DOE/CE/23810-34

SOLUBILITY, VISCOSITY AND DENSITY OF REFRIGERANT/LUBRICANT MIXTURES

Final Technical Report

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April 1994

Prepared for
The Air-Conditioning and Refrigeration Technology Institute
Under
.ARTI MCLR Project Number 655-51200

This project is supported, in part, by U. S. Department of Energy (Office of Building Technology) grant number DE-FG02-91CE23810: Materials Compatibility and Lubricants Research (MCLR) on CFC-Refrigerant Substitutes. Federal funding supporting this project constitutes 93.67% of allowable costs Funding from non-government sources supporting this project consists of direct cost sharing of 6.33% of allowable costs, and in-kind contributions from the air-conditioning and refrigeration industry.

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Addendum to DOE/CE/23810-34

Several pages in the ARTI MCLR Final Report DOE/CE/23810-34, *Solubility, Viscosity and Density of Refrigerant/Lubricant Mixtures*, dated April 1994, have been revised. Please remove the following pages and insert the attached revised pages:

15 through 18
23 through 26
29 & 30
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SOLUBILITY, VISCOSITY AND DENSITY OF REFRIGERANT/LUBRICANT MIXTURES

ABSTRACT

This report presents the results of experimental measurements on low refrigerant concentration mixtures (0, 10, 20 and 30 weight percent) and high refrigerant concentration mixtures (80, 90 and 100 weight percent) of chlorofluorocarbon (CFC) 12, hydrochlorofluorocarbons (HCFC's) 22, 123, 124 and 142b, and hydrofluorocarbons (HFC's) 134a, 32, 125, 152a and 143a with mineral oil, alkylbenzene, polyalkylene glycol and polyolester lubricants. Viscosity, solubility (vapor pressure) and density data are reported for thirty-five working fluids, which are selected combinations of these refrigerants and companion lubricants.

These data have been reduced to engineering form and are presented in the form of a Daniel Chart[1] and a plot of density versus temperature and composition. Extensive numerical analysis has been performed in order to derive equations which allow two independent variables (temperature and composition) and to provide for corrections in composition due to vapor space volume in the test apparatus; details of these calculations are provided in Appendix A. This report supersedes all previous quarterly reports.

SCOPE

The broad scope of this research is to measure the solubility (pressure), viscosity and density of the thirty-five refrigerant/lubricant mixtures over composition and temperature ranges as given in Table 1. The experimental data are graphically reported in the Daniel Chart format, and mathematical relationships have been derived.

ACKNOWLEDGMENTS

The support and assistance of many people has made this work possible. Our appreciation is extended to DuPont Chemical Company, ICI Chemicals and Polymers and AlliedSignal for donation of refrigerants, and to Witco Chemical Corporation, ICI Chemicals and Polymers, Mobil Corporation, Castrol Corporation, Henkel Corporation and Shrieve Chemical Corporation for donation of the lubricants. The experimental measurements were performed by Mr. Robert Clark and Mr. Richard Levy, whose diligence and devotion to quality are greatly appreciated. Thanks are due to the project manager, Mr. Steven Szymurski, and to the Air Conditioning and Refrigeration Technology Institute for diligent report review and guidance. Thanks are also extended to Dr. H. O. Spauschus, who provided support and guidance at crucial junctures.

[1] G. Daniel, M. J. Anderson, W. Schmid and M. Tokumitsu, "Performance of Selected Synthetic Lubricants in Industrial Heat Pumps," Heat Recovery Systems, Vol. 2, No. 4, 1982. pp. 359-368.

Table 1: Refrigerant/Lubricant Mixtures Under Study

	Refrigerant/Lubricant	Low Refrigerant Concentrations[1] Temp. Range C	High Refrigerant Concentrations[2] Temp. Range C
1.	12/ISO 32 MO[3]	0 to 100	-40 to +40
2.	12/ISO 100 MO	0 to 100	-40 to +40
3.	22/ISO 32 MO	0 to 100	-40 to +40
4.	134a/ISO 68 PAG[4]	0 to 100	-40 to +40
5.	134a/ISO 22 POE-MA #1[5]	0 to 100	-40 to +40
6.	134a/ISO 32 POE-MA #1	0 to 100	-40 to +40
7.	134a/ISO 68 POE-MA #1	0 to 100	-40 to +40
8.	134a/ISO 100 POE-MA	0 to 100	-40 to +40
9.	134a/ISO 22 POE-BA[6]	0 to 100	-40 to +40
10.	134a/ISO 32 POE-MA#2	0 to 100	-40 to +40
11.	134a/ISO 68 POE-BA	0 to 100	-40 to +40
12.	134a/ISO 100 POE-BA	0 to 100	-40 to +40
13.	123/ISO 32 MO	0 to 100	-20 to +40
14.	123/ISO 100 MO	0 to 100	-20 to +40
15.	123/150 SUS AB[7]	0 to 100	-20 to +40
16.	123/300 SUS AB	0 to 100	-20 to +40
17.	32/ISO 22 POE-MA #2	0 to 75	-50 to +40
18.	32/ISO 68 POE-MA #2	0 to 75	-50 to +40
19.	32/ISO 32 POE-BA	0 to 75	-50 to +40
20.	32/ISO 100 POE-BA	0 to 75	-50 to +40
21.	125/ISO 22 POE-MA #1	0 to 65	-40 to +40
22.	125/ISO 68 POE-MA #2	0 to 65	-40 to +40
23.	125/ISO 32 POE-BA	0 to 65	-40 to +40
24.	125/ISO 100 POE-BA	0 to 65	-40 to +40
25.	152a/150 SUS AB	0 to 100	-40 to +40
26.	152a/300 SUS AB	0 to 100	-40 to +40
27.	152a/ISO 22 POE-MA #1	0 to 100	-40 to +40
28.	152a/ISO 68 POE-MA #1	0 to 100	-40 to +40
29.	143a/ISO 22 POE-MA #2	0 to 70	-45 to +40
30.	143a/ISO 68 POE-MA #2	0 to 70	-45 to +40
31.	143a/ISO 32 POE-BA	0 to 70	-45 to +40
32.	143a/ISO 100 POE-BA	0 to 70	-45 to +40
33.	124/150 SUS AB	0 to 100	-40 to +40
34.	124/300 SUS AB	0 to 100	-40 to +40
35.	142b/150 SUS AB	0 to 100	-40 to +40

[1]Low Refrigerant Concentrations are 0, 10, 20 and 30 weight percent refrigerant.
[2]High Refrigerant Concentrations are 80, 90 and 100 weight percent refrigerant.
[3]Mineral Oil
[4]Polyalkylene Glycol (butyl monoether)
[5]Polyolester (Pentaerythritol) - Mixed Acid
[6]Polyolester (Pentaerythritol) - Branched Acid
[7]Alkylbenzene

SIGNIFICANT RESULTS

Low Refrigerant Concentration Mixtures

Experimental data are presented in the form of mathematical models and two charts, the first giving the density, the second giving the viscosity and solubility (pressure) as functions of temperature and composition (Daniel Chart[1]). On the upper portion of the Daniel Chart are isobaric viscosity curves, which have been algebraically generated from the measured data.

In order to generate these isobaric curves, the assumption has been made that interpolation between measured composition curves is valid over the temperature range for which data has been obtained. It is also assumed that these fluids are two component mixtures having one liquid phase and one vapor phase; application of the Gibbs Phase Rule then gives two degrees of freedom. Accompanying each set of charts is a table of regression constants and correlation coefficients, which is explained below.

Functions of two independent variables are chosen to represent the experimental data; generally, the simplest form, which represents the data accurately, has been employed. The relationship chosen to represent the viscosity data is a modified form of the Walther equation:

$$\log\{\log(\eta + 0.7)\} = \{a_1 + a_2 \cdot \log(T) + a_3 \cdot \log^2(T)\} + \omega \cdot \{a_4 + a_5 \cdot \log(T) + a_6 \cdot \log^2(T)\} + \omega^2 \cdot \{a_7 + a_8 \cdot \log(T) + a_9 \cdot \log^2(T)\} \quad (1)$$

where

η = absolute viscosity, centipoise
T = Temperature, Kelvin
ω = mass fraction refrigerant
log = logarithm to the base 10
a_1 through a_9 = constants.

Vapor pressure is given by

$$P = \{a_1 + a_2 \cdot T + a_3 \cdot T^2\} + \omega \cdot \{a_4 + a_5 \cdot T + a_6 \cdot T^2\} + \omega^2 \cdot \{a_7 + a_8 \cdot T + a_9 \cdot T^2\} \quad (2)$$

where

P = pressure, kilopascals
T = Temperature, Kelvin
ω = mass fraction refrigerant
a_1 through a_9 = constants (different from equation (1)).

Density is given by

$$\rho = \{a_1 + a_2 \cdot T + a_3 \cdot T^2\} + \omega \cdot \{a_4 + a_5 \cdot T + a_6 \cdot T^2\} + \omega^2 \cdot \{a_7 + a_8 \cdot T + a_9 \cdot T^2) \quad (3)$$

where

ρ = density, g/cc
T = Temperature, Kelvin
ω = mass fraction refrigerant
a_1 through a_9 = constants.

Kinematic viscosity is given by

$$\log\{\log(\nu + 0.7)\} = \{a_1 + a_2 \cdot \log(T) + a_3 \cdot \log^2(T)\} + \omega \cdot \{a_4 + a_5 \cdot \log(T) + a_6 \cdot \log^2(T)\} + \omega^2 \cdot \{a_7 + a_8 \cdot \log(T) + a_9 \cdot \log^2(T)\} \qquad (4)$$

where

ν = kinematic viscosity, centistokes
T = Temperature, Kelvin
ω = mass fraction refrigerant
log = logarithm to the base 10
a_1 through a_9 = constants.

Multivariate correlation coefficients are given as a measure of how well the regression equations fit the data. These coefficients, denoted by σ, are the square root of the explained variation divided by the total variation. Mathematically, we have

$$\text{Unexplained variation} = \Sigma(y_i - y_c)^2$$

$$\text{Total variation} = \Sigma(y_i - y_{av})^2$$

$$\text{Explained variation} = \text{Total variation} - \text{Unexplained variation}$$

where

y_i = experimental data point
y_c = calculated data point
y_{av} = average of experimental data points

giving

$$\sigma = \sqrt{\frac{\Sigma(y_i - y_{av})^2 - \Sigma(y_i - y_c)^2}{\Sigma(y_i - y_{av})^2}}$$

As detailed in Appendix A, the computer program REFPROP 4.0 issued by the National Institute of Standards and Technology, has been used to determine the amount of refrigerant gas in the free volume above the liquid in the test apparatus, and thus calculate the true composition of the fluid under study at the measured data points.

High Refrigerant Concentration Mixtures

These mixture data are also presented in the form of two charts. The density plot is a straightforward presentation of density versus temperature at constant compositions, and the viscosity/solubility graph follows the method given by Daniel et.al., with the modifications that the temperature and viscosity axes are linear instead of singly and doubly logarithmic, respectively. Corrections for vapor space volume have been applied as given in Appendix A, and isobaric viscosity curves have been generated as outlined previously.

Regions of immiscibility are observed for some of these refrigerant/lubricant mixtures and are clearly indicated on the diagrams. Total immiscibility (i.e. 10 and 20 weight percent lubricant mixtures are two phased at room temperature) was observed for the mixtures listed below; hence, no data is reported for these fluids.

- HFC-32/ISO 68 pentaerythritol ester mixed acid #2
- HFC-32/ISO 100 pentaerythritol ester branched acid
- HFC-152a/ISO 32 alkylbenzene
- HFC-152a/ISO 68 alkylbenzene
- HFC-143a/ISO 22 pentaerythritol ester mixed acid #2
- HFC-143a/ISO 68 pentaerythritol ester mixed acid #2
- HFC-143a/ISO 32 pentaerythritol ester branched acid
- HFC-143a/ISO 100 pentaerythritol ester branched acid

Again, functions of the two variables temperature and composition have been derived, with the notable exceptions of working fluids containing HFC-125 and HFC-152a. In these two cases, the density of the refrigerant is near the density of the lubricant, which results in data that is not modeled well by the many polynomial forms examined here (crossovers occur near the temperature where the refrigerant and lubricant density are equal). For these mixtures, equations are given for each curve of constant composition separately; the tables which accompany each set of charts contain a correlation coefficient for each curve of constant composition, instead of a single correlation coefficient (see, for example, Table 21-2). Equations 5 through 8 below then apply to all mixtures except those containing refrigerants HFC-125 and HFC- 152a.

Dynamic viscosity is represented by

$$\log(\eta) = \{a_1 + a_2/T + a_3/T^2\} + \omega \cdot \{a_4 + a_5/T + a_6/T^2\} + \omega^2 \cdot \{a_7 + a_8/T + a_9/T^2\} \qquad (5)$$

where

η = absolute viscosity, centipoise
T = Temperature, Kelvin
ω = mass fraction refrigerant
log = logarithm to the base 10
a_1 through a_9 = constants.

Vapor pressure is given by

$$\log(P) = \{a_1 + a_2/T + a_3/T^2\} + \omega\cdot\{a_4 + a_5/T + a_6/T^2\} + \omega^2\cdot\{a_7 + a_8/T + a_9/T^2\} \qquad (6)$$

where

P = pressure, kilopascals
T = Temperature, Kelvin
ω = mass fraction refrigerant
log = logarithm to the base 10
a_1 through a_9 = constants.

Density is given by

$$\rho = \{a_1 + a_2\cdot T_r + a_3\cdot T_r^2\} + \omega\cdot\{a_4 + a_5\cdot T_r + a_6\cdot T_r^2\} + \omega^2\cdot\{a_7 + a_8\cdot T_r + a_9\cdot T_r^2\} \qquad (7)$$

where

ρ = density, g/cc
$T_r = 1 - T/T_c$
T = temperature, Kelvin
T_c = critical temperature, Kelvin
ω = mass fraction refrigerant
a_1 through a_9 = constants.

Kinematic viscosity is given by

$$\log(\nu) = \{a_1 + a_2/T + a_3/T^2\} + \omega\cdot\{a_4 + a_5/T + a_6/T^2\} + \omega^2\cdot\{a_7 + a_8/T + a_9/T^2\} \qquad (8)$$

where

ν = kinematic viscosity, centistokes
T = Temperature, Kelvin
ω = mass fraction refrigerant
log = logarithm to the base 10
a_1 through a_9 = constants.

For fluids containing HFC-125 or HFC-152a, equations 9 through 11 apply:

Kinematic viscosity is represented by

$$
\begin{aligned}
\log(\nu_{100}) &= a_1 + a_2/T + a_3/T^2 \\
\log(\nu_{90}) &= a_4 + a_5/T + a_6/T^2 \\
\log(\nu_{80}) &= a_7 + a_8/T + a_9/T^2
\end{aligned}
\qquad (9)
$$

where

ν = kinematic viscosity, centistokes
T = Temperature, Kelvin
log = logarithm to the base 10
a_1 through a_9 = constants, and
the subscripts 100, 90 and 80 refer to mass fraction refrigerant.

Vapor pressure is given by

$$
\begin{aligned}
\log(P_{100}) &= a_1 + a_2/T + a_3/T^2 \\
\log(P_{90}) &= a_4 + a_5/T + a_6/T^2 \\
\log(P_{80}) &= a_7 + a_8/T + a_9/T^2
\end{aligned}
\qquad (10)
$$

where

P = pressure, kilopascals
T = Temperature, Kelvin
log = logarithm to the base 10
a_1 through a_9 = constants, and
the subscripts 100, 90 and 80 refer to mass fraction refrigerant.

Density is given by

$$
\begin{aligned}
\rho_{100} &= a_1 + a_2 \cdot T + a_3 \cdot T^2 \\
\rho_{90} &= a_4 + a_5 \cdot T + a_6 \cdot T^2 \\
\rho_{80} &= a_7 + a_8 \cdot T + a_9 \cdot T^2
\end{aligned}
\qquad (11)
$$

where

ρ = density, g/cc
T = Temperature, Kelvin
a_1 through a_9 = constants, and
the subscripts 100, 90 and 80 refer to mass fraction refrigerant.

DISCUSSION

The main body of this report consists of four pages reporting the results for each of the thirty five mixtures listed in Table 1, except in those cases where the high refrigerant concentration mixtures are immiscible at room temperature. In these cases, two pages giving the low refrigerant concentration mixture data are reported.

This data is applicable to abroad range of refrigeration and air-conditioning equipment. Some of the refrigerants, such as HFC-134a, have seen widespread acceptance in various applications, while others such as HFC-152a are hindered by other concerns (flammability, etc.). Many are being considered as blend components for replacement of HCFC-22 and R-502. The viscosity, solubility and density data reported here provides a good starting point for understanding the behavior of these mixtures, and serves as a relatively comprehensive data set for validation of computer models which predict the properties of mixtures based on the properties of the refrigerant and lubricant alone.

Some general observations may be made:

Low Refrigerant Concentration Mixtures

1. Density data tends to be equally spaced straight lines, except when the density of the neat refrigerant is close to the density of the neat lubricant (Figure 28-1 represents an extreme case). Crossovers also occur (Figure 20-1).

2. In all cases, the viscosity data are linear under the Walther equation transformation; i.e. there is no curvature with respect to temperature in the refrigerant/lubricant mixtures (or the neat lubricants).

3. In most cases, the mixture viscosity lines are approximately parallel (to the neat lubricant line) and approximately equally spaced (see Figure 5-2, for example). Some fluids deviate from this behavior, showing progressively larger (Figure 20-2) or smaller (Figure 26-2) reductions in viscosity with increasing refrigerant concentration; some fluids show increasing viscosity/temperature slope with increasing refrigerant concentration (Figure 31-2).

4. As would be expected, increasing the refrigerant concentration increases the vapor pressure of the mixture at all temperatures, but the magnitude of the increase is not linear with concentration. Figure 26-2 is an extreme example; note the effect on viscosity of this "decreasing solubility."

Some specific observations can also be made, grouped by refrigerant:

CFC-12 and HCFC-22

1. These fluids are included as baselines for comparison.

HFC-134a

1. Data is included for an ISO 68 PAG, which shows less change in viscosity with temperature than does either of the ISO 68 POEs. Although the vapor pressure of these three mixtures is very nearly the same at all concentrations and temperatures, the viscosity of the PAG mixtures is generally higher than the POE mixtures due to the higher viscosity index of the neat oil.

2. When compared at the same ISO grade (22, 68 and 100) and at common temperature and composition, the pentaerythritol ester mixed acid lubricant mixtures exhibit slightly higher vapor pressure and slightly lower viscosity than do the branched acid lubricant mixtures. The ISO 22 mixed acid has a slightly higher viscosity index than does the branched acid, but the opposite is true for the ISO 68 and ISO 100 lubricants.

3. The ISO 100 POE mixed acid and branched acid both show lower viscosity at low temperatures and higher viscosity at elevated temperatures than the CFC-12/ISO 100 mineral oil mixtures, due to the higher viscosity index of the neat oils and the fact that the mixture viscosity lines are very nearly parallel to the neat lubricant line. This effect is more pronounced for the branched acid than for the mixed acid.

4. Small differences in viscosity are observed between the two ISO 32 pentaerythritol ester mixed acids, with number 1 exhibiting slightly lower viscosity than number 2 at all temperatures and compositions. The differences are more pronounced in the 10 and 20 percent oil range than at 30 percent. Both show lower viscosity at low temperatures and higher viscosity at elevated temperatures than the CFC-12/ISO 32 mineral oil mixtures, for the reasons given in (3) above.

5. Viscosities of both ISO 22 mixed acid and ISO 22 branched acid are somewhat lower at all temperatures and compositions than CFC-12/mineral oil. Looking at this situation another way, for a given temperature and pressure, the HFC-134a mixtures are lower in refrigerant concentration (more oil rich) which tends to offset the reduction in viscosity caused by the different ISO grades. Vapor pressure of the HFC-134a mixtures at common temperatures and compositions is significantly higher in both cases than is CFC-12/mineral oil.

HCFC-123

1. Comparison of the ISO 32 mineral oil and the ISO 32 alkylbenzene reveals that the vapor pressure and viscosity are lower at common temperatures and compositions for the alkylbenzene than for the mineral oil. Alternatively, at a given temperature and pressure, the mineral oil mixture is more oil rich than the alkylbenzene.

2. The ISO 68 alkylbenzene is virtually identical in vapor pressure to the ISO 32 alkylbenzene, but the mixture viscosities are higher, and in fact are higher than the ISO 32 mineral oil mixtures at all temperatures and compositions. This means that at a constant temperature and pressure, the ISO 32 mineral oil mixture is more oil rich than the ISO 68 alkylbenzene mixture, but this is offset by the higher ISO viscosity grade.

HFC-32

1. Viscosity of the mixtures shows large reductions compared to the neat oil, as evidenced by the relatively wide spacing of the viscosity lines. The vapor pressure of the mixtures is high, as might be expected for mixtures containing this high-pressure refrigerant.

2. No obvious differences are noted between POE mixed acid and branched acid lubricants.

HFC-125

1. The dilution effects on viscosity tend to become greater as the refrigerant concentration is increased, meaning that at a given temperature, the reduction in viscosity caused by 30 weight percent dilution is greater than the reduction caused by 20 percent, which is in turn greater than the reduction caused by 10 percent.

2. Differences between POE mixed acid and branched acid lubricants are again very subtle, if present.

HFC-152a

1. Viscosity behavior with the two alkylbenzenes is unusual; it appears that dilution effects are limited, since the viscosity reduction from 20 to 30 percent lubricant is much less than the reduction from 10 to 20 or from 0 to 10. (Compare with the ISO 22 and ISO 68 POE mixed acids).

2. When compared to CFC-12/ISO 32 mineral oil, the HFC-152a/ISO 32 alkylbenzene mixtures are quite a bit lower in viscosity at the same temperature and composition, although this difference becomes less pronounced as HFC-152a concentration is increased. Vapor pressure of the HFC-152a mixtures is significantly higher. These same comments apply when comparing HFC-152a/ ISO 22 POE mixed acid to CFC-12/ISO 32 mineral oil.

3. Vapor pressures for the ISO 68 alkylbenzene mixtures are higher than for the ISO 68 POE mixed acid. Viscosity of the alkylbenzene is lower in the 10 to 20 percent refrigerant range, but becomes higher in the 20 to 30 percent range due to the effect given in subparagraph 1, above.

HFC-143a

The most striking observation concerning this refrigerant is the large change in viscosity/ temperature slope with increasing HFC-143a concentration for the POE branched acid lubricants. This effect is more pronounced for the ISO 32 lubricant than for the ISO 100.

HCFC-124

No unusual behavior is evident.

HCFC-142b

No unusual behavior is evident.

High Refrigerant Concentration Mixtures

General observations concerning this data are:

1. Density data behavior is more complicated than for the low refrigerant concentration mixtures. All refrigerants studied exhibit some non-linearity with respect to temperature; HFC-134a is fairly linear, while HFC-125 exhibits curvature, and mixtures of these refrigerants with generally linear lubricants can result in complex behavior. Crossovers occur as seen in Figure 21-3. HFC-125 with the ISO 32 pentaerythritol ester branched acid (Figure 23-3) is an interesting case in that these mixtures demonstrate nearly ideal behavior (the crossovers occur at a single temperature). Figure 21-3 demonstrates the deviations from ideal behavior which are more commonly observed.

2. Although vapor pressure is only minimally affected by the addition of 10 and 20 weight percent oil, the viscosity of the fluid is dramatically increased. At a given temperature, the increase in viscosity from 10 to 20 percent oil is greater than the increase from 0 to 10 percent. As the temperature is lowered, the effect increases.

3. The small changes in vapor pressure due to the presence of the oil result in isobaric viscosity curves which are nearly vertical, i.e. small changes in temperature at a constant pressure result in large changes in viscosity.

Specific observations, grouped by refrigerant are:

CFC-12 and HCFC-22

1. Again, these fluids are included for baseline reference. It has been well documented that HCFC-22/ISO 32 mineral oil exhibits an immiscible region at low temperatures, which is clearly indicated in Figures 3-3 and 3-4.

HFC-134a

1. Regions of immiscibility are noted for three of the five POE mixed acid lubricants studied, while complete miscibility was observed for all three POE branched acids over the temperature range -40 to +40°C.

2. The ISO 68 PAG/HFC-134a solutions exhibit significantly higher viscosity than the ISO 100/CFC-12 mixtures, particularly at low temperatures, even though the ISO grade of the PAG is lower. This is most likely due to higher solubility of mineral oil in CFC-12.

3. Significant differences in viscosity and vapor pressure are not observed between the mixed acid and branched acid POE lubricants for ISO viscosity grades 22, 68 and 100.

4. When compared to CFC-12/ISO 100 mineral oil, the ISO 100 POE mixed acid and branched acid lubricants with HFC-134a are both slightly higher in viscosity at common temperatures and compositions.

5. ISO 32 POE mixed acid and branched acid oils with HFC-134a show higher viscosity than CFC-12/ISO 32 mineral oil mixtures at all temperatures and compositions.

6. With the exception of immiscible regions noted above, significant differences are not observed between HFC-134a/ISO 22 mixed acid or branched acid lubricants and CFC-12/ISO 32 mineral oil. The pressure of CFC-12/mineral oil mixtures at higher temperatures are more linear with respect to composition than are the HFC-134a/synthetics.

HCFC-123

1. The presence of mineral oil, whether 10 or 20 percent, reduces the vapor pressure by approximately the same amount, while there are clear differences between the presence of 10 or 20 percent alkylbenzene. This effect is more pronounced at higher ISO viscosity grades.

2. Viscosity is affected as might be expected. Addition of a given amount of a higher ISO grade lubricant results in higher viscosity elevation than the same amount of a lower ISO grade.

HFC-32

I . This refrigerant was found to be immiscible at room temperature, 10 and 20 weight percent lubricant compositions, with ISO 68 POE mixed acid #2 and ISO 100 POE branched acid. Regions of immiscibility were also observed for the other lubricants studied, ISO 22 POE mixed acid #2 and ISO 32 POE branched acid. This region extends to much higher temperatures for the mixed acid than for the branched acid.

2. Vapor pressure of the refrigerant is markedly unaffected by the presence of the oil at low temperatures.

HFC-125

An unexpected region of immiscibility was observed for HFC-125/ISO 68 POE mixed acid #2 at higher temperatures (30°C).

HFC-152a

1. HFC-152a is immiscible with both ISO 32 and ISO 68 alkylbenzene at 10 and 20 weight percent oil, room temperature.

2. Significant differences in viscosity or vapor pressure are not observed between ISO 22 POE and ISO 68 POE mixed acid lubricants.

HFC-143a

This refrigerant is immiscible with all four lubricants studied at 10 and 20 weight percent oil, room temperature.

HCFC-124

No significant differences are observed between the ISO 32 and ISO 68 alkylbenzene lubricants.

HCFC-142b

No comments.

COMPLIANCE WITH AGREEMENT

No significant modifications or deviations from the technical performance of work as described in the contract agreement have been necessary during this reporting period.

PRINCIPAL INVESTIGATOR EFFORT

During the course of this project, Mr. David R. Henderson directed and/or performed the following activities:

-Project management and laboratory supervision
-Data reduction/mathematical modeling
-Reporting

Table 1-1: Viscosity, Solubility and Density Parameters
CFC-12/ISO 32 Naphthenic Mineral Oil
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.15995E+1	-1.59687E+3	1.11406	1.10102E+1
a_2	-4.58293	9.88634	-7.68203E-4	-4.34077
a_3	0	-1.51588E-2	2.11750E-7	0
a_4	-9.34249	1.84554E+4	-3.53798E-4	-8.39345
a_5	3.37151	-1.64047E+2	2.25848E-3	2.98919
a_6	0	3.65567E-1	-3.87969E-6	0
a_7	1.00417E+1	4.55865E+4	1.73572	1.04819E+1
a_8	-4.27188	-2.46160E+2	-8.27677E-3	-4.51152
a_9	0	2.88658E-1	1.00529E-5	0
σ	0.9993	0.9995	0.9998	0.9990

Figure 1-1: Density of CFC-12/ISO 32 Naphthenic Mineral Oil
Low Refrigerant Concentration Mixtures

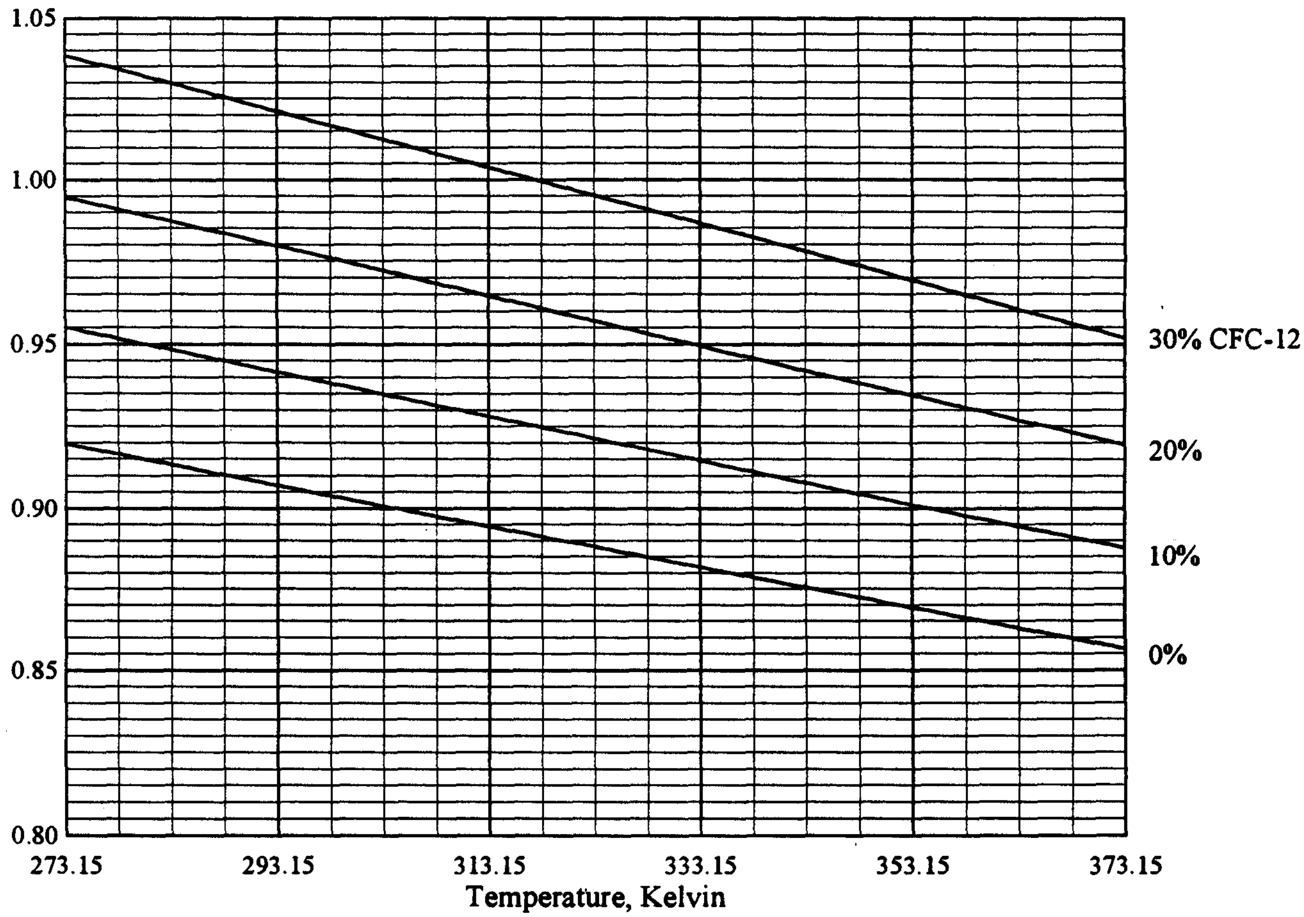


Figure 1-2: Viscosity and Solubility of CFC-12/ISO 32 Naphthenic Mineral Oil Low Refrigerant Concentration Mixtures

