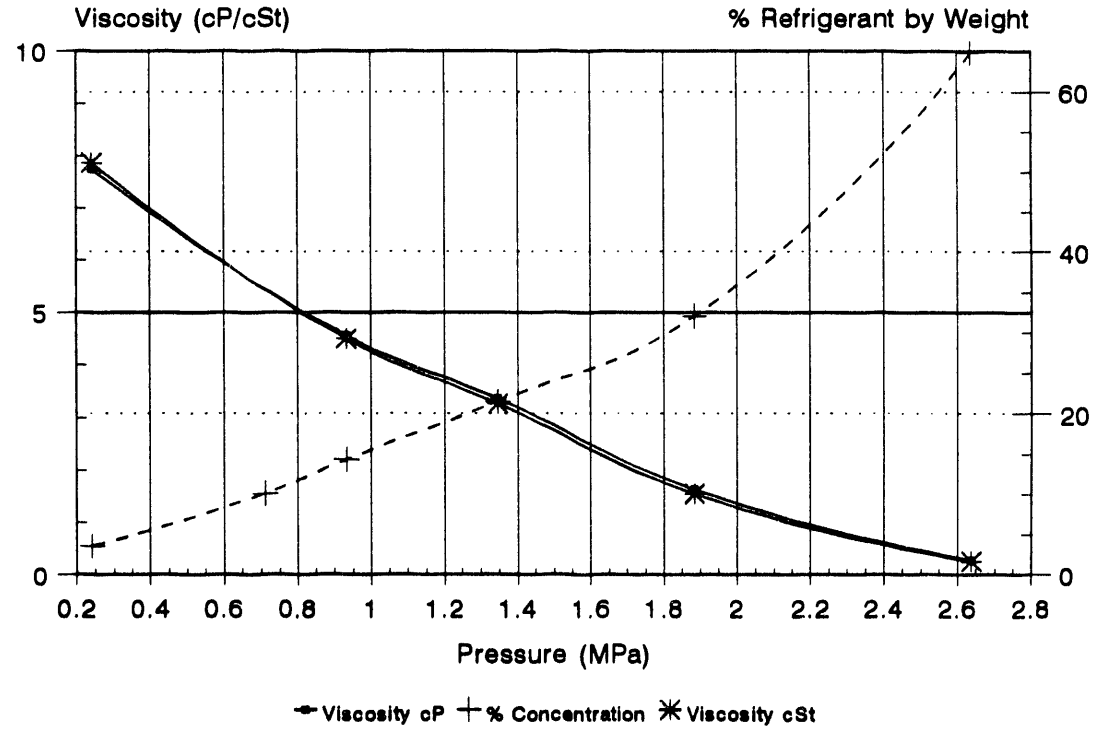


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Branched Acid Polyolester with HFC-134a at 80°C

Figure E.2

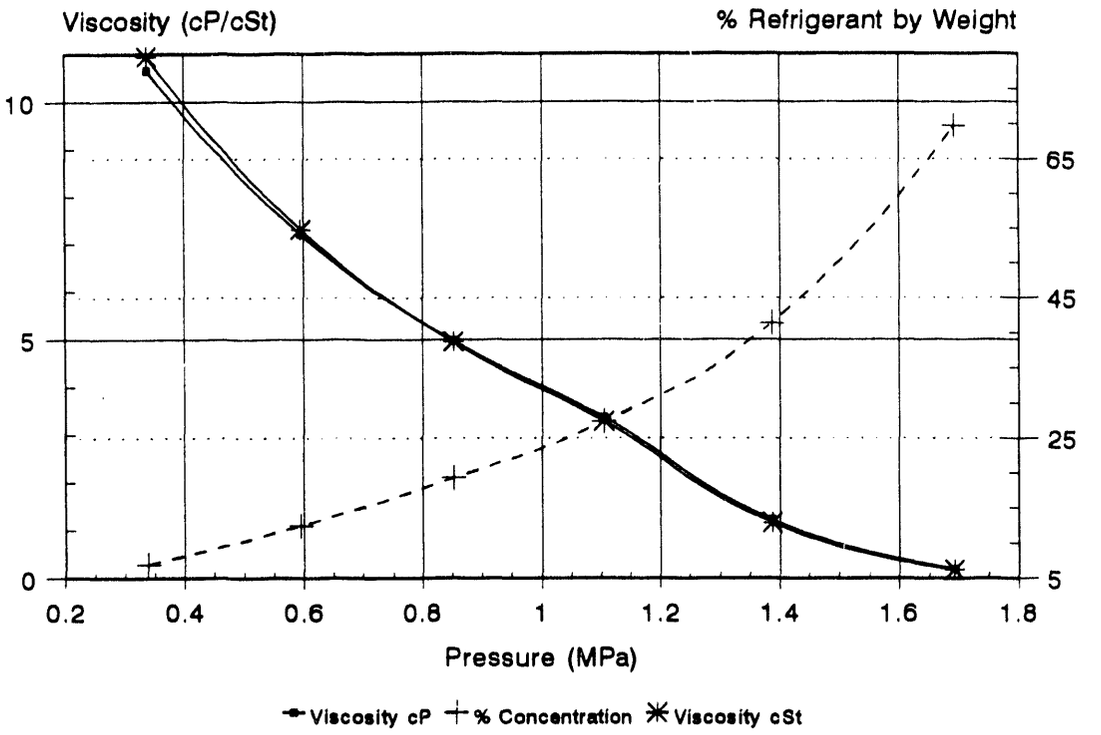


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Branched Acid Polyolester with HFC-134a at 60°C

Figure E.3

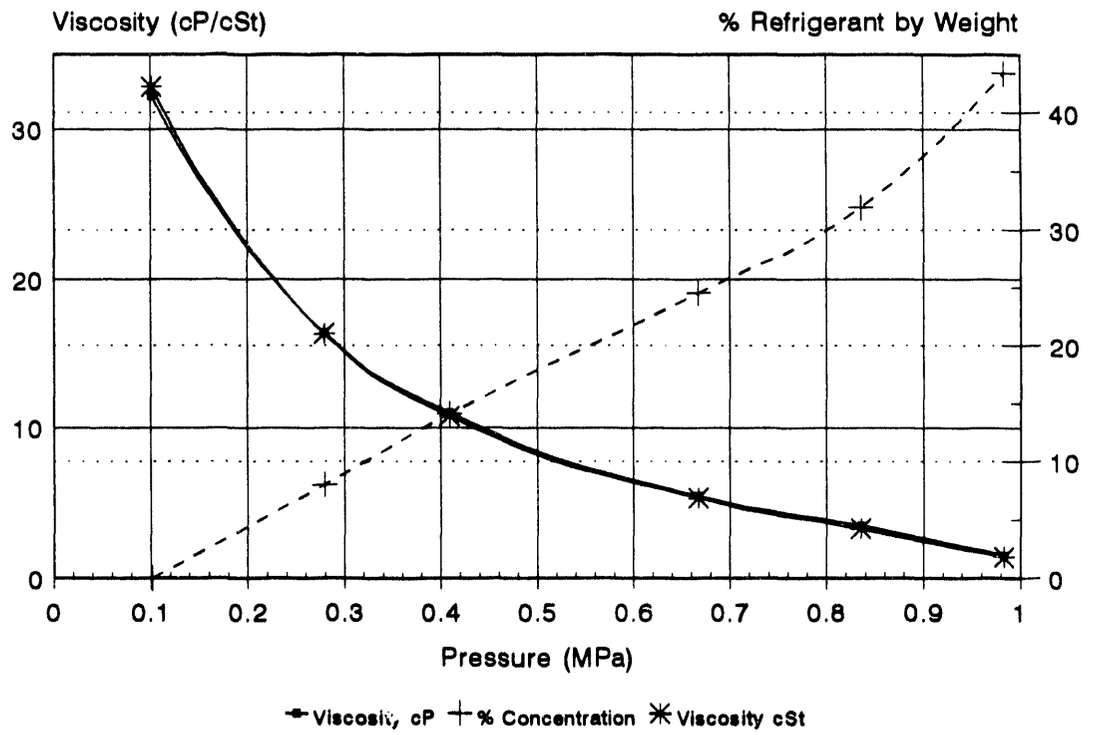


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Branched Acid Polyolester with HFC-134a at 40°C

Figure E.4

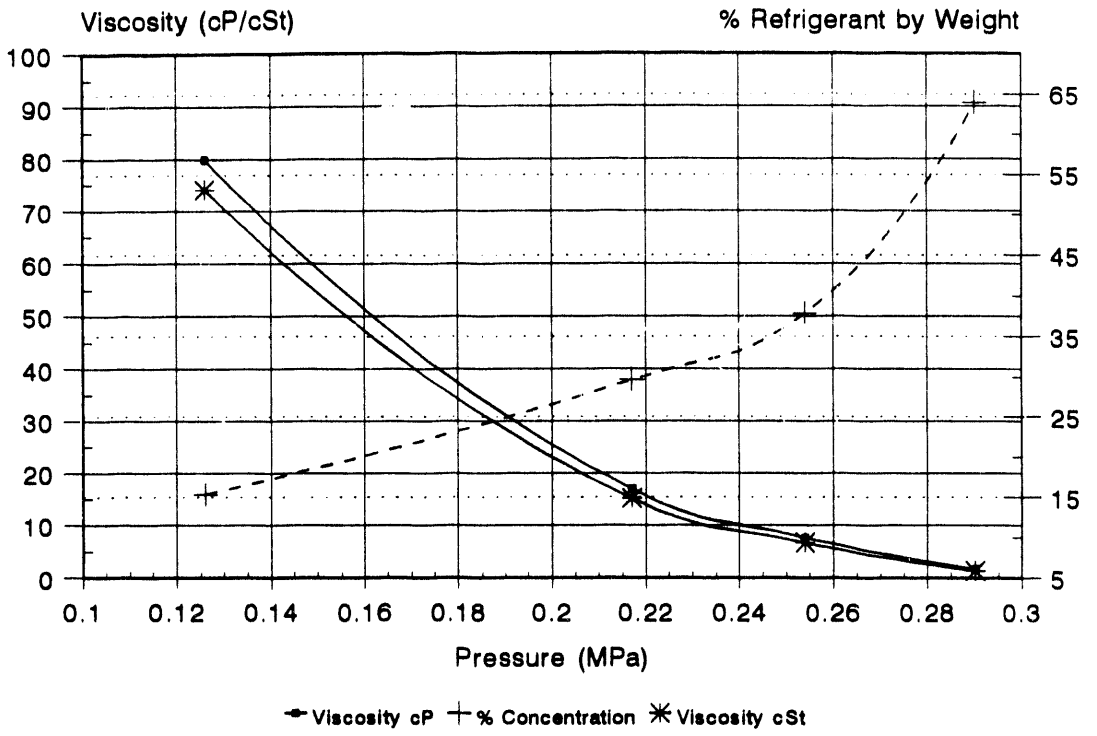


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-134a at 0°C

Figure E.5



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
32 ISO VG Branched Acid Polyolester with HFC–134a
Table E.1

125 °C Temperature
500.0 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.951	80.00	0.552	3.95	3.41	3.58
0.956	130.00	0.897	6.30	3.08	3.22
0.967	206.50	1.425	10.27	2.42	2.50
1.003	396.50	2.736	18.42	1.74	1.95
1.022	499.25	3.445	26.19	1.13	1.11

40 °C Temperature
147.673 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.000	40.50	0.279	8.00	16.40	16.41
1.013	59.25	0.409	14.08	10.88	10.74
1.035	96.50	0.666	24.54	5.26	5.22
1.058	120.76	0.833	31.92	3.29	3.11
1.066	142.50	0.983	43.39	1.47	1.38

80 °C Temperature
382 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.985	35.00	0.242	3.56	7.75	7.86
1.009	103.00	0.711	10.14	5.10	4.77
1.013	135.00	0.932	14.35	4.56	4.50
1.029	195.00	1.346	21.49	3.36	3.27
1.054	272.50	1.880	32.07	1.64	1.55
1.086	382.00	2.636	64.83	0.28	0.25

0°C Temperature
41.98 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.079	18.25	0.126	15.38	79.83	73.99
1.122	31.50	0.217	29.65	16.93	15.09
1.145	36.75	0.254	37.85	7.60	6.63
1.206	41.98	0.290	63.96	1.70	1.41

60 °C Temperature
245.2 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.973	49.00	0.338	7.01	10.66	10.95
0.986	86.75	0.599	12.51	7.21	7.31
1.004	123.50	0.852	19.30	4.98	4.96
1.025	160.50	1.107	27.35	3.36	3.28
1.050	201.25	1.389	41.45	1.22	1.16
1.088	245.20	1.692	69.78	0.19	0.18

Neat Viscosity Check
Polyolester alone.
40°C, 14.7 psia

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
0.9812	14.7	0.101	0.00	32.837	33.466	Oscillating Bob Viscometer
n/a	14.7	0.101	0.00	n/a	33.4	Cannon Viscometer #300 645T

APPENDIX F:

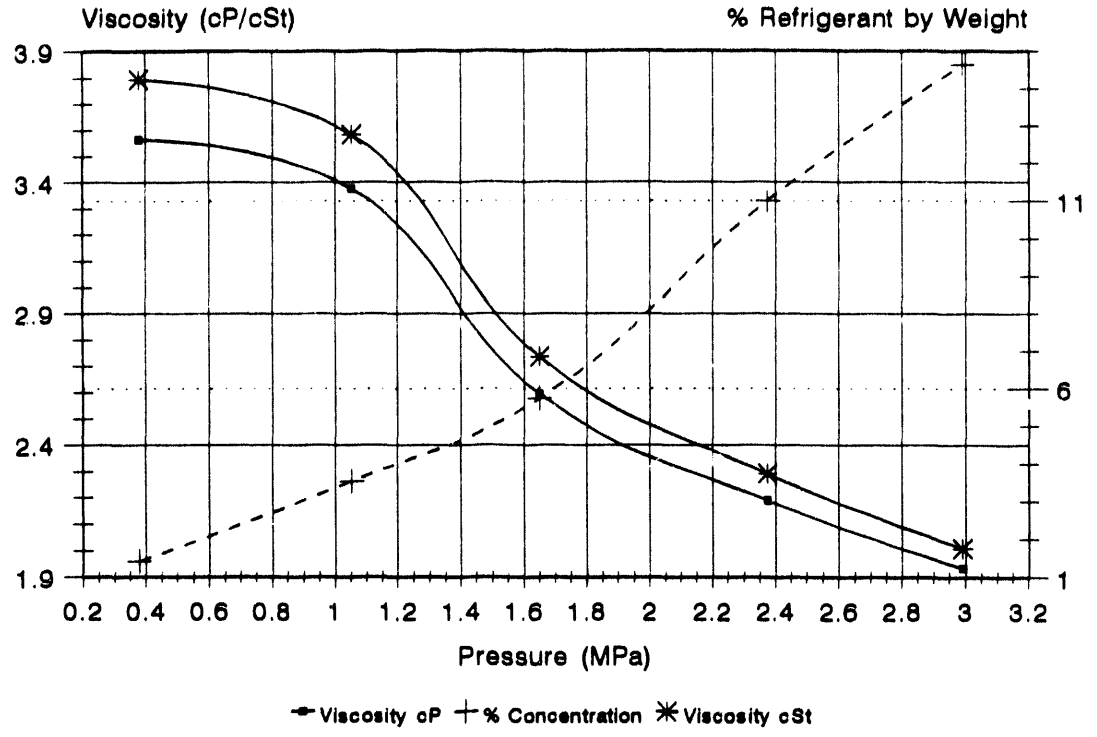
Viscosity, Density and Gas Solubility of 32 ISO VG Branched Acid Polyolester at Various Temperatures with HFC-143a