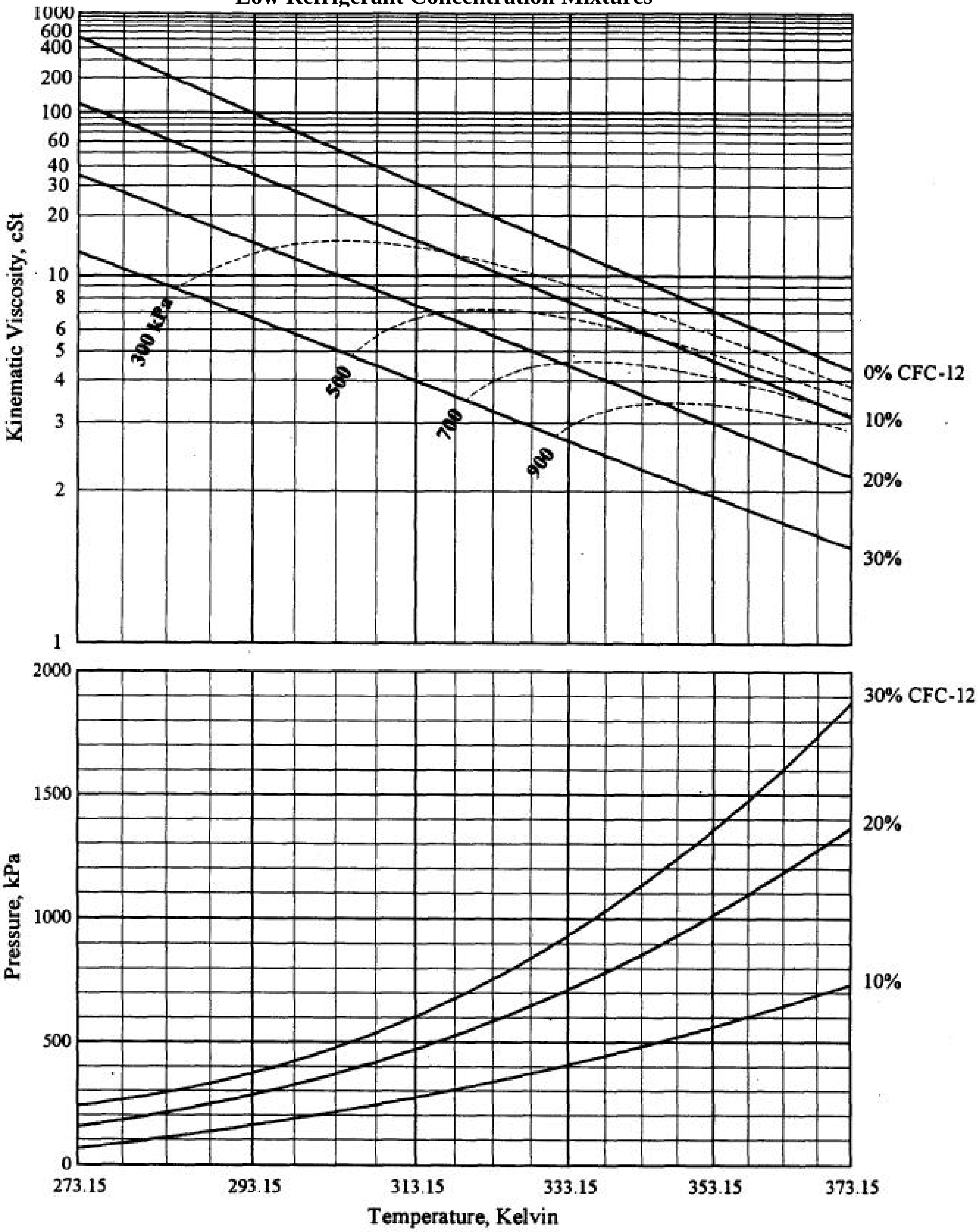


Table 1-2: Viscosity, Solubility and Density Parameters
CFC-12/ISO 32 Naphthenic Mineral Oil
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	2.52153	6.35033	4.65438	8.35930E-1
a_2	2.71475E+2	-1.09059E+3	-1.48563E+1	4.32691E+2
a_3	-2.49679E+4	0	1.35083E+1	6.62249E+4
a_4	-7.87786	4.71518E-2	-8.64438	-4.59494
a_5	-7.88056E+2	6.55429	2.70478E+1	-5.63657E+2
a_6	3.00321E+5	0	-2.09473E+1	1.14518E+4
a_7	3.41502	5.29574E-2	4.93363	2.50134
a_8	9.59812E+2	2.16896E-2	-1.01950E+1	1.96070E+2
a_9	-2.93382E+5	0	6.18252	-5.47519E+4
σ	0.9998	0.9997	0.9998	0.9999

Figure 1-3: Density of CFC-12/ISO 32 Naphthenic Mineral Oil
High Refrigerant Concentration Mixtures

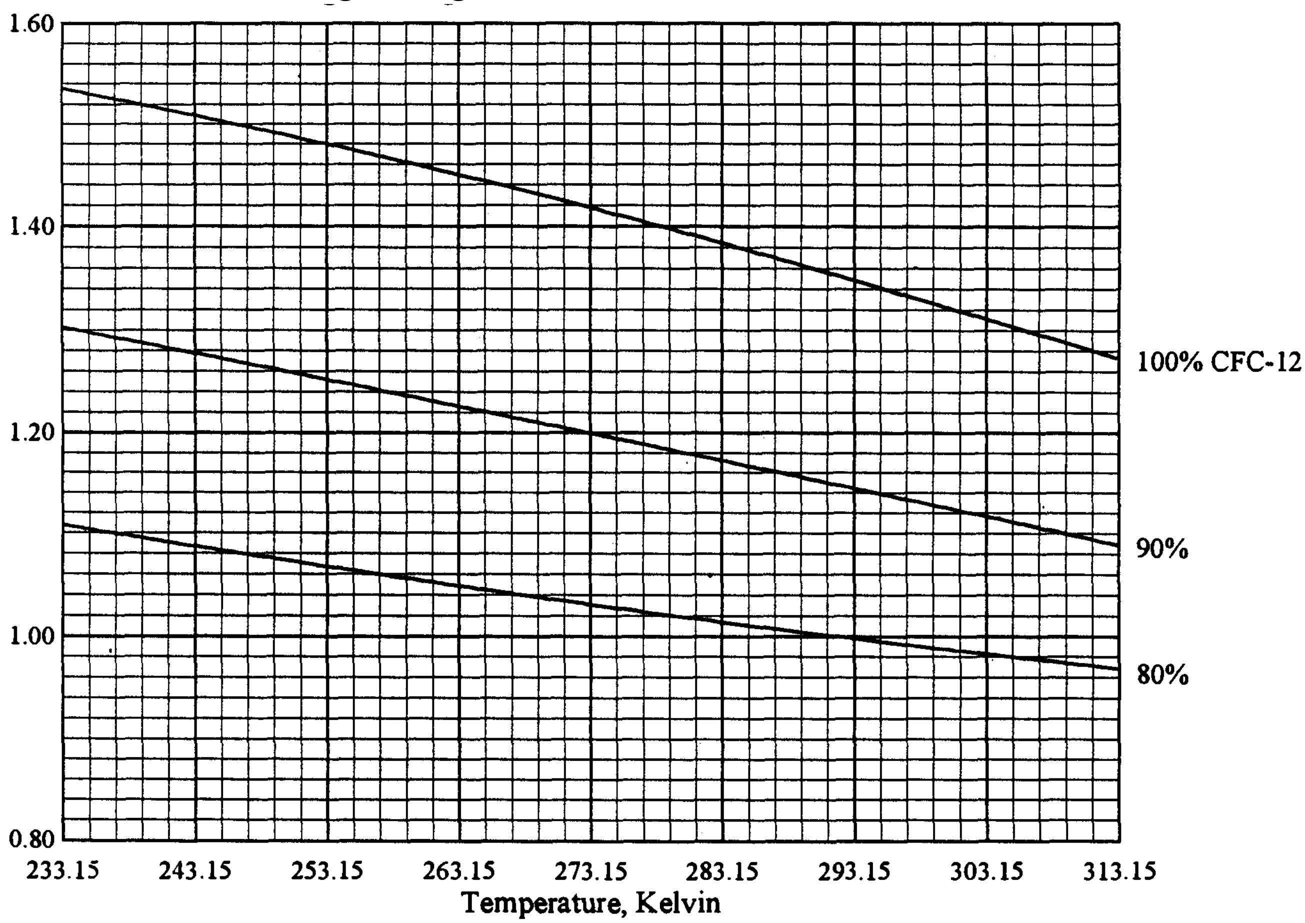


Figure 1-4: Viscosity and Solubility of CFC-12/ISO 32 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

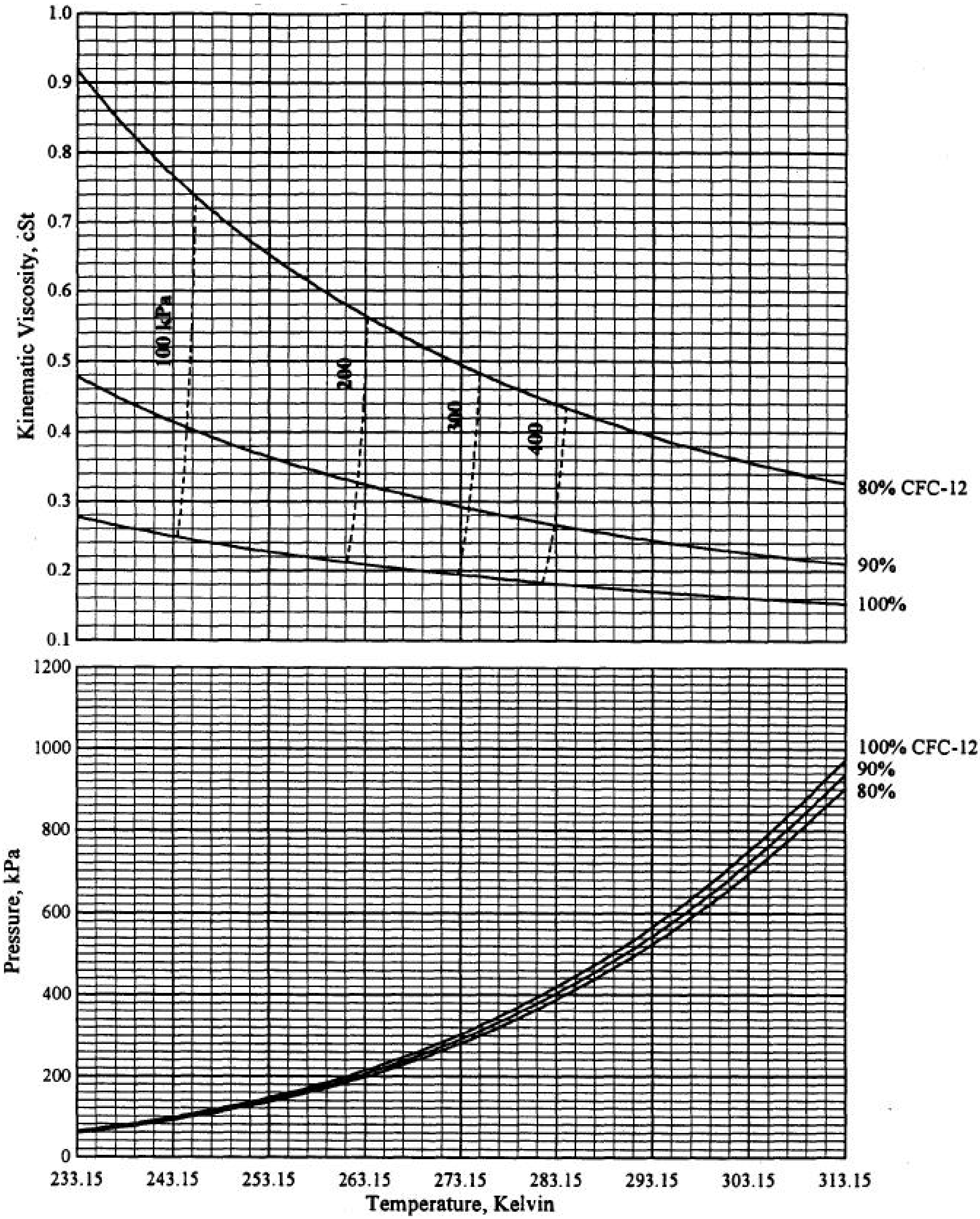


Table 2-1: Viscosity, Solubility and Density Parameters
CFC-12/ISO 100 Naphthenic Mineral Oil
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.09537E+1	-1.08308E+3	1.00639	1.05578E+1
a_2	-4.27298	6.79237	-6.68745E-5	-4.10944
a_3	0	-1.05801E-2	-8.46682E-7	0
a_4	1.51772	-1.94619E+4	1.72297	7.30299E-1
a_5	-1.01427	6.56341E+1	-8.09109E-3	-6.99619E-1
a_6	0	2.74629E-2	1.12909E-5	0
a_7	-1.04316E+1	1.85191E+5	-2.87944	-6.23288
a_8	3.99066	-1.12393E+3	1.89765E-2	2.25878
a_9	0	1.64396	-2.90452E-5	0
σ	0.9998	0.9997	0.9997	0.9999

Figure 2-1: Density of CFC-12/ISO 100 Naphthenic Mineral Oil
Low Refrigerant Concentration Mixtures

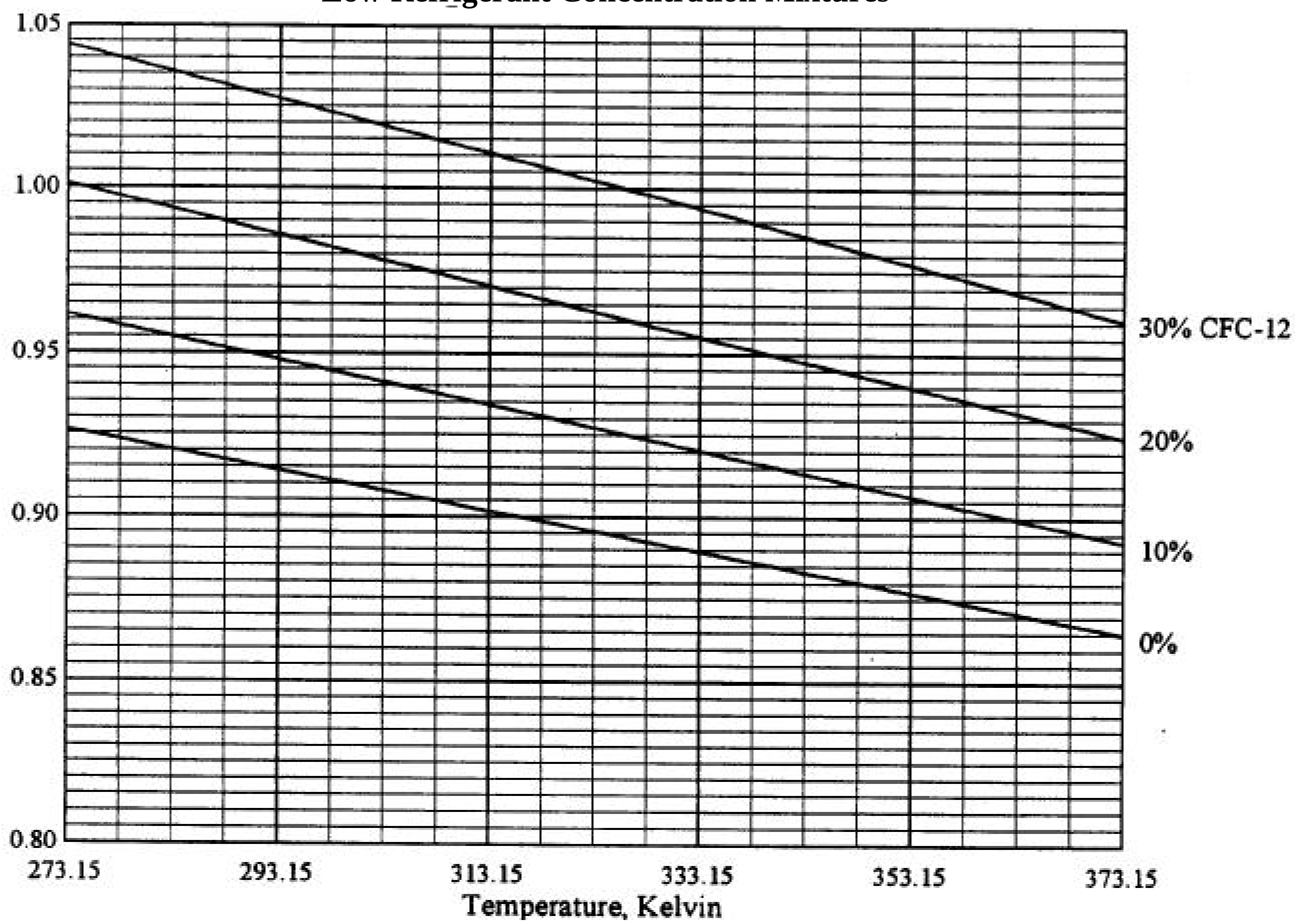


Figure 2-2: Viscosity and Solubility of CFC-12/ISO 100 Naphthenic Mineral Oil Low Refrigerant Concentration Mixtures

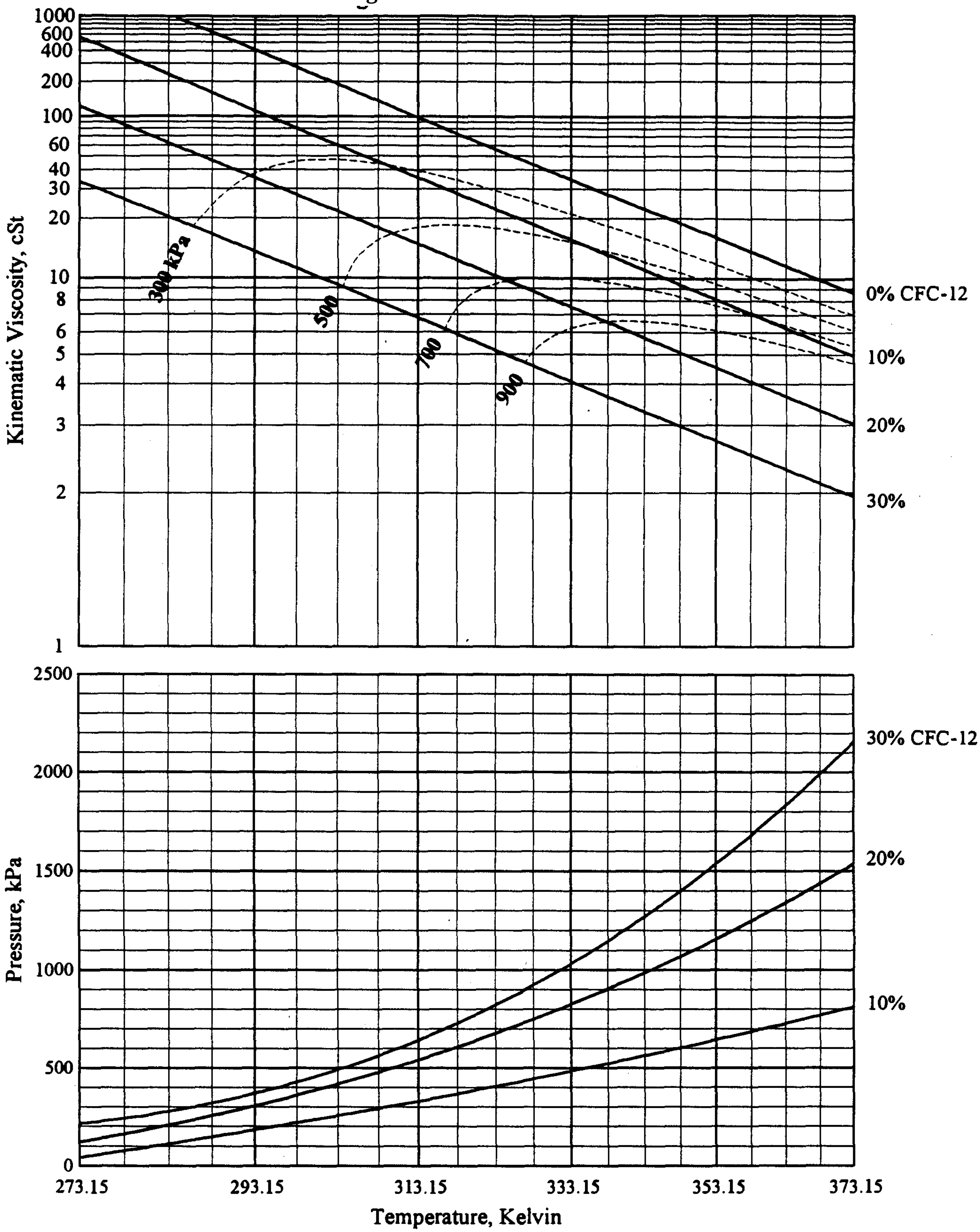


**Table 2-2: Viscosity, Solubility and Density Parameters
CFC-12/ISO 100 Naphthenic Mineral Oil
High Refrigerant Concentration Mixtures**

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-6.71771	2.48246	8.12458E-1	-5.50621
a_2	1.06710E+3	1.44205E+2	-6.29756	8.59078E+2
a_3	5.41193E+5	-8.14886E+4	7.85332	5.70185E+5
a_4	9.41863	4.68174	-4.21582E-1	8.46324
a_5	-9.38004E+2	-3.27056E+2	1.14752E+1	-1.15040E+3
a_6	-1.11725E+6	-1.79490E+5	-1.48582E+1	-1.09345E+6
a_7	-4.68190	-8.66500E-1	6.16181E-1	-4.43253
a_8	3.46318E+2	-8.33427E+2	-3.59571	4.84318E+2
a_9	5.51623E+5	2.53933E+5	6.39664	5.27037E+5
σ	0.9987	0.9999	0.9999	0.9987

**Figure 2-3: Density of CFC-12/ISO 100 Naphthenic Mineral Oil
High Refrigerant Concentration Mixtures**

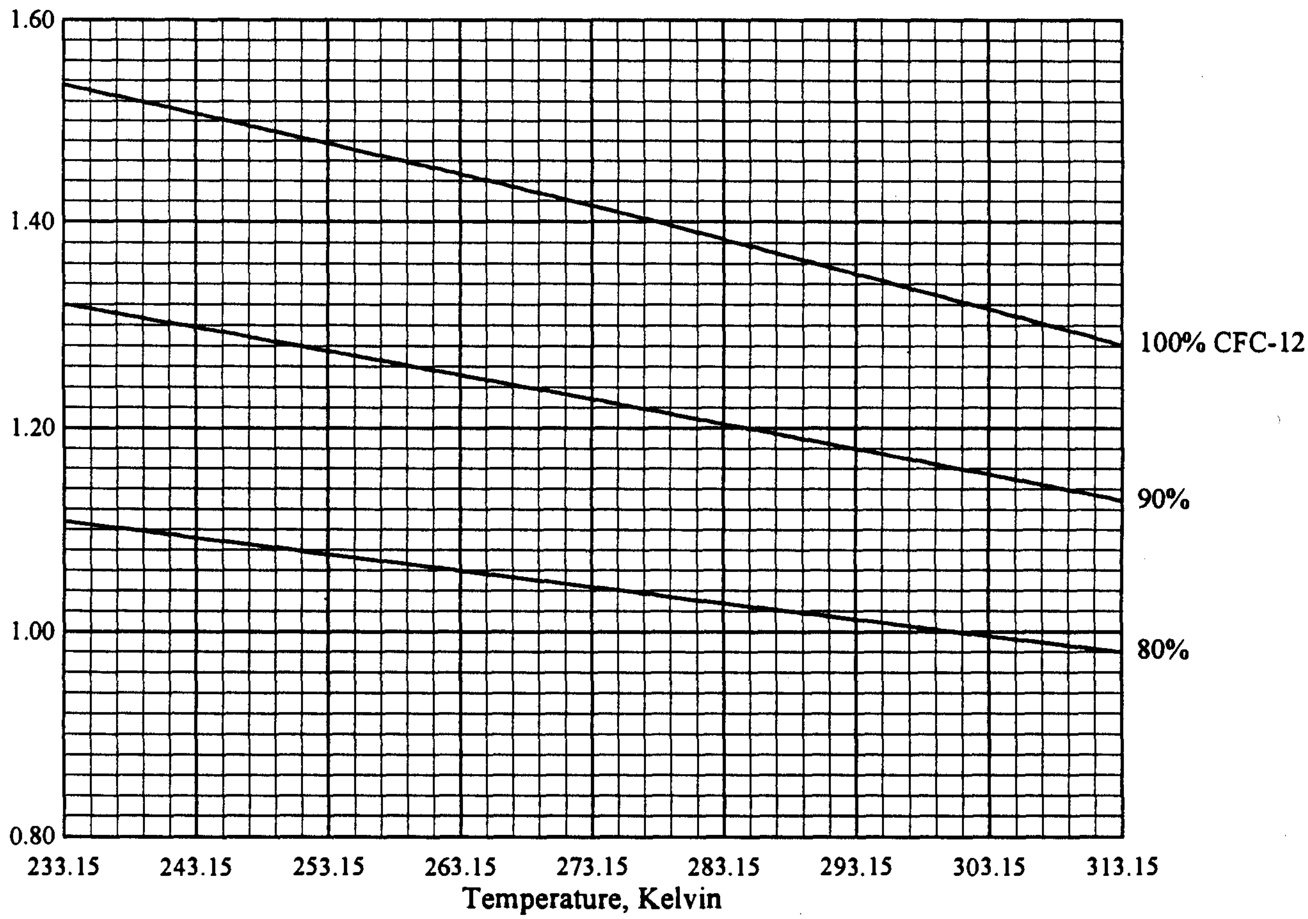


Figure 2-4: Viscosity and Solubility of CFC-12/ISO 100 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

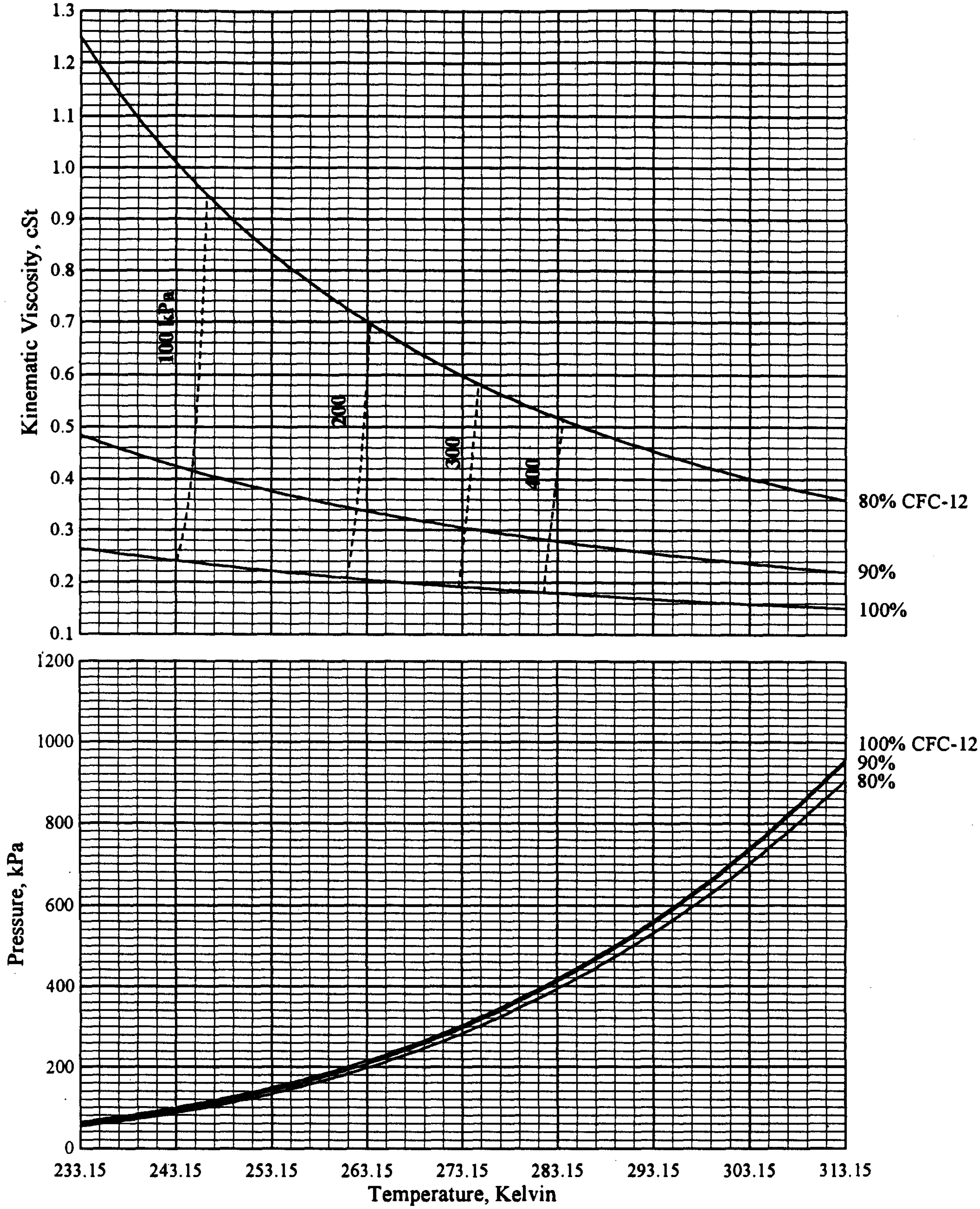


Table 3-1: Viscosity, Solubility and Density Parameters
HCFC-22/ISO 32 Naphthenic Mineral Oil
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.13470E+1	1.12559E+3	1.05151	1.07731E+1
a_2	-4.48233	-7.10812	-3.80446E-4	-4.24625
a_3	0	1.12005E-2	-3.89391E-7	0
a_4	-4.76237	-9.87924E+3	1.49570	-4.64107
a_5	1.34287	-2.26798E+1	-6.67300E-3	1.29807
a_6	0	2.37689E-1	8.84854E-6	0
a_7	-9.14286	1.49360E+5	-1.77719	-9.38421
a_8	3.79339	-8.97235E+2	1.06283E-2	3.84080
a_9	0	1.26802	-1.53662E-5	0
σ	0.9995	0.9996	0.9998	0.9994

Figure 3-1: Density of HCFC-22/ISO 32 Naphthenic Mineral Oil
Low Refrigerant Concentration Mixtures

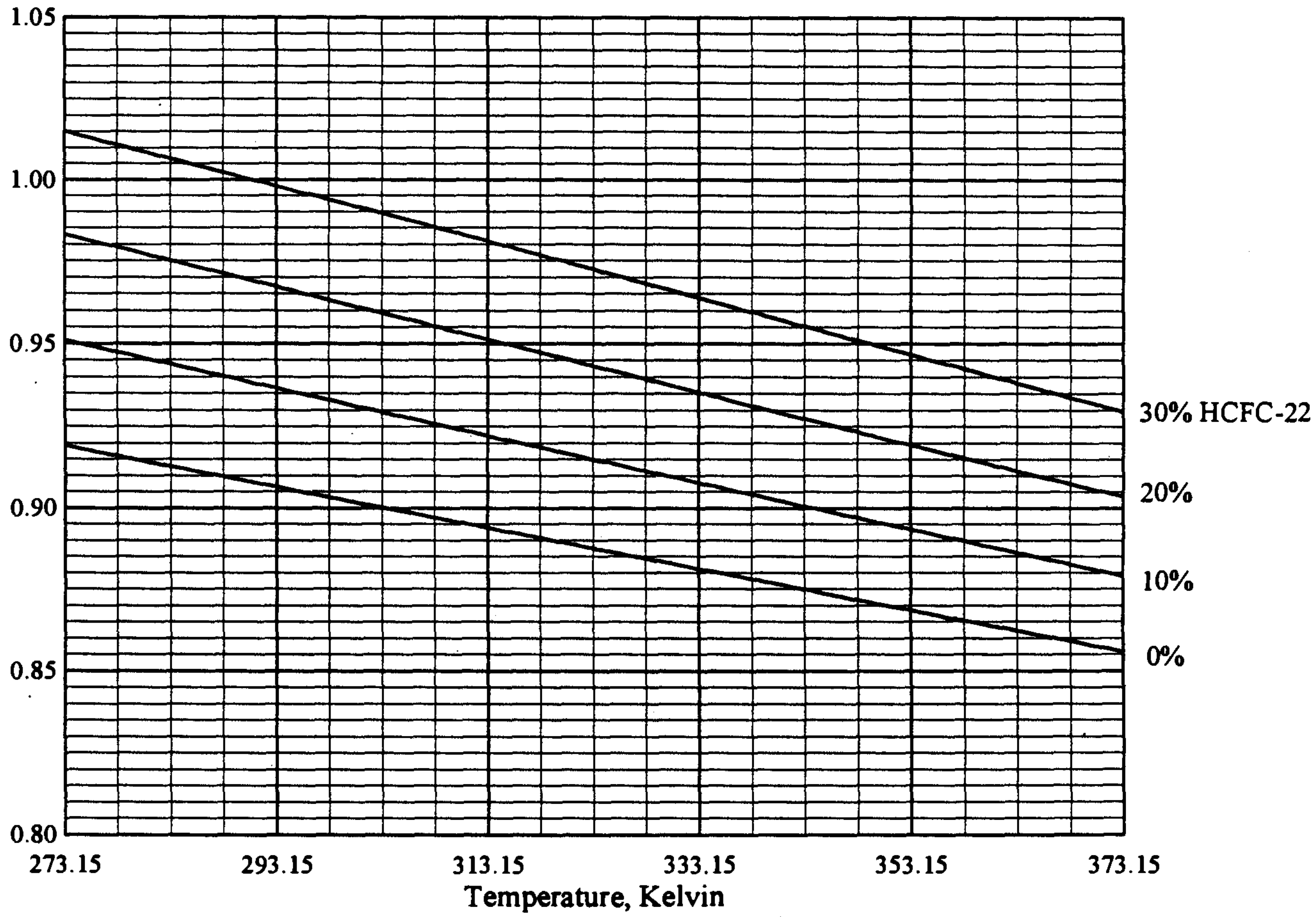


Figure 3-2: Viscosity and Solubility of HCFC-22/ISO 32 Naphthenic Mineral Oil Low Refrigerant Concentration Mixtures

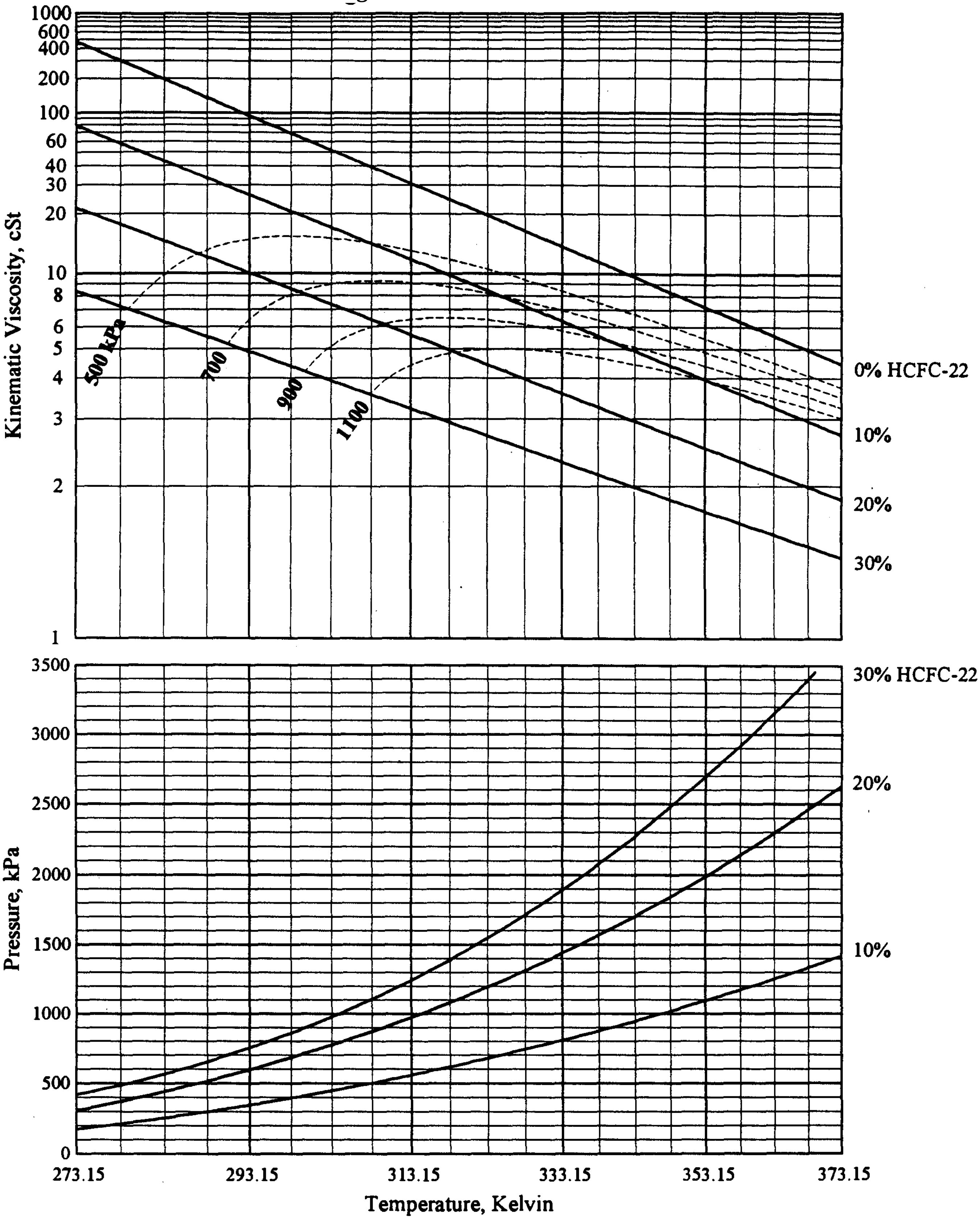


Table 3-2: Viscosity, Solubility and Density Parameters HCFC-22/ISO 32 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-1.40916	7.50188	-6.20235E-1	-7.46898E-1
a_2	4.75733E+2	-1.33279E+3	1.83625E+1	8.69777E+1
a_3	1.31939E+5	-6.98797E+3	-8.90091E+1	2.73817E+5
a_4	-1.29141	-1.39953	3.24038	-1.82724
a_5	-2.00775E+1	1.08477E+2	-4.73335E+1	5.04941E+2
a_6	-2.51781E+5	9.59839E+4	2.09671E+2	-5.07449E+5
a_7	9.78531E-1	9.47234E-1	-1.71981	1.66028
a_8	-1.53782E+2	-1.12910E+2	3.06554E+1	-6.99676E+2
a_9	1.17313E+5	-4.91922E+4	-1.21515E+2	2.74676E+5
σ	0.9995	0.9998	0.9987	0.9995

Figure 3-3: Density of HCFC-22/ISO 32 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

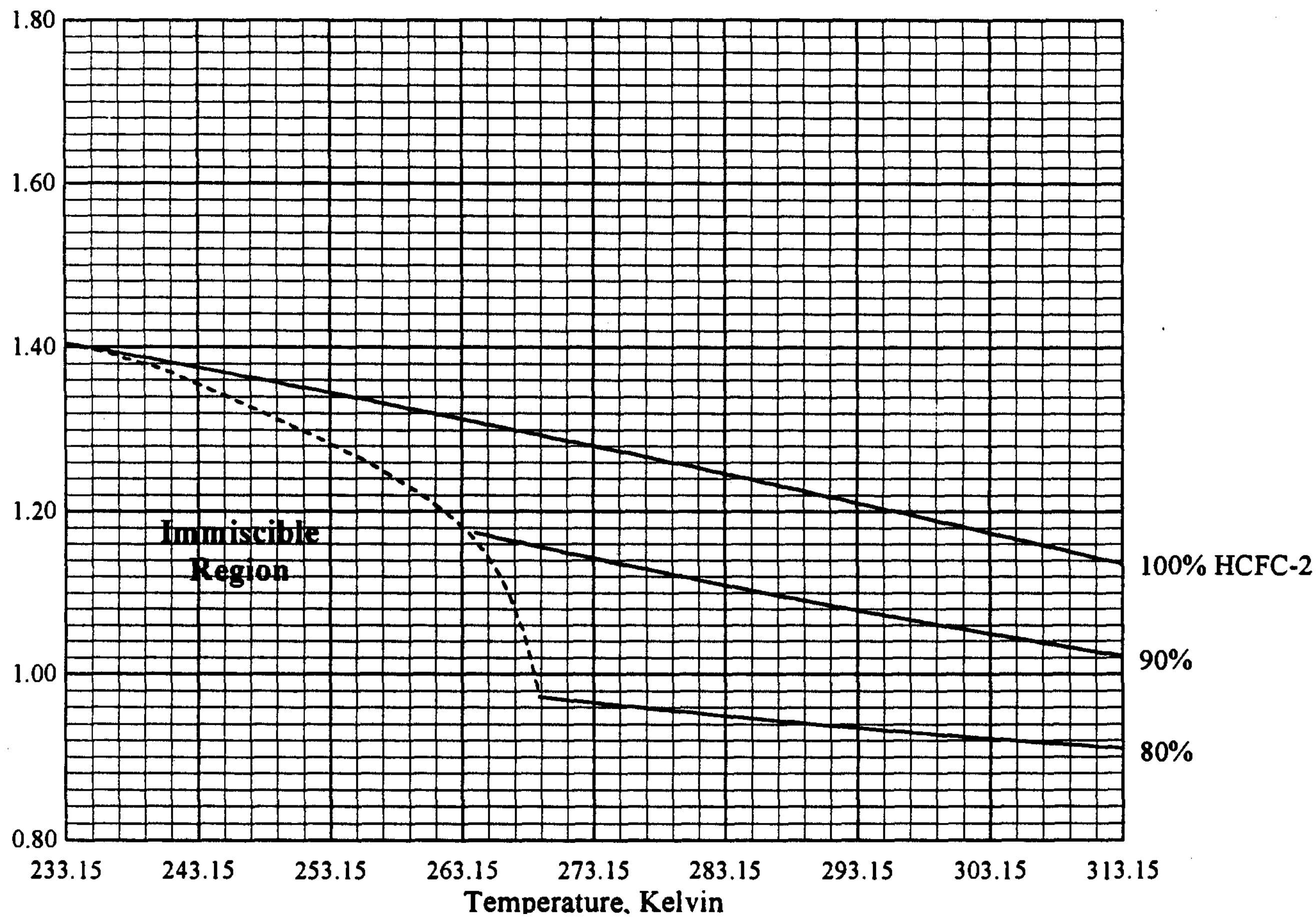


Figure 3-4: Viscosity and Solubility of HCFC-22/ISO 32 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

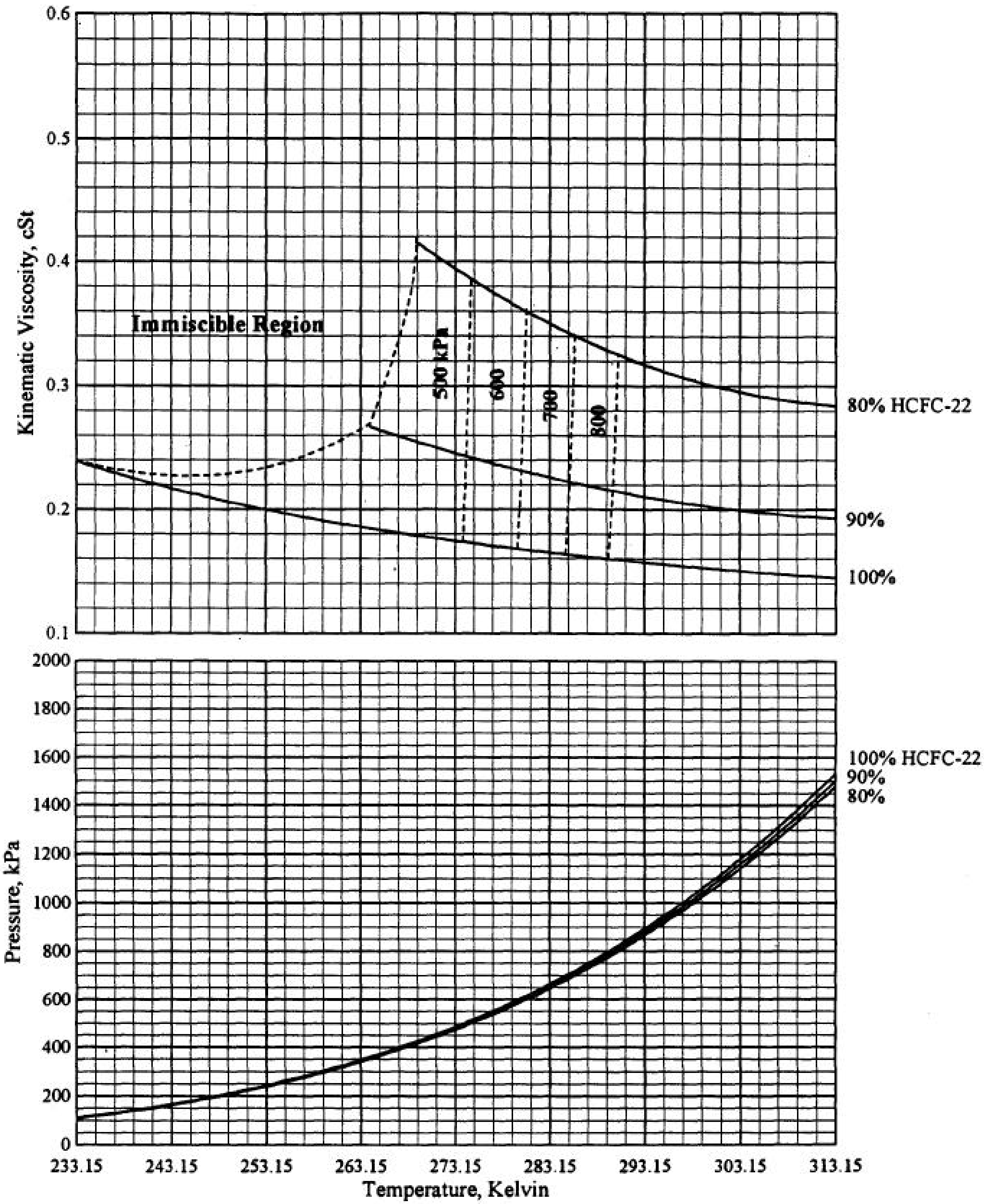


Table 4-1: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 68 Polyalkylene Glycol
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	7.83489	-2.46848E+2	1.31774	7.62442
a_2	-3.03935	1.56988	-1.43562E-3	-2.96348
a_3	0	-2.47395E-3	1.05878E-6	0
a_4	-1.02376	6.34708E+4	-1.17378	-1.65925
a_5	1.10793E-1	-4.86298E+2	1.02665E-2	3.55118E-1
a_6	0	9.42835E-1	-1.78756E-5	0
a_7	8.13697	-7.09542E+4	6.19030	1.01143E+1
a_8	-3.34055	5.37748E+2	-4.06607E-2	-4.14735
a_9	0	-1.03223	6.55791E-5	0
σ	0.9995	0.9999	0.9997	0.9995

Figure 4-1: Density of HFC-134a/ISO 68 Polyalkylene Glycol
Low Refrigerant Concentration Mixtures

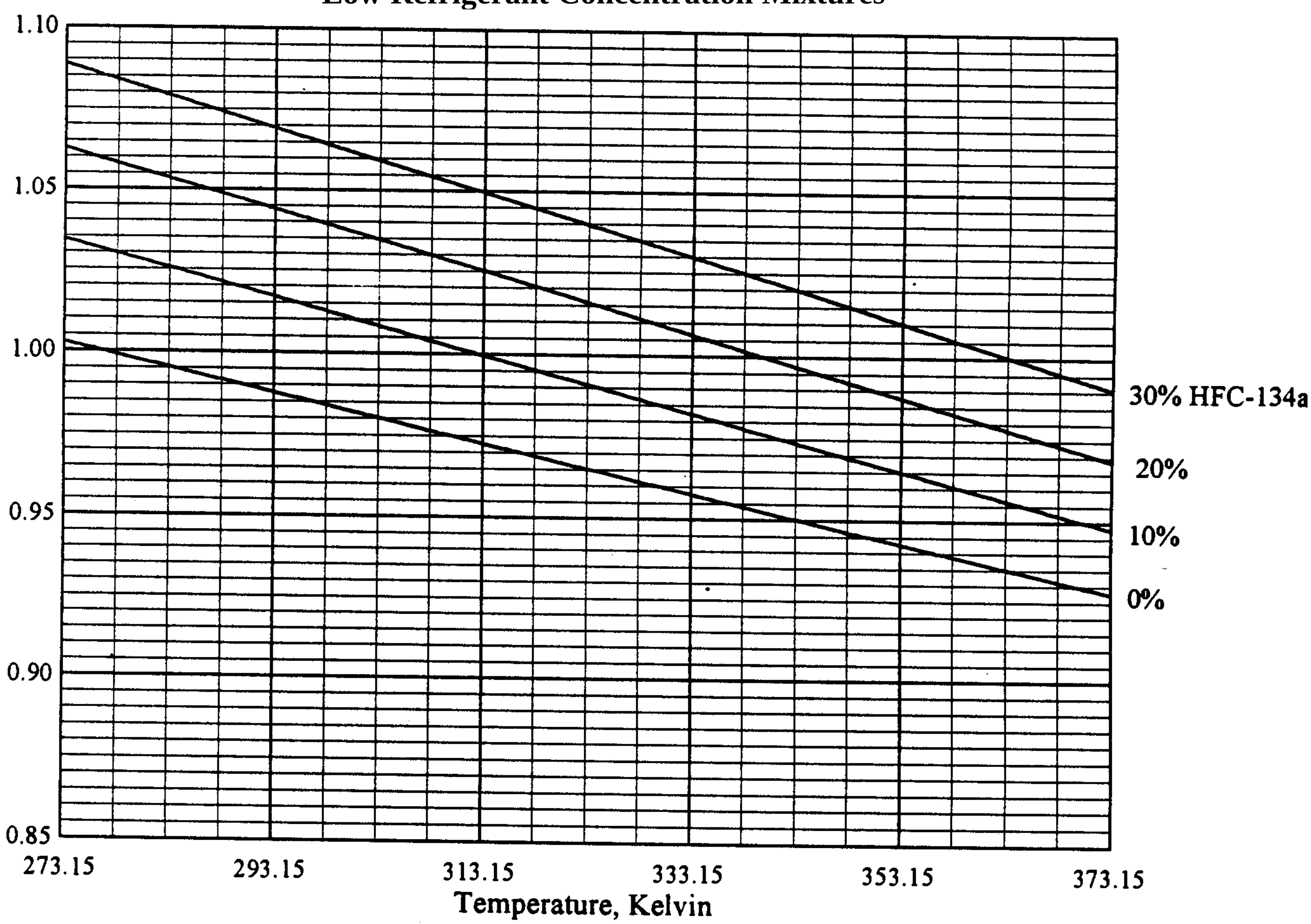


Figure 4-2: Viscosity and Solubility of HFC-134a/ISO 68 Polyalkylene Glycol Low Refrigerant Concentration Mixtures

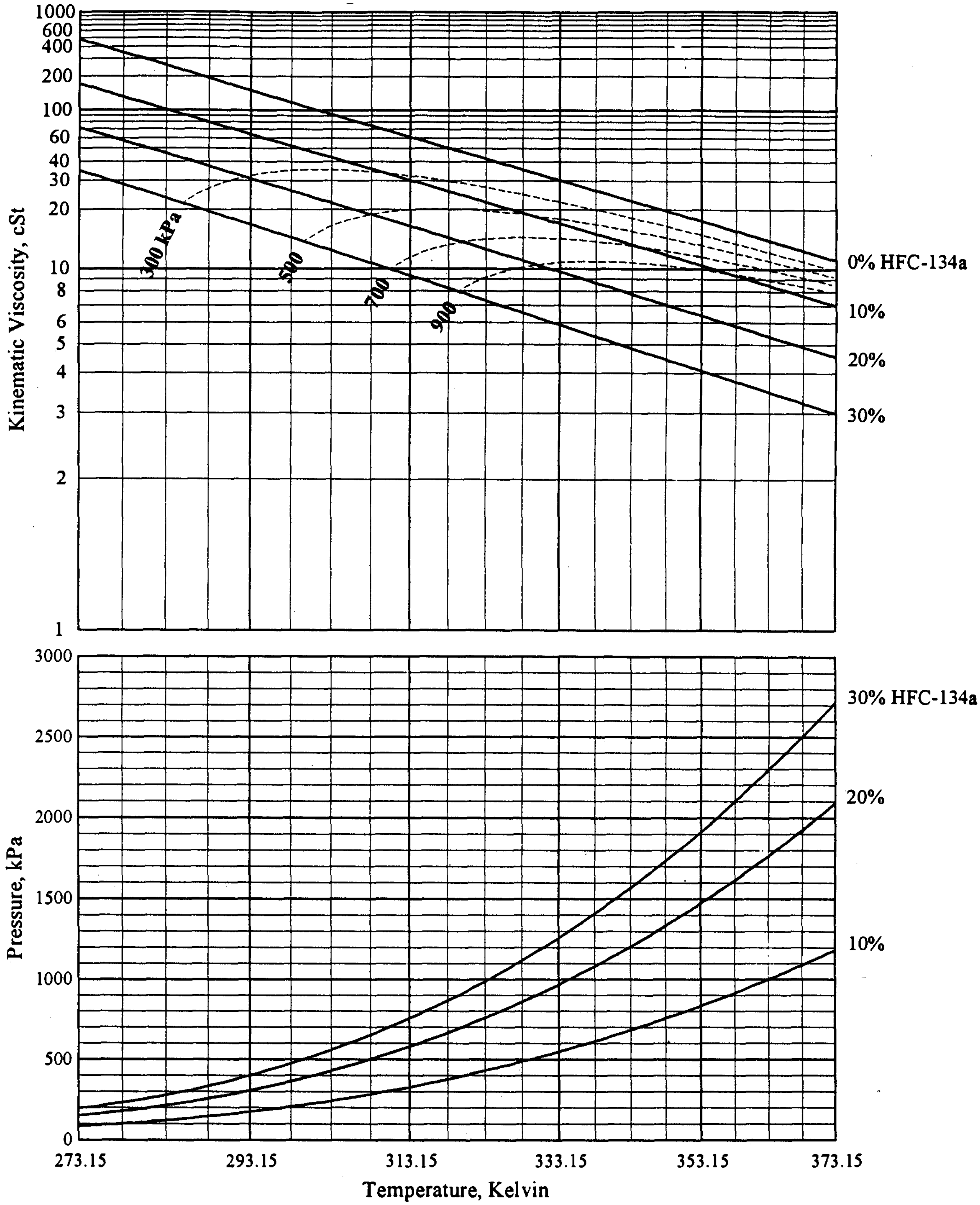


Table 4-2: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 68 Polyalkylene Glycol
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	3.99621E-1	4.00090	-1.64988E-1	1.34116
a_2	1.68334E+2	-3.69972E+2	-8.62806E-1	-3.35572E+1
a_3	1.12328E+5	-6.80128E+4	7.83936	1.36182E+5
a_4	-2.19557	3.46077	1.77557	-2.96004
a_5	-4.71551E+2	-1.81426E+2	1.07203	-4.86531E+2
a_6	3.70718E+4	-9.88128E+4	-1.65791E+1	3.84056E+4
a_7	-6.16014E-1	2.55592E-1	-7.11820E-1	-1.27779E-1
a_8	8.61643E+2	-1.15984E+3	1.34051	7.44484E+2
a_9	-1.67914E+5	2.40735E+5	8.18415	-1.59378E+5
σ	0.9999	0.9999	0.9999	0.9999

Figure 4-3: Density of HFC-134a/ISO 68 Polyalkylene Glycol
High Refrigerant Concentration Mixtures

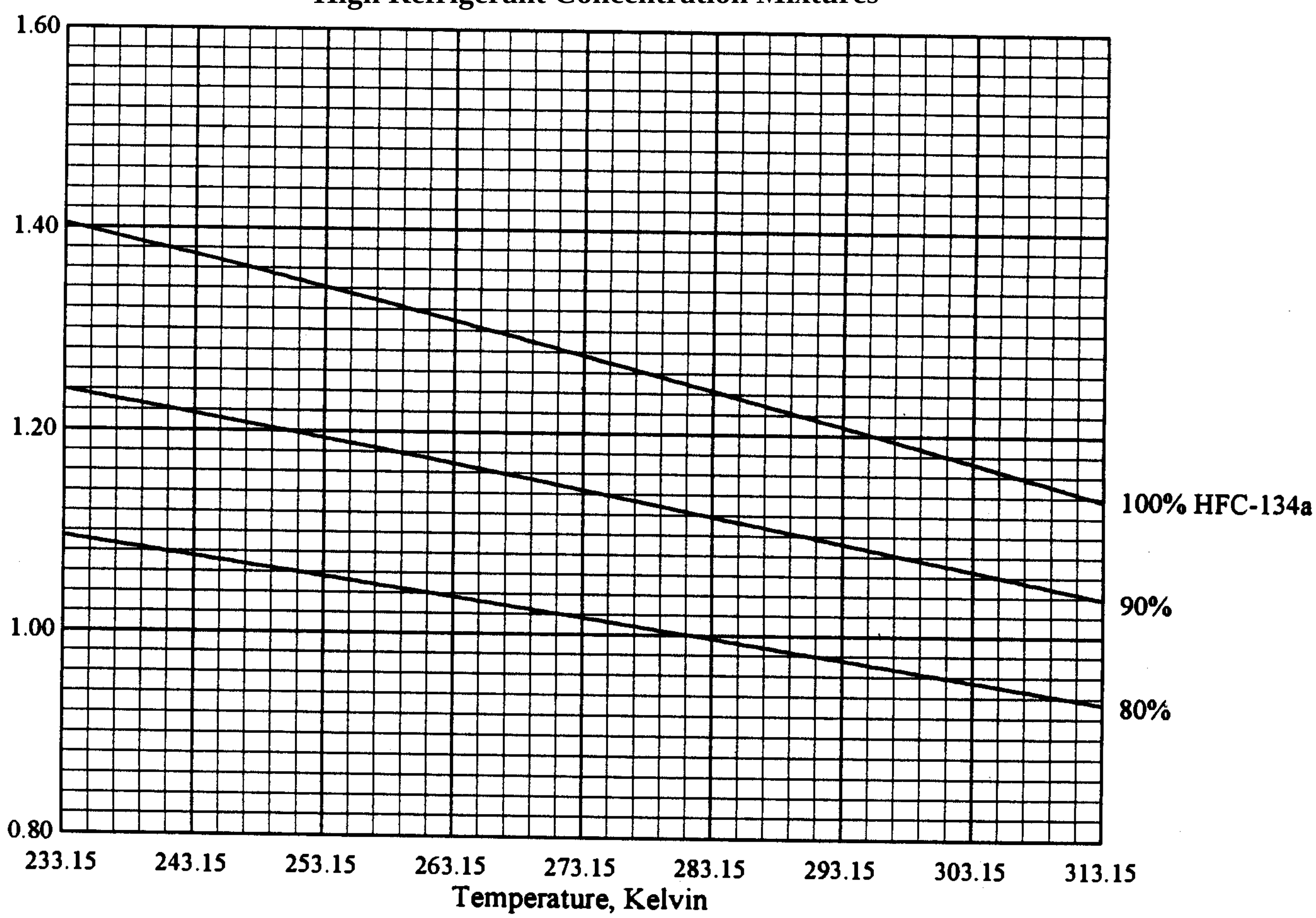


Figure 4-4: Viscosity and Solubility of HFC-134a/ISO 68 Polyalkylene Glycol High Refrigerant Concentration Mixtures

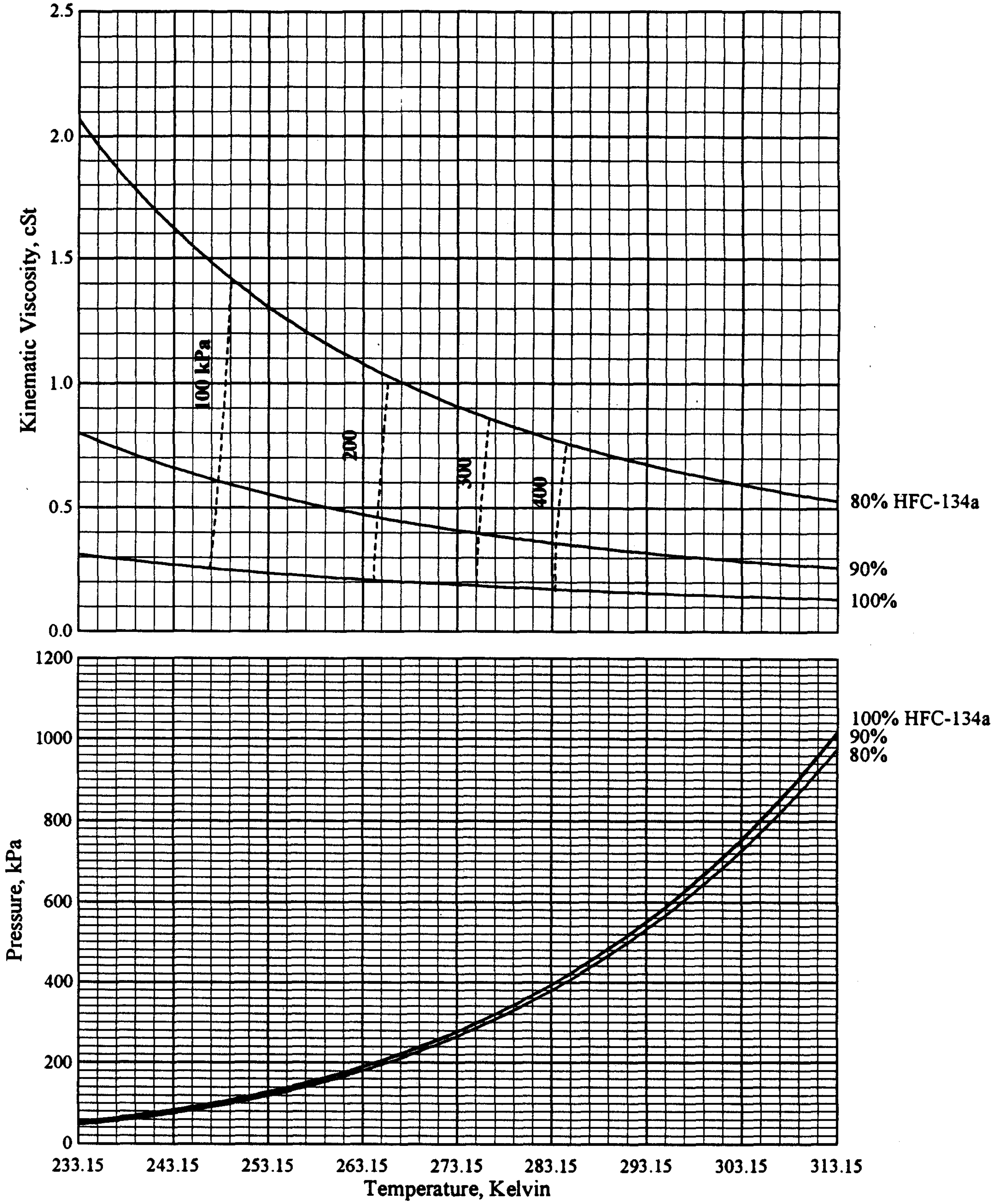


**Table 5-1: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 22 Penaterythritol Ester Mixed Acid #1
Low Refrigerant Concentration Mixtures**

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.41763	2.89782E+3	1.13723	9.12234
a_2	-3.72081	-1.80787E+1	-2.89916E-4	-3.60079
a_3	0	2.79895E-2	-6.99544E-7	0
a_4	-3.92777	-1.93339E+4	1.29823	-3.96304
a_5	1.21271	3.73956E+1	-5.99345E-3	1.21758
a_6	0	1.22336E-1	8.03992E-6	0
a_7	3.18980E+1	1.97368E+5	-1.75900	3.10843E+1
a_8	-1.30212E+1	-1.15833E+3	1.17233E-2	-1.27116E+1
a_9	0	1.62636	-1.95375E-5	0
σ	0.9995	0.9997	0.9998	0.9995

**Figure 5-1: Density of HFC-134a/ISO 22 Pentaerythritol Ester Mixed Acid #1
Low Refrigerant Concentration Mixtures**

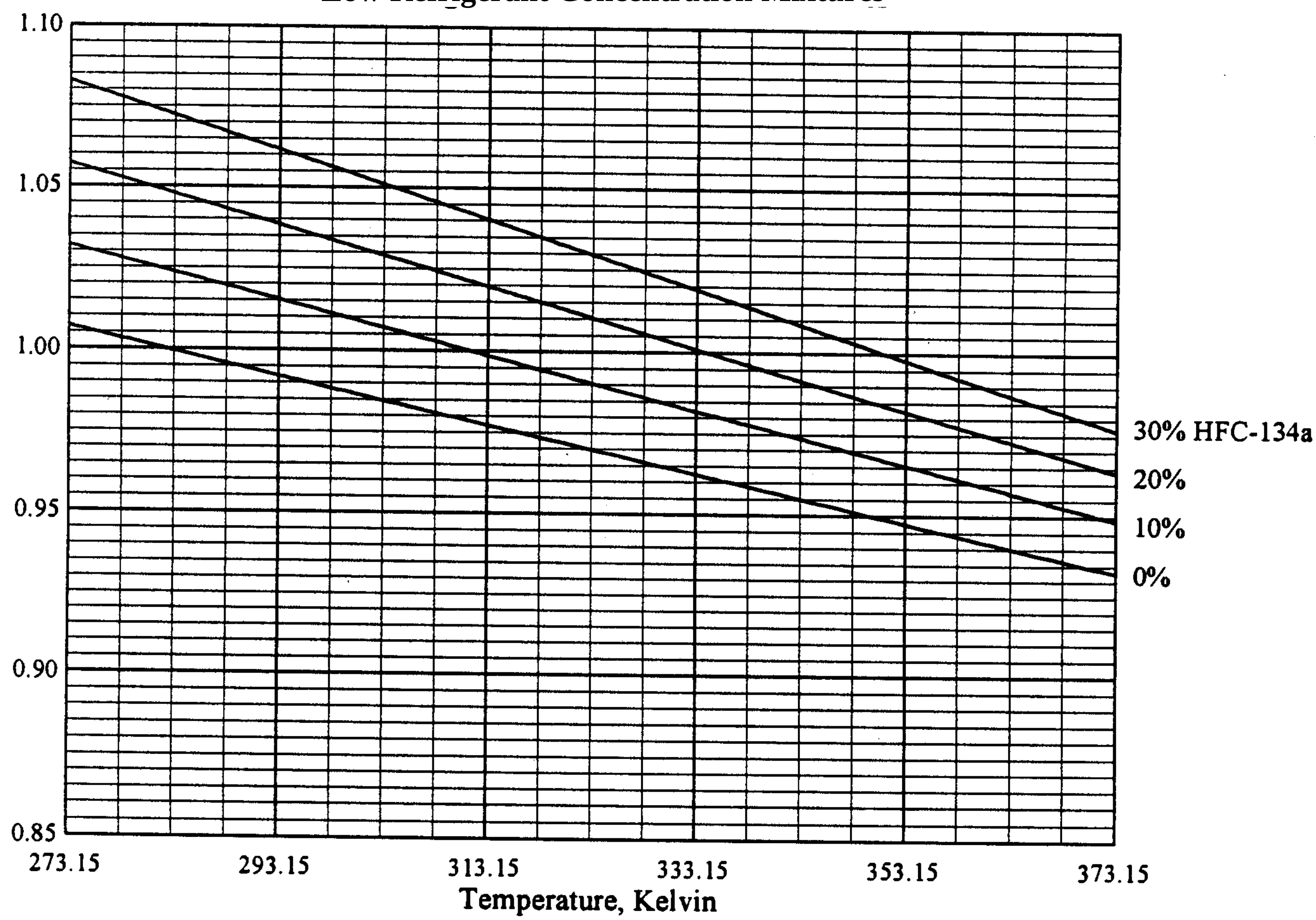


Figure 5-2: Viscosity and Solubility of HFC-134a/ISO 22 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