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

Viscosity and Gas Solubility

32 ISO VG Branched Acid Polyolester with HFC-143a at 125°C

Figure F.1

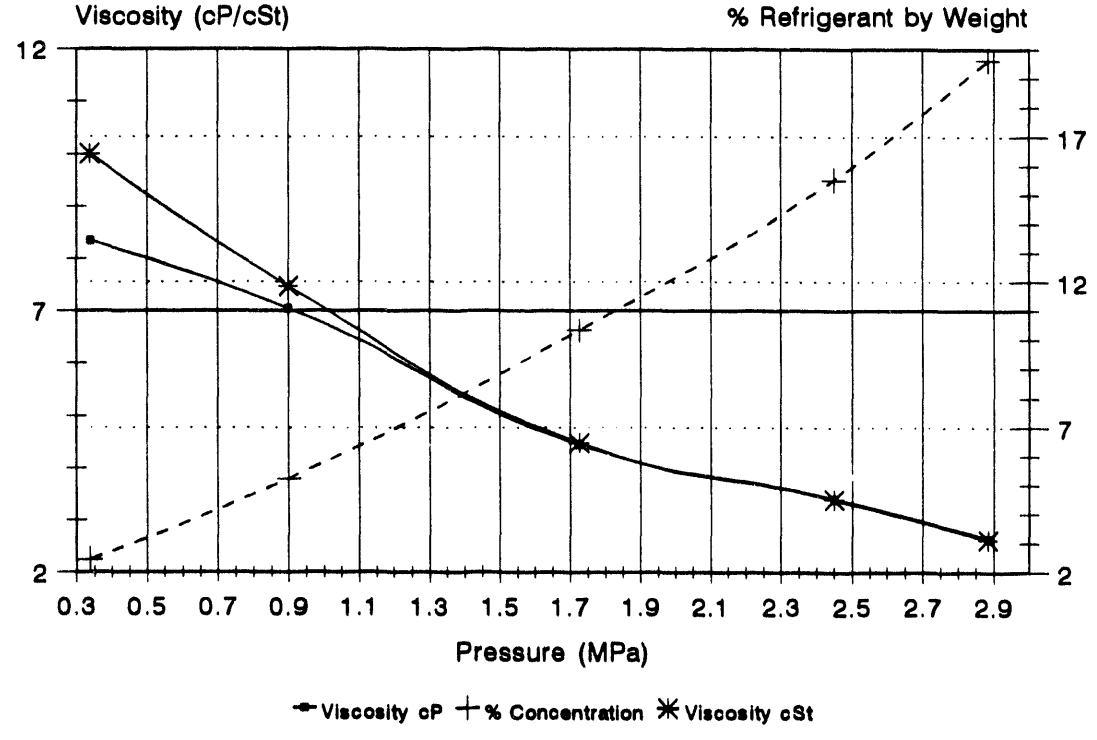


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Branched Acid Polyolester with HFC-143a at 80°C

Figure F.2

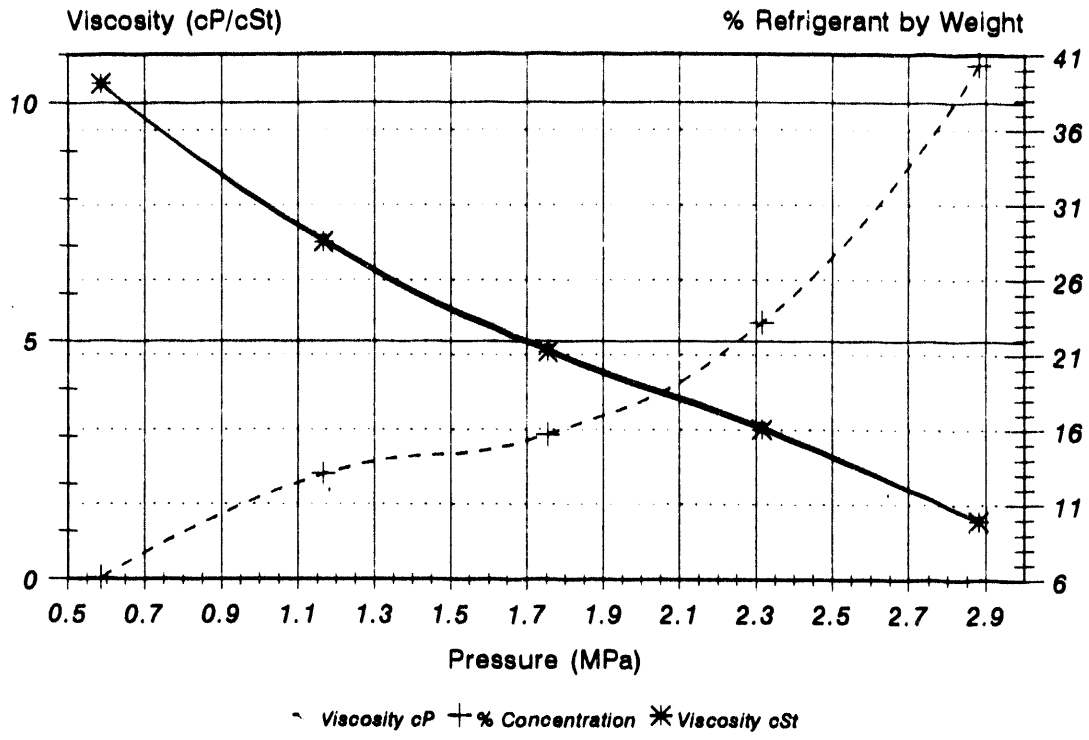


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Branched Acid Polyolester with HFC-143a at 60°C

Figure F.3

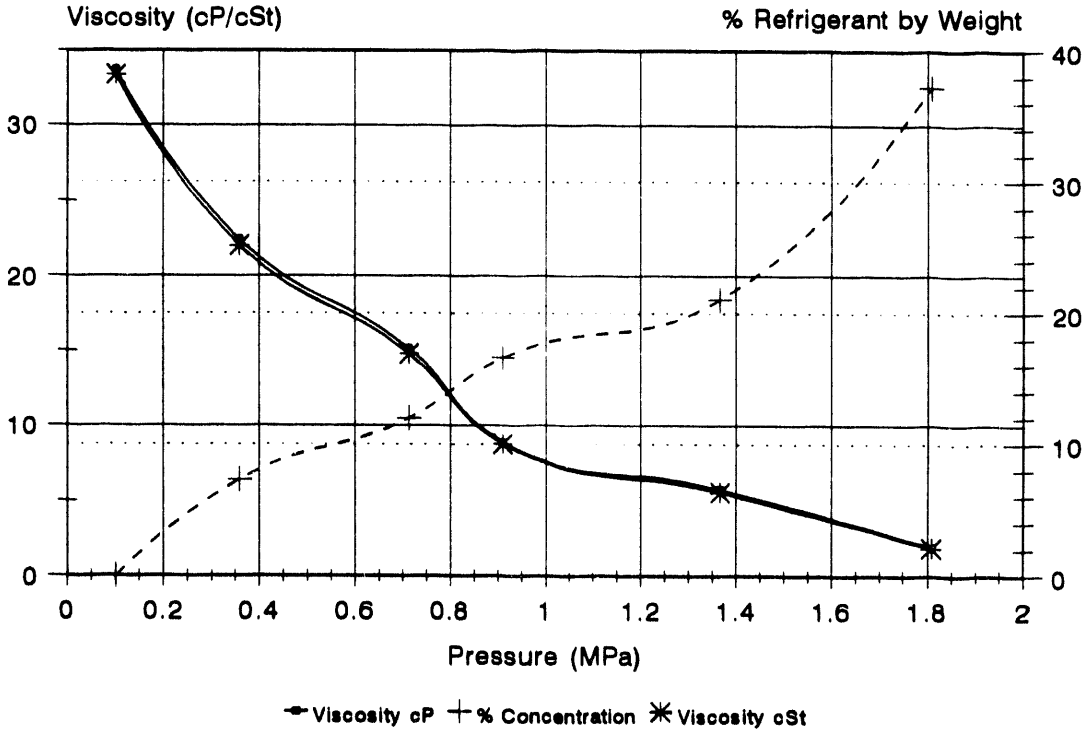


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO Branched Acid Polyolester with HFC-143a at 40°C

Figure F.4



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
32 ISO Branched Acid Polyolester with HFC-143a
Table F.1

125.0°C Temperature
>500.0 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.939	55.00	0.380	1.41	3.56	3.79
0.942	152.50	1.052	3.54	3.38	3.58
0.948	239.00	1.649	5.74	2.60	2.74
0.956	344.00	2.374	11.01	2.19	2.29
0.963	433.50	2.991	14.64	1.94	2.01

80 °C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.835	49.00	0.338	2.41	8.35	10.00
0.944	130.50	0.900	5.23	7.05	7.47
0.992	250.00	1.725	10.33	4.45	4.48
1.004	355.00	2.450	15.51	3.40	3.39
1.008	416.00	2.884	19.63	2.64	2.62

60 °C Temperature
417.37 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.000	85.00	0.587	6.09	10.40	10.40
1.008	169.00	1.166	13.02	7.14	7.08
1.014	254.25	1.754	15.68	4.85	4.78
1.022	335.50	2.315	23.16	3.22	3.15
1.022	417.37	2.880	40.34	1.26	1.23

Neat Viscosity Check
Polyolester alone.
40°C, 14.7 psia

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
1.0036	14.7	0.101	0.00	33.922	33.799	Oscillating Bob Viscometer
n/a	14.7	0.101	0.00	n/a	33.4	Cannon Viscometer #300 645T

40 °C Temperature
266.69 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.010	14.70	0.101	0.00	33.71	33.38
1.017	52.00	0.359	7.32	22.39	22.01
1.023	103.50	0.714	12.01	15.12	14.78
1.029	162.00	1.118	16.60	8.90	8.64
1.033	198.00	1.366	21.07	5.77	5.58
1.033	262.00	1.806	37.25	1.94	1.88

20 °C Temperature
160.30 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.032	32.00	0.221	4.11	49.73	48.19
1.035	64.00	0.442	8.07	34.59	33.43
1.042	92.00	0.635	13.79	20.20	19.38
1.046	132.00	0.911	19.88	9.72	9.28
1.054	160.00	1.104	38.75	2.73	2.59

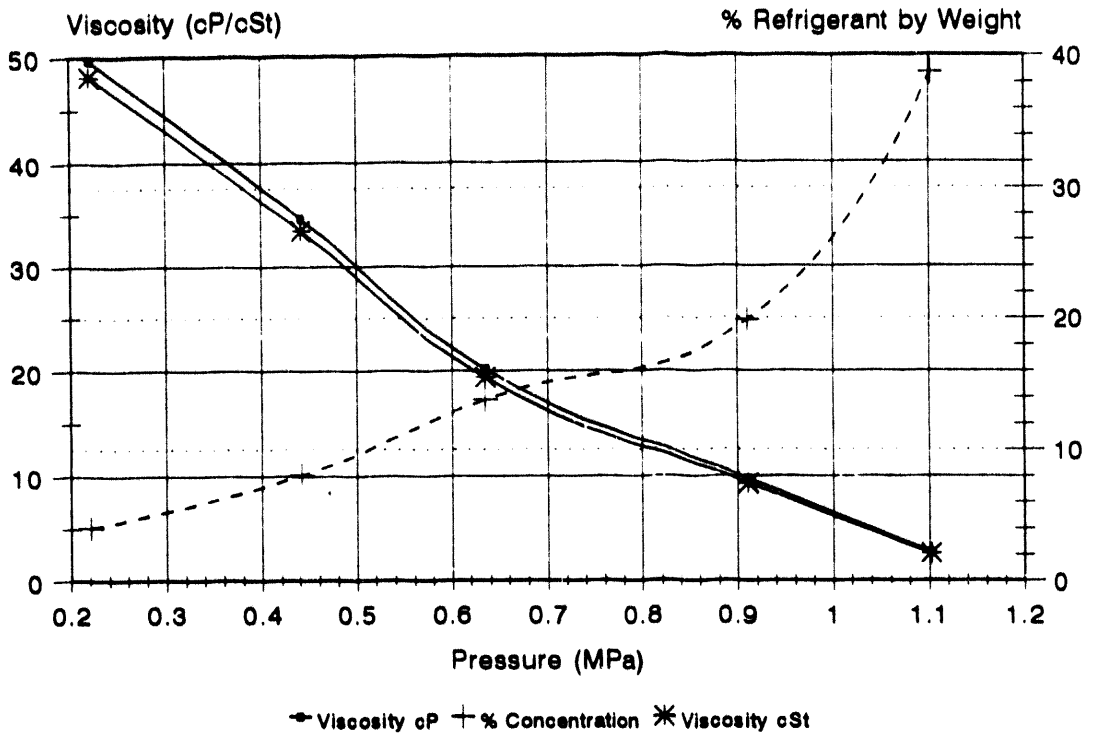
0 °C Temperature
89.43 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.047	23.50	0.162	5.02	154.26	147.28
1.053	38.75	0.267	8.37	110.34	104.83
1.061	60.00	0.414	12.68	56.72	53.44
1.064	74.25	0.512	16.59	23.73	22.30
1.072	89.43	0.617	31.01	7.82	7.30

Viscosity and Gas Solubility

32 ISO VG Branched Acid Polyolester with HFC-143a at 20°C

Figure F.5

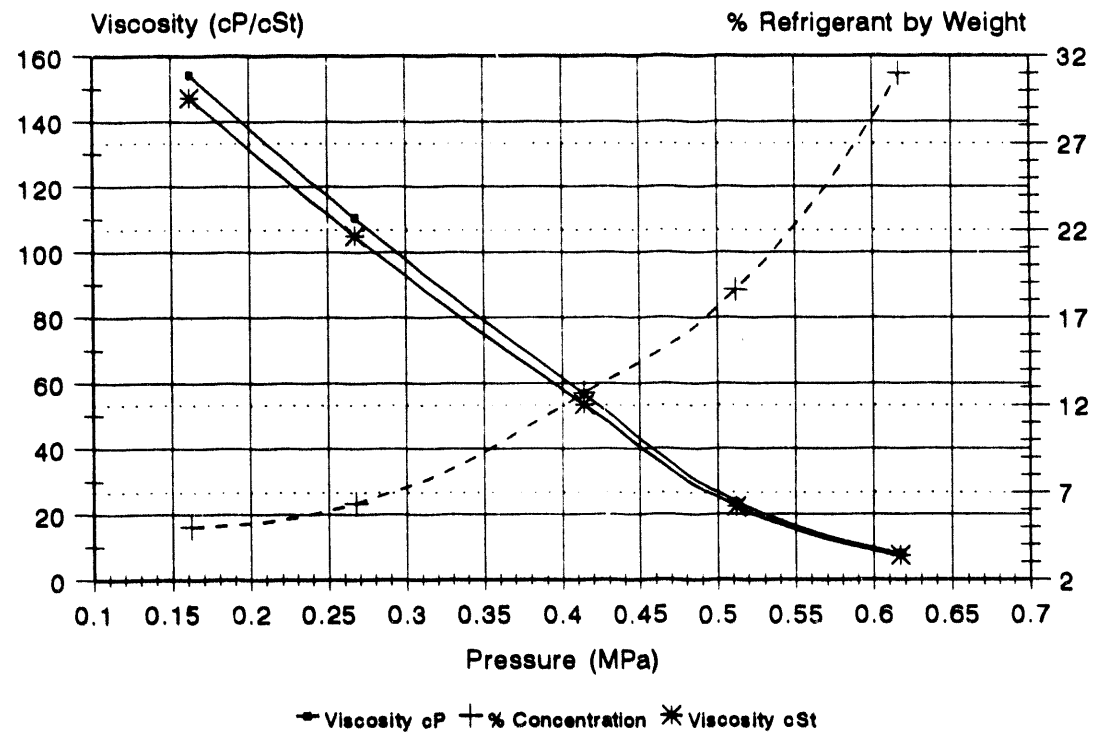


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Branched Acid Polyolester with HFC-143a at 0°C

Figure F.6



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

APPENDIX G:

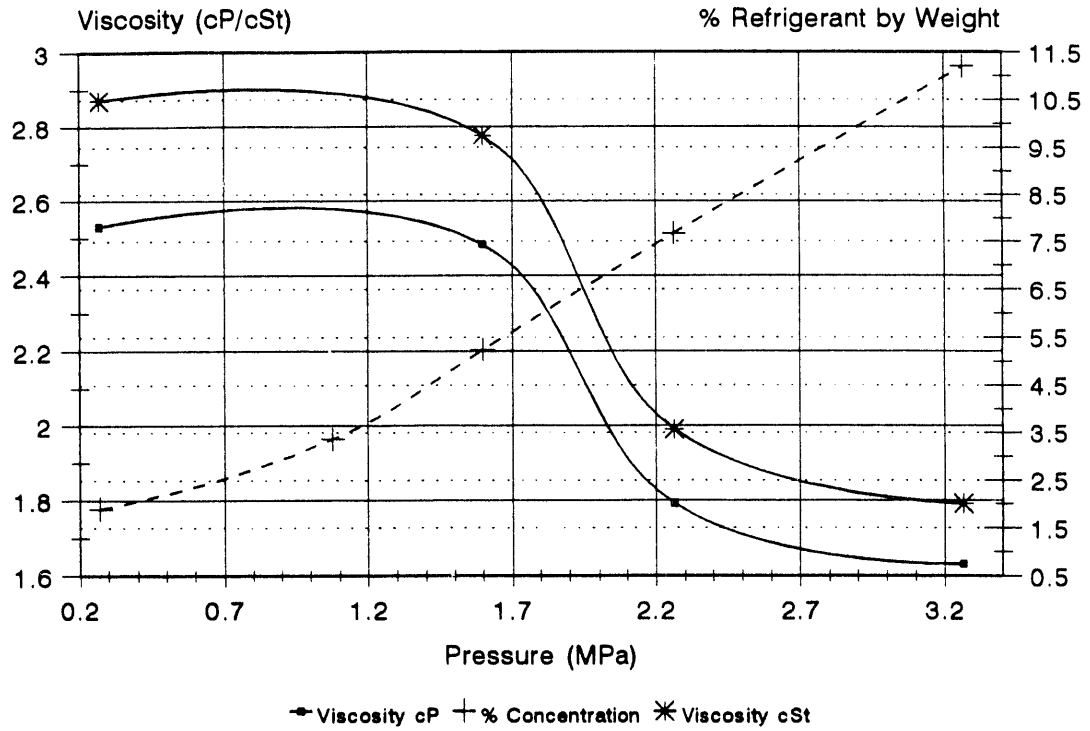
Viscosity, Density and Gas Solubility of 32 ISO VG Mixed Acid Polyolester at Various Temperatures with HFC-143a

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-143a at 125°C

Figure G.1

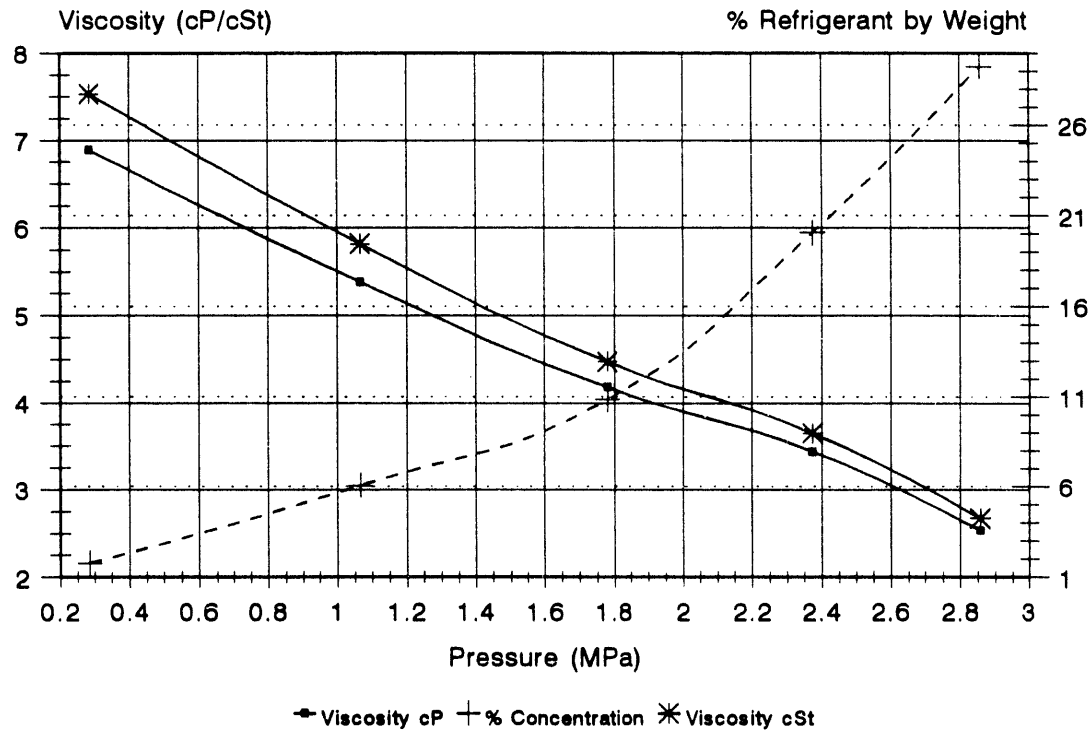


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-143a at 80°C

Figure G.2

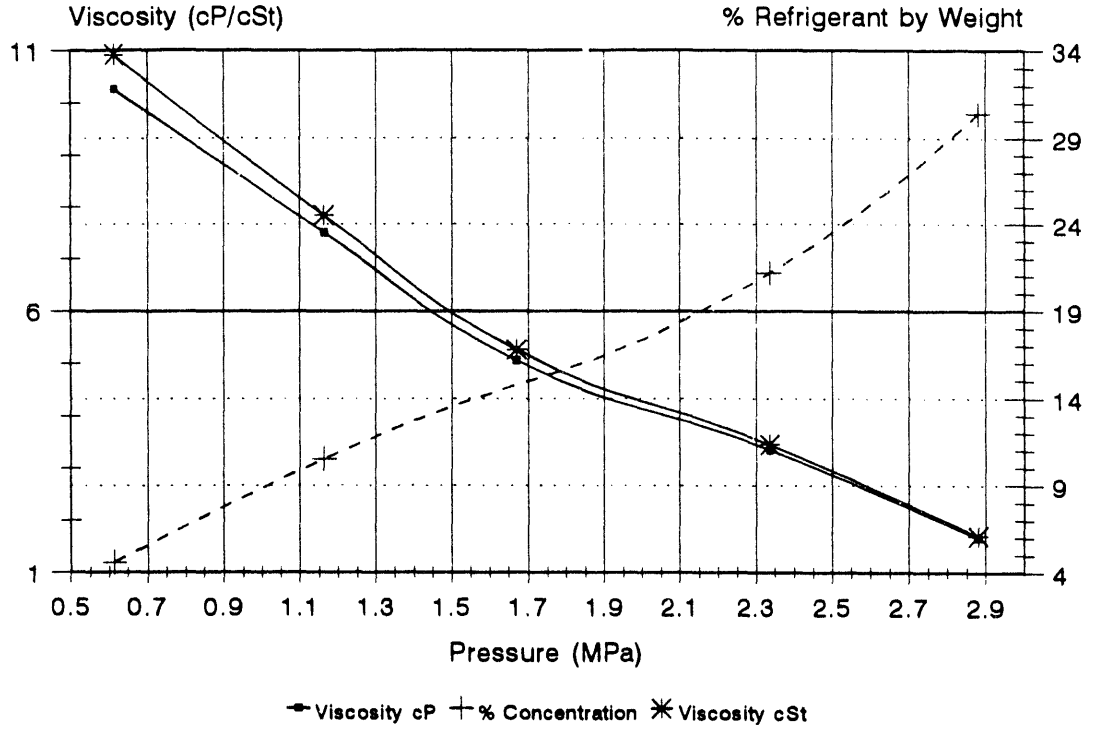


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-143a at 60°C

Figure G.3

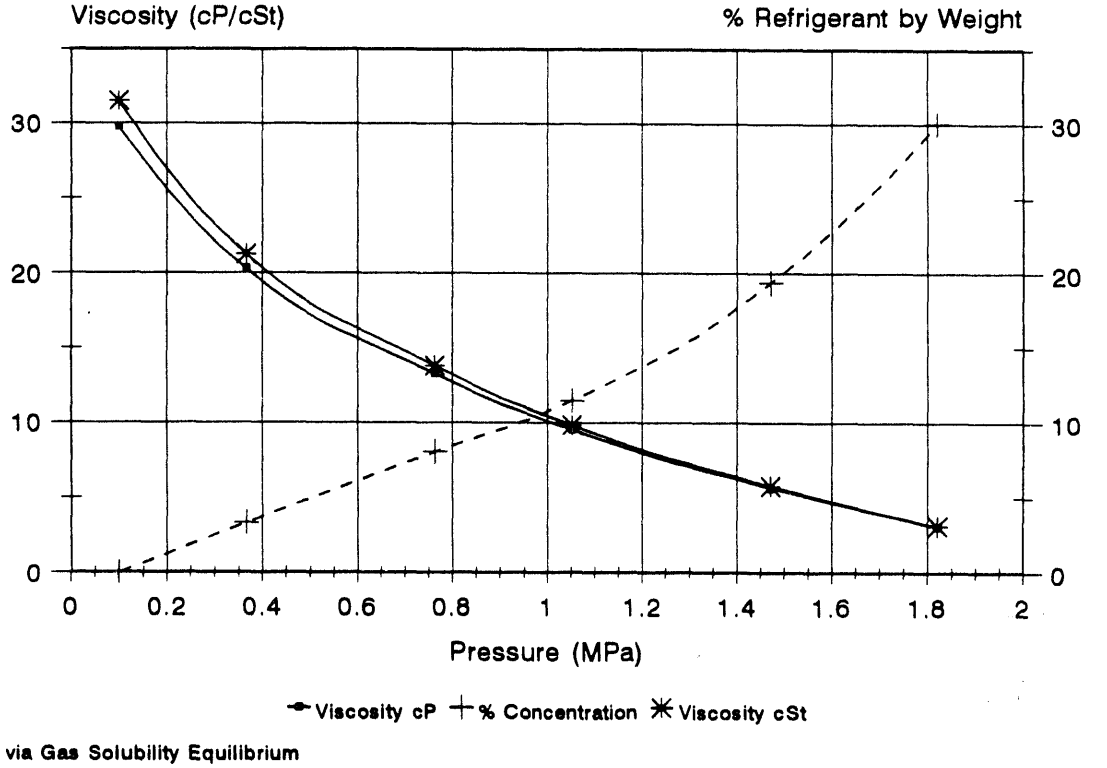


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-143a at 40°C

Figure G.4

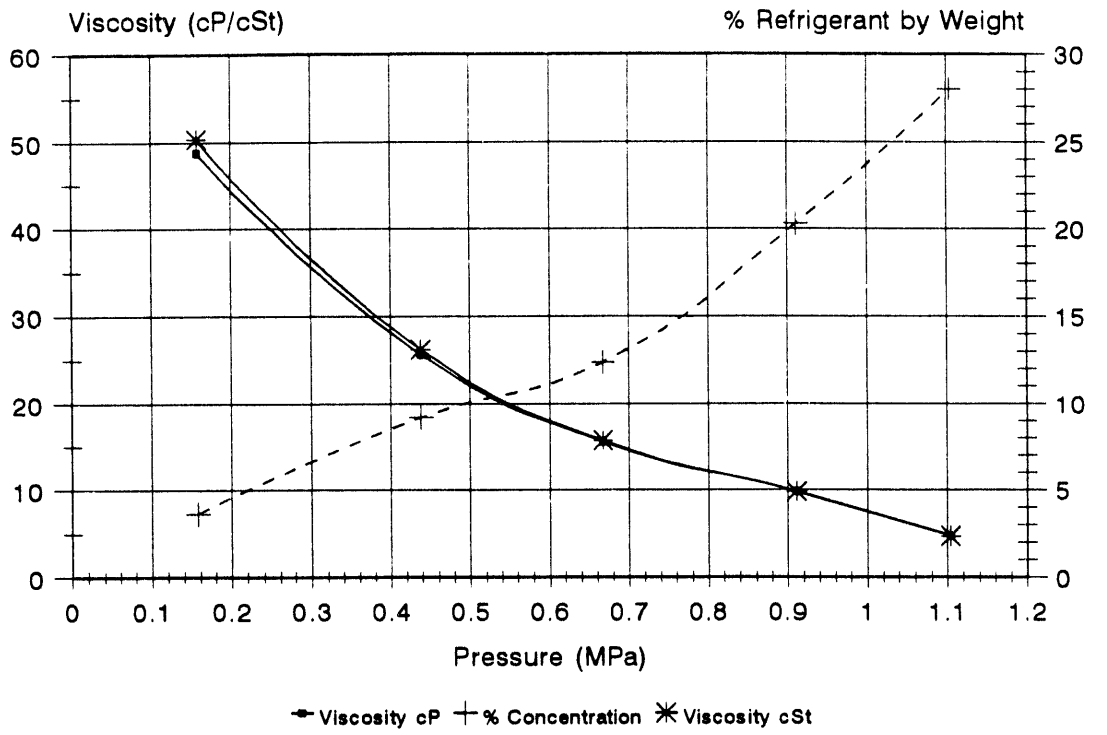


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-143a at 20°C

Figure G.5

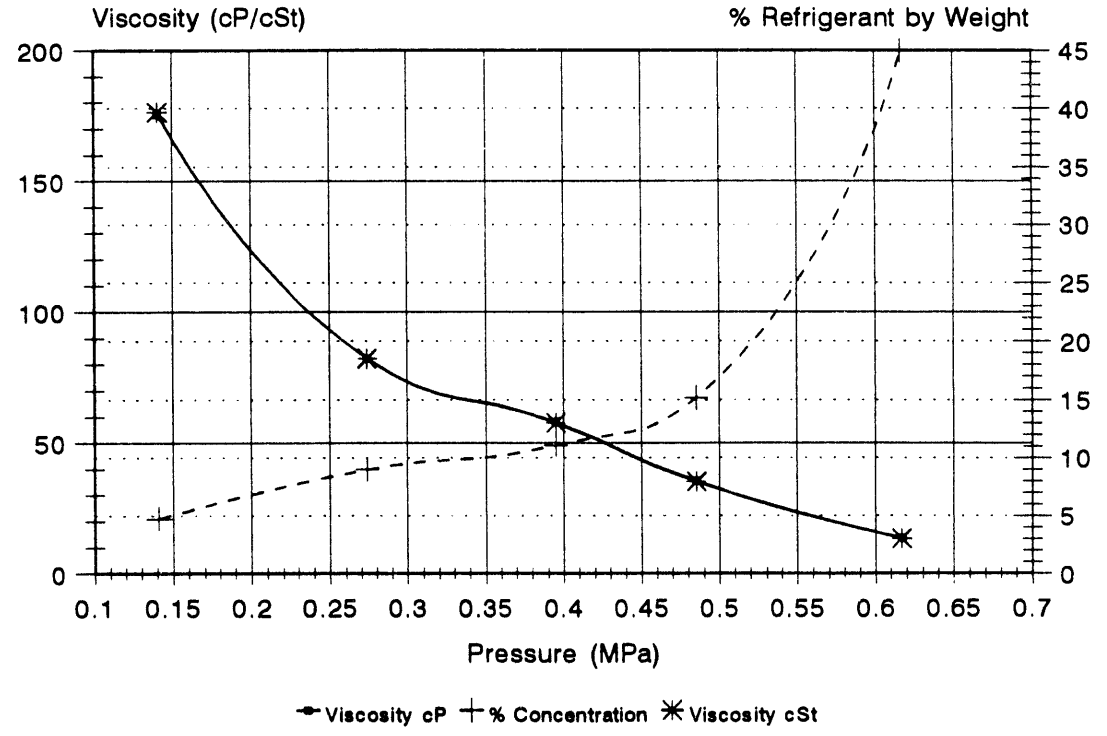


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity and Gas Solubility

32 ISO VG Mixed Acid Polyolester with HFC-143a at 0°C

Figure G.6



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
32 ISO Mixed Acid Polyolester with HFC–143a
Table G.1

125.0°C Temperature
>500.0 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.881	39.25	0.271	1.90	2.53	2.87
0.889	156.00	1.076	3.36	2.58	2.91
0.894	231.75	1.599	5.24	2.48	2.78
0.901	328.00	2.263	7.67	1.79	1.99
0.910	473.00	3.264	11.20	1.63	1.79

80 °C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.915	41.25	0.285	1.76	6.89	7.53
0.925	154.50	1.066	6.06	5.38	5.82
0.934	258.00	1.780	10.86	4.18	4.48
0.942	344.00	2.374	20.06	3.44	3.65
0.948	414.00	2.857	29.26	2.53	2.67

60 °C Temperature
417.37 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.941	89.00	0.614	4.58	10.28	10.92
0.957	168.50	1.163	10.53	7.50	7.83
0.961	242.50	1.673	17.00	5.06	5.26
0.972	338.50	2.336	21.19	3.35	3.45
0.981	417.37	2.880	30.43	1.67	1.70

Neat Viscosity Check
Polyolester alone.
40°C, 14.7 psia

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
0.945	14.7	0.101	0.00	29.79	31.51	Oscillating Bob Viscometer
0.957	14.7	0.101	0.00	29.90	31.24	Cannon Viscometer #300 645T

40 °C Temperature
266.69 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.945	14.70	0.101	0.00	29.79	31.51
0.954	53.00	0.366	3.32	20.28	21.25
0.961	110.75	0.764	8.05	13.28	13.81
0.969	152.50	1.052	11.49	9.53	9.84
0.982	213.25	1.471	19.39	5.69	5.79
0.989	264.00	1.822	30.04	3.11	3.14

20 °C Temperature
160.30 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.969	22.75	0.157	3.64	48.75	50.32
0.979	63.50	0.438	9.20	25.71	26.25
0.989	96.50	0.666	12.39	15.55	15.72
1.003	132.00	0.911	20.29	9.81	9.79
1.011	160.00	1.104	28.01	4.75	4.70

0 °C Temperature
89.43 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.996	20.50	0.141	4.75	175.55	176.31
1.001	39.75	0.274	8.97	82.31	82.22
1.006	57.25	0.395	11.06	58.02	57.70
1.010	70.75	0.488	15.14	35.53	35.18
1.015	89.43	0.617	44.98	13.62	13.41

APPENDIX H:

Viscosity, Density and Gas Solubility of 32 ISO VG Branched Acid Polyolester at Various Temperatures with Blend HFC-125/143a/134a (44/52/4% w/w)

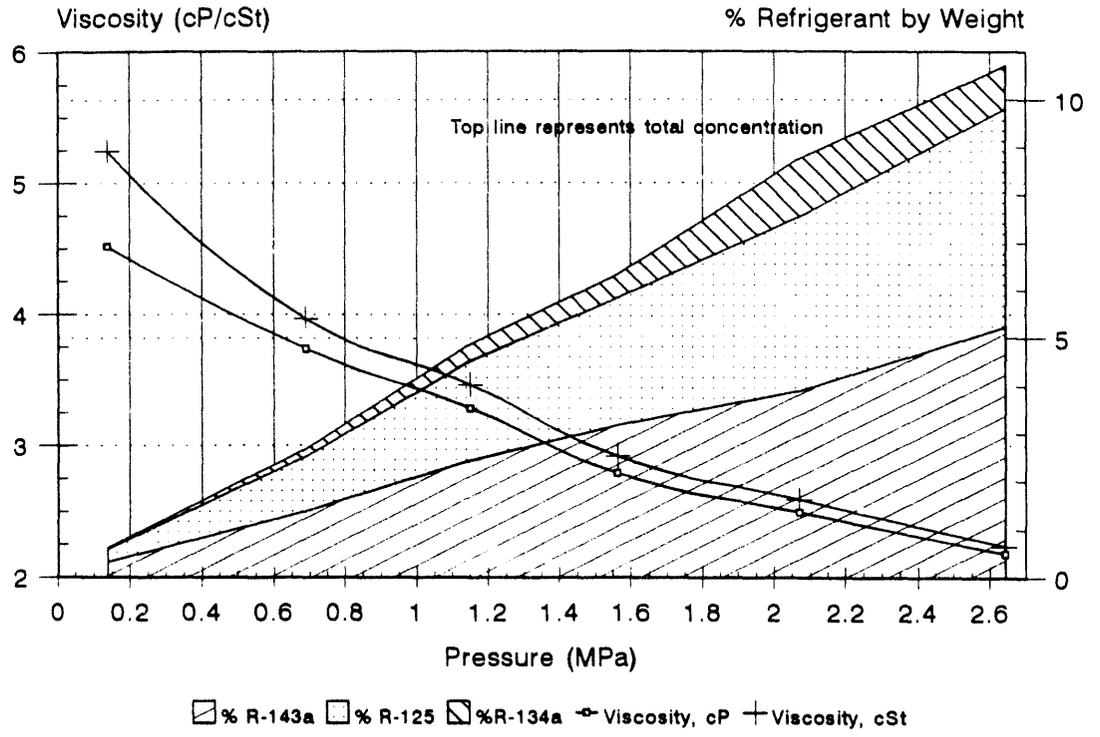
The following graphs show the concentrations of the blend components as shaded areas. These areas are cumulative, not overlapped. For example, in Figure H.1, the concentration in the lubricant of HFC-143a alone is slightly more than five percent. The concentration of HFC-125 is slightly less than five 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 the blend, slightly less than eleven percent.

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 125°C

Figure H.1

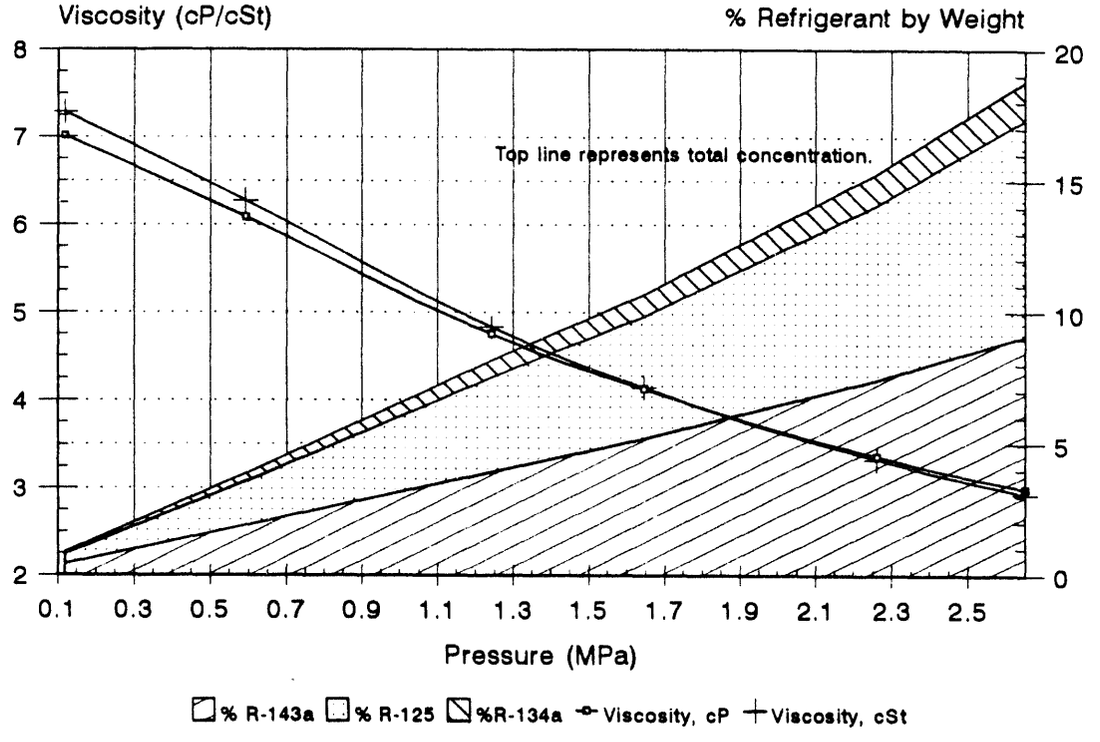


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 90°C

Figure H.2

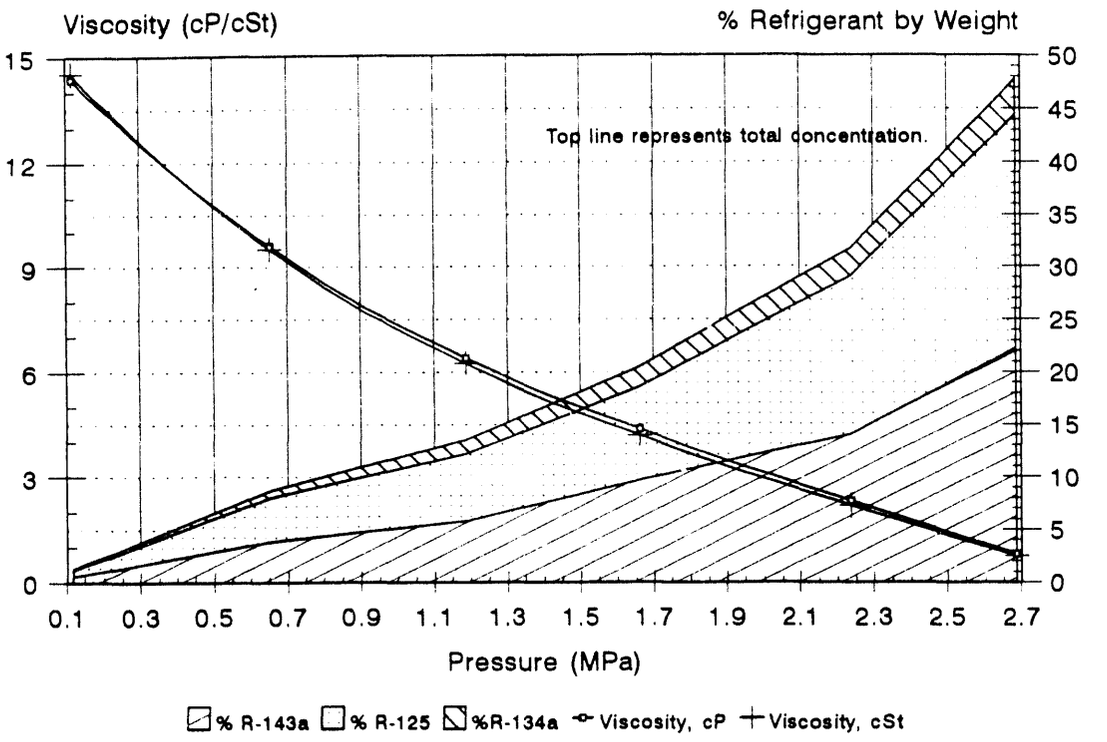


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 60°C

Figure H.3

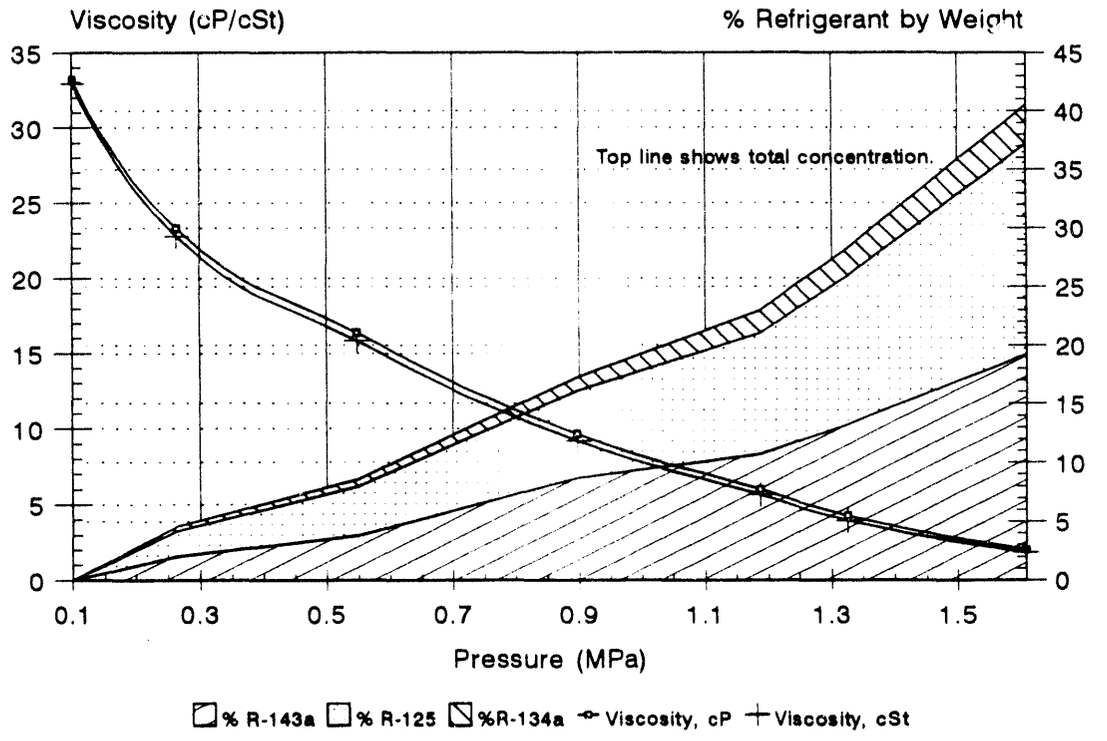


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 40°C

Figure H.4

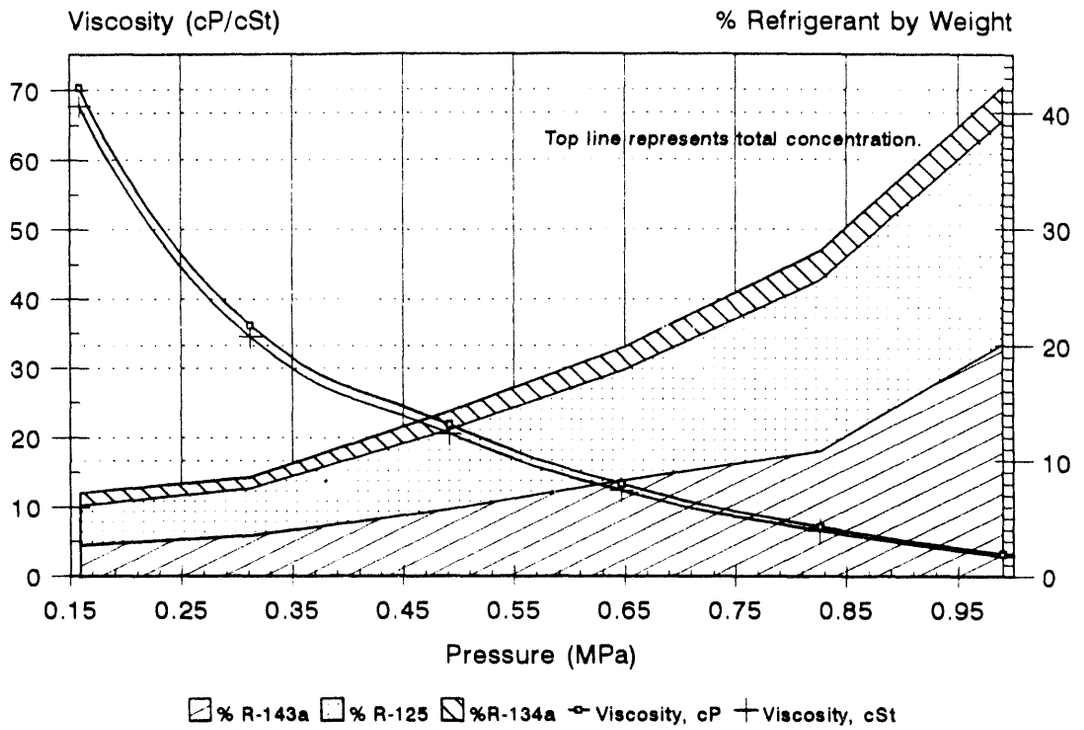


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 20°C

Figure H.5

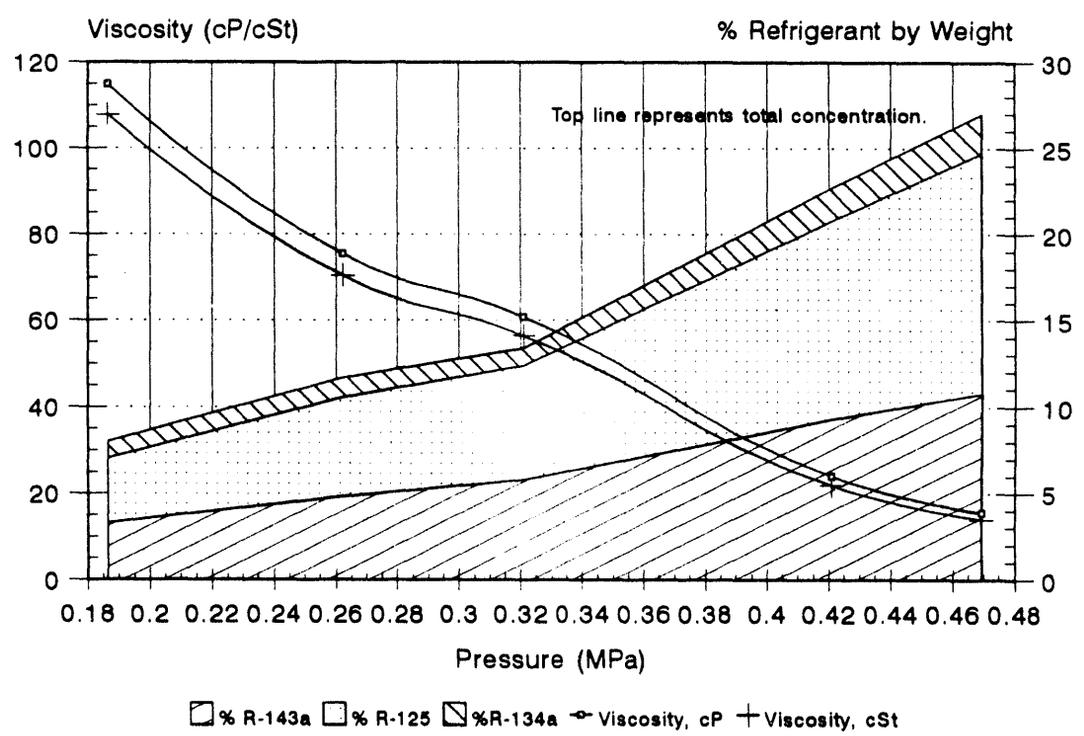


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 0°C

Figure H.6



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
32 ISO VG Branched Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w)
Table H.1