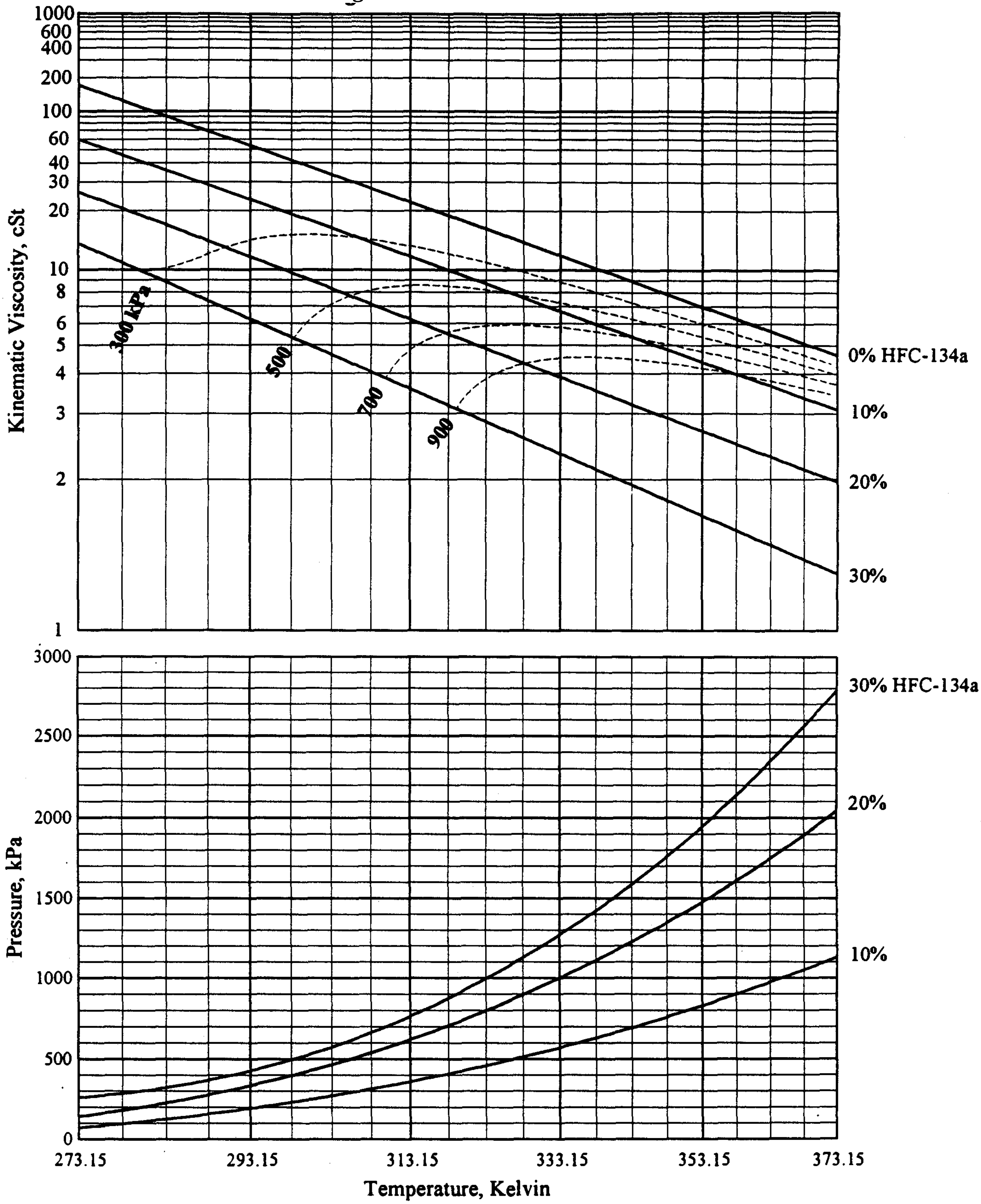


Table 5-2: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 22 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-1.33242	1.53235E+1	5.08957E-1	2.55101
a_2	9.70941E+2	-2.33421E+3	-1.82916	-1.94202E+3
a_3	8.87030E+4	-3.89417E+5	4.24439	6.48884E+5
a_4	-8.45040E-1	-1.92482E+1	1.92860E-1	-1.37002
a_5	-1.69168E+3	2.49136E+3	2.30237	4.68322E+2
a_6	2.96994E+4	8.95875E+5	-7.28064	-6.08082E+5
a_7	3.28006E-2	1.20861E+1	1.99842E-1	-2.78250
a_8	1.13606E+3	-2.08984E+3	1.05660	1.62105E+3
a_9	-1.17941E+5	-4.05323E+5	2.51343	-1.54687E+4
σ	0.9997	0.9997	0.9999	0.9999

Figure 5-3: Density of HFC-134a/ISO 22 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

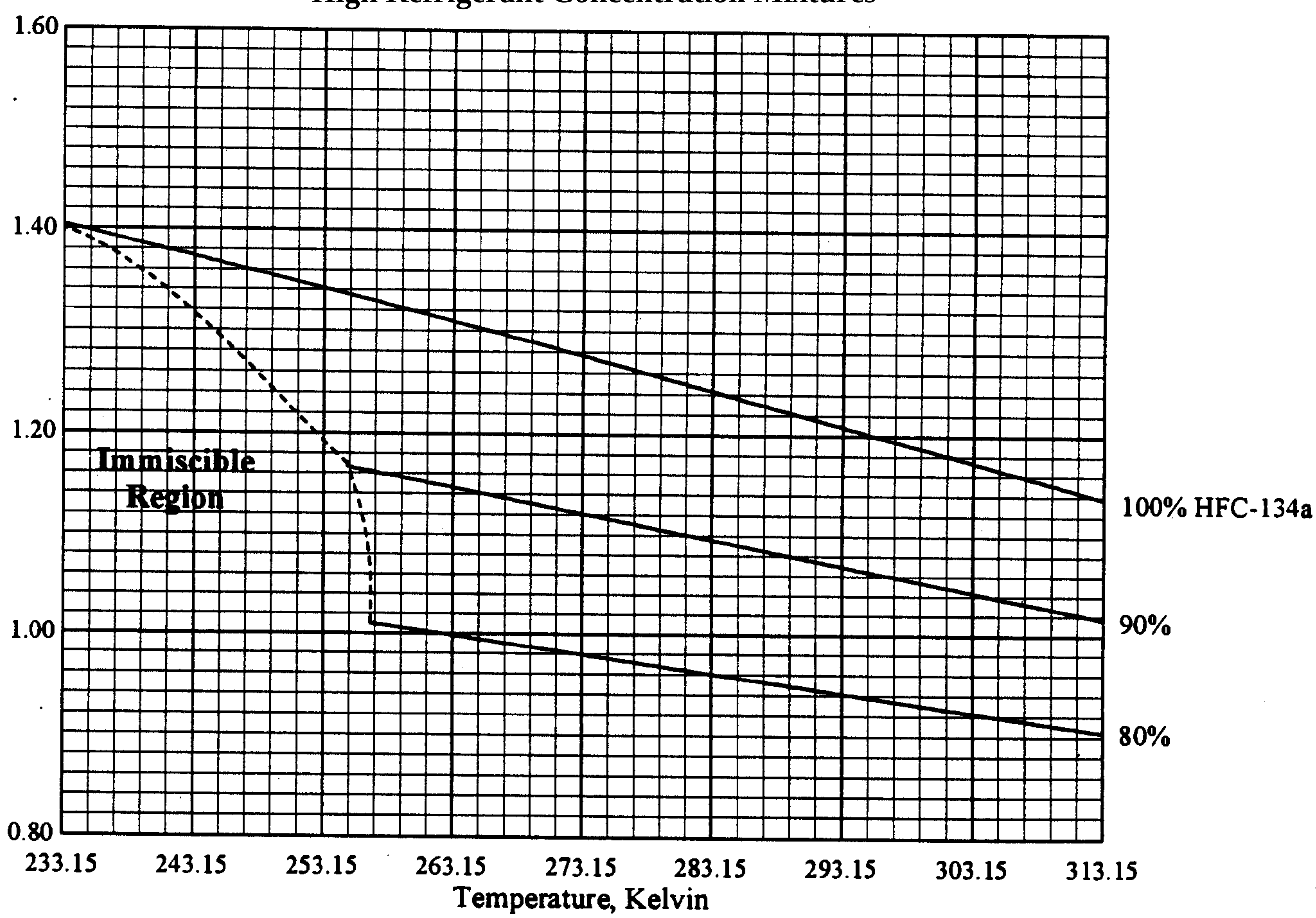


Figure 5-4: Viscosity and Solubility of HFC-134a/ISO 22 Pentaerythritol Ester Mixed Acid #1 High Refrigerant Concentration Mixtures

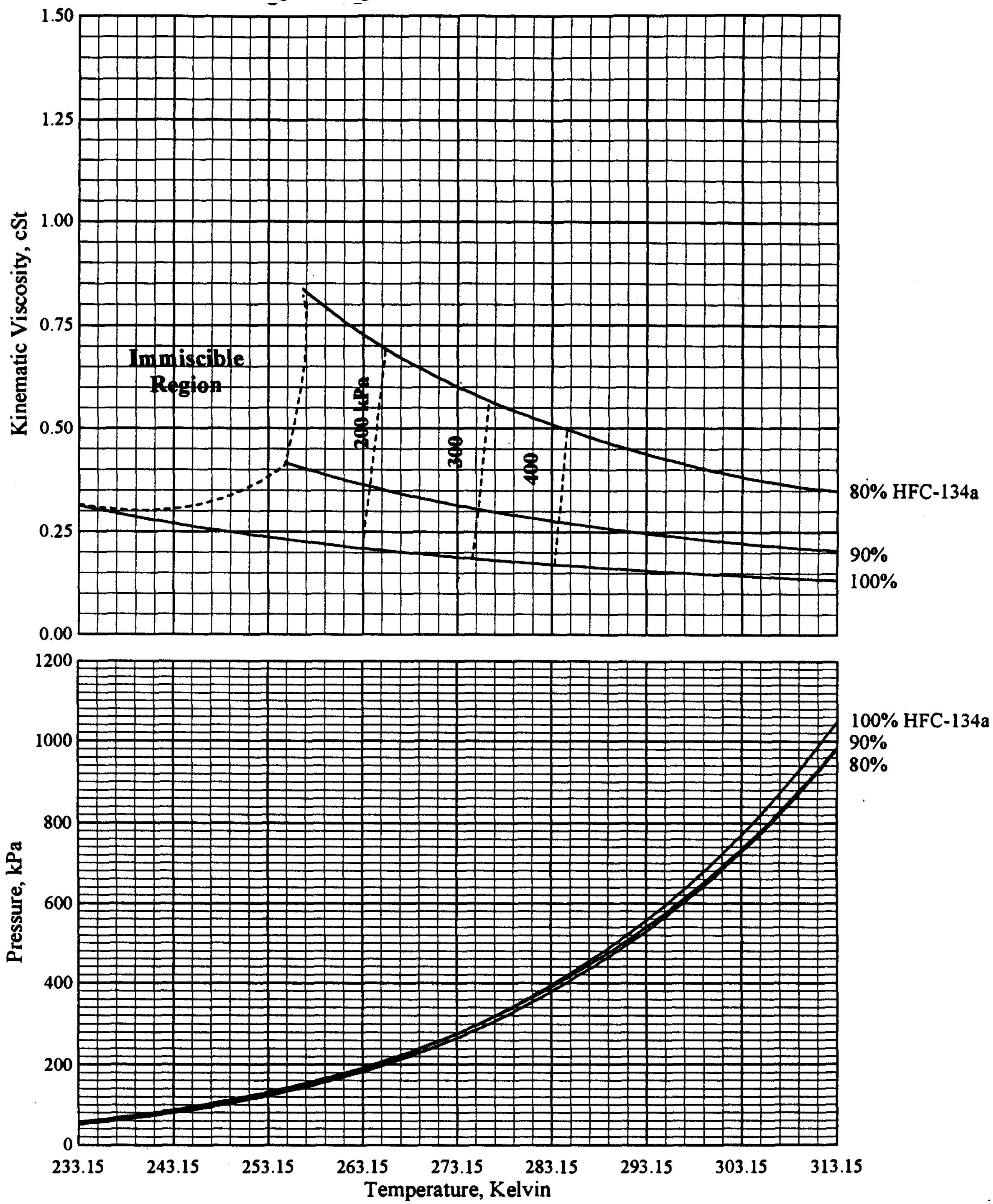


Table 6-1: Viscosity, Solubility and Density Parameters HFC-134a/ISO 32 Penaterythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.71405	1.27542E+3	1.34514	9.41351
a_2	-3.82561	-7.91056	-1.58808E-3	-3.70360
a_3	0	1.21662E-2	1.29457E-6	0
a_4	-5.05546	2.92274E+4	-3.36407	-5.31056
a_5	1.63031	-2.60650E+2	2.37279E-2	1.72804
a_6	0	5.71536E-1	-3.90503E-5	0
a_7	1.37735E+1	2.10810E+4	1.40018E+1	1.44990E+1
a_8	-5.65688	-6.14452E+1	-8.93090E-2	-5.99063
a_9	0	-5.87043E-2	1.42326E-4	0
σ	0.9998	0.9999	0.9990	0.9998

Figure 6-1: Density of HFC-134a/ISO 32 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentrations

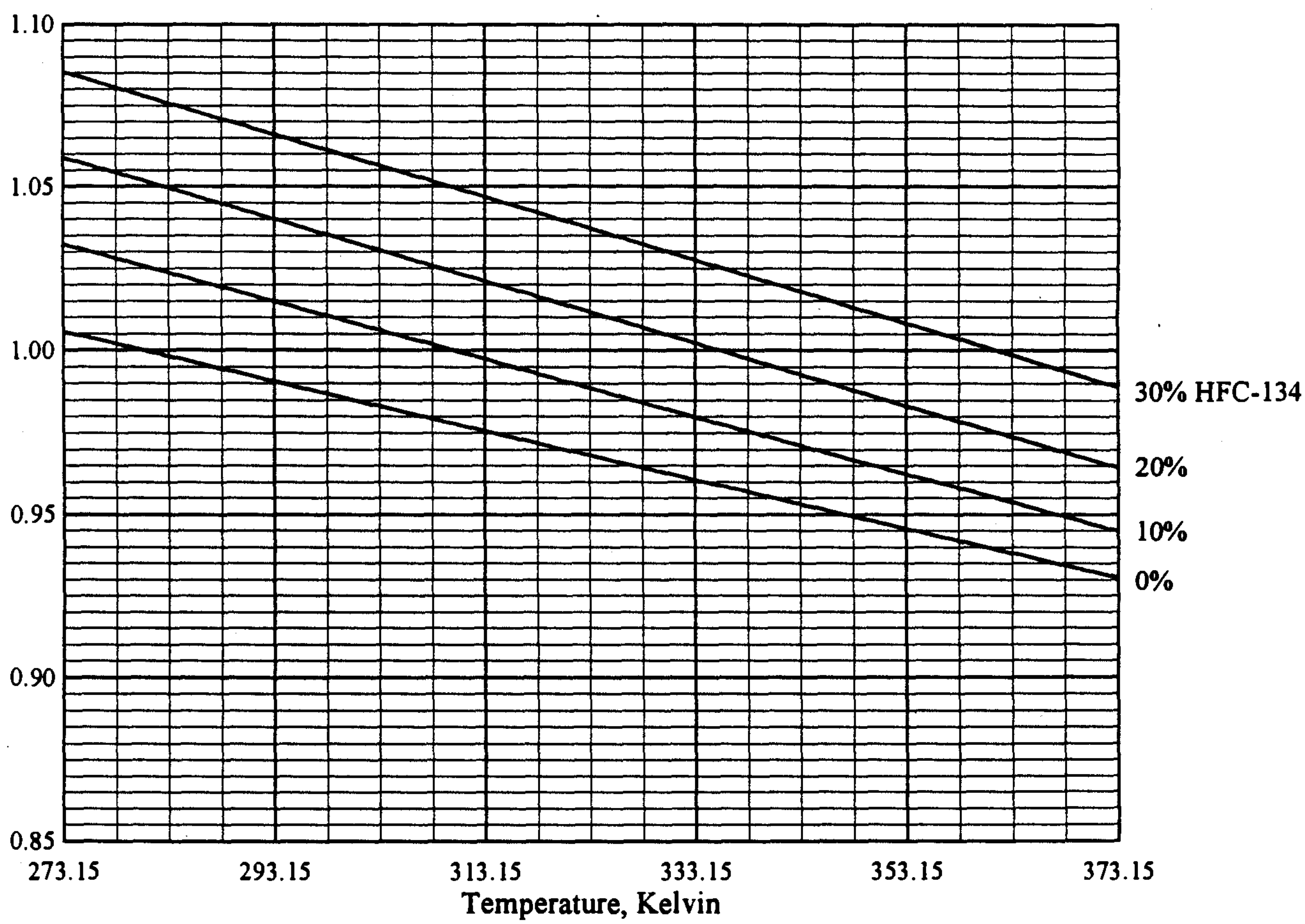


Figure 6-2: Viscosity and Solubility of HFC-134a/ISO 32 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

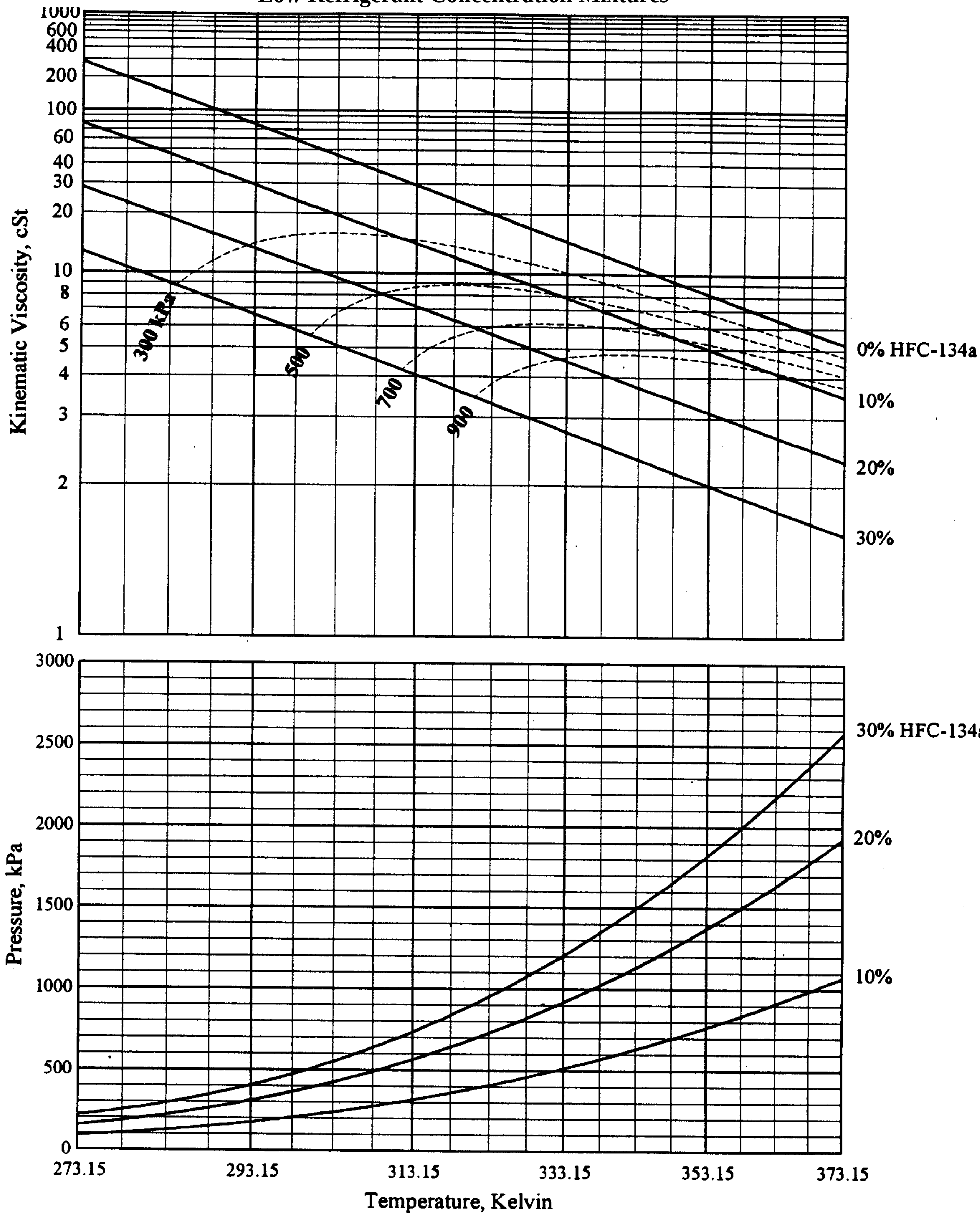


Table 6-2: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 32 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	3.39811	5.37133	2.34069E-1	3.59949
a_2	-1.14448E+3	-1.28321E+3	-2.03786	-1.13351E+3
a_3	1.24832E+5	1.22493E+5	8.75742	1.44254E+5
a_4	-1.08310E+1	1.56043	8.58589E-1	-8.44161
a_5	3.11806E+3	9.87105E+2	2.46750	1.85517E+3
a_6	-1.34295E+5	-3.69272E+5	-1.71901E+1	-1.71839E+4
a_7	5.43103	8.92865E-1	-1.86696E-1	3.26937
a_8	-1.61918E+3	-1.46681E+3	1.06708	-5.74315E+2
a_9	1.59094E+4	3.26736E+5	7.96983	-1.03822E+5
σ	0.9991	0.9999	0.9999	0.9993

Figure 6-3: Density of HFC-134a/ISO 32 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

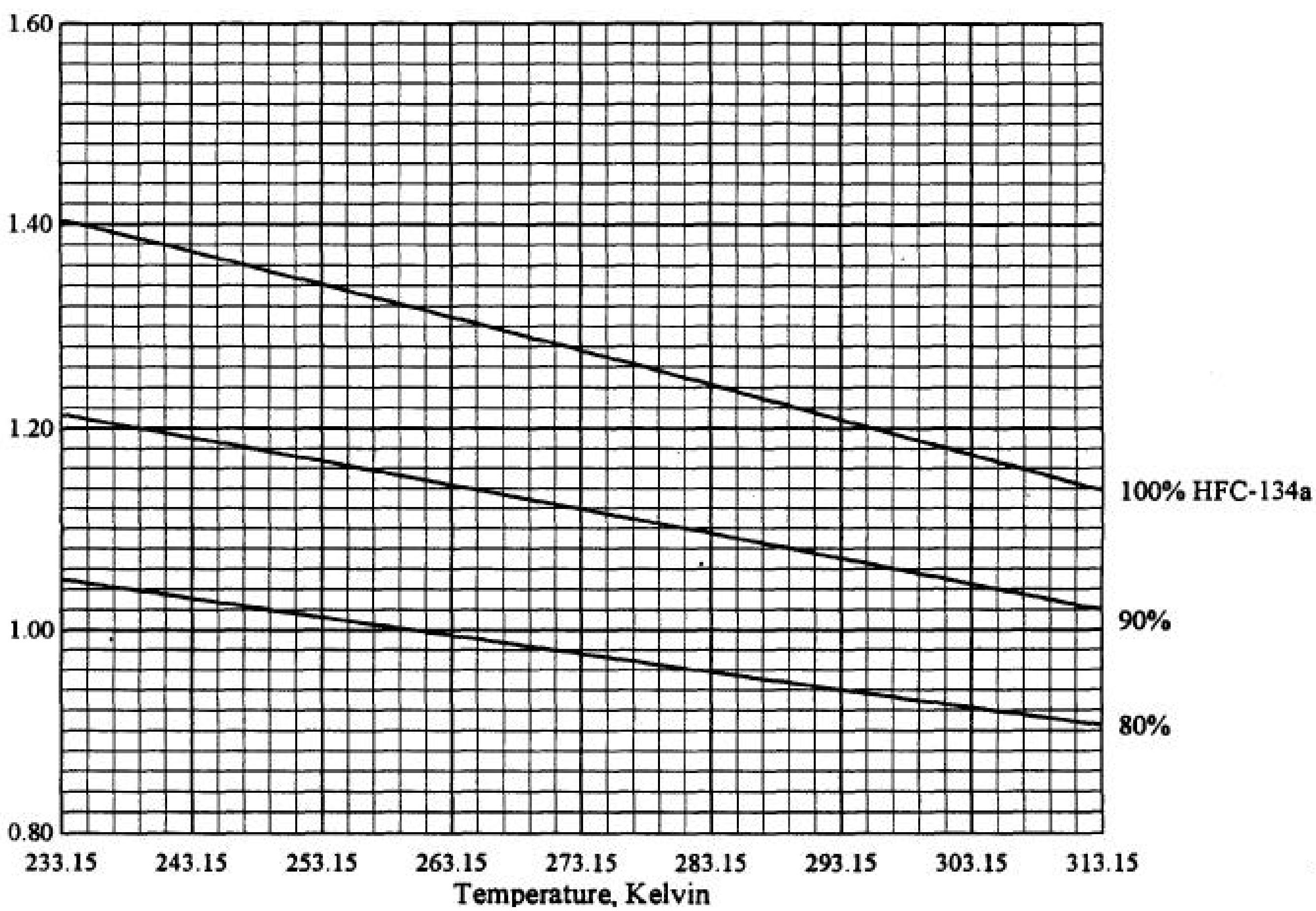


Figure 6-4: Viscosity and Solubility of HFC-134a/ISO 32 Pentaerythritol Ester Mixed Acid #1 High Refrigerant Concentration Mixtures

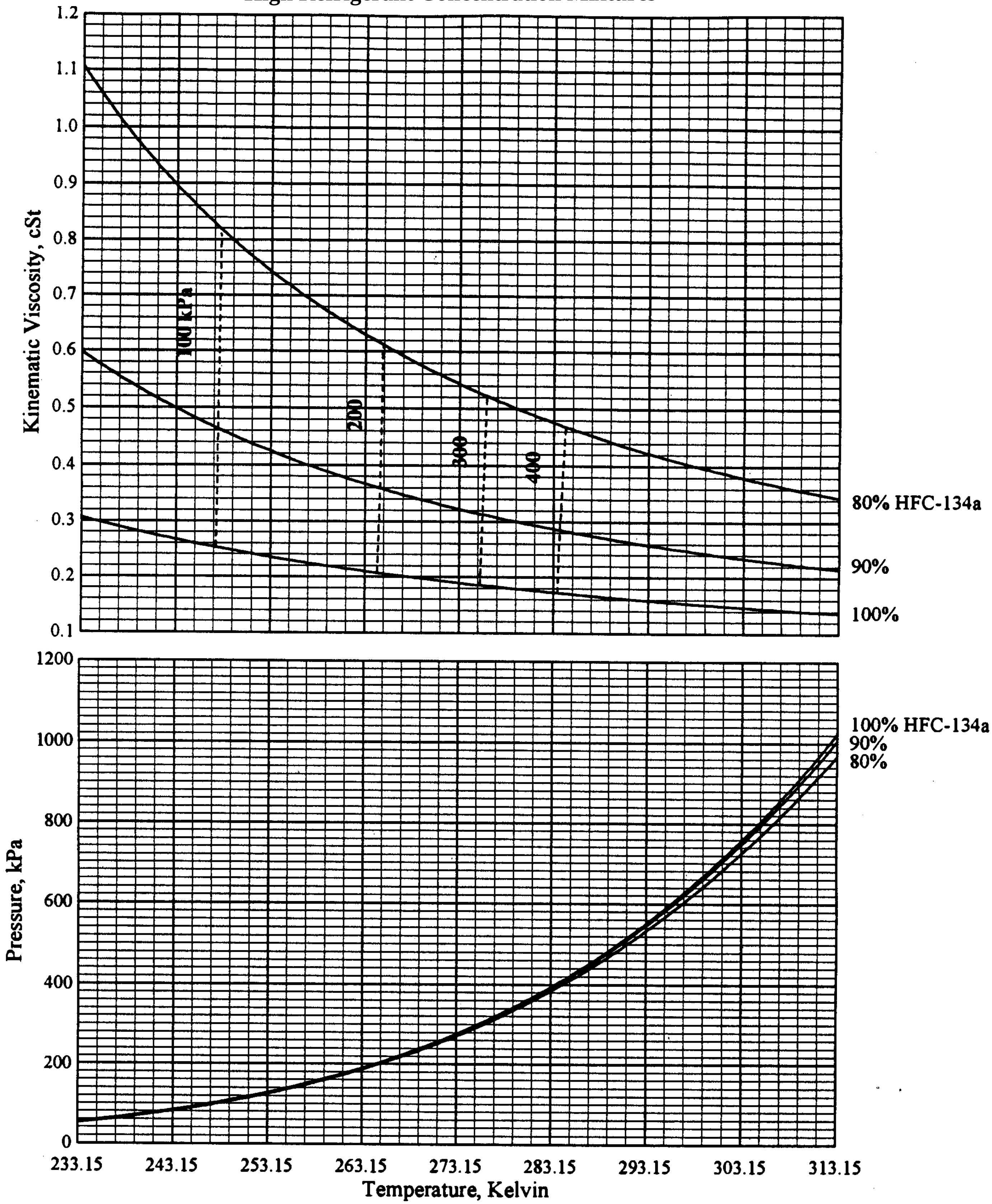


Table 7-1: Viscosity, Solubility and Density Parameters HFC-134a/ISO 68 Penaterythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.05204E+1	1.16900E+3	1.20668	1.02380E+1
a_2	-4.11222	-7.39656	-9.16226E-4	-3.99658
a_3	0	1.16084E-2	3.28702E-7	0
a_4	-1.17928E+1	-5.87454E+3	3.67221E-1	-1.20459E+1
a_5	4.18034	-5.09869E+1	4.48469E-5	4.27634
a_6	0	2.65209E-1	-1.13568E-6	0
a_7	2.55320E+1	1.79697E+5	8.22484E-1	2.57746E+1
a_8	-9.93423	-1.02803E+3	-4.69511E-3	-1.00588E+1
a_9	0	1.39473	5.95292E-6	0
σ	0.9993	0.9998	0.9999	0.9993

Figure 7-1: Density of HFC-134a/ISO 68 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