125°C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.862	20.00	0.138	0.61 (42/52/6)*	4.52	5.25
0.942	100.00	0.690	2.68 (43/51/6)*	3.74	3.97
0.948	166.75	1.151	4.88 (43/50/7)*	3.29	3.46
0.956	226.50	1.563	6.33 (42/50/8)*	2.79	2.92
0.963	300.00	2.070	8.75 (42/44/14)*	2.49	2.59
0.975	383.00	2.643	10.71 (43/49/8)*	2.18	2.24

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

40°C Temperature
263.7 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.008	14.70	0.101	0.00 (0/0/0)*	33.20	32.92
1.023	38.25	0.264	4.60 (47/44/9)*	23.31	22.78
1.033	79.50	0.549	8.52 (49/44/7)*	16.38	15.84
1.048	130.00	0.897	17.23 (43/50/7)*	9.65	9.21
1.063	171.25	1.182	22.93 (45/47/8)*	6.00	5.64
1.079	192.00	1.325	26.25 (45/47/8)*	4.26	3.95
1.088	233.00	1.608	40.53 (45/47/8)*	2.01	1.84

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

90°C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.963	17.25	0.119	0.87 (43/49/8)*	7.01	7.28
0.970	86.00	0.593	3.88 (43/49/8)*	6.09	6.27
0.984	180.50	1.245	8.16 (44/48/8)*	4.75	4.83
0.997	238.50	1.646	10.68 (43/49/8)*	4.13	4.14
1.010	327.50	2.260	15.29 (43/49/8)*	3.36	3.33
1.020	384.00	2.650	18.80 (44/48/8)*	2.99	2.93

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

20°C Temperature
158.7 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.038	23.00	0.159	7.24 (47/37/16)*	70.30	67.74
1.050	45.25	0.312	8.59 (48/41/11)*	36.25	34.54
1.061	71.25	0.492	14.25 (48/41/11)*	21.85	20.59
1.078	93.75	0.647	19.75 (48/42/10)*	13.33	12.37
1.088	119.75	0.826	28.13 (53/38/9)*	7.16	6.58
1.105	143.50	0.990	42.20 (48/47/7)*	3.22	2.92

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

60 °C Temperature
416.7 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.989	17.00	0.117	1.30 (47/45/8)*	14.37	14.53
1.008	94.75	0.654	8.73 (47/45/8)*	9.60	9.52
1.025	172.50	1.190	13.53 (47/43/10)*	6.41	6.25
1.044	240.75	1.661	20.50 (44/47/9)*	4.37	4.19
1.058	324.25	2.237	31.71 (48/44/8)*	2.31	2.18
1.075	389.25	2.686	47.75 (47/46/7)*	0.80	0.75

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

0°C Temperature
87.0 psia Saturation Pressure

Density	Pressure	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.066	27.00	0.186	8.01 (47/41/12)*	114.90	107.81
1.072	38.00	0.262	11.66 (49/41/10)*	75.40	70.36
1.078	46.50	0.321	13.39 (49/43/8)*	60.79	56.42
1.098	61.00	0.421	22.68 (51/41/8)*	24.06	21.91
1.110	68.00	0.469	26.97 (52/40/8)*	15.53	13.99

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

Neat Viscosity Check
Polyolester alone.
40 °C

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
1.008	14.7	0.101	0.00	33.20	32.92	Oscillating Bob Viscometer
n/a	14.7	0.101	0.00	n/a	33.4	Cannon Viscometer # 300 645T

APPENDIX I:

Viscosity, Density and Gas Solubility of 32 ISO VG Mixed Acid Polyolester at Various Temperatures with Blend HFC-125/143a/134a (44/52/4% w/w)

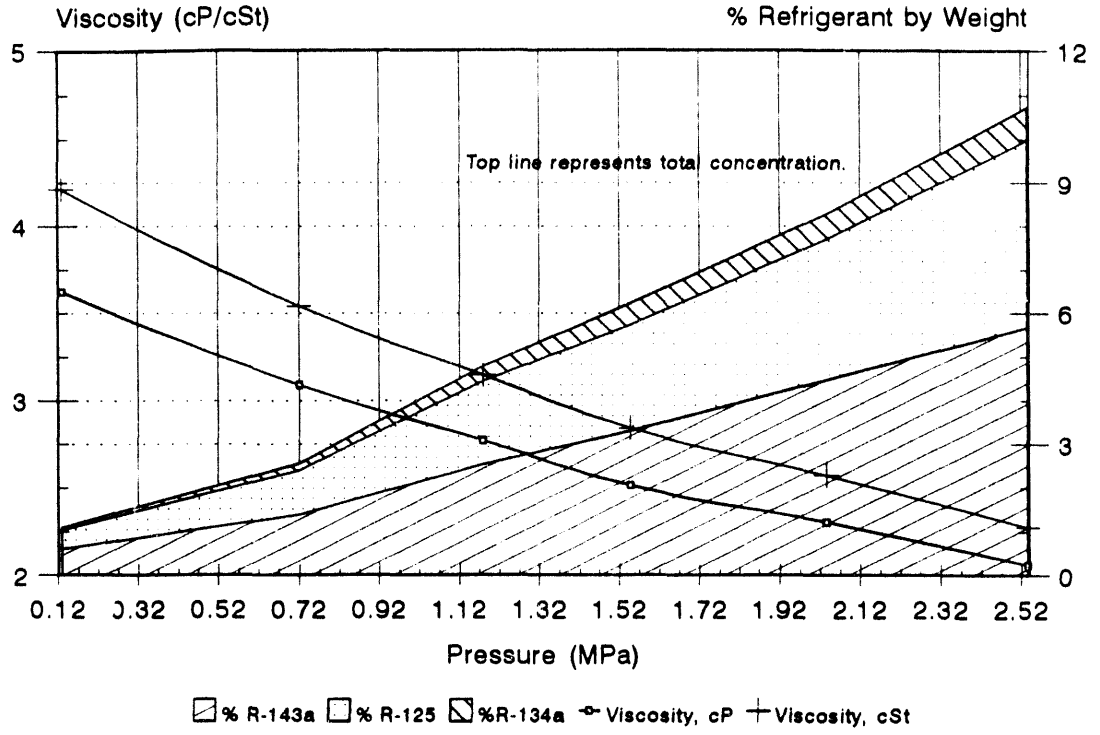
The following graphs show the concentrations of the blend components as shaded areas. These areas are cumulative, not overlapped. For example, in Figure I.1, the concentration in the lubricant of HFC-143a alone is slightly less than six percent. The concentration of HFC-125 is slightly more than four 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 the blend, slightly less than eleven percent.

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 125°C

Figure I.1

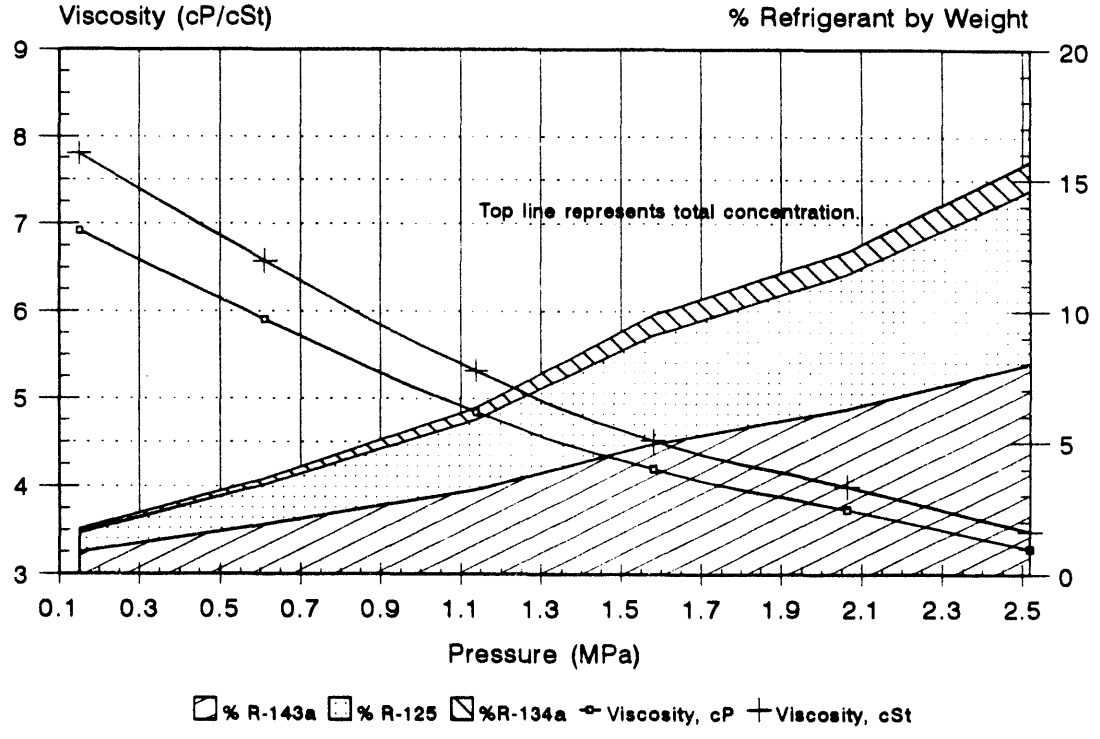


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a/1341 (44/52/4% w/w) at 90°C