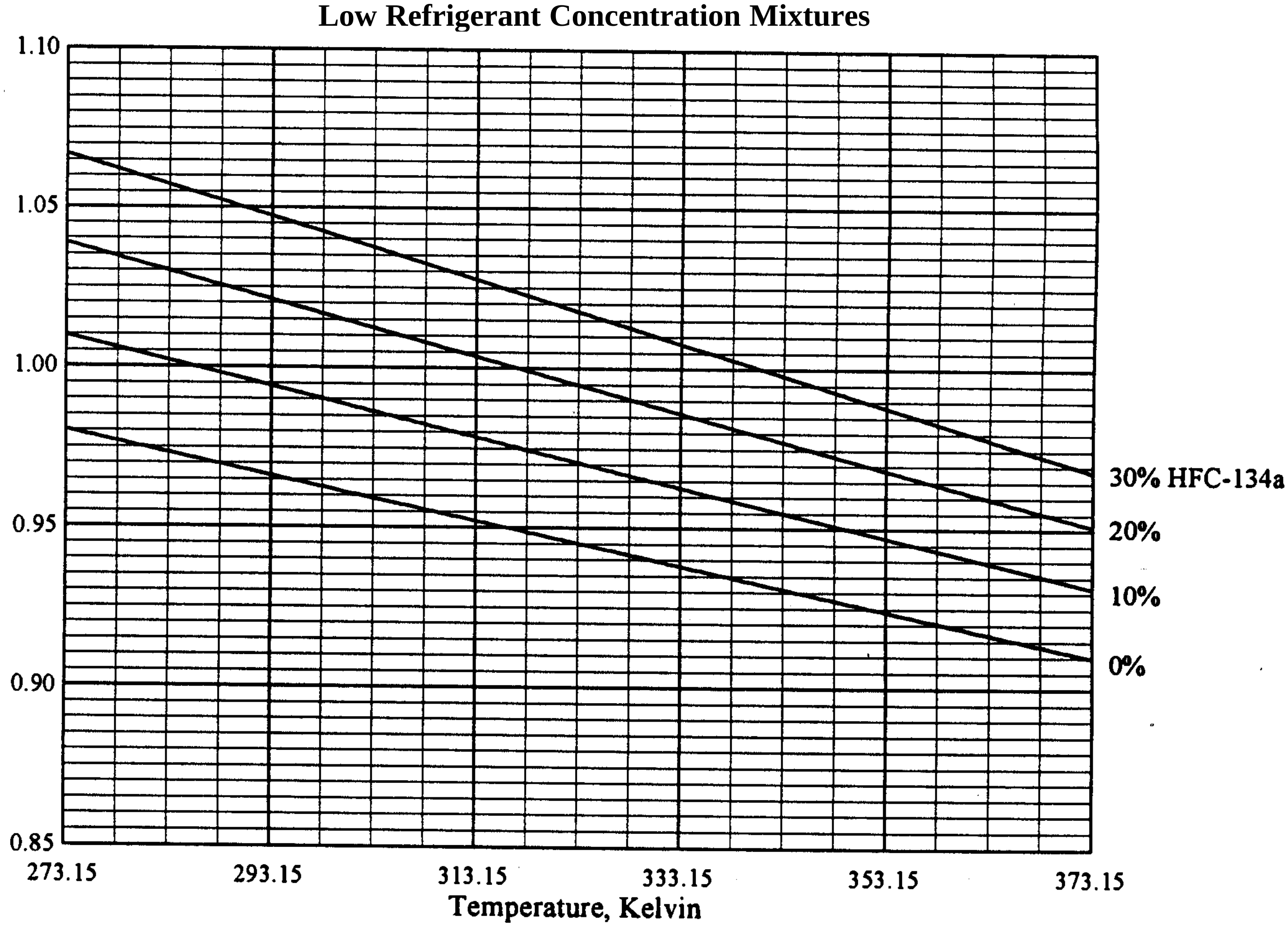


Figure 7-2: Viscosity and Solubility of HFC-134a/ISO 68 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

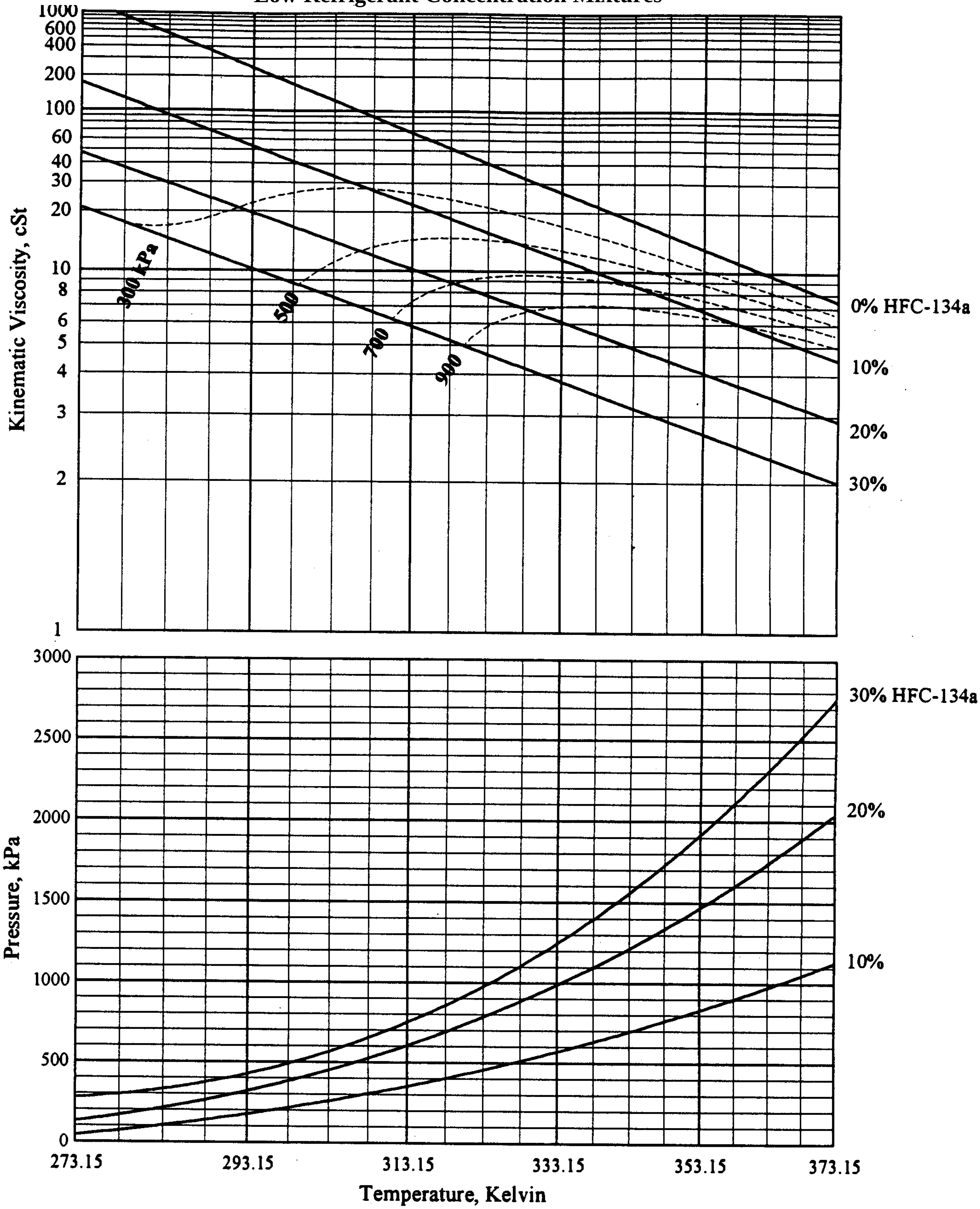


Table 7-2: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 68 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-1.54267E-1	4.93501	-6.03916E-2	6.70804E-1
a_2	-1.30839E+2	-3.90373E+2	-2.50554	-1.13257E+2
a_3	1.89773E+5	-9.75213E+4	1.66826	1.90778E+5
a_4	-1.35162	1.98743	1.30515	-2.54713
a_5	-1.84121E+2	-6.29632E+2	5.39346	-2.84865E+2
a_6	-9.66564E+4	5.83317E+4	-4.46156	-9.66465E+4
a_7	-7.89904E-1	9.65170E-1	-3.42380E-1	3.26527E-1
a_8	8.13268E+2	-7.75785E+2	-1.35909	5.19287E+2
a_9	-1.03939E+5	1.23434E+5	2.26507	-6.55262E+4
σ	0.9999	0.9999	0.9999	0.9999

Figure 7-3: Density of HFC-134a/ISO 68 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

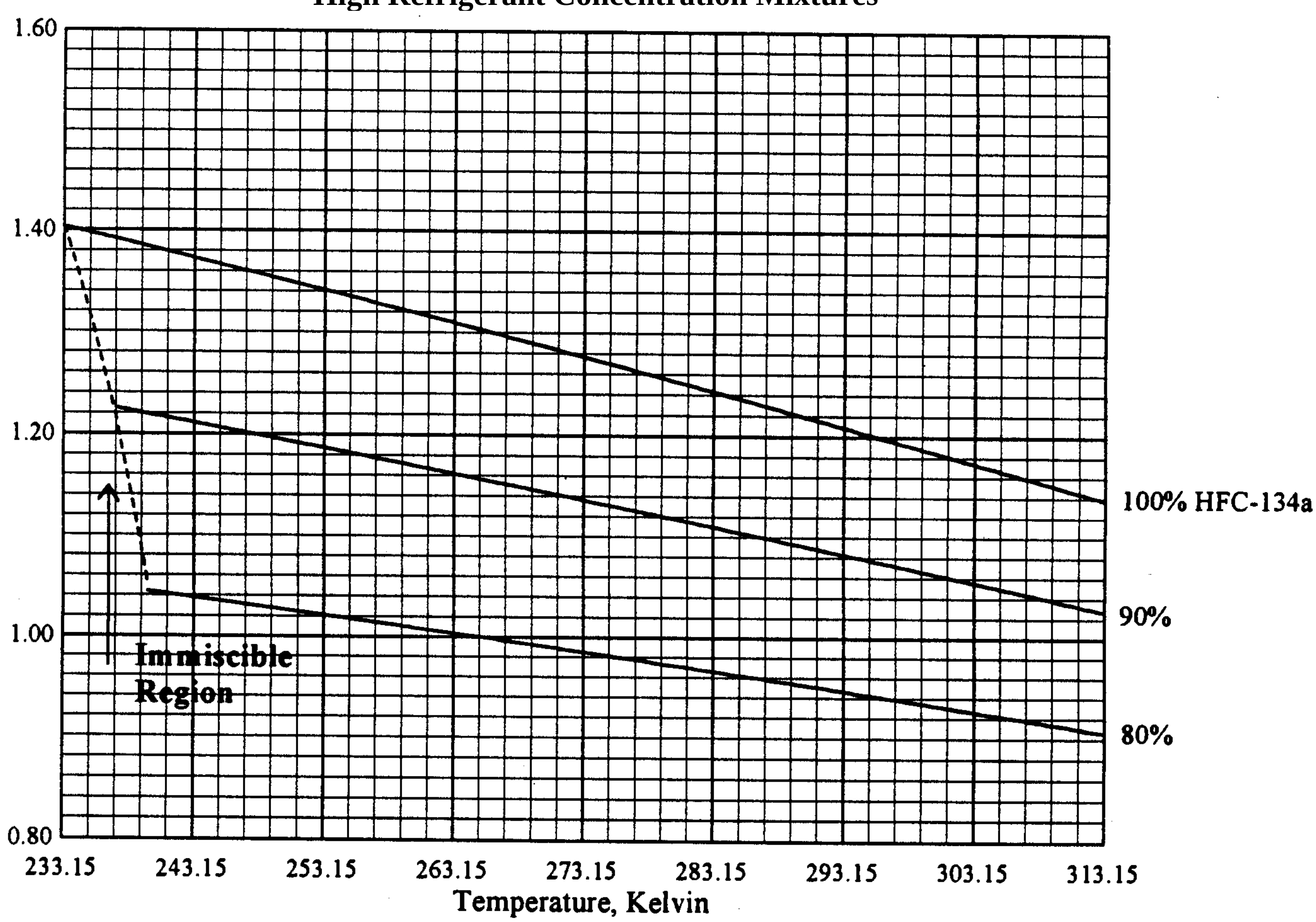


Figure 7-4: Viscosity and Solubility of HFC-134a/ISO 68 Pentaerythritol Ester Mixed Acid #1 High Refrigerant Concentration Mixtures

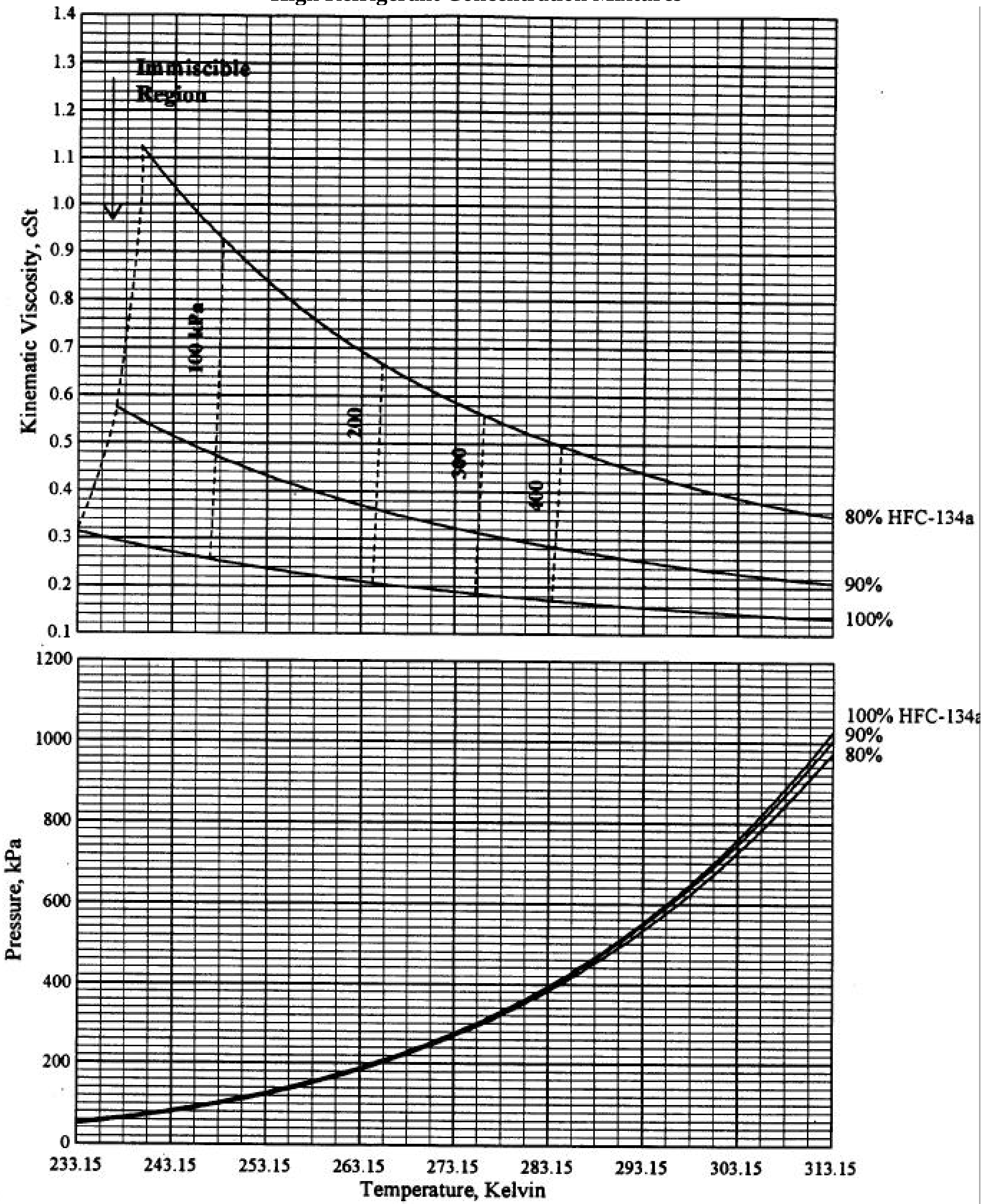


**Table 8-1: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 100 Penaterythritol Ester Mixed Acid
Low Refrigerant Concentration Mixtures**

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.39516	-8.80444E+2	1.16601	9.10304
a_2	-3.64649	5.45176	-6.38053E-4	-3.52779
a_3	0	-8.34803E-3	-8.42418E-8	0
a_4	-6.52943E-1	3.36783E+4	5.56811E-1	-7.32339E-1
a_5	-2.03770E-1	-2.92160E+2	-9.07772E-4	-1.70566E-1
a_6	0	6.28817E-1	-4.07430E-7	0
a_7	9.04645	5.25646E+4	9.58743E-1	1.00748E+1
a_8	-3.68209	-2.54871E+2	-6.88770E-3	-4.13950
a_9	0	2.32627E-1	1.24329E-5	0
σ	0.9995	0.9999	0.9998	0.9997

**Figure 8-1: Density of HFC-134a/ISO 100 Pentaerythritol Ester Mixed Acid
Low Refrigerant Concentration Mixtures**

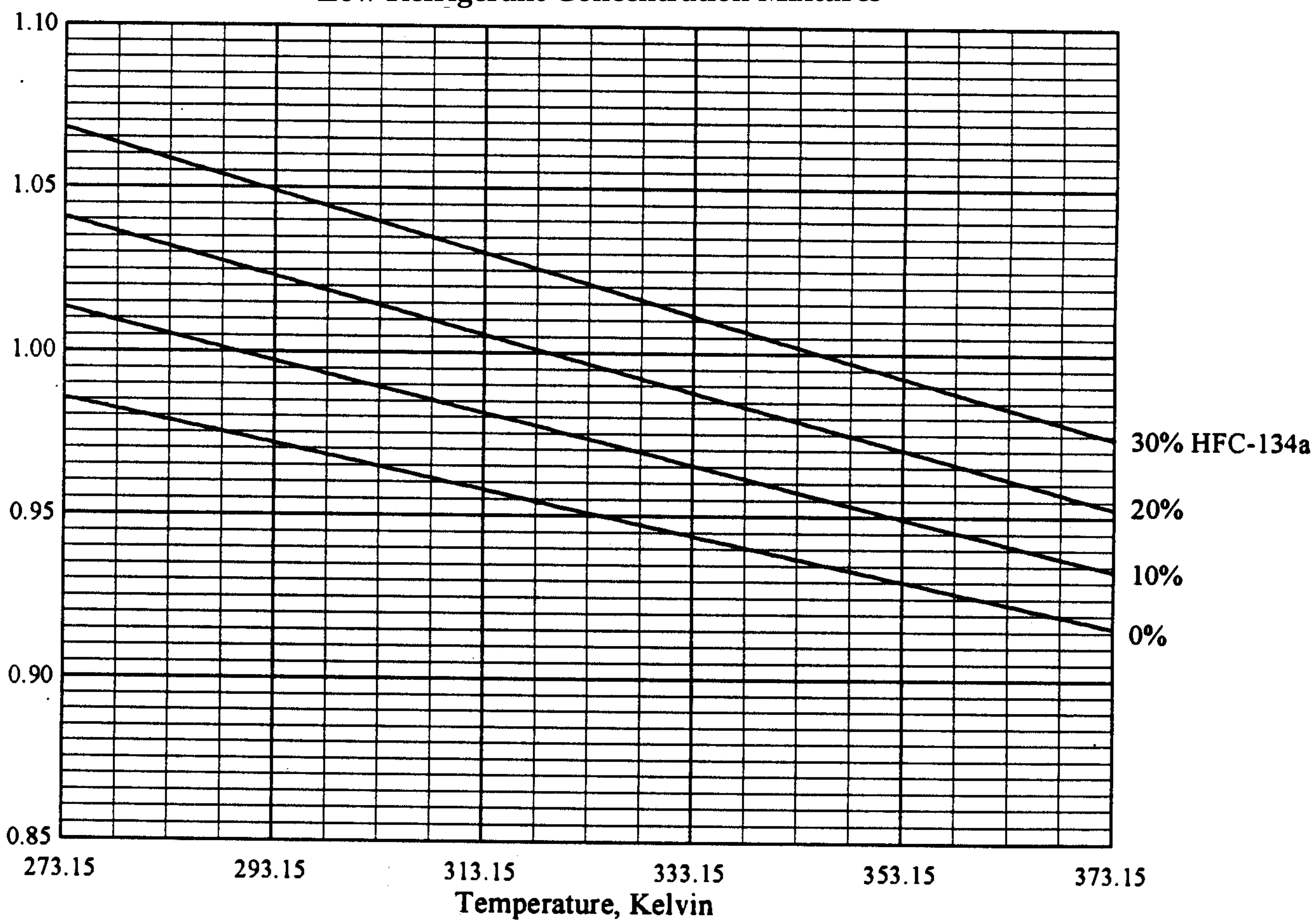


Figure 8-2: Viscosity and Solubility of HFC-134a/ISO 100 Pentaerythritol Ester Mixed Acid Low Refrigerant Concentration Mixtures

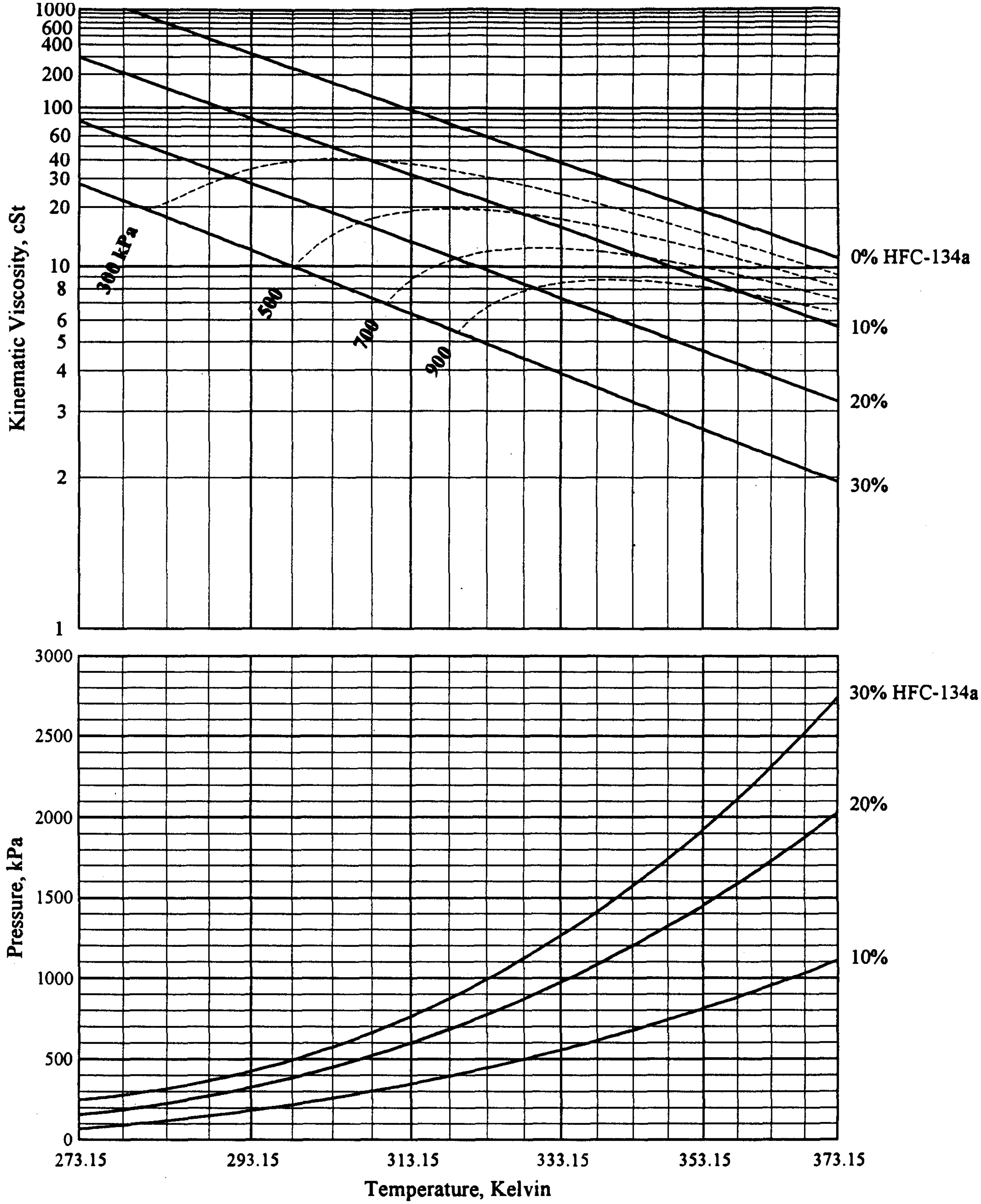


Table 8-2: Viscosity, Solubility and Density Parameters HFC-134a/ISO 100 Pentaerythritol Ester Mixed Acid High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-3.15040	3.34517	-1.94056E-1	-1.34681E-1
a_2	9.35516E+2	-3.38366E+1	2.18604E-1	-6.50651E+2
a_3	1.05291E+5	-6.53110E+4	-5.30749	3.74637E+5
a_4	1.03070E+1	4.18610	1.33892	5.91882E-1
a_5	-5.40294E+3	-7.34708E+2	9.72285E-1	9.88778E+1
a_6	5.07096E+5	-9.91095E+4	8.19127	-3.70120E+5
a_7	-9.15198	3.85718E-1	-1.68005E-1	-1.69327
a_8	4.81098E+3	-1.04375E+3	-1.65734E-1	5.04946E+2
a_9	-6.03417E+5	2.50991E+5	-2.58563	4.63713E+4
σ	0.9999	0.9999	0.9999	0.9999

Figure 8-3: Density of HFC-134a/ISO 100 Pentaerythritol Ester Mixed High Refrigerant Concentration Mixtures

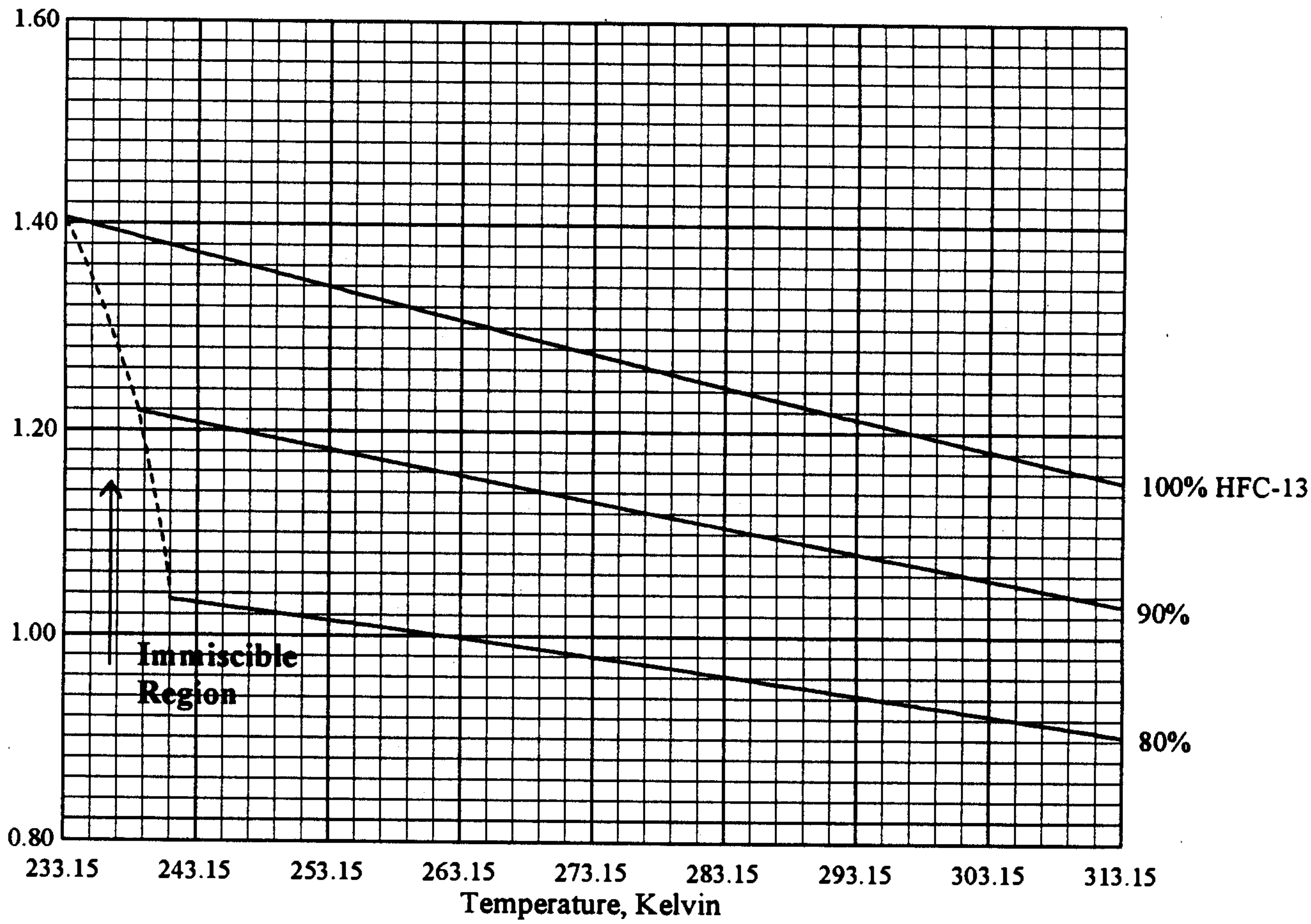


Figure 8-4: Viscosity and Solubility of HFC-134a/ISO 100 Pentaerythritol Ester Mixed Acid High Refrigerant Concentration Mixtures

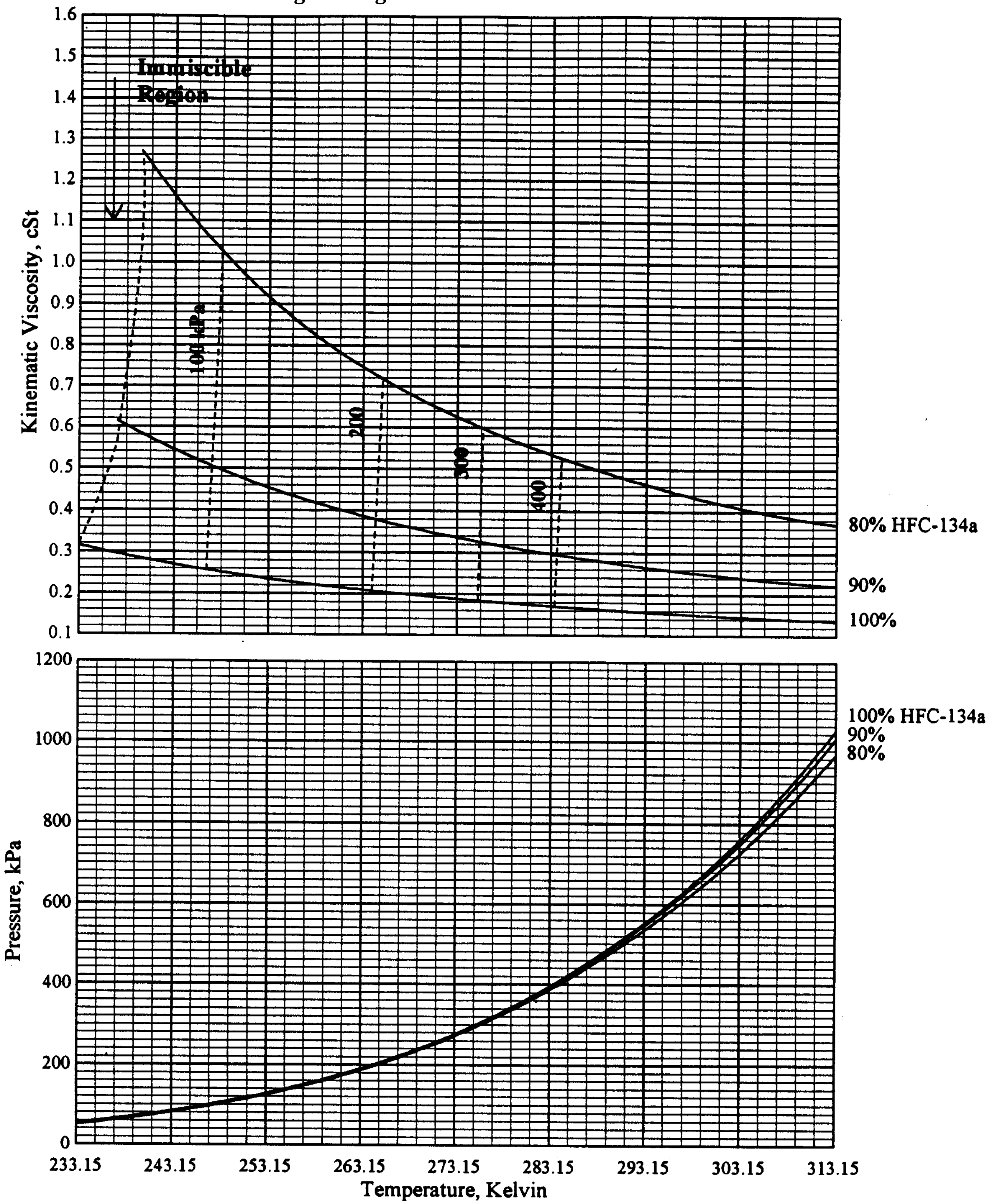


Table 9-1: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 22 Penaterythritol Ester Branched Acid
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.01115E+1	3.88610E+2	1.22814	9.89055
a_2	-3.99968	-2.44464	-6.05295E-4	-3.91129
a_3	0	3.83619E-3	-2.83877E-7	0
a_4	-5.51364	-1.12283E+4	1.98417	-5.50167
a_5	1.90066	2.20125E-1	-1.05468E-2	1.88419
a_6	0	1.49557E-1	1.56200E-5	0
a_7	1.83841E+1	1.93083E+5	-3.24206	1.88386E+1
a_8	-7.73434	-1.15237E+3	2.05857E-2	-7.94982
a_9	0	1.67014	-3.25410E-5	0
σ	0.9993	0.9997	0.9998	0.9994