Figure I.2

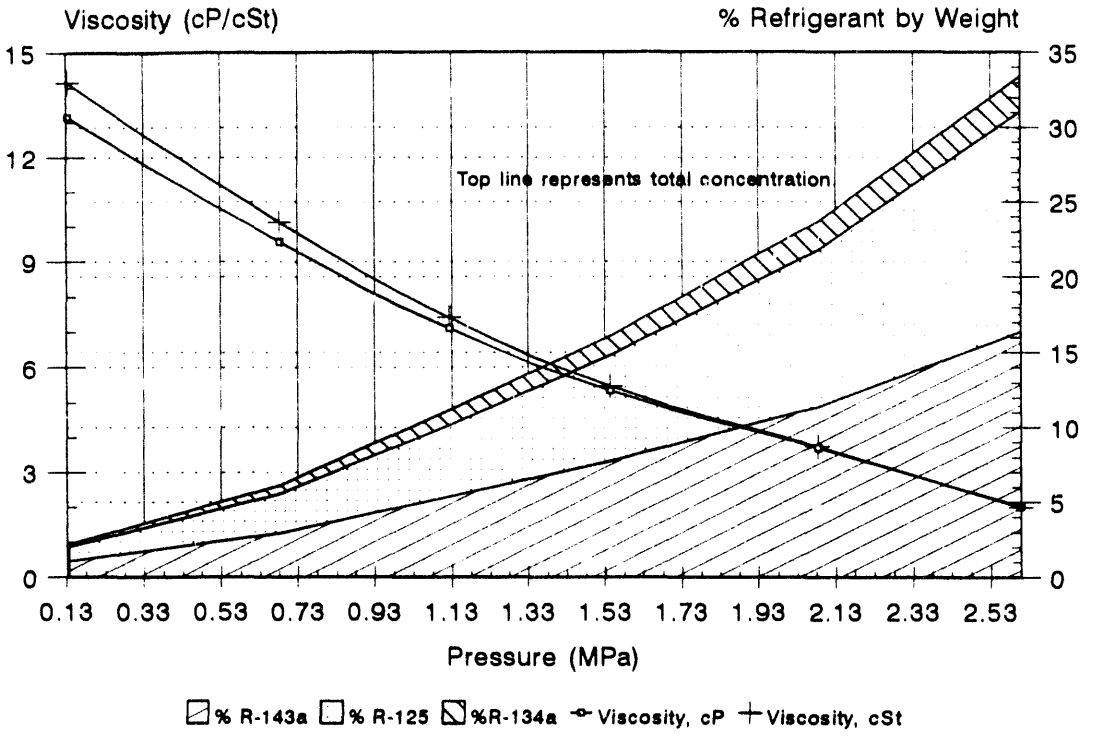


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 60°C

Figure I.3

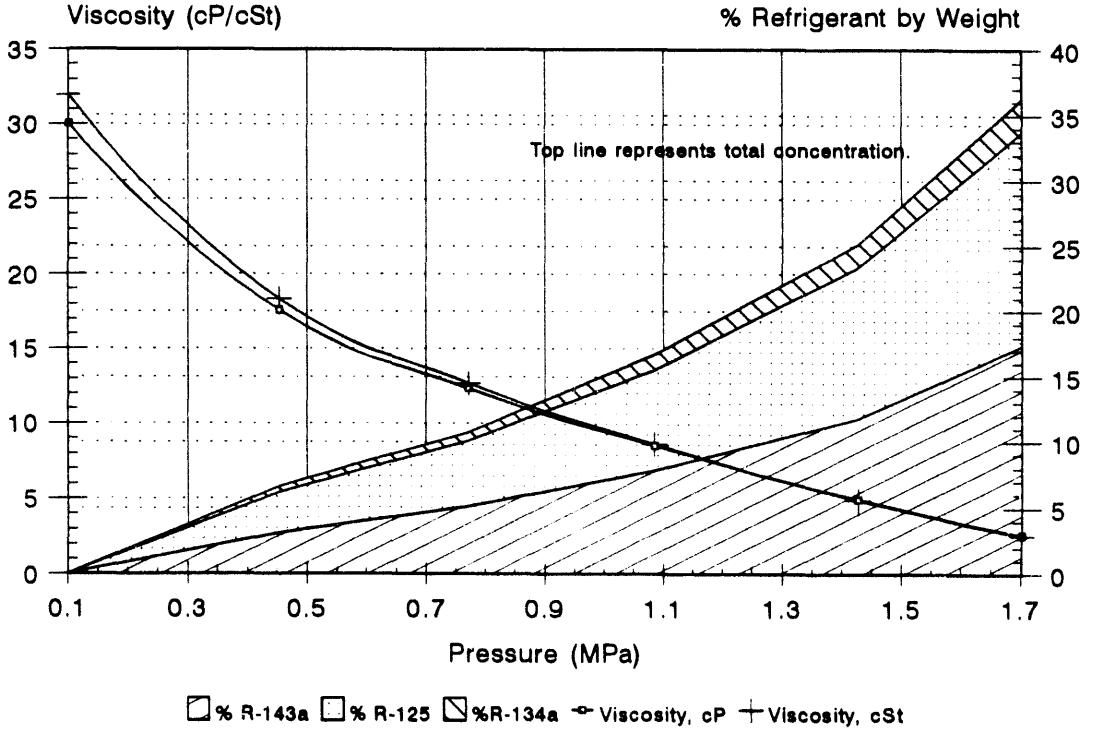


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 40°C

Figure I.4

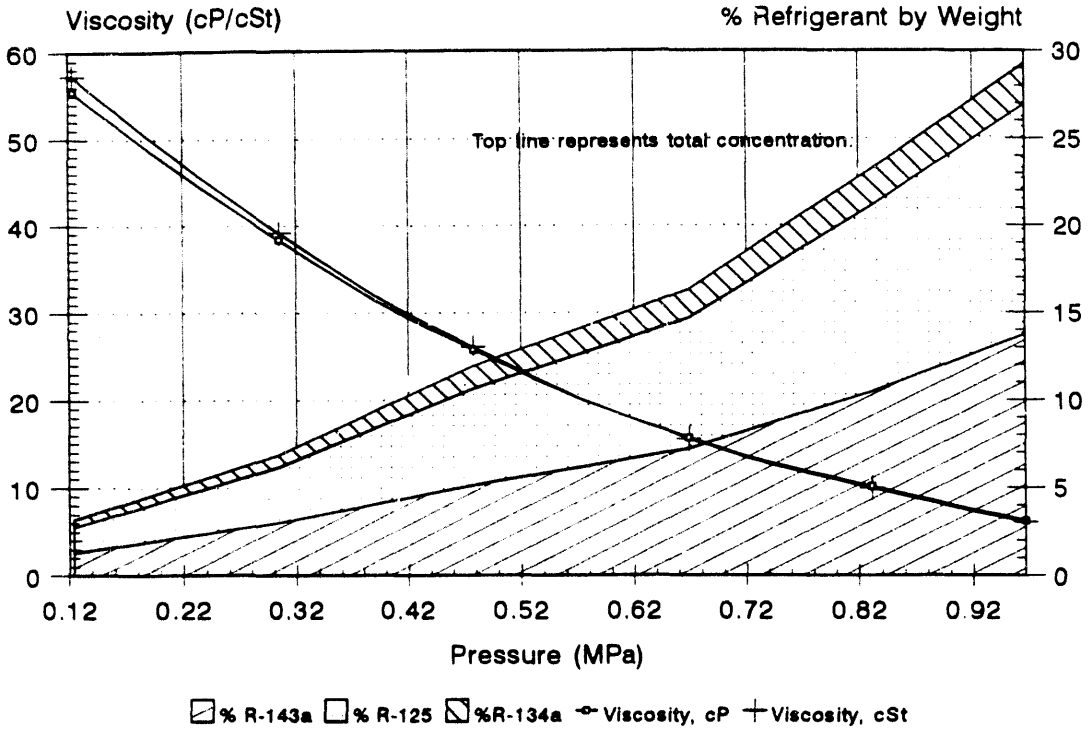


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 20°C

Figure I.5

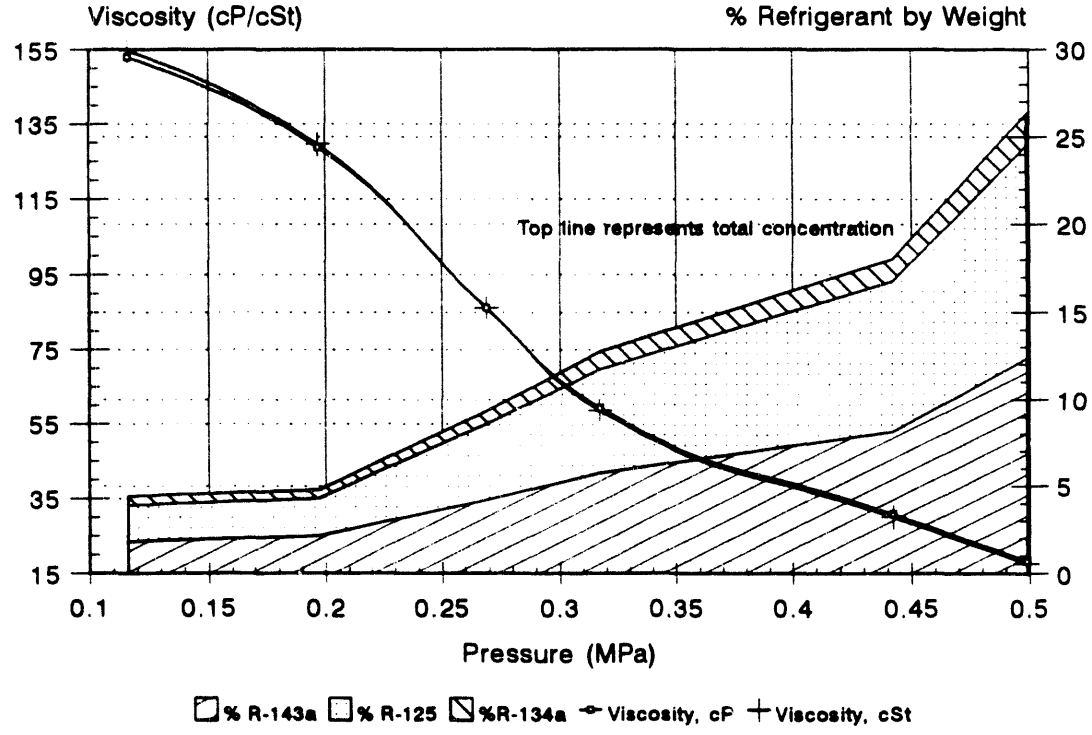


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w) at 0°C

Figure I.6



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Density, and Solubility
32 ISO VG Mixed Acid Polyolester with Blend 125/143a/134a (44/52/4% w/w)
Table I.1

125°C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.860	18.75	0.129	1.09 (39/55/6)*	3.62	4.21
0.872	104.50	0.721	2.56 (40/54/6)*	3.09	3.54
0.881	171.00	1.180	4.78 (40/53/7)*	2.77	3.15
0.885	224.25	1.547	6.22 (39/53/8)*	2.51	2.84
0.895	295.00	2.036	8.27 (39/54/7)*	2.30	2.57
0.906	367.50	2.536	10.72 (40/53/7)*	2.06	2.27

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

40 °C Temperature
263.7 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.941	14.70	0.101	0.00 (0/0/0)*	30.06	31.94
0.947	19.25	0.133	2.44 (44/50/6)*	26.22	27.69
0.959	65.75	0.454	6.65 (46/47/7)*	17.56	18.32
0.972	111.75	0.771	10.71 (46/48/6)*	12.34	12.69
0.986	157.25	1.085	16.70 (46/47/7)*	8.51	8.63
1.006	207.00	1.426	25.16 (46/47/7)*	4.97	4.92
1.031	246.75	1.703	36.26 (45/48/7)*	2.63	2.55

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

90°C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.887	21.75	0.150	1.69 (43/49/8)*	6.92	7.80
0.898	88.75	0.612	3.61 (42/52/6)*	5.91	6.57
0.912	165.00	1.139	6.30 (42/51/7)*	4.64	5.31
0.929	229.25	1.582	9.88 (42/50/8)*	4.20	4.52
0.934	299.00	2.063	12.29 (42/51/7)*	3.74	4.00
0.944	365.00	2.519	15.70 (42/51/7)*	3.30	3.49

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

20 °C Temperature
158.7 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.969	16.00	0.124	3.16 (46/41/13)*	55.51	57.29
0.979	44.25	0.305	6.66 (46/44/10)*	38.37	39.18
0.988	69.25	0.478	11.96 (46/43/11)*	25.77	26.08
1.007	97.00	0.669	16.31 (46/44/10)*	15.60	15.49
1.019	120.50	0.831	23.16 (46/45/9)*	10.11	9.93
1.032	140.00	0.966	29.26 (45/47/8)*	6.24	6.04

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

60 °C Temperature
416.7 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.929	19.50	0.135	2.17 (43/49/8)*	13.15	14.16
0.944	99.00	0.683	6.12 (43/48/9)*	9.56	10.13
0.956	163.00	1.125	11.16 (43/48/9)*	7.12	7.43
0.976	223.50	1.542	16.06 (44/48/8)*	5.35	5.48
0.991	302.00	2.084	23.65 (44/48/8)*	3.69	3.73
1.016	378.00	2.608	33.42 (44/49/7)*	2.03	2.00

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

0°C Temperature
72.3 psia Saturation Pressure

Density	Pressure	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.988	16.75	0.116	4.43 (41/47/12)	153.02	154.89
0.994	28.50	0.197	4.78 (45/45/10)	128.81	129.62
1.001	39.00	0.269	9.32 (45/47/8)	86.27	86.17
1.013	46.00	0.317	12.76 (45/47/8)	59.35	58.60
1.028	64.00	0.442	18.02 (45/48/7)	30.81	29.99
1.042	72.30	0.499	26.33 (47/46/7)	18.32	17.58

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

Neat Viscosity Check – –
Polyolester alone
40 °C

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
0.941	14.7	0.101	0.00	30.06	31.66	Oscillating Bob Viscometer
0.9571	14.7	0.101	0.00	29.9	31.24	Cannon Viscometer #300 645T

APPENDIX J:

Viscosity, Density and Gas Solubility of 32 ISO VG Mixed Acid Polyolester at Various Temperatures with Blend HFC-125/143a (50/50% w/w)

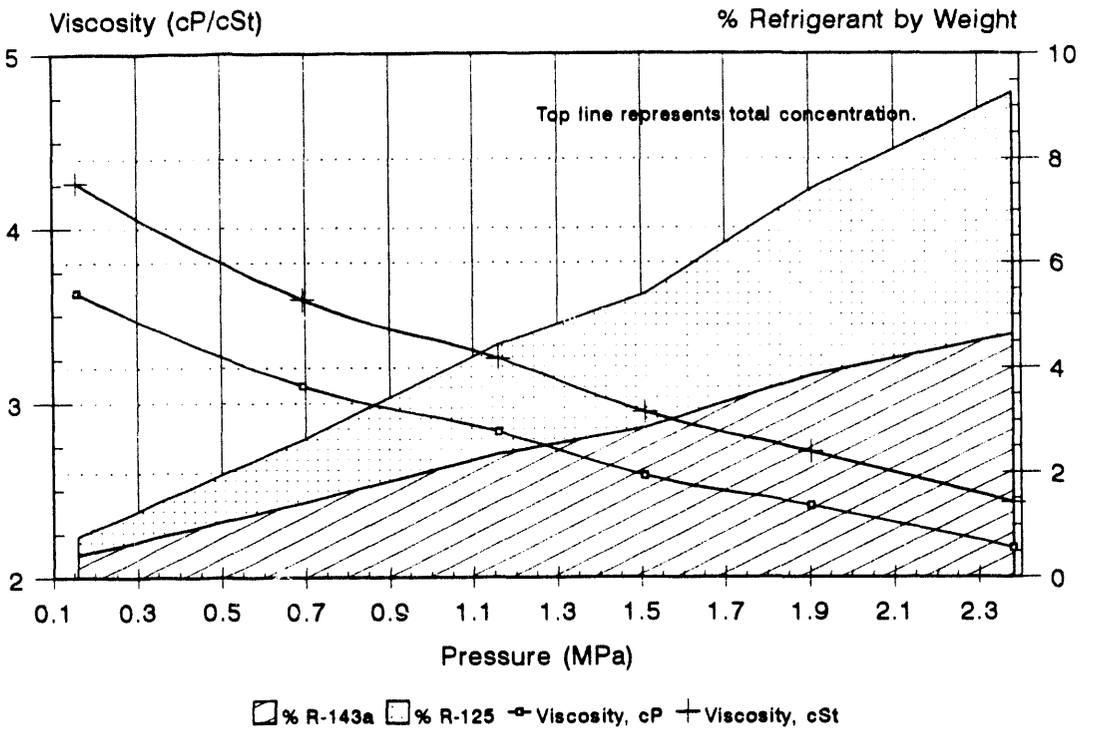
The following graphs show the concentrations of the blend components as shaded areas. These areas are cumulative, not overlapped. For example, in Figure J.1, the concentration in the lubricant of HFC-143a alone is slightly more than four percent. The concentration of HFC-125 is slightly more than five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