Figure 9-1: Density of HFC-134a/ISO 22 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

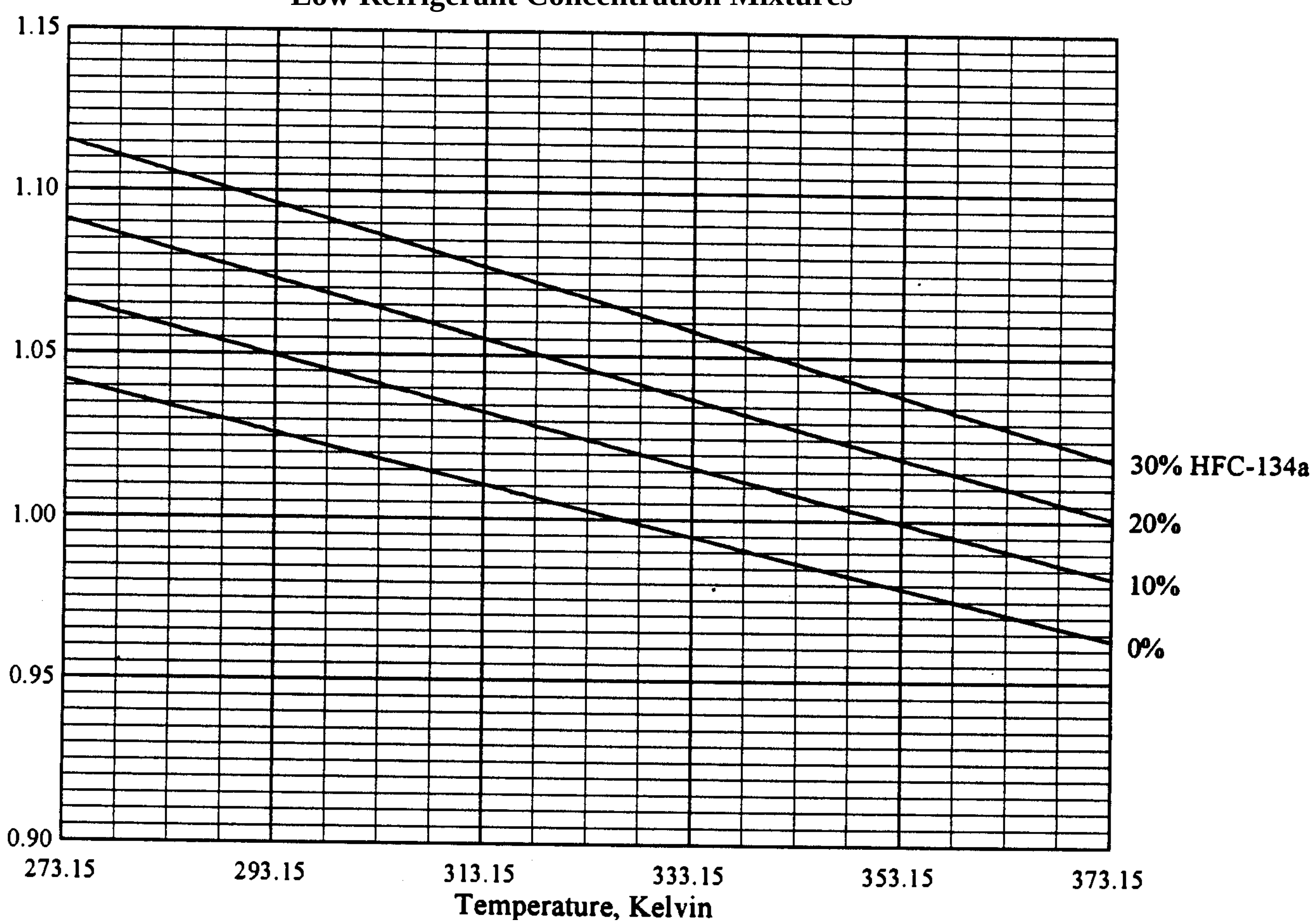


Figure 9-2: Viscosity and Solubility of HFC-134a/ISO 22 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

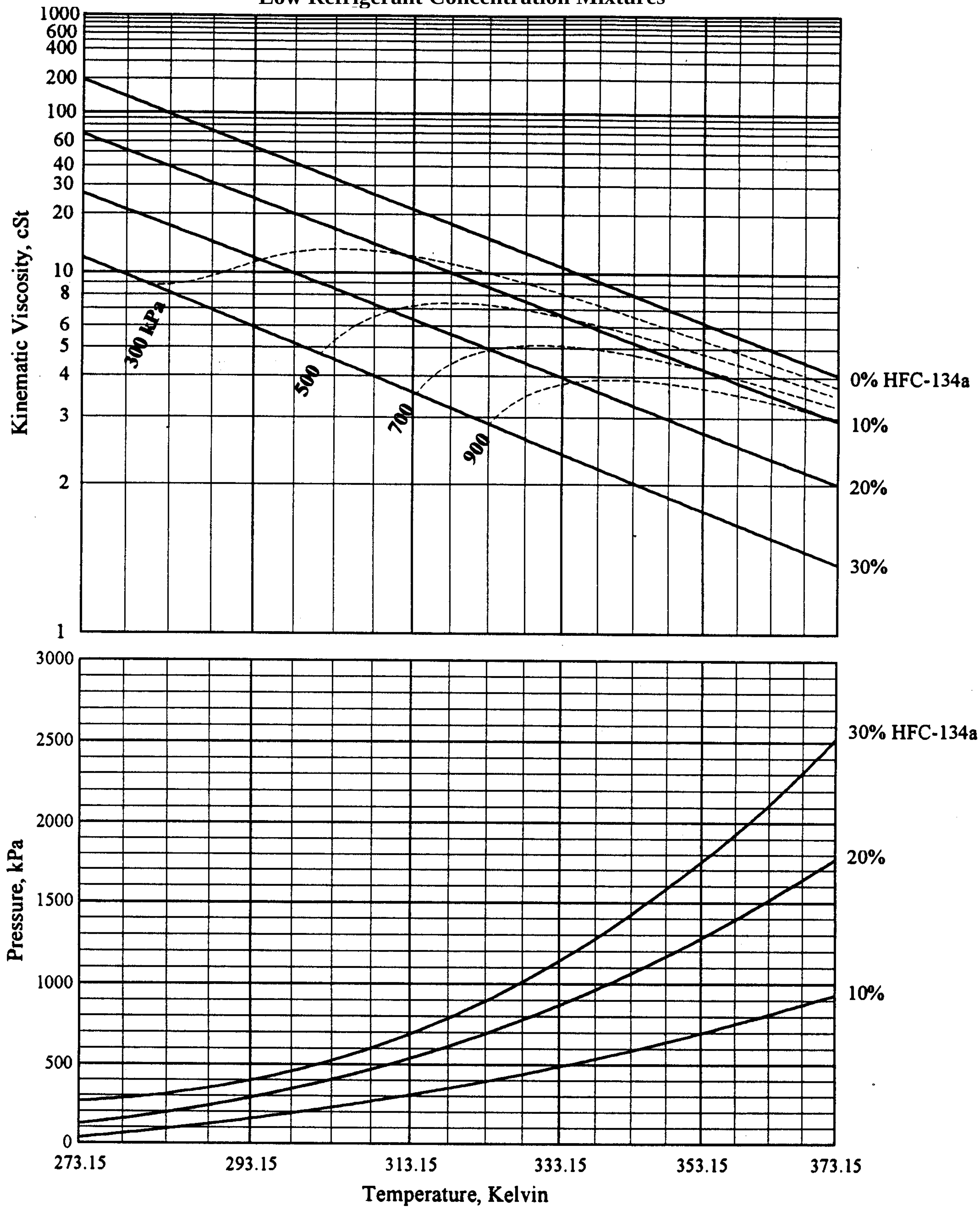


Table 9-2: Viscosity, Solubility and Density Parameters HFC-134a/ISO 22 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-2.13068	8.17274	-7.28853E-1	-7.80031E-1
a_2	-3.11644E+2	-3.79886E+2	-5.18003	-3.59970E+2
a_3	2.67276E+5	-3.12174E+5	1.81220E+1	2.51073E+5
a_4	3.60679	-6.21892	3.07139	-2.46749E-2
a_5	1.56397E+2	-1.56993E+2	1.00223E+1	8.55352E+2
a_6	-3.06662E+5	4.72009E+5	-3.90141E+1	-3.54099E+5
a_7	-3.64889	5.84111	-1.44391	-5.53661E-1
a_8	5.89491E+2	-1.19898E+3	-3.29785	-4.75386E+2
a_9	3.68104E+4	-8.49250E+4	2.03565E+1	1.44870E+5
σ	0.9999	0.9998	0.9999	0.9999

Figure 9-3: Density of HFC-134a/ISO 22 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

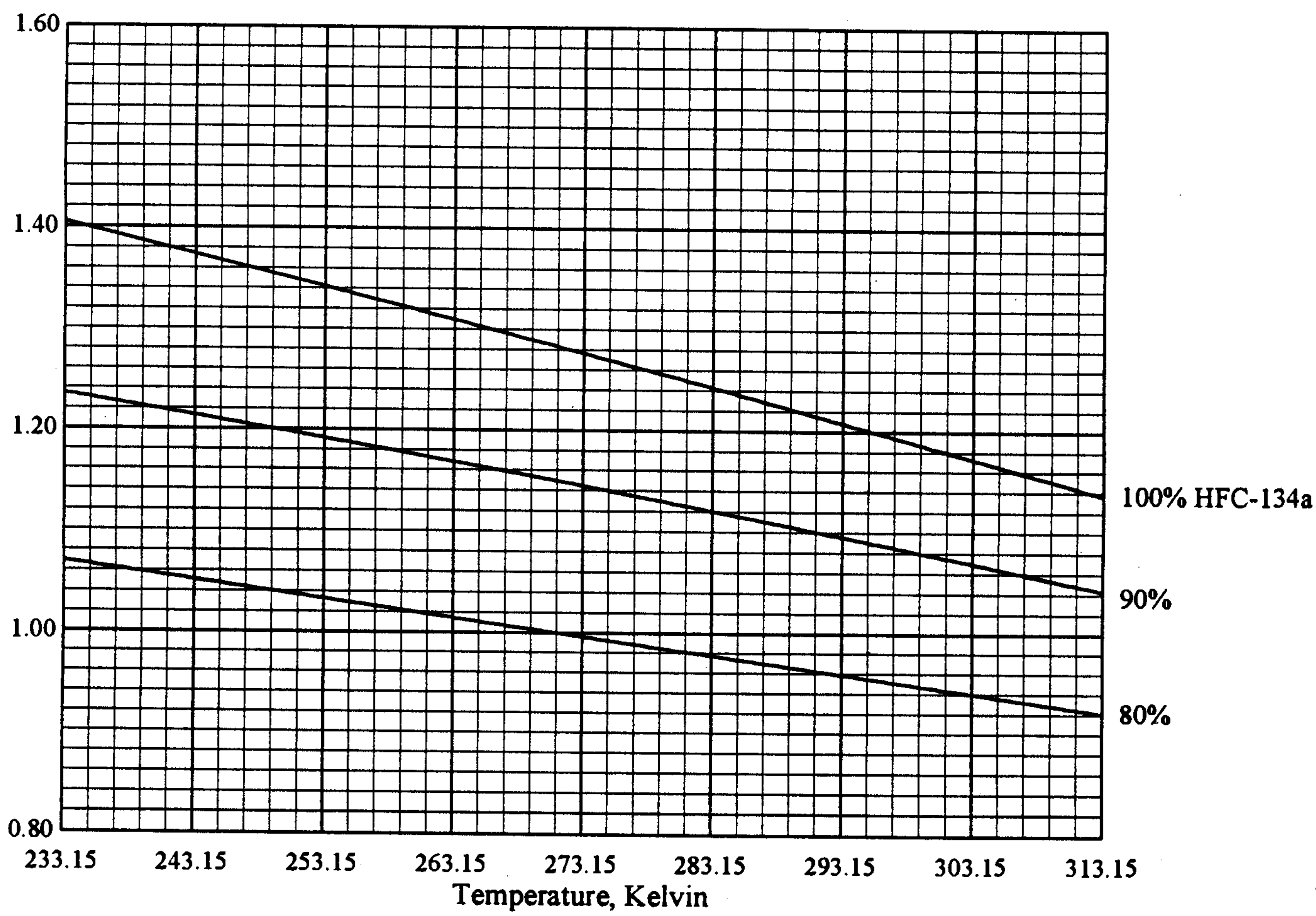


Figure 9-4: Viscosity and Solubility of HFC-134a/ISO 22 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

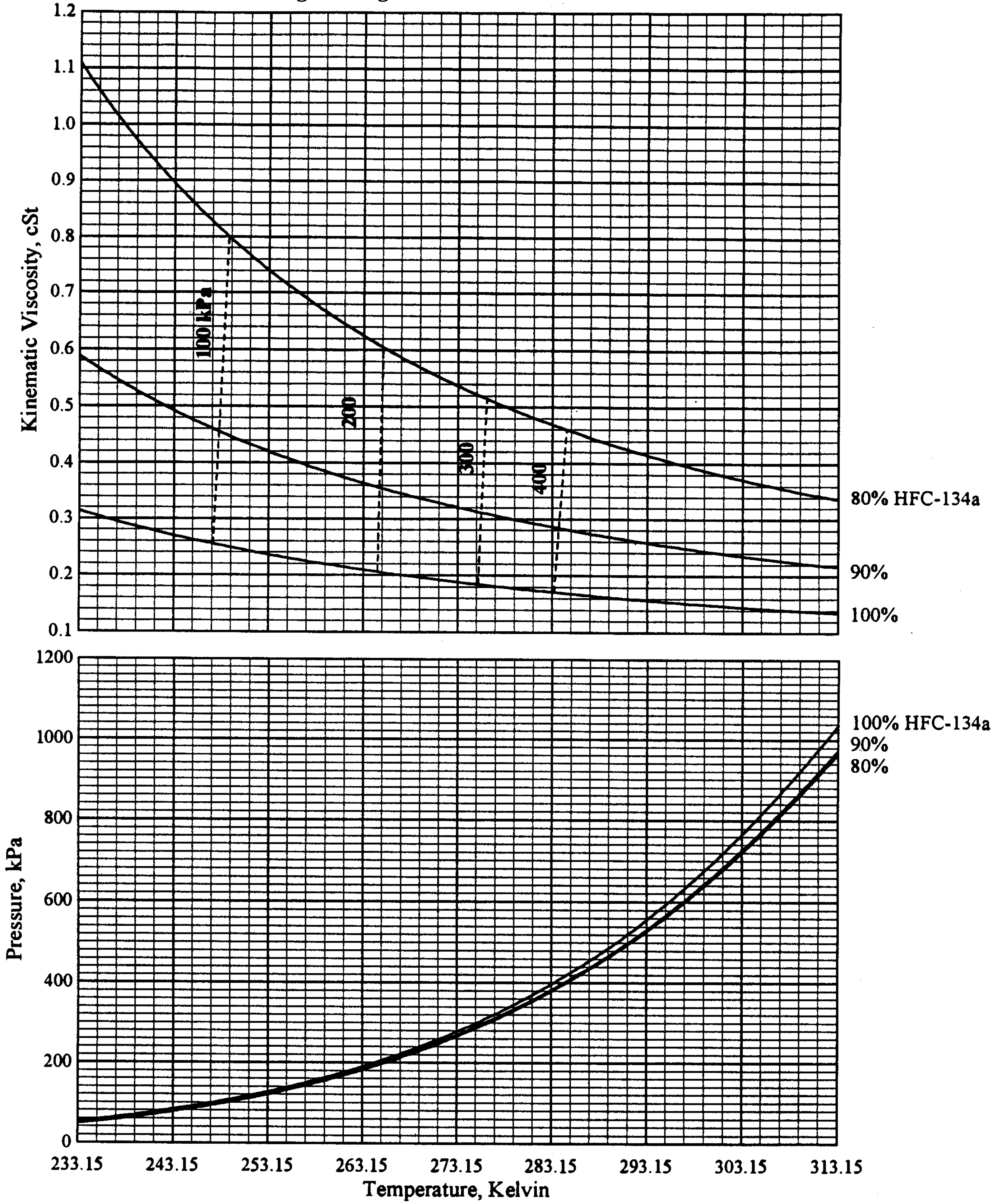


Table 10-1: Viscosity, Solubility and Density Parameters HFC-134a/ISO 32 Penaterythritol Ester Mixed Acid #2 Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.44017	-1.57280E+3	1.50177	9.17097
a_2	-3.71459	9.66073	-2.52139E-3	-3.60543
a_3	0	-1.46003E-2	2.73051E-6	0
a_4	-7.89364E-2	3.74572E+4	-4.44085	-1.15777E-1
a_5	-2.41486E-1	-2.92537E+2	3.01571E-2	-2.33594E-1
a_6	0	5.78510E-1	4.83419E-5	0
a_7	3.31716E-1	4.77228E+4	1.57784E+1	8.53491E-1
a_8	-6.38203E-1	-3.22227E+2	-9.93488E-2	-8.84028E-1
a_9	0	5.39861E-1	1.55625E-4	0
σ	0.9998	0.9978	0.9992	0.9998

Figure 10-1: Density of HFC-134a/ISO 32 Pentaerythritol Ester Mixed Acid #2 Low Refrigerant Concentration Mixtures

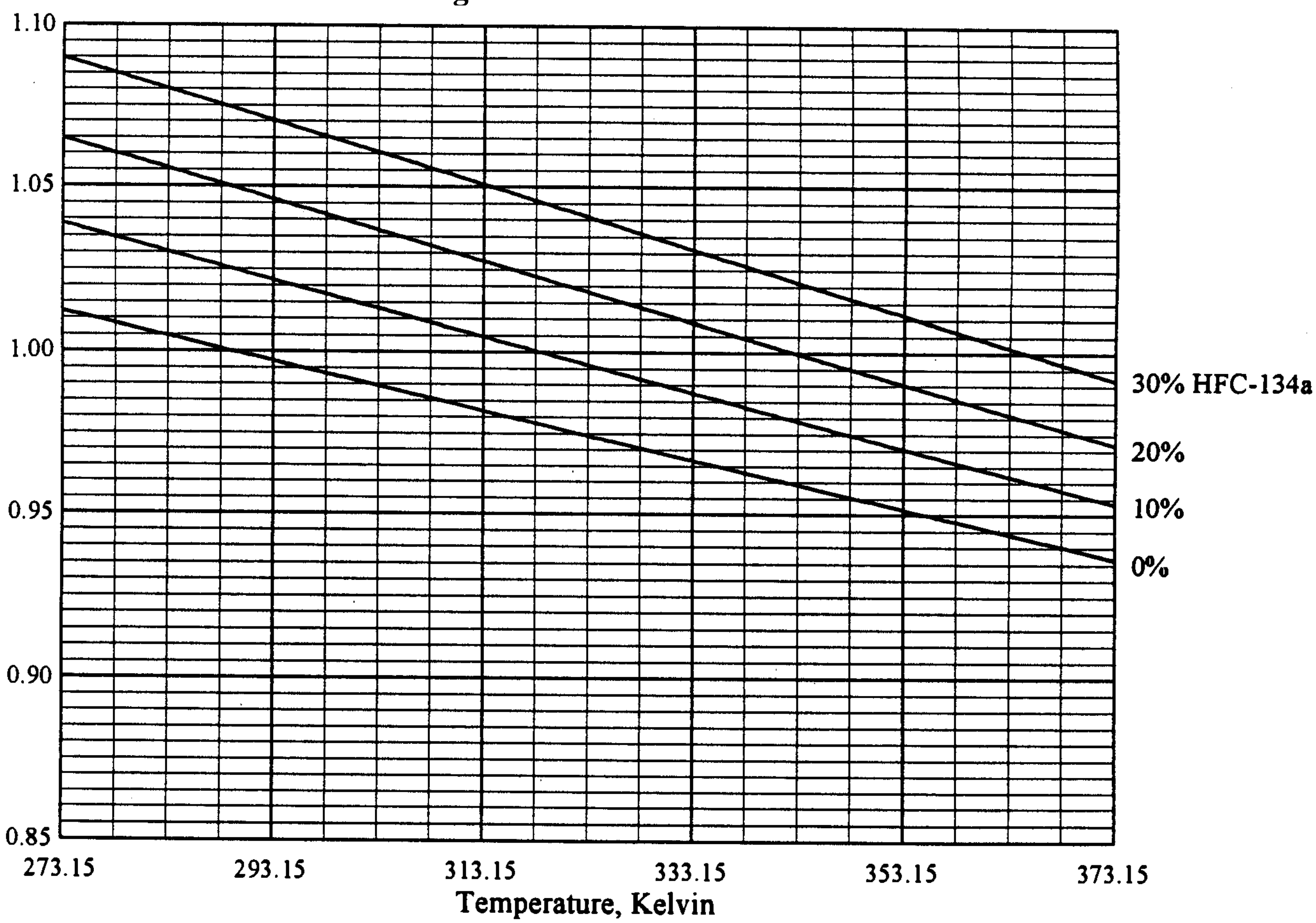


Figure 10.2: Viscosity and Solubility of HFC-134a/ISO 32 Pentaerythritol Ester Mixed Acid #2 Low Refrigerant Concentration Mixtures

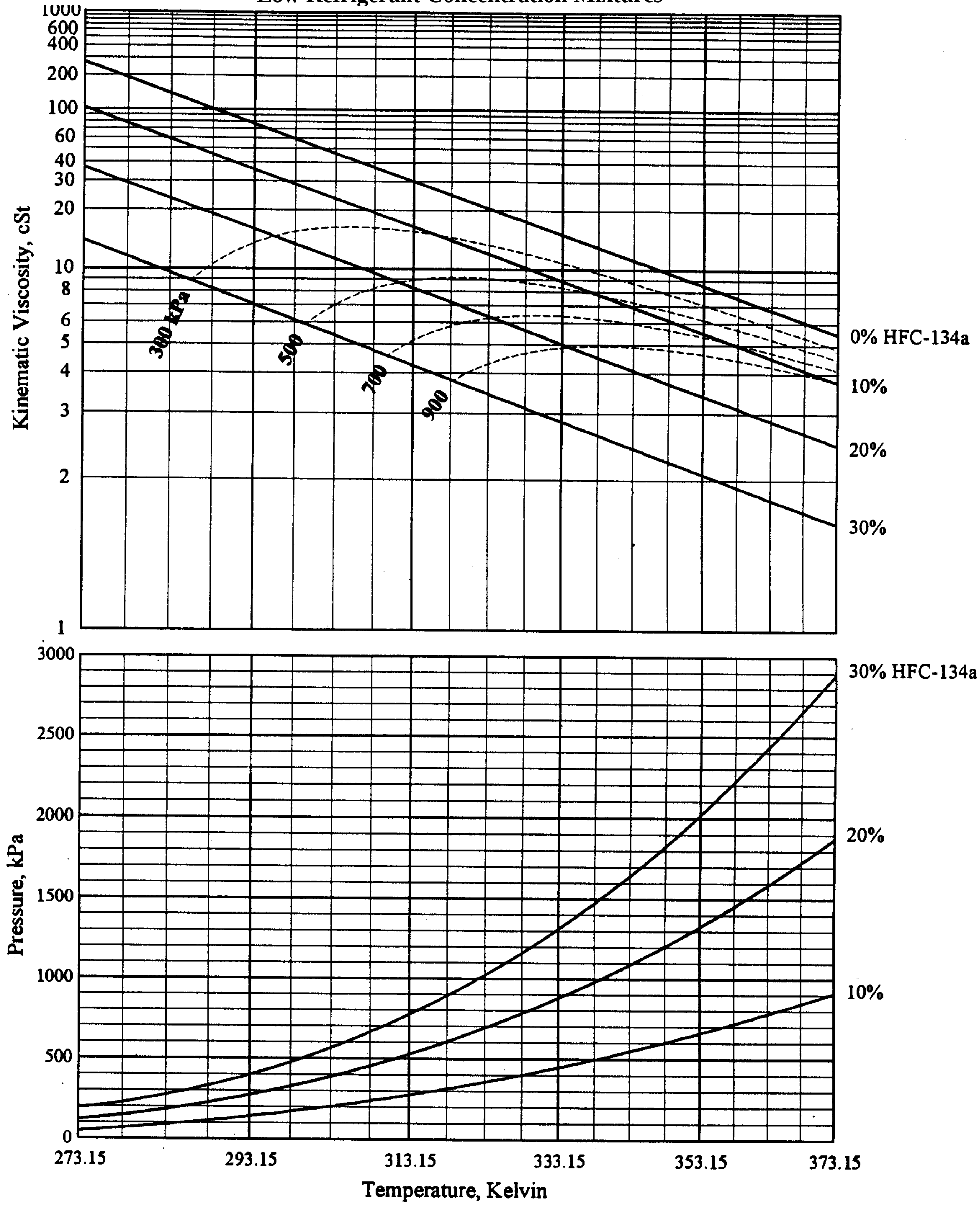


Table 10-2: Viscosity, Solubility and Density Parameters HFC-134a/ISO 32 Pentaerythritol Ester Mixed Acid #2 High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	2.28826E-1	3.26218	-5.20544E-2	1.25921
a_2	-1.22901E+3	1.43578E+2	-8.48211	-1.65156E+3
a_3	4.65930E+5	-1.13312E+5	3.50146E+1	5.45549E+5
a_4	3.75901	4.32627	1.35558	3.45701
a_5	-8.72288E+2	-1.15328E+3	1.80809E+1	-7.16272E+2
a_6	-3.20701E+5	1.50216E+4	-7.80529E+1	-3.98281E+5
a_7	-6.65343	5.25739E-1	-3.99086E-1	-6.76491
a_8	2.79318E+3	-9.08547E+2	-8.12848	2.75135E+3
a_9	-1.81129E+5	1.98948E+5	4.26825E+1	-1.52802E+5
σ	0.9999	0.9999	0.9997	0.9997

Figure 10-3: Density of HFC-134a/ISO 32 Pentaerythritol Ester Mixed Acid #2 High Refrigerant Concentration Mixtures

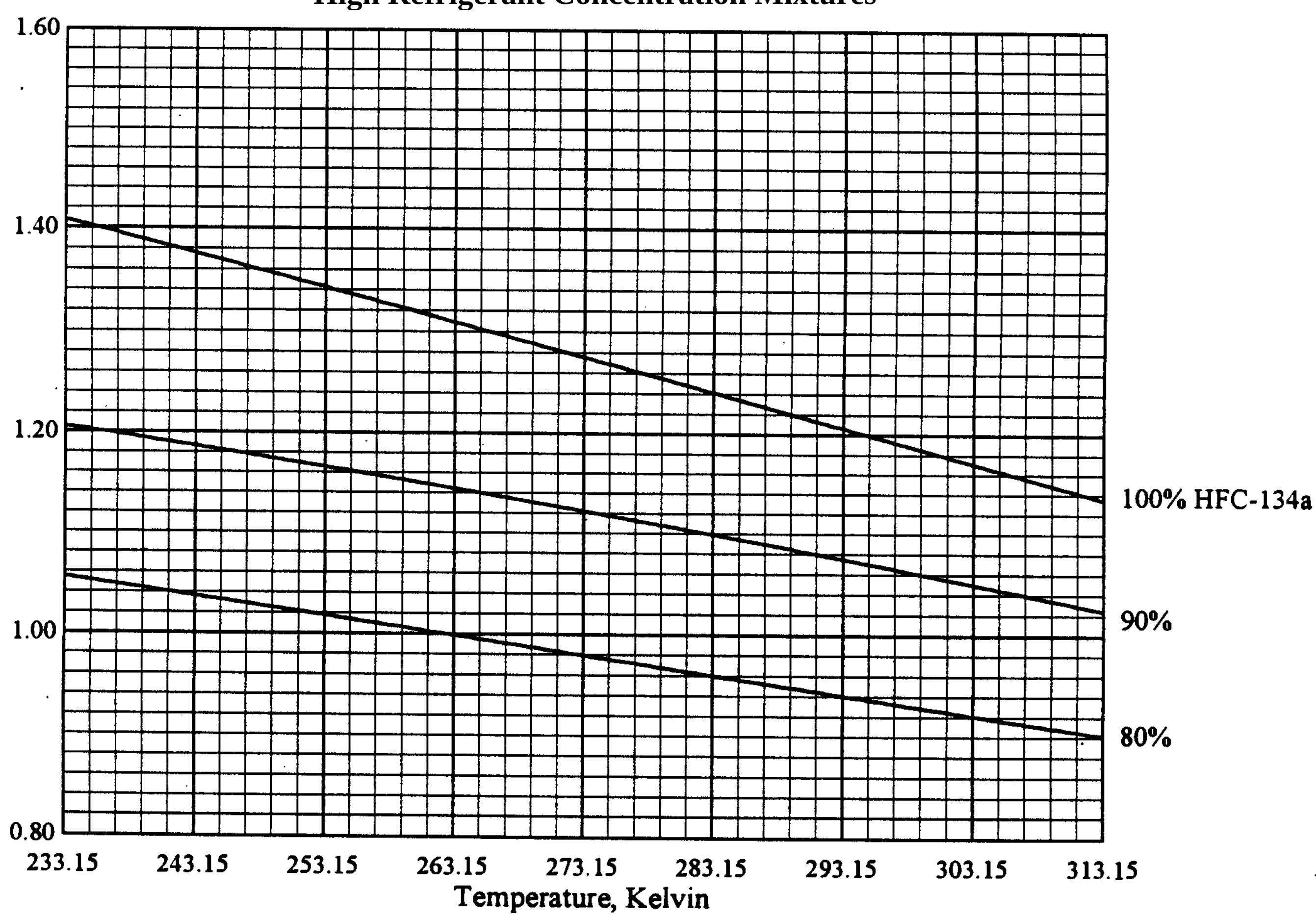


Figure 10.4: Viscosity and Solubility of HFC-134a/ISO 32 Penaterythritol Ester Mixed Acid #2 High Refrigerant Concentration Mixtures

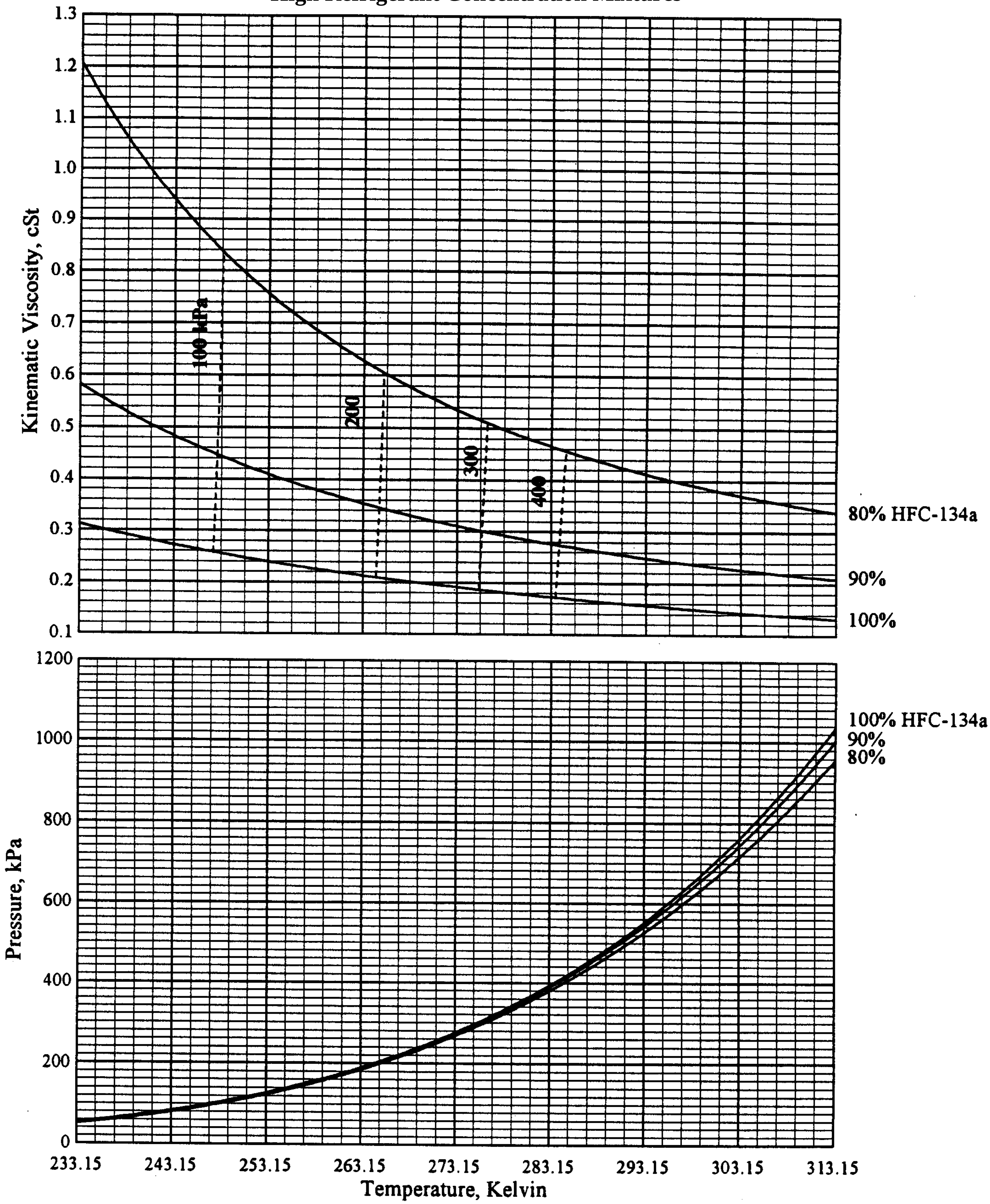


**Table 11-1: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 68 Penaterythritol Ester Branched Acid
Low Refrigerant Concentration Mixtures**

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.36879	1.15698E+3	1.35141	9.24857
a_2	-3.64973	-7.24740	-1.25841E-3	-3.60255
a_3	0	1.12673E-2	7.44833E-7	0
a_4	-8.16203	1.10499E+4	4.20602E-1	-8.05857
a_5	2.92595	-1.47866E+2	-7.74779E-4	2.87554
a_6	0	3.98728E-1	2.89145E-7	0
a_7	2.70277E+1	1.05859E+5	2.38246E-2	2.64283E+1
a_8	-1.10738E+1	-5.87685E+2	5.16019E-4	-1.08610E+1
a_9	0	7.46136E-1	-2.34721E-6	0
σ	0.9996	0.9999	0.9995	0.9996

**Figure 11-1: Density of HFC-134a/ISO 68 Pentaerythritol Ester Branched Acid
Low Refrigerant Concentration Mixtures**

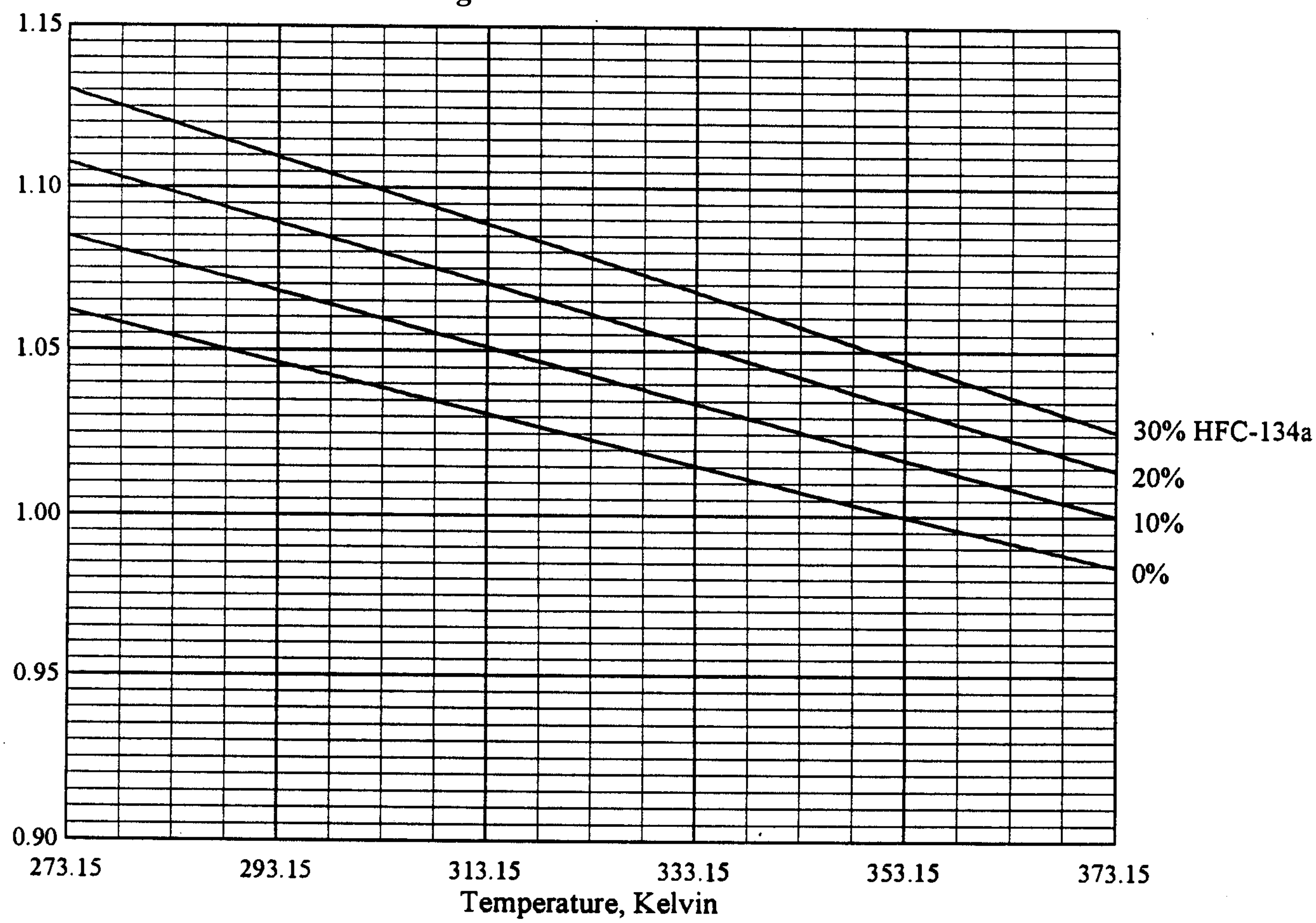


Figure 11-2: Viscosity and Solubility of HFC-134a/ISO 68 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

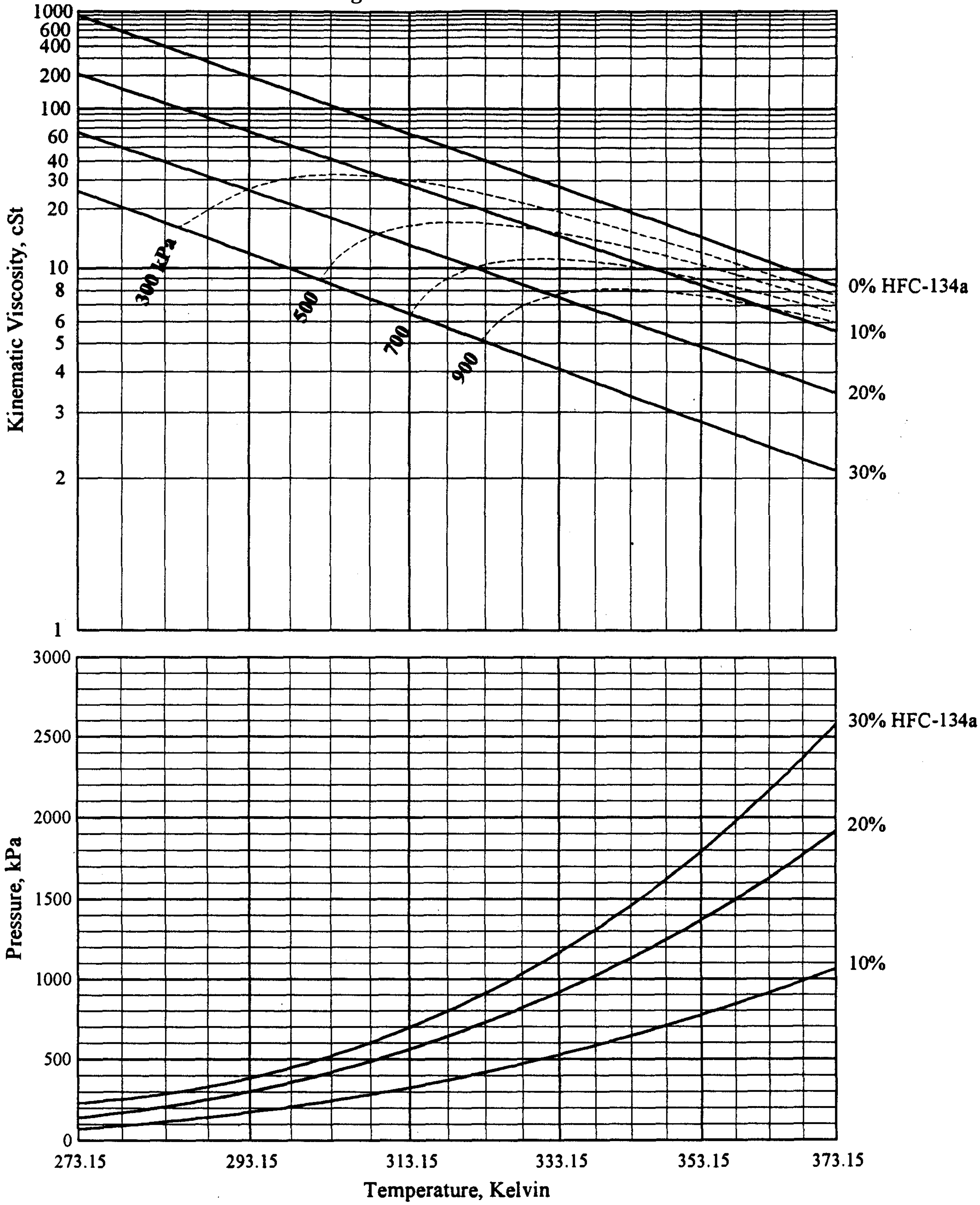


Table 11-2: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 68 Pentaerythritol Ester Branched Acid
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-8.72650E-1	4.50356	-6.00005E-1	-1.65635E-1
a_2	2.48588E+2	-1.02368E+3	-1.36300	8.11046E+1
a_3	8.21631E+4	1.21007E+5	2.90542	1.43170E+5
a_4	-4.73166E-1	6.68778	2.70040	-4.59212E-1
a_5	-3.26905E+2	-1.29817E+3	2.31427	-5.64881E+2
a_6	2.51007E+4	-1.42206E+5	-6.55983	-3.29294E+4
a_7	-7.59013E-1	-3.86121	-1.19931	-8.40052E-1
a_8	4.75836E+2	8.23932E+2	5.89474E-1	5.60054E+2
a_9	-1.04921E+5	6.59348E+4	3.10129	-7.57655E+4
σ	0.9999	0.9999	0.9999	0.9999

Figure 11-3: Density of HFC-134a/ISO 68 Pentaerythritol Ester Branched Acid
High Refrigerant Concentration Mixtures

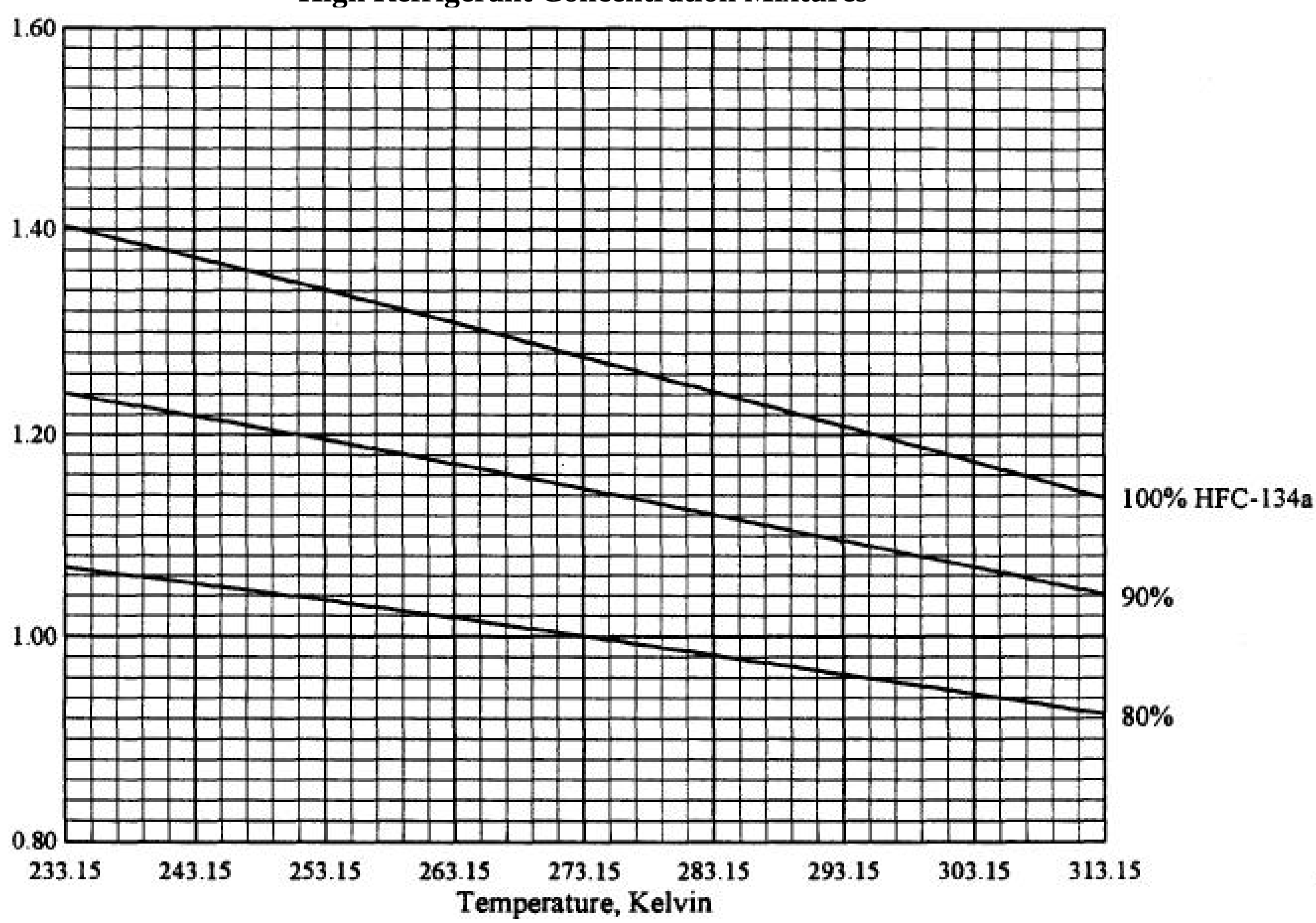


Figure 11-4: Viscosity and Solubility of HFC-134a/ISO 68 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

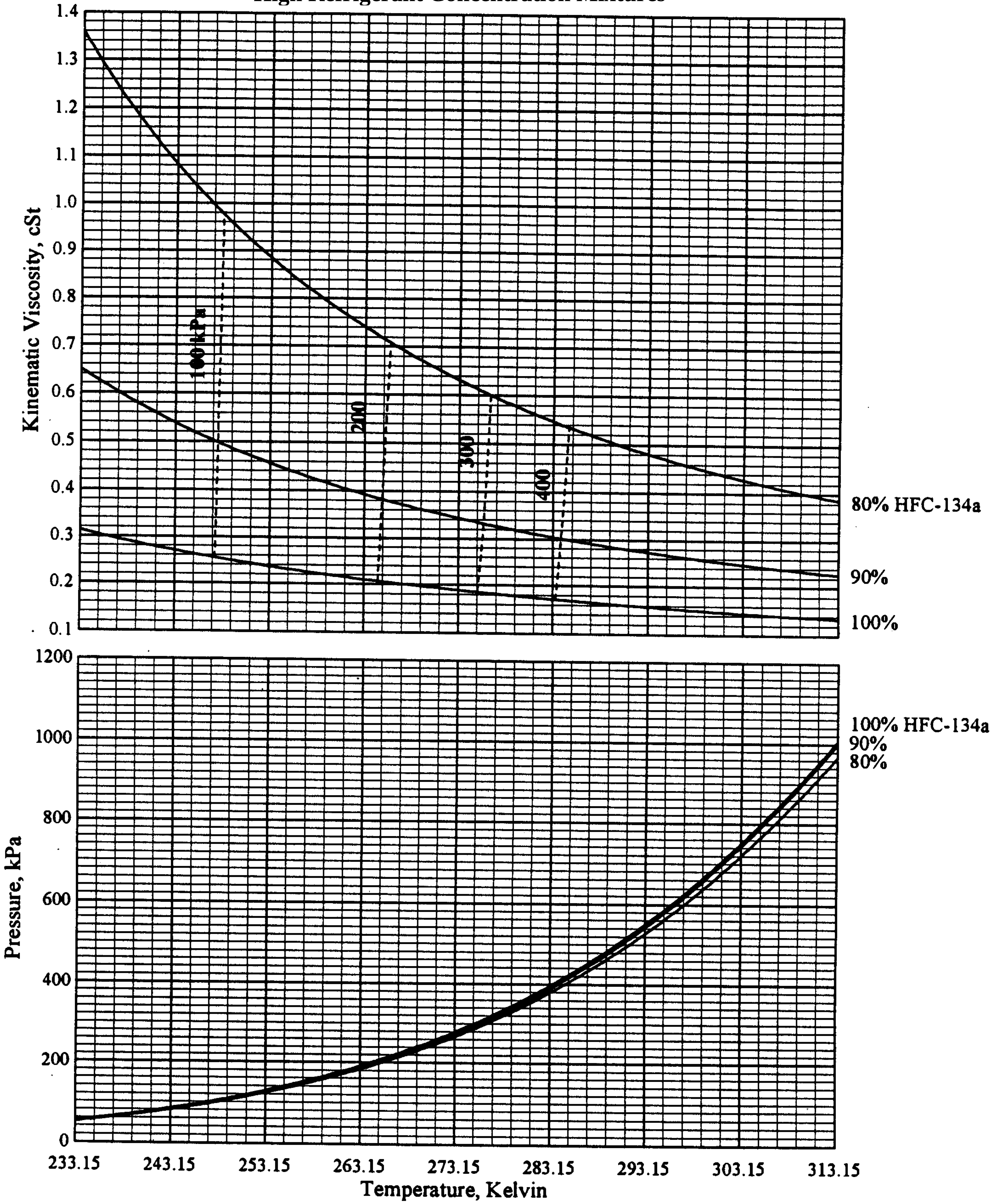


Table 12-1: Viscosity, Solubility and Density Parameters HFC-134a/ISO 100 Penaterythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	8.29980	3.47568E+2	1.29320	8.20711
a_2	-3.20316	-2.22002	-8.33097E-4	-3.16733
a_3	0	3.53118E-03	9.35243E-8	0
a_4	9.57472E-2	2.05216E+4	1.61662	2.63799E-2
a_5	-5.03322E-1	-2.13651E+2	-7.88841E-3	-4.84972E-1
a_6	0	5.12602E-1	1.05986E-5	0
a_7	-2.92346	7.14765E+4	-4.08554	-2.67496
a_8	1.34790	-3.57939E+2	2.46902E-2	1.22030
a_9	0	3.64799E-1	-3.64865E-5	0
σ	0.9999	0.9999	0.9991	0.9999

Figure 12-1: Density of HFC-134a/ISO 100 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

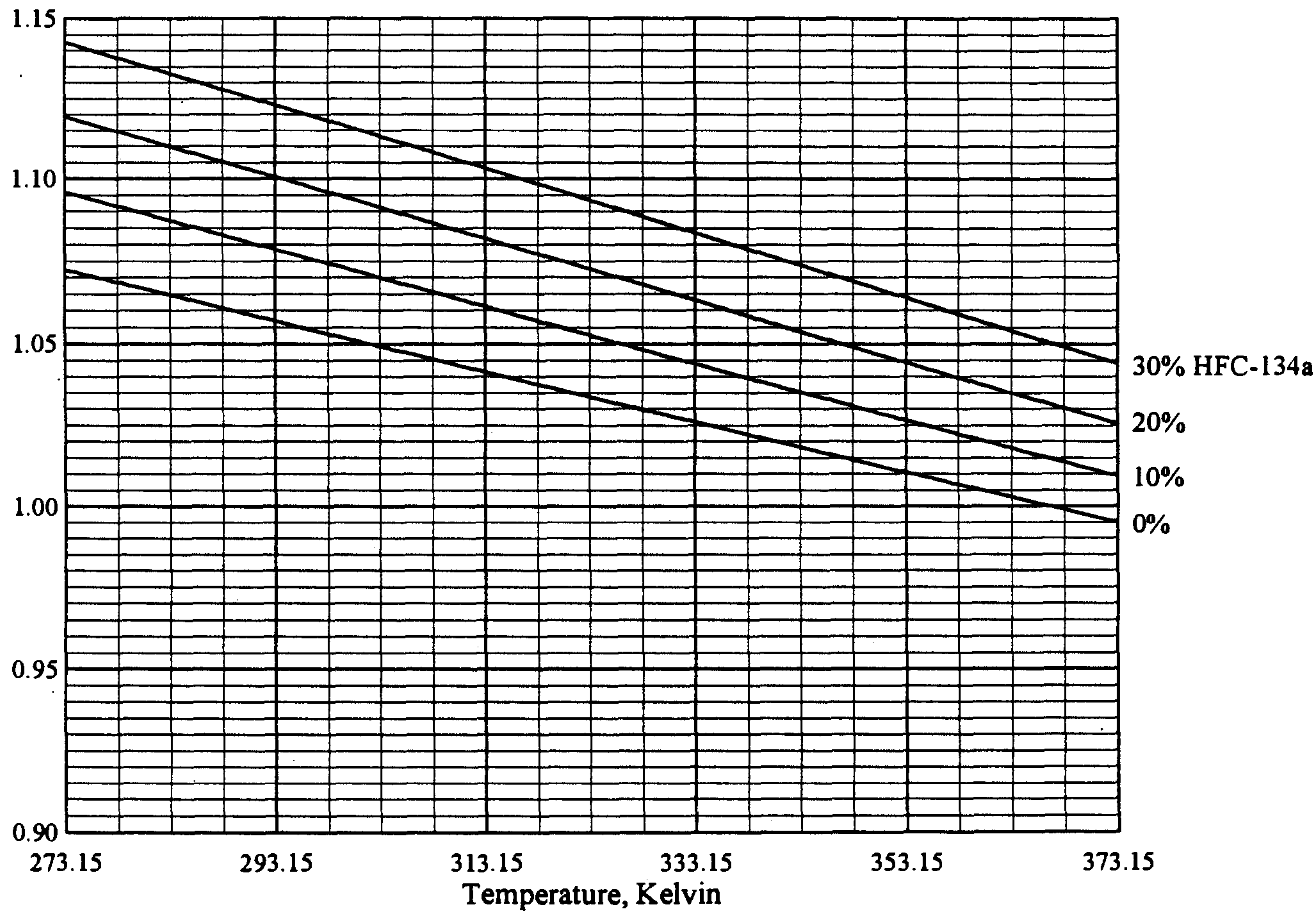


Figure 12-2: Viscosity and Solubility of HFC-134a/ISO 100 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

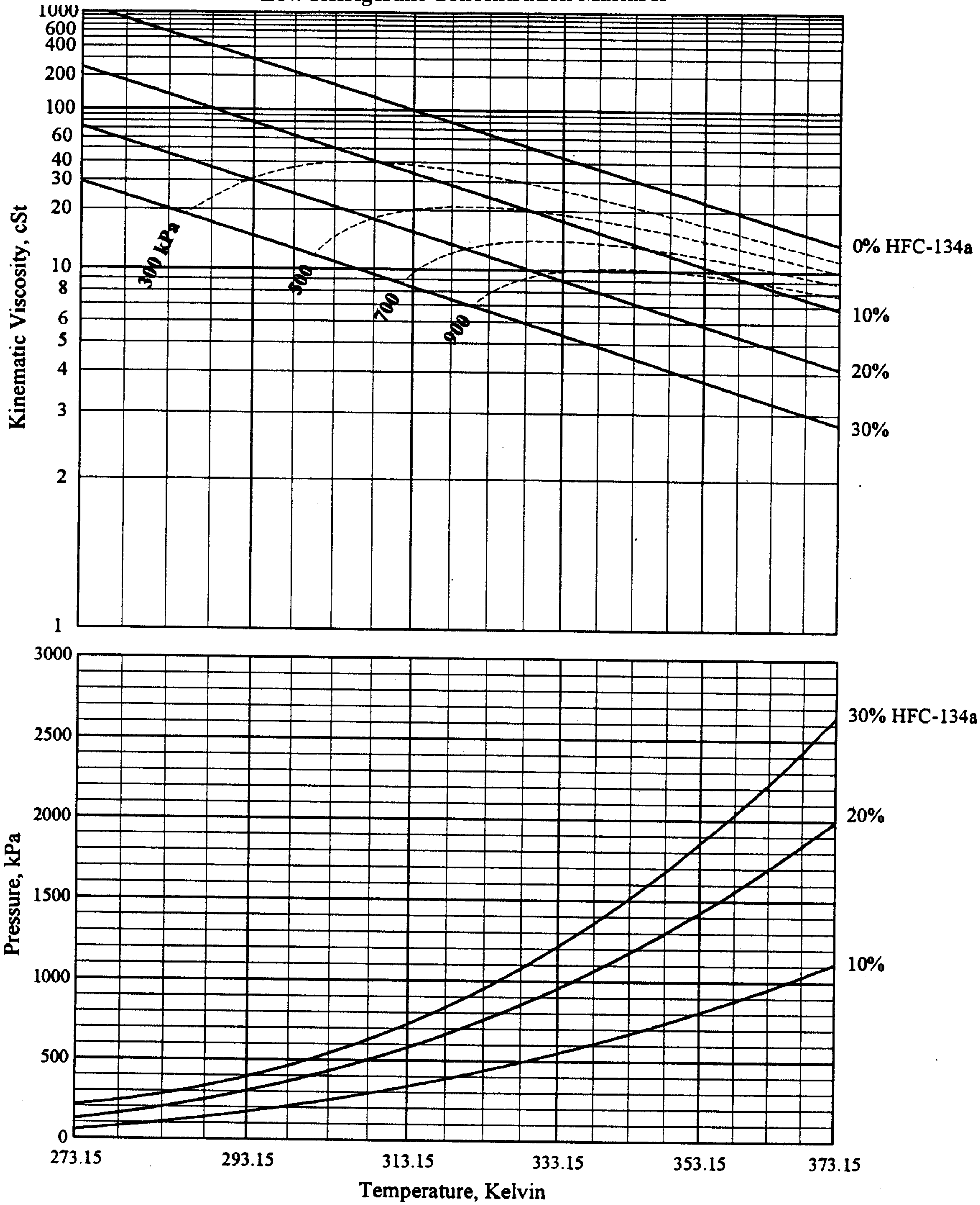


Table 12-2: Viscosity, Solubility and Density Parameters
HFC-134a/ISO 100 Pentaerythritol Ester Branched Acid
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	6.12636E-3	2.23668	2.06600	-4.96936E-2
a_2	9.94122E+2	-1.15988E+2	2.56923	-2.69268E+2
a_3	-5.54165E+4	-2.47171E+4	1.49475	2.53663E+5
a_4	-6.80521E-1	6.43171	-3.25589	1.72877
a_5	-2.91353E+3	-3.65985E+2	-6.91930	-1.05160E+3
a_6	4.70750E+5	-2.22909E+5	-2.54820	-9.67116E+4
a_7	-1.69372	-3.61286E-1	2.09312	-3.49643
a_8	2.46146E+3	-1.54866E+3	5.87213	1.58715E+3
a_9	-4.32625E+5	3.64466E+5	5.38856E-1	-1.47831E+5
σ	0.9999	0.9994	0.9999	0.9999

Figure 12-3: Density of HFC-134a/ISO 100 Pentaerythritol Ester Branched Acid
High Refrigerant Concentration Mixtures

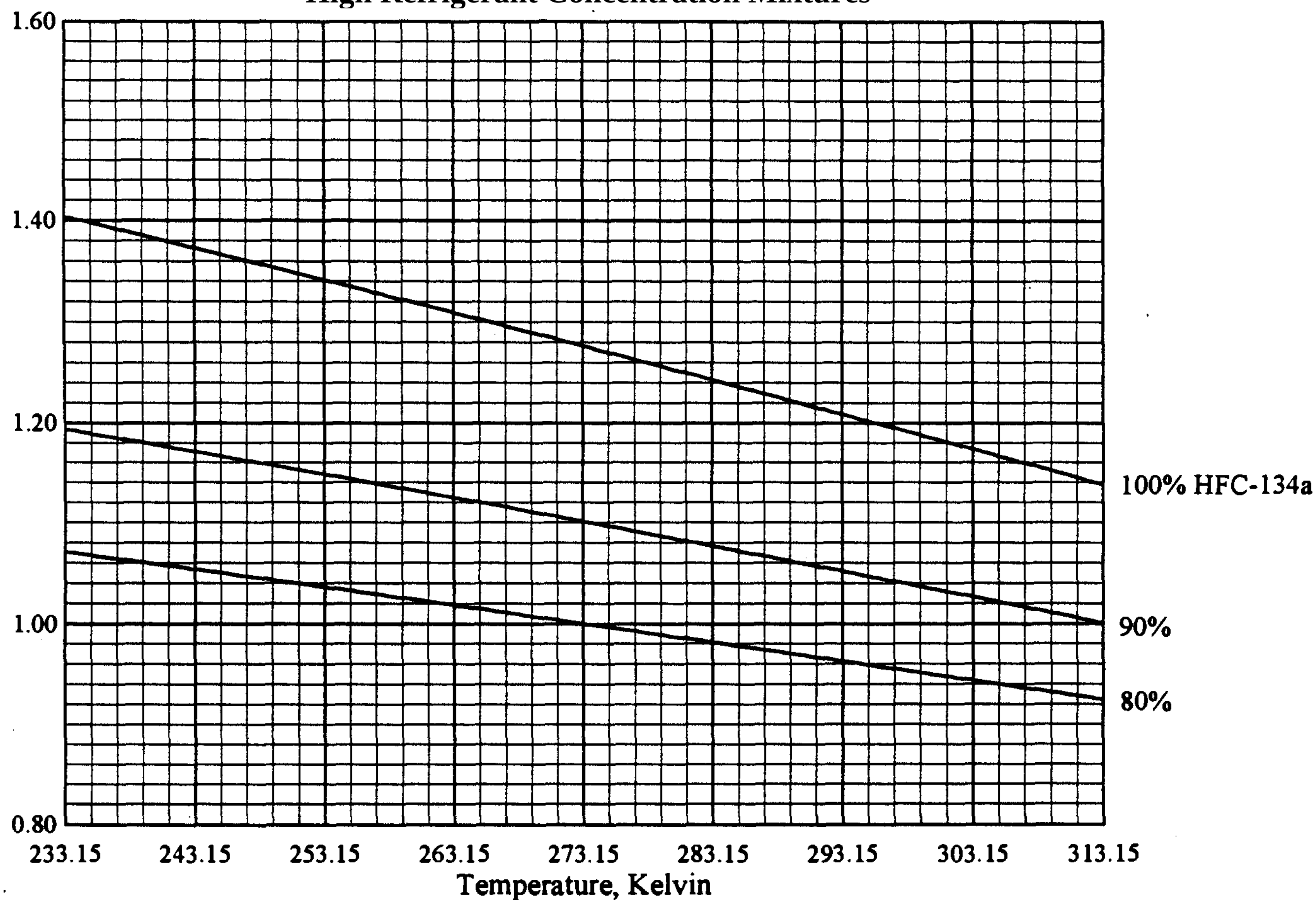


Figure 12-4: Viscosity and Solubility of HFC-134a/ISO 100 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