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a (50/50% w/w) at 125°C

Figure J.1

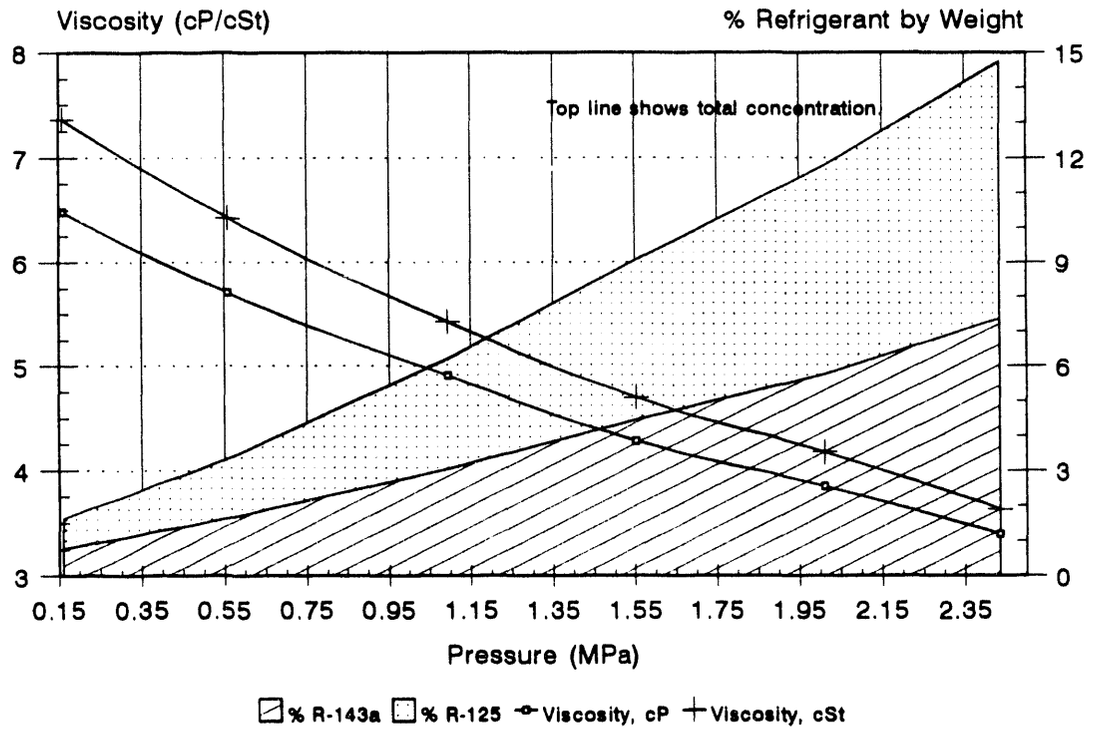


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a (50/50% w/w) at 90°C

Figure J.2

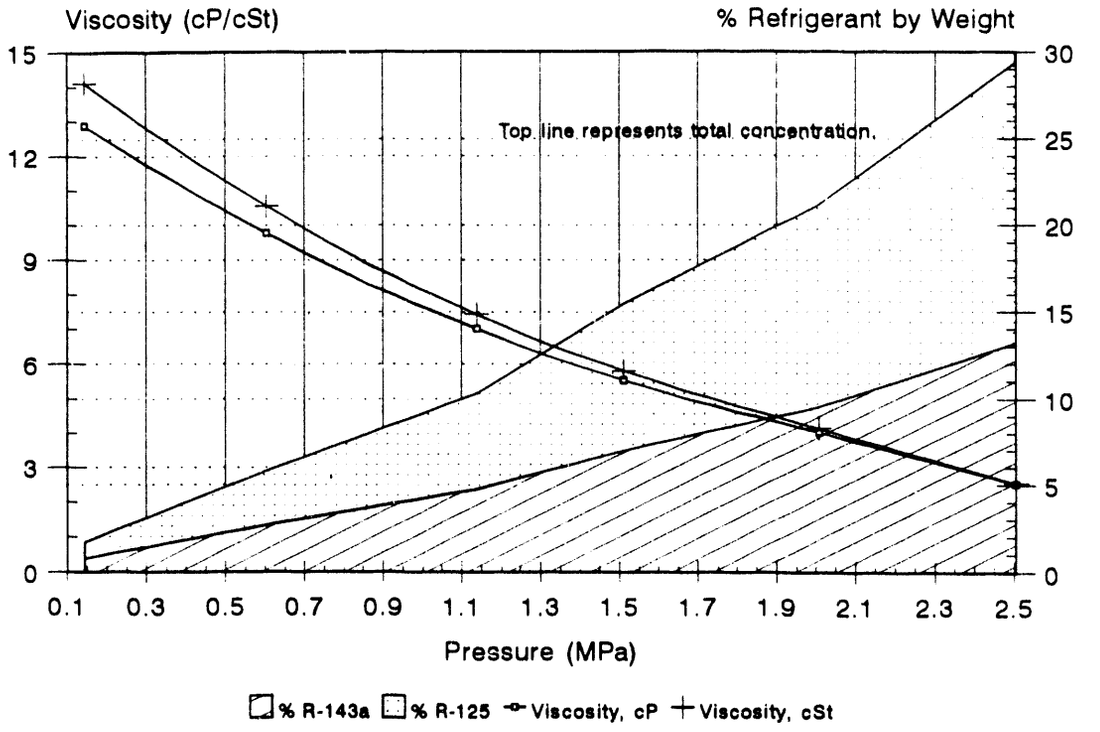


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a (50/50% w/w) at 60°C

Figure J.3

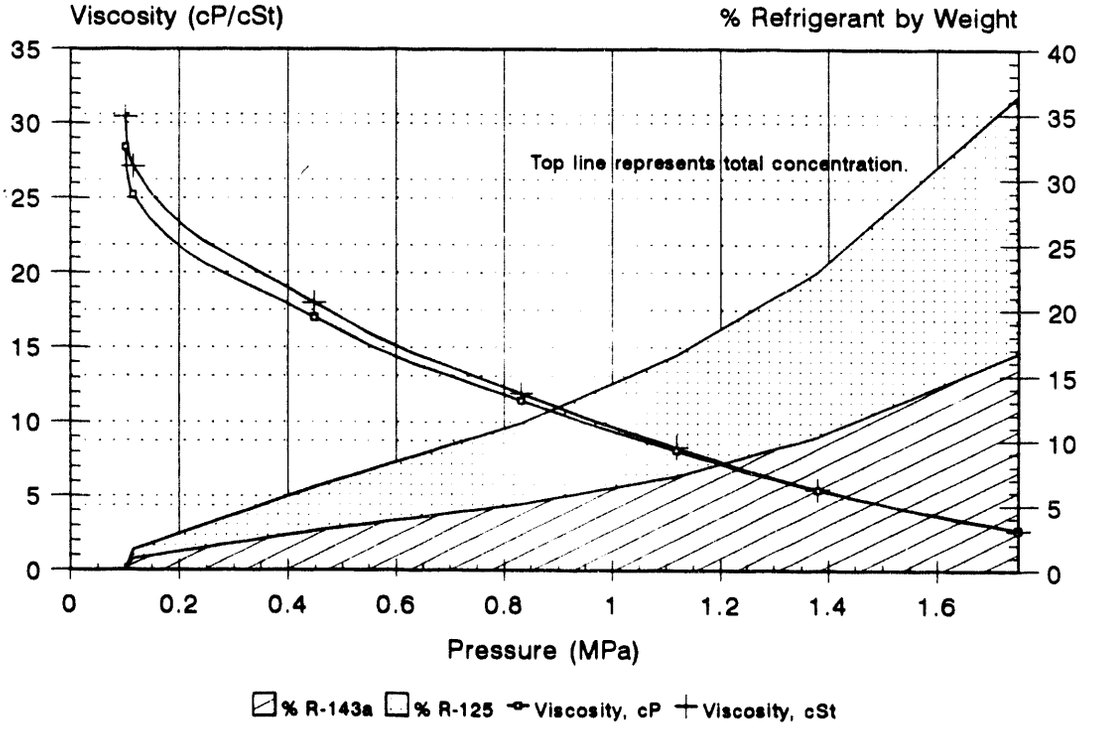


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a (50/50%) at 40°C

Figure J.4

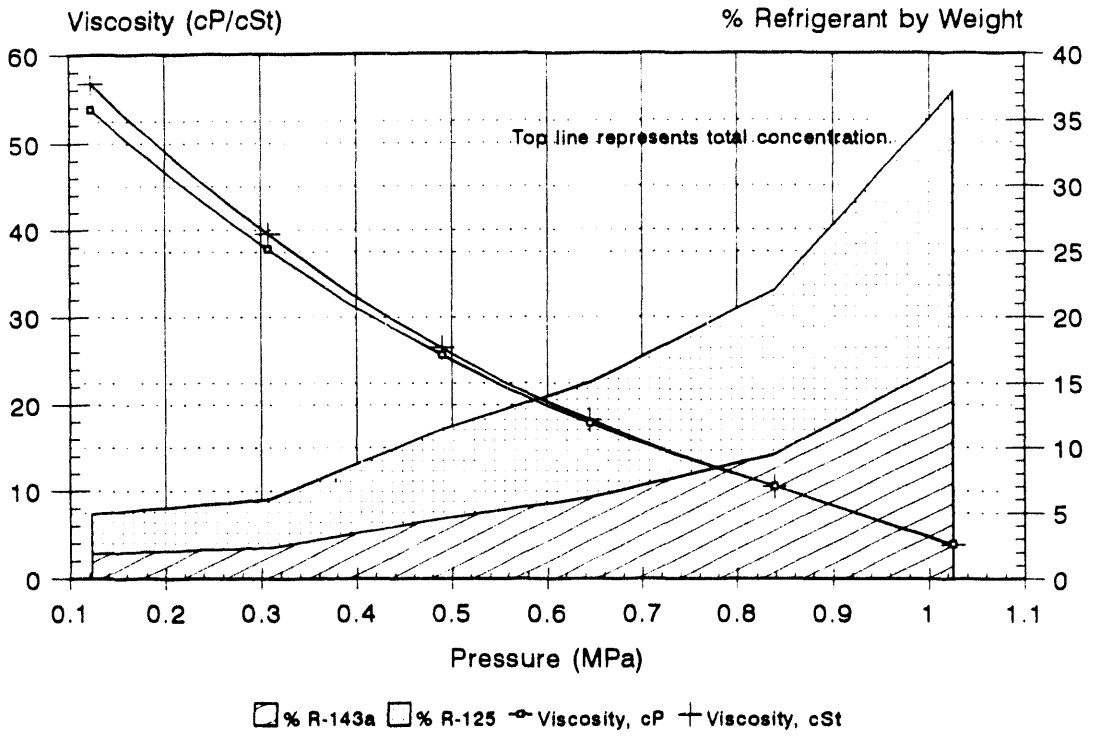


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a (50/50% w/w) at 20°C

Figure J.5

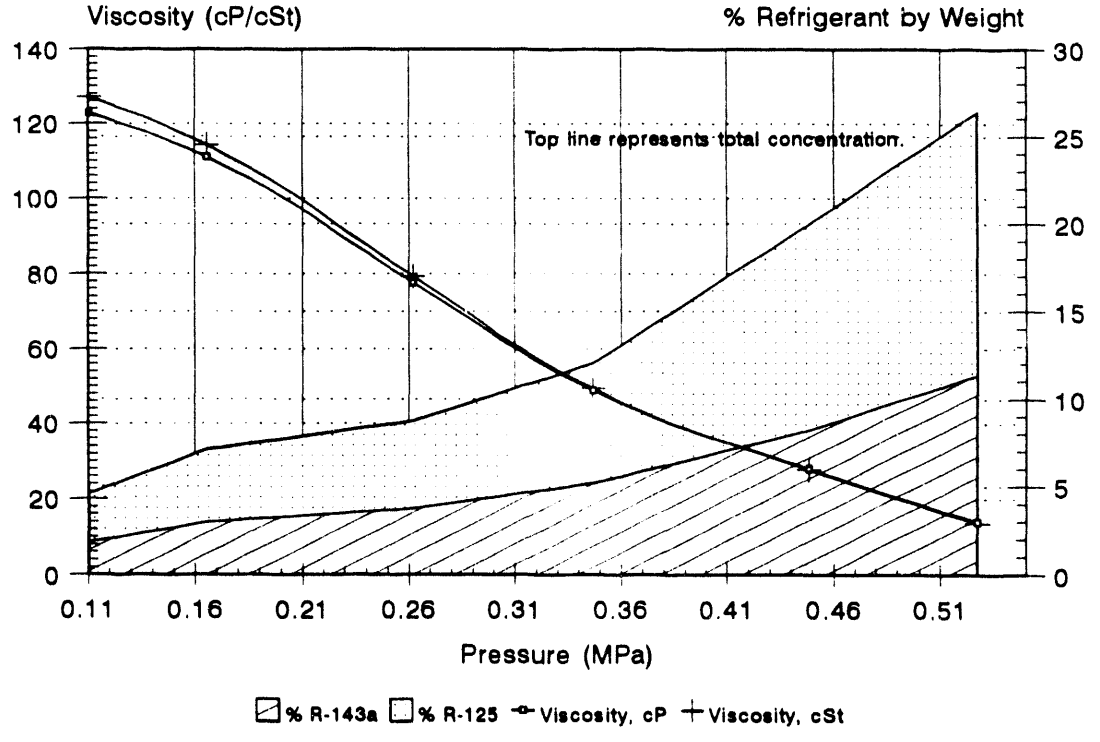


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Mixed Acid Polyolester with Blend 125/143a (50/50% w/w) at 0°C

Figure J.6



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
32 ISO VG Mixed Acid Polyolester with Blend 125/143a (50/50% w/w)
Table J.1

125°C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.851	23.00	0.159	0.79 (45/55)*	3.63	4.26
0.863	100.50	0.693	2.64 (46/54)*	3.10	3.59
0.870	168.00	1.159	4.44 (47/53)*	2.83	3.25
0.876	218.50	1.506	5.39 (47/53)*	2.58	2.95
0.887	275.75	1.903	7.40 (52/48)*	2.41	2.72
0.894	345.00	2.381	9.26 (50/50)*	2.17	2.43

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

90°C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.881	23.25	0.160	1.63 (53/47)*	6.48	7.36
0.888	81.00	0.559	3.34 (51/49)*	5.71	6.43
0.904	158.50	1.094	6.21 (51/49)*	4.91	5.43
0.912	225.00	1.553	9.07 (51/49)*	4.28	4.70
0.922	291.50	2.011	11.76 (51/49)*	3.65	4.18
0.935	352.75	2.434	14.73 (50/50)*	3.40	3.63

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

60 °C Temperature
433.4 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.913	20.75	0.143	1.69 (54/46)*	12.89	14.12
0.926	87.50	0.604	5.79 (54/46)*	9.78	10.55
0.944	165.00	1.139	10.30 (54/46)*	7.03	7.44
0.953	219.00	1.511	15.46 (55/45)*	5.54	5.81
0.972	291.00	2.008	21.15 (55/45)*	4.02	4.14
0.994	363.00	2.505	29.44 (55/45)*	2.53	2.55

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

Neat Viscosity Check
Polyolester alone.
40 °C

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
0.934	14.7	0.101	0.00	28.40	30.42	Oscillating Bob Viscometer
0.9571	14.7	0.101	0.00	29.9	31.24	Cannon Viscometer #300 645T

40 °C Temperature
272.6 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc	Viscosity cP	Viscosity cSt
0.934	14.70	0.101	0.00 (0/0)*	28.40	30.42
0.929	16.75	0.116	1.58 (45/55)*	25.21	27.13
0.945	65.00	0.449	6.42 (52/47)*	17.00	17.99
0.960	120.50	0.831	11.35 (55/45)*	11.47	11.95
0.976	162.00	1.118	16.54 (56/44)*	8.12	8.31
0.991	200.00	1.380	22.96 (55/45)*	5.44	5.49
1.019	253.50	1.749	36.41 (54/46)*	2.75	2.70

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

20 °C Temperature
163.3 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.*	Viscosity cP	Viscosity cSt
0.946	17.75	0.122	4.93 (61/39)*	53.84	56.76
0.956	44.50	0.307	6.20 (61/39)*	37.80	39.56
0.970	71.00	0.490	11.42 (60/40)*	25.74	26.53
0.981	93.50	0.645	15.03 (59/41)*	17.84	18.19
1.000	121.50	0.838	22.02 (57/43)*	10.53	10.53
1.032	148.60	1.025	37.11 (55/45)*	3.96	3.84

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

0°C Temperature
91.0 psia Saturation Pressure

Density	Pressure psia	Pressure MPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.966	16.00	0.110	4.57 (60/40)*	122.77	127.10
0.972	24.00	0.166	7.10 (58/42)*	111.09	114.32
0.979	38.00	0.262	8.73 (57/43)*	77.73	79.39
0.989	50.25	0.347	12.05 (57/43)*	48.98	49.51
1.008	65.00	0.449	19.98 (59/41)*	28.07	27.83
1.029	76.40	0.527	26.36 (57/43)*	13.99	13.60

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

APPENDIX K:

Viscosity, Density and Gas Solubility of 32 ISO VG Branched Acid Polyolester at Various Temperatures with Blend HFC-125/143a (50/50% w/w)

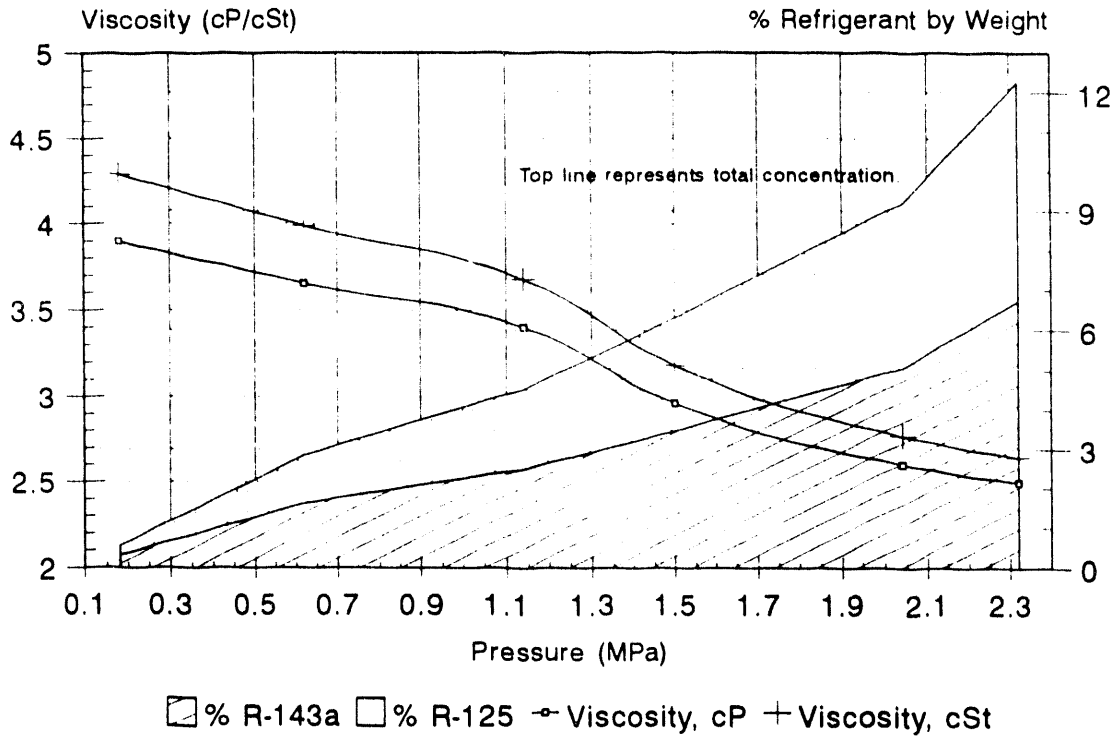
The following graphs show the concentrations of the blend components as shaded areas. These areas are cumulative, not overlapped. For example, in Figure H.1, the concentration of HFC-143a alone is slightly more than six percent. The concentration of HFC-125 is also about six percent. . These areas are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

Pressures are given in megapascals. Psia = MPa/.0069. Temperatures are show in degrees Celsius (°C) To convert to degrees Fahrenheit (°F), multiply the Celsius temperature by 9/5 (°F/°C), then add 32.

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a (50/50% w/w) at 125°C

Figure K.1

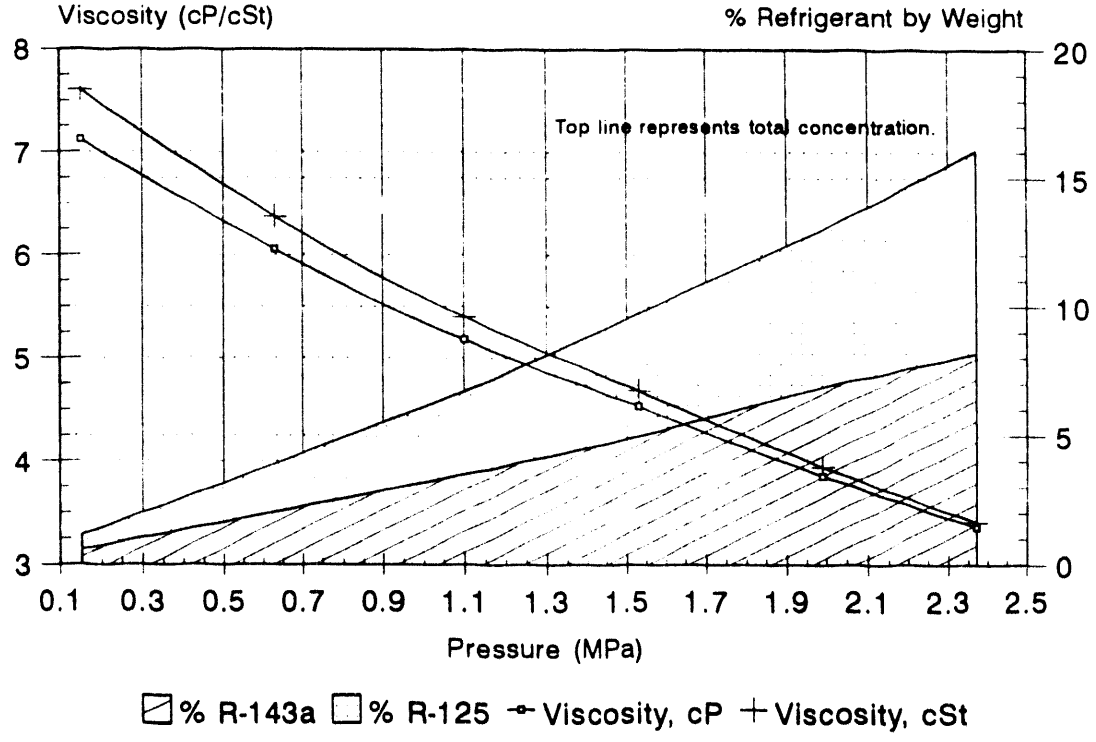


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a (50/50% w/w) at 90°C

Figure K.2

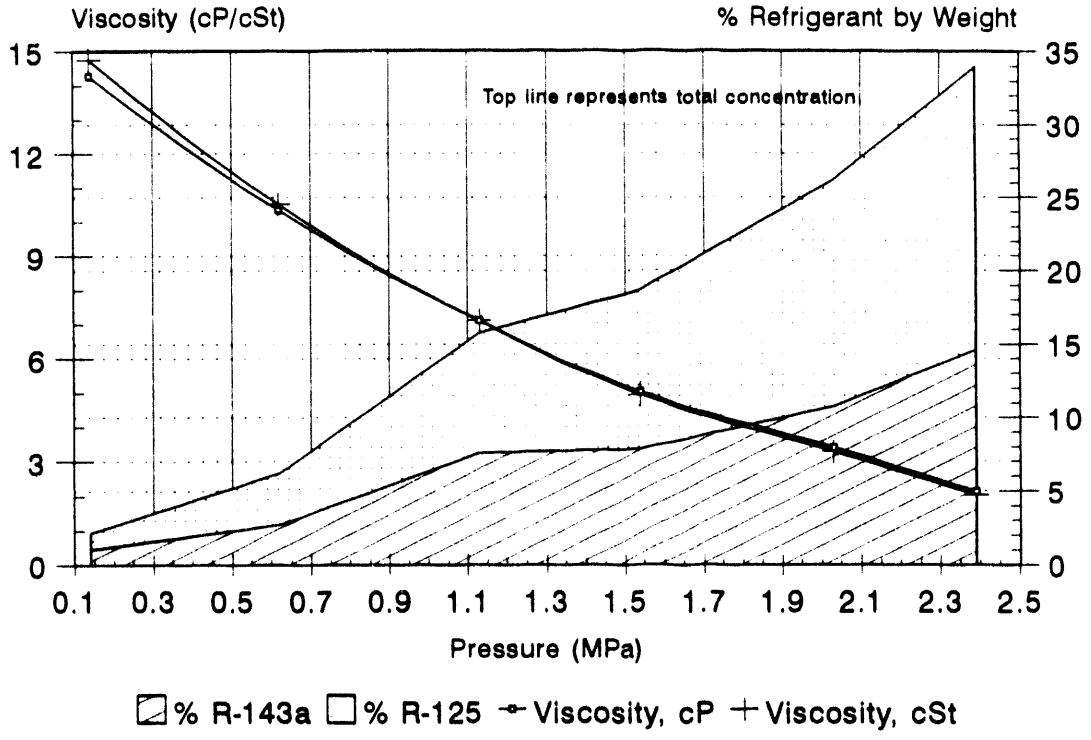


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a (50/50% w/w) at 60°C

Figure K.3

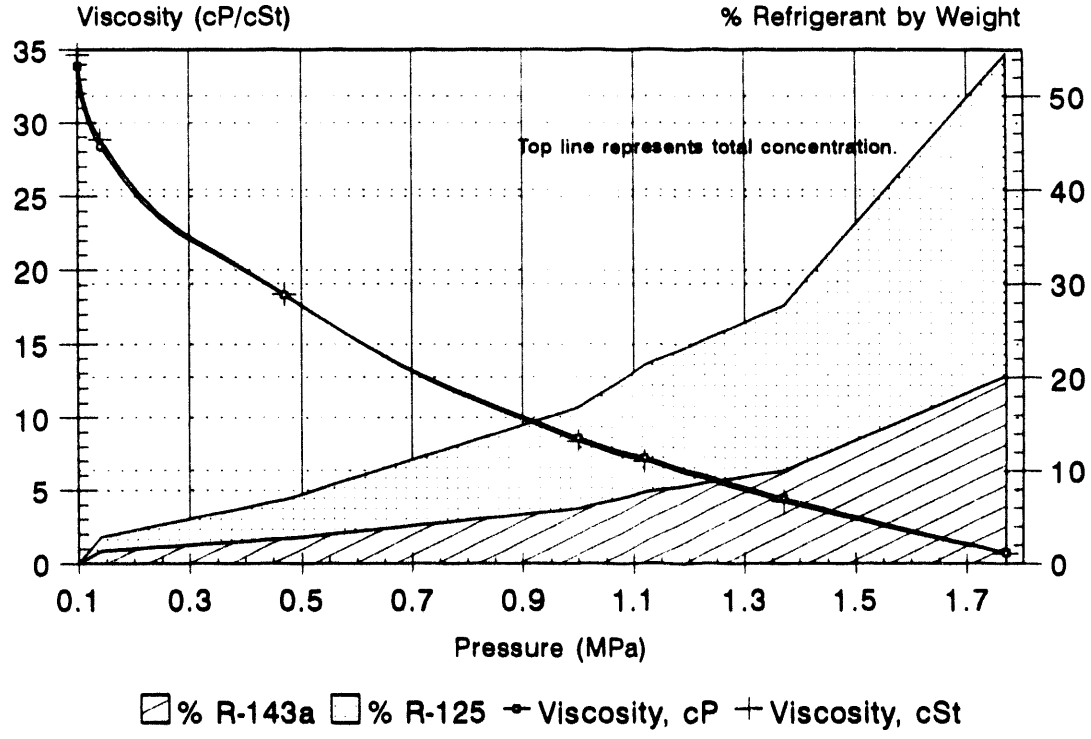


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a (50/50% w/w) at 40°C

Figure K.4

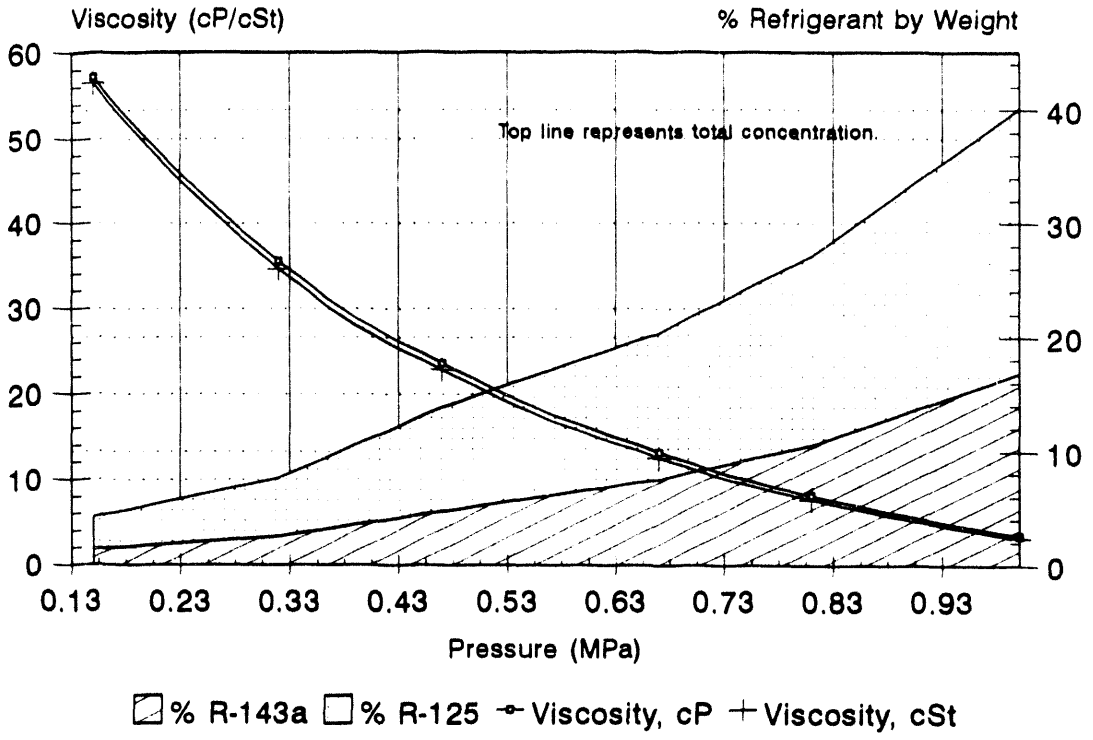


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a (50/50% w/w) at 20°C

Figure K.5

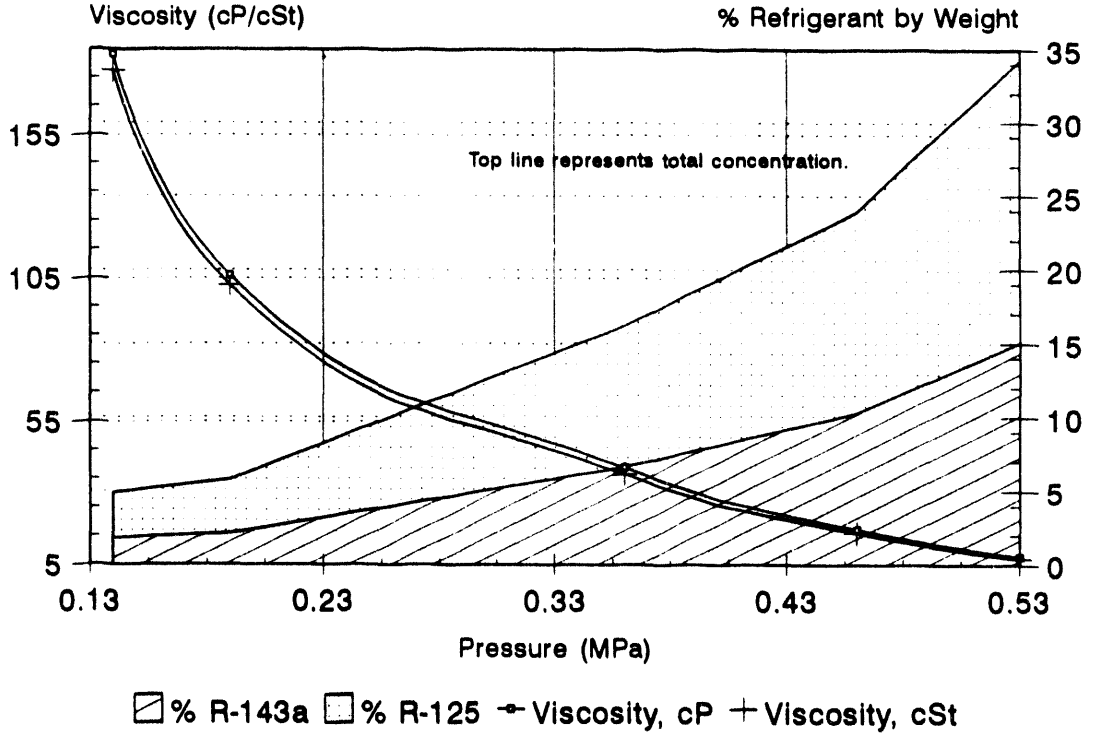


Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Viscosity, Solubility, and Gas Fractionation

32 ISO VG Branched Acid Polyolester with Blend 125/143a (50/50% w/w) at

Figure K.6



Viscosity via Gas Solubility Equilibrium
Oil degassed to 20 Millitorr

Raw Data: Viscosity, Density, and Solubility
32 ISO VG Branched Acid Polyolester with Blend 125/143a (50/50% w/w)
Figure K.1

125°C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure mPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.909	26.50	0.18	0.55 (43/57)*	3.90	4.29
0.916	90.50	0.62	2.65 (43/57)*	3.65	3.99
0.925	165.50	1.14	4.53 (45/55)*	3.40	3.68
0.931	218.00	1.50	6.31 (45/55)*	2.96	3.18
0.939	296.50	2.04	9.17 (45/55)*	2.60	2.77
0.944	336.50	2.32	12.26 (45/55)*	2.50	2.65

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

40 °C Temperature
272.6 psia Saturation Pressure

Density	Pressure psia	Pressure mPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.976	14.70	0.10	0.00 (0/0)*	33.67	34.65
0.984	20.00	0.14	2.83 (52/48)*	28.36	28.84
0.997	67.50	0.47	6.66 (61/39)*	18.32	18.38
1.025	145.00	1.00	16.79 (65/35)*	8.61	8.40
1.029	162.00	1.12	21.26 (64/36)*	7.24	7.03
1.047	198.00	1.37	27.66 (64/36)*	4.45	4.25
1.070	256.50	1.77	54.49 (63/37)*	0.75	0.70

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

90°C Temperature
>500 psia Saturation Pressure

Density	Pressure psia	Pressure mPa	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.937	21.75	0.15	1.14 (49/51)*	7.12	7.60
0.950	90.75	0.63	3.90 (48/52)*	6.05	6.36
0.959	159.25	1.10	6.70 (48/52)*	5.18	5.40
0.967	222.00	1.53	9.73 (49/51)*	4.54	4.69
0.976	288.00	1.99	13.00 (47/53)*	3.86	3.95
0.986	343.75	2.37	16.07 (49/51)*	3.36	3.41

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

20 °C Temperature
163.3 psia Saturation Pressure

Density	Pressure (psia)	Pressure (mPa)	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.011	21.75	0.15	4.19 (67/33)*	57.17	56.52
1.026	46.00	0.32	7.63 (67/33)*	35.52	34.62
1.035	68.25	0.47	13.90 (66/30)*	23.66	22.86
1.051	97.75	0.67	20.36 (63/37)*	13.23	12.59
1.063	117.50	0.81	27.09 (61/39)*	8.17	7.69
1.083	145.00	1.00	40.14 (58/42)*	3.49	3.22

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

60 °C Temperature
433.4 psia Saturation Pressure

Density	Pressure (psia)	Pressure (mPa)	% Refrig. Conc.	Viscosity cP	Viscosity cSt
0.967	21.00	0.14	2.17 (52/48)*	14.27	14.76
0.984	90.00	0.62	6.21 (56/44)*	10.35	10.52
1.001	164.25	1.13	15.75 (52/48)*	7.12	7.11
1.016	223.00	1.54	18.66 (58/42)*	5.03	4.95
1.032	294.00	2.03	26.18 (59/41)*	3.40	3.30
1.047	346.75	2.39	33.93 (57/43)*	2.12	2.03

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

0°C Temperature
91.1 psia Saturation Pressure

Density	Pressure (psia)	Pressure (mPa)	% Refrig. Conc.	Viscosity cP	Viscosity cSt
1.032	20.50	0.14	4.88 (63/37)*	183.17	177.50
1.033	27.50	0.19	5.76 (63/37)*	105.87	102.44
1.039	42.00	0.29	6.19 (62/38)*	88.44	85.09
1.061	51.75	0.36	16.19 (59/41)*	38.95	36.69
1.076	67.00	0.46	23.92 (57/43)*	17.38	16.16
1.098	76.40	0.53	34.29 (56/44)*	7.79	7.09

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

Neat Viscosity Check
Polyolester alone.
40 °C

Density	Pressure (psia)	Pressure (mPa)	% Refrig. Conc.	Viscosity cP	Viscosity cSt	
0.976	14.7	0.101	0.00	33.67	34.65	Oscillating Bob Viscometer
n/a	14.7	0.101	0.00	n/a	33.4	Cannon Viscometer #300 645T

DATE
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5/19/94
END