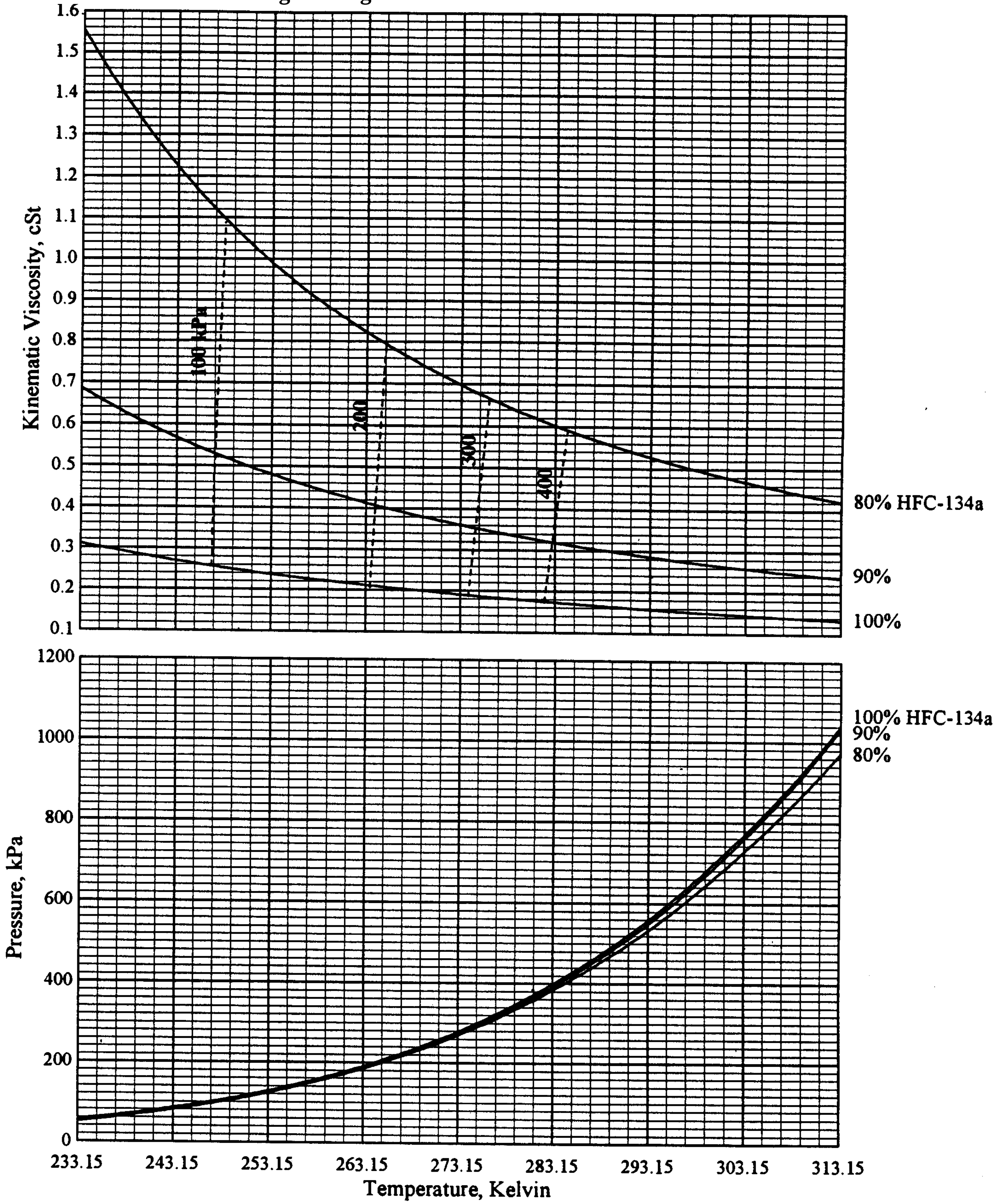


Table 13-1: Viscosity, Solubility and Density Parameters
HCFC-123/ISO 32 Naphthenic Mineral Oil
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.13003E+1	1.81411E+3	1.17296	1.07384E+1
a_2	-4.46433	-1.12892E+1	-1.14095E-3	-4.23286
a_3	0	1.74243E-2	7.82273E-7	0
a_4	-1.73171	-1.44306E+4	-3.69578E-1	-7.76490E-1
a_5	4.12488E-1	7.75987E+1	6.01599E-3	1.11672E-2
a_6	0	-9.37333E-2	-1.05875E-5	0
a_7	1.59771	6.33527E+4	2.04857	2.29578E-1
a_8	-8.06383E-1	-3.86512E+2	-1.55154E-2	-2.55951E-1
a_9	0	5.78166E-1	2.44133E-5	0
σ	0.9995	0.9970	0.9984	0.9993

Figure 13-1: Density of HCFC-123/ISO 32 Naphthenic Mineral Oil
Low Refrigerant Concentration Mixtures

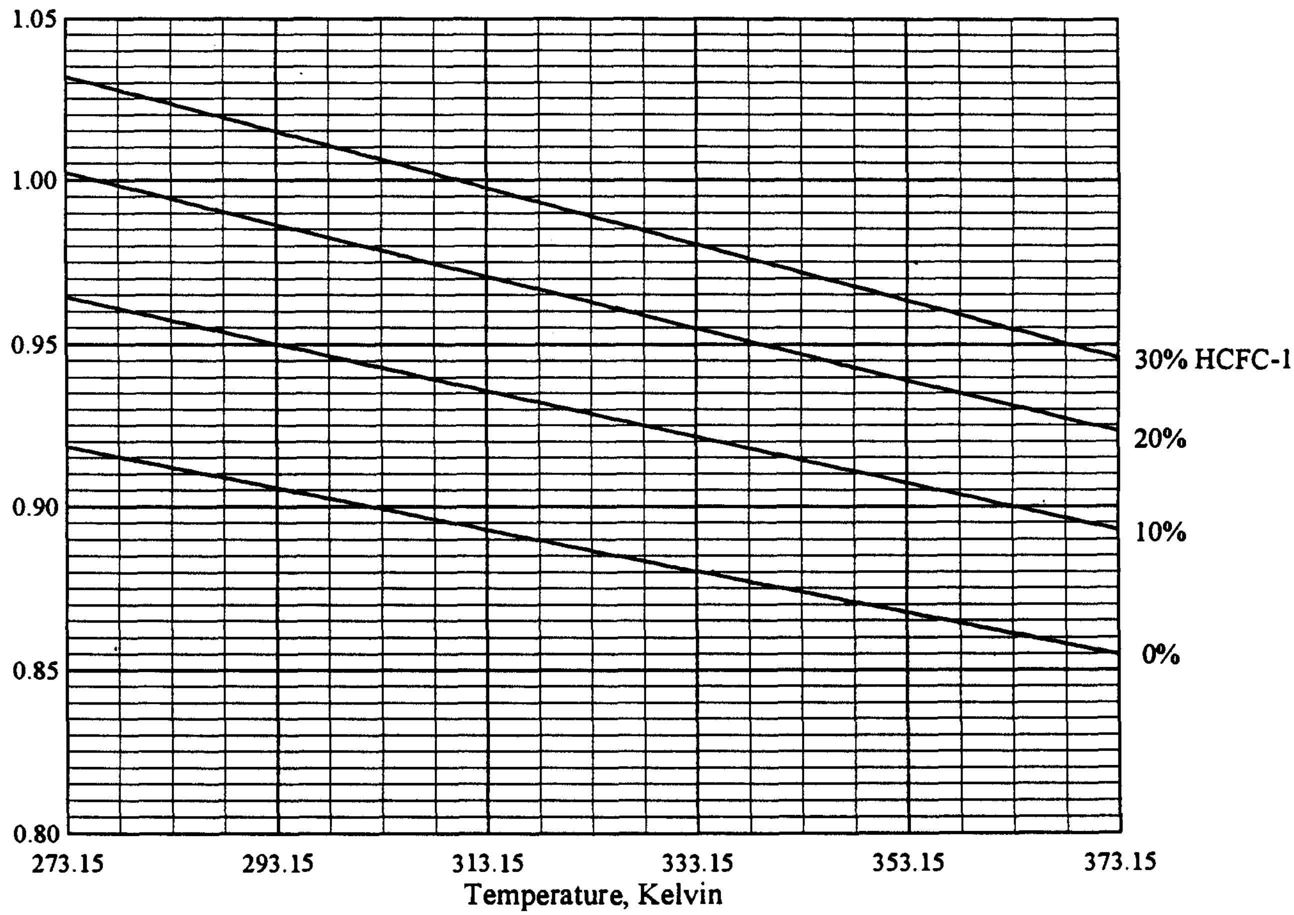


Figure 13-2: Viscosity and Solubility of HCFC-123/ISO 32 Naphthenic Mineral Oil Low Refrigerant Concentration Mixtures

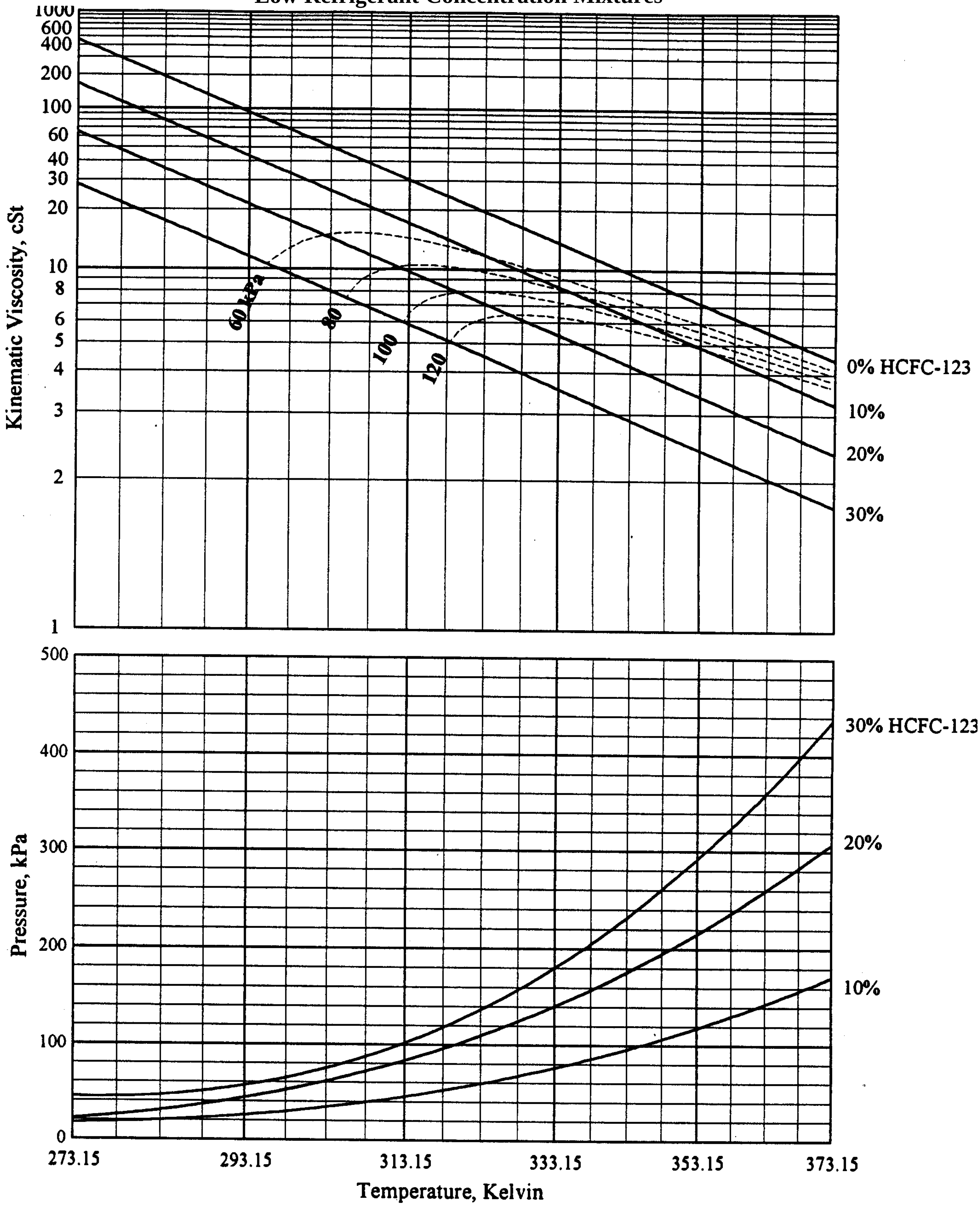


Table 13-2: Viscosity, Solubility and Density Parameters HCFC-123/ISO 32 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-5.78828	4.55077	1.12175	-4.79328
a_2	1.49235E+3	-4.44155E+2	-3.28467E-1	1.37176E+3
a_3	2.12697E+5	-1.23557E+4	6.80806E-3	2.08296E+5
a_4	4.23615	4.92224	-6.80007E-1	2.99021
a_5	-4.30602E+1	-2.65297E+3	-4.94063	1.74577E+1
a_6	-6.53301E+5	1.30167E+5	6.12868	-6.18517E+5
a_7	-2.03924E-1	3.09690	5.22858E-1	3.46612E-1
a_8	-1.03794E+3	-1.75635E+3	6.94263	-1.18735E+3
a_9	4.43159E+5	3.86596E+5	-6.78944	4.33829E+5
σ	0.9994	0.9994	0.9999	0.9994

Figure 13-3: Density of HCFC-123/ISO 32 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

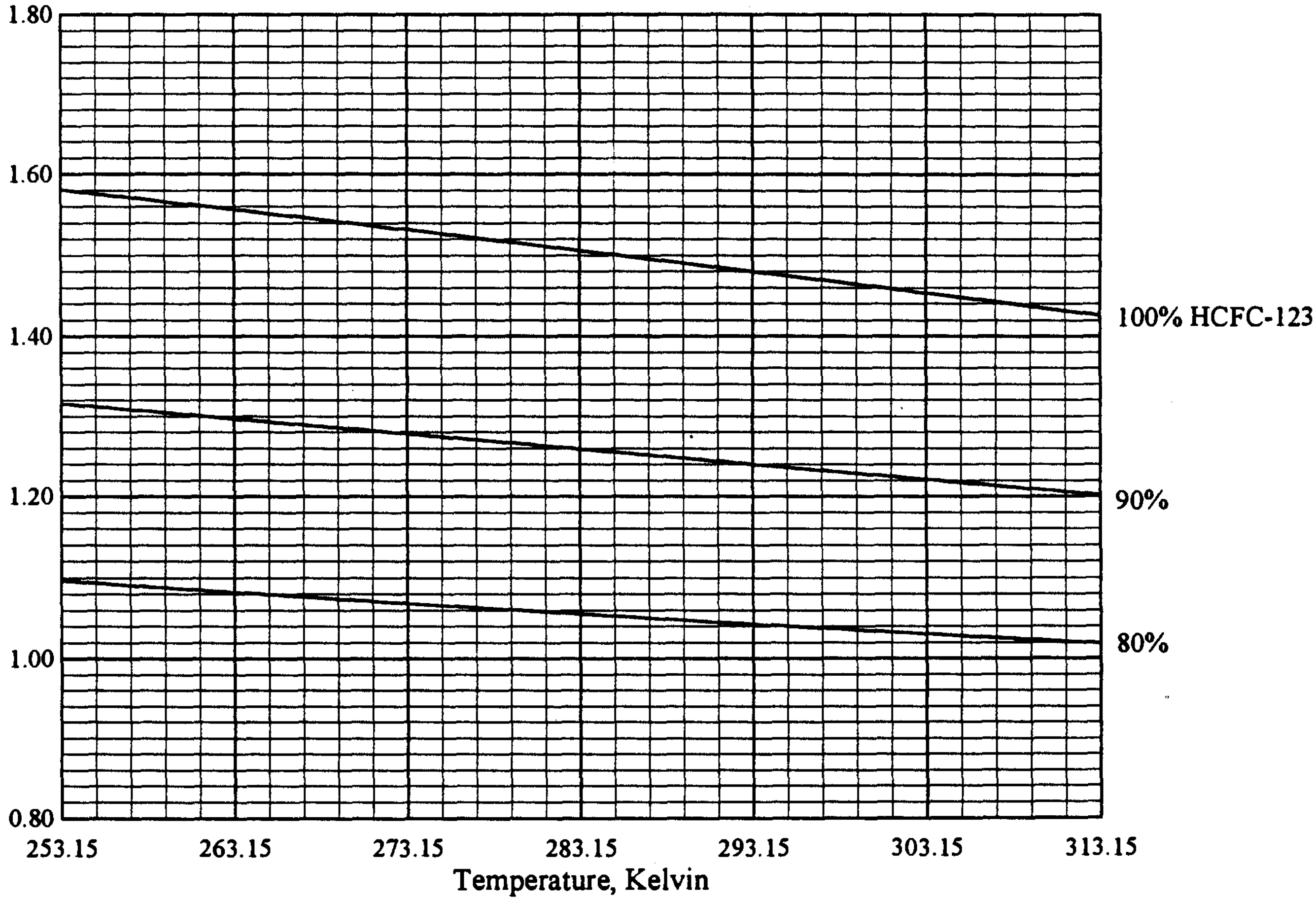


Figure 13-4: Viscosity and Solubility of HCFC-123/ISO 32 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

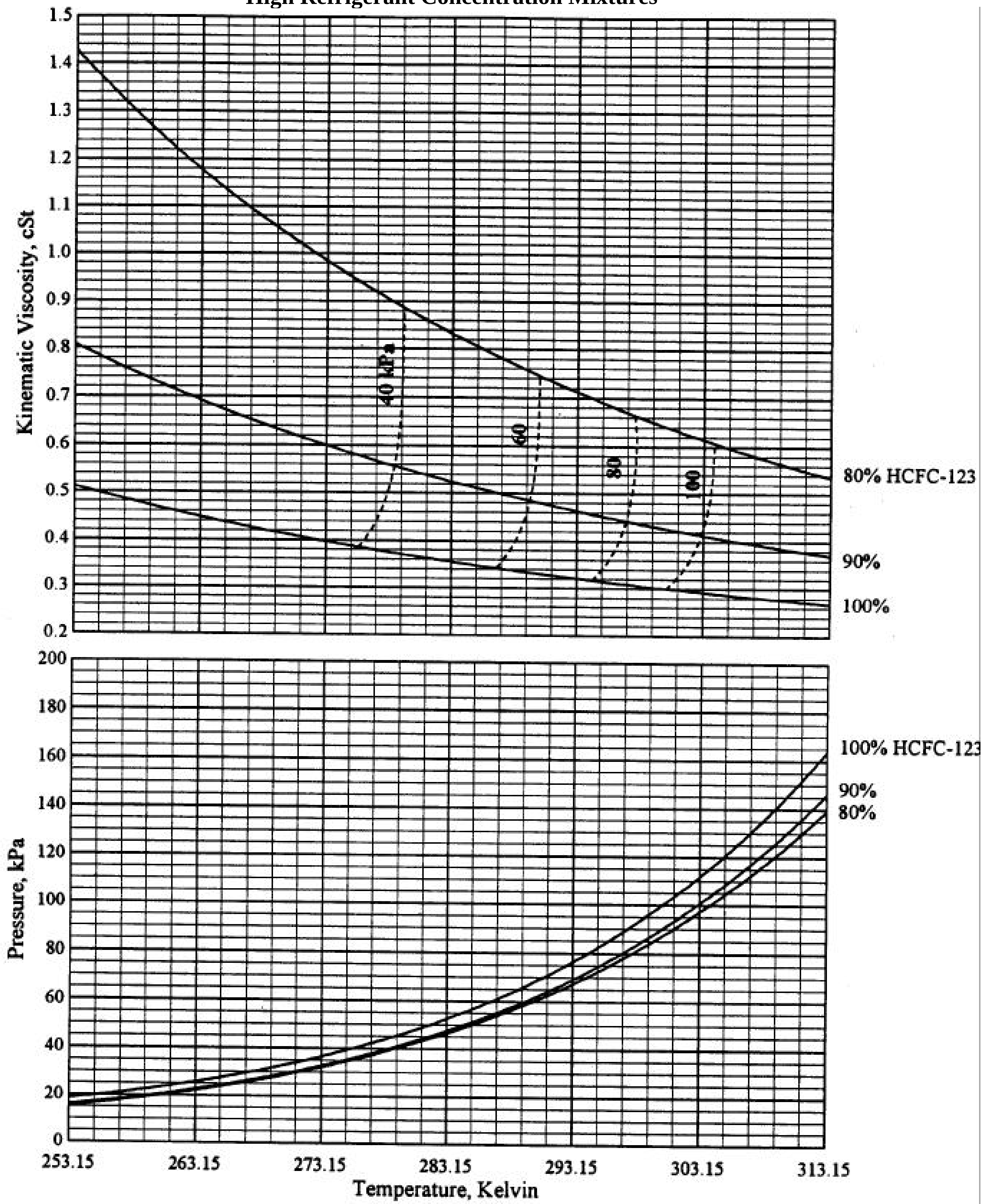


Table 14-1: Viscosity, Solubility and Density Parameters HCFC-123/ISO 100 Naphthenic Mineral Oil Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.14595E+1	8.43706E+2	1.16854	1.10461E+1
a_2	-4.47431	-5.27985	-1.07174E-3	-4.30424
a_3	0	8.20619E-3	6.91350E-7	0
a_4	-3.49838	-8.27868E+3	2.23383E-2	-3.61976
a_5	1.06930	3.62398E+1	2.73672E-3	1.11223
a_6	0	-2.45732E-2	-5.49060E-6	0
a_7	-5.25781	6.34394E+4	1.92854	-3.09248
a_8	2.05277	3.77117E+2	-1.08573E-2	1.14872
a_9	0	5.46464E-1	1.65614E-5	0
σ	0.9997	0.9984	0.9996	0.9996

Figure 14-1: Density of HCFC-123/ISO 100 Naphthenic Mineral Oil Low Refrigerant Concentration Mixtures

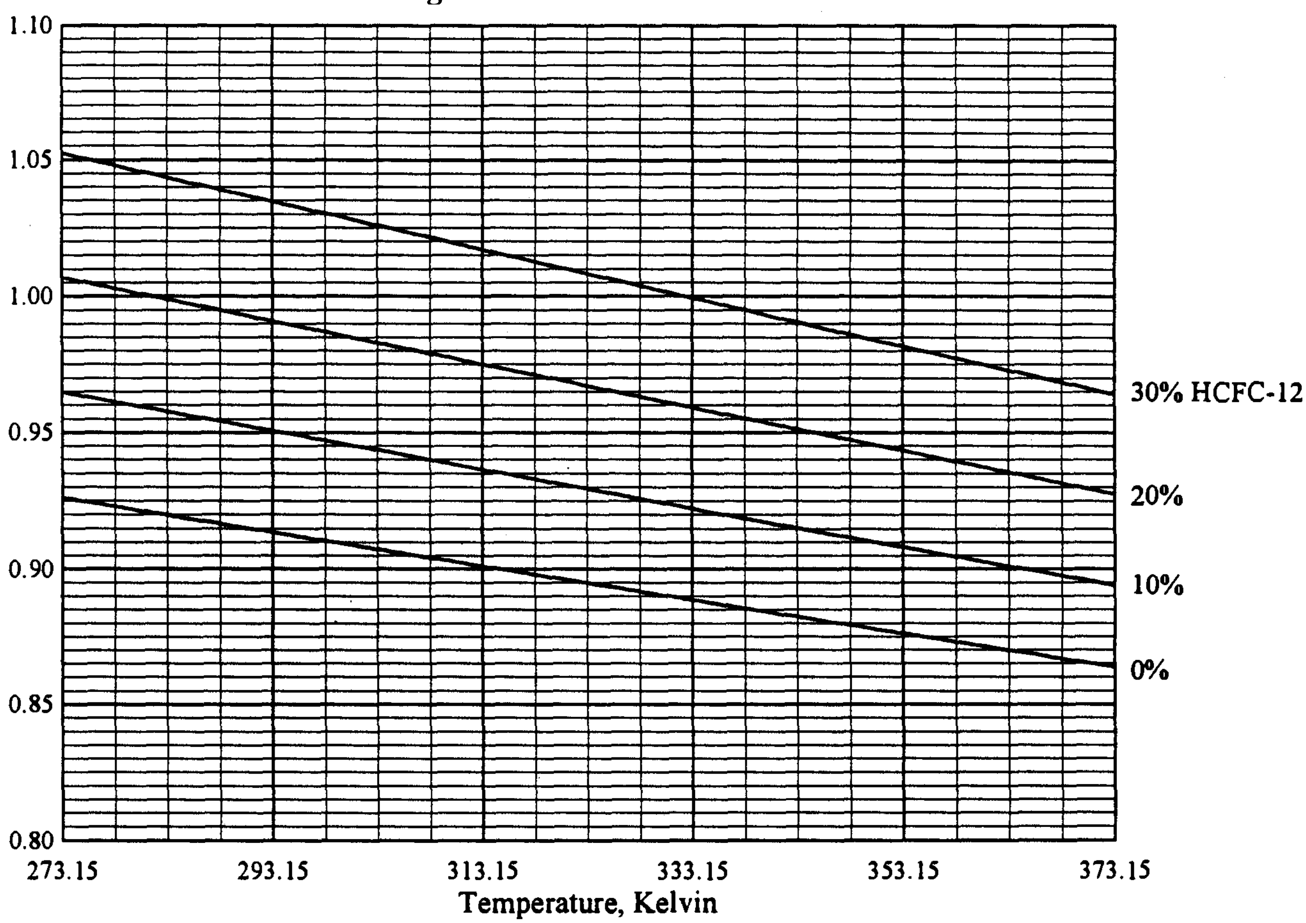


Figure 14-2: Viscosity and Solubility of HCFC-123/ISO 100 Naphthenic Mineral Oil Low Refrigerant Concentration Mixtures

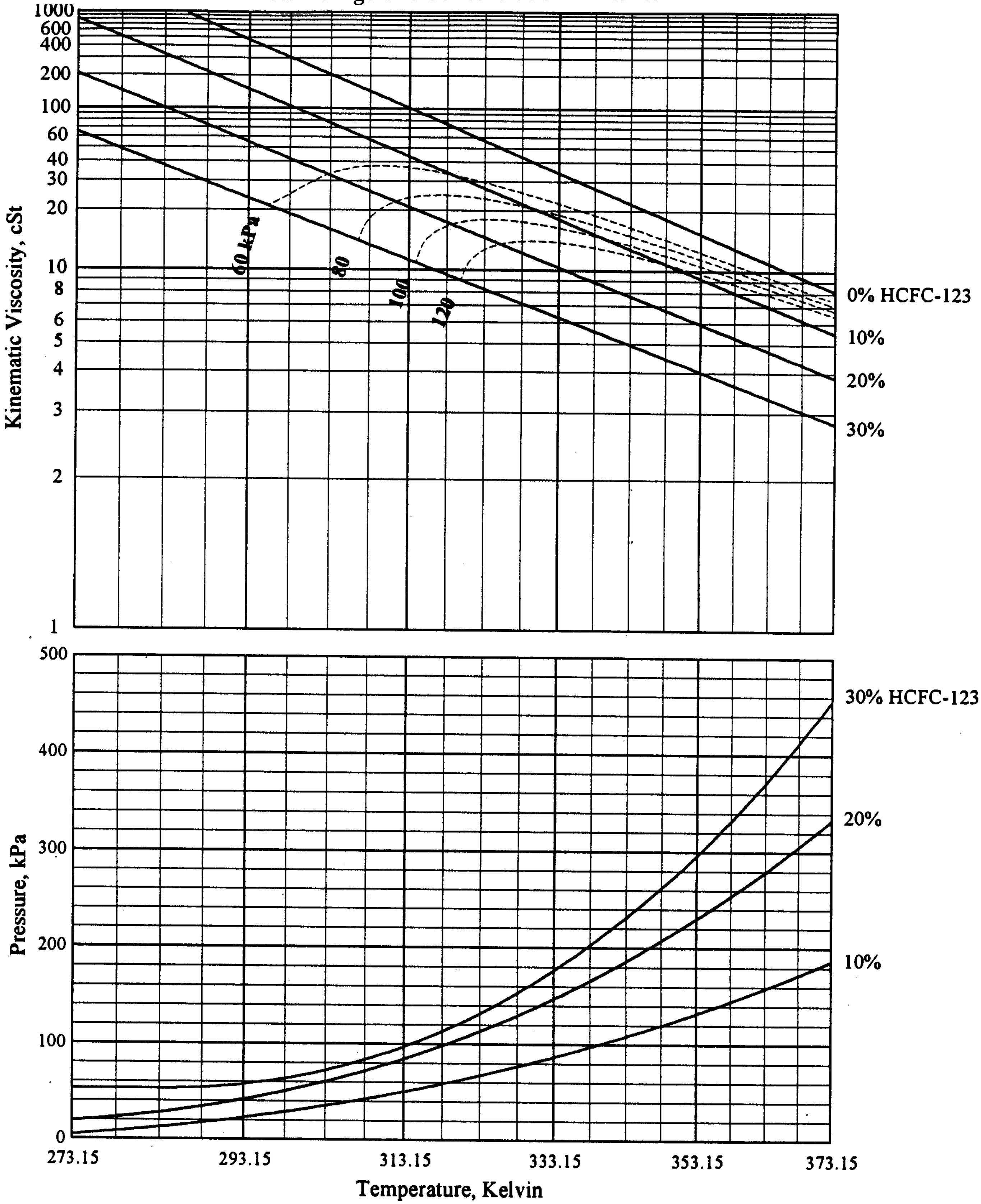


Table 14-2: Viscosity, Solubility and Density Parameters HCFC-123/ISO 100 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	2.26678	8.73483	5.46174E-1	3.36124
a_2	-1.28696E+2	-1.77023E+3	-4.51877	-2.32065E+2
a_3	1.17700E+5	1.09044E+5	1.05472E+1	1.17369E+5
a_4	-6.66652	3.68254	-3.14395E-1	-8.14062
a_5	-3.38866E+2	-3.39249E+3	9.42414	-3.13254E+2
a_6	1.53719E+5	2.30708E+5	-2.35521E+1	1.76303E+5
a_7	3.03720	-3.05497	7.69951E-1	3.69470
a_8	6.77322E+2	2.12913E+3	-3.41961	5.56928E+2
a_9	-2.43346E+5	-9.25108E+4	1.25833E+1	-2.46000E+5
σ	0.9998	0.9989	0.9999	0.9998

Figure 14-3: Density of HCFC-123/ISO 100 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

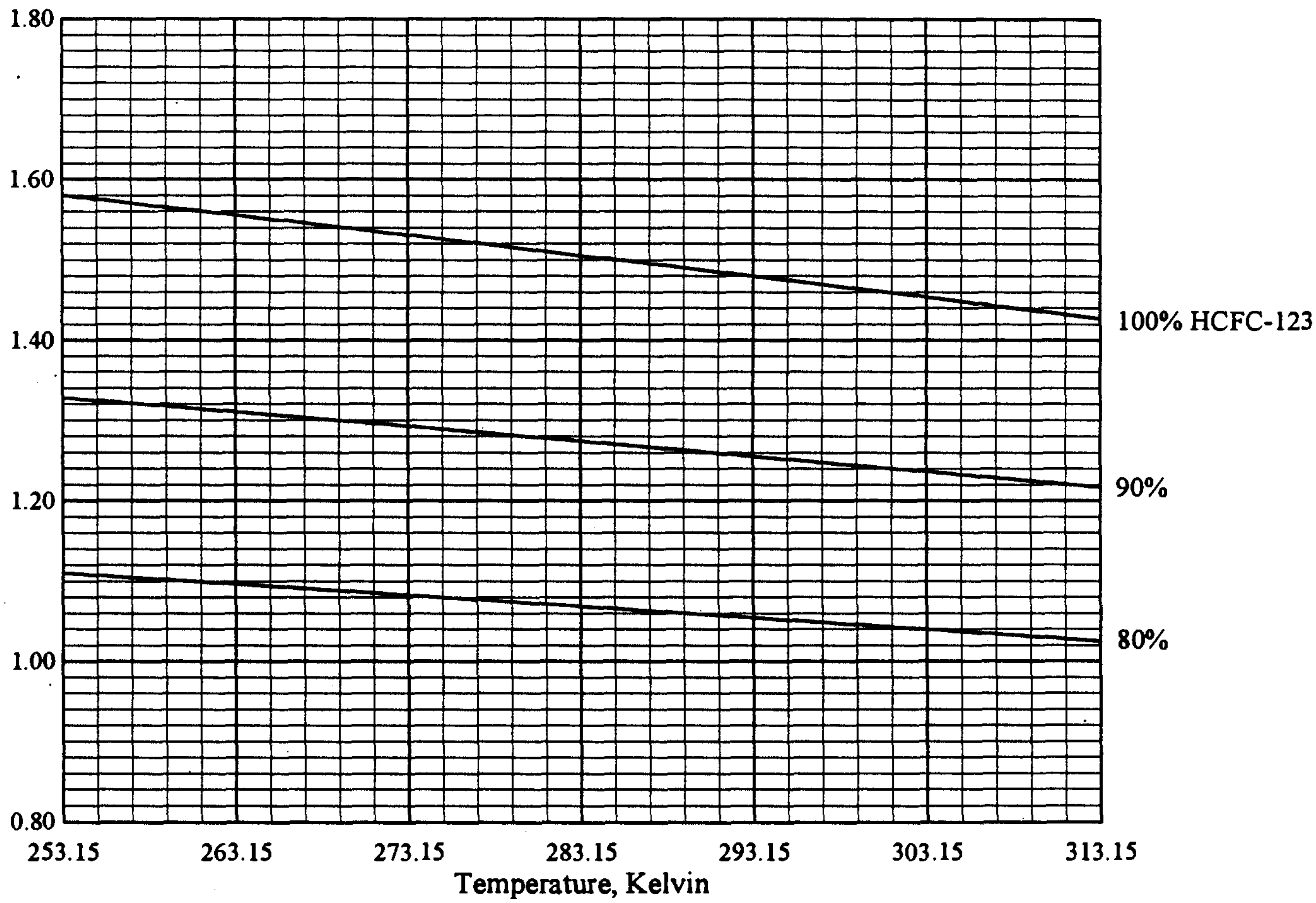


Figure 14-4: Viscosity and Solubility of HCFC-123/ISO 100 Naphthenic Mineral Oil High Refrigerant Concentration Mixtures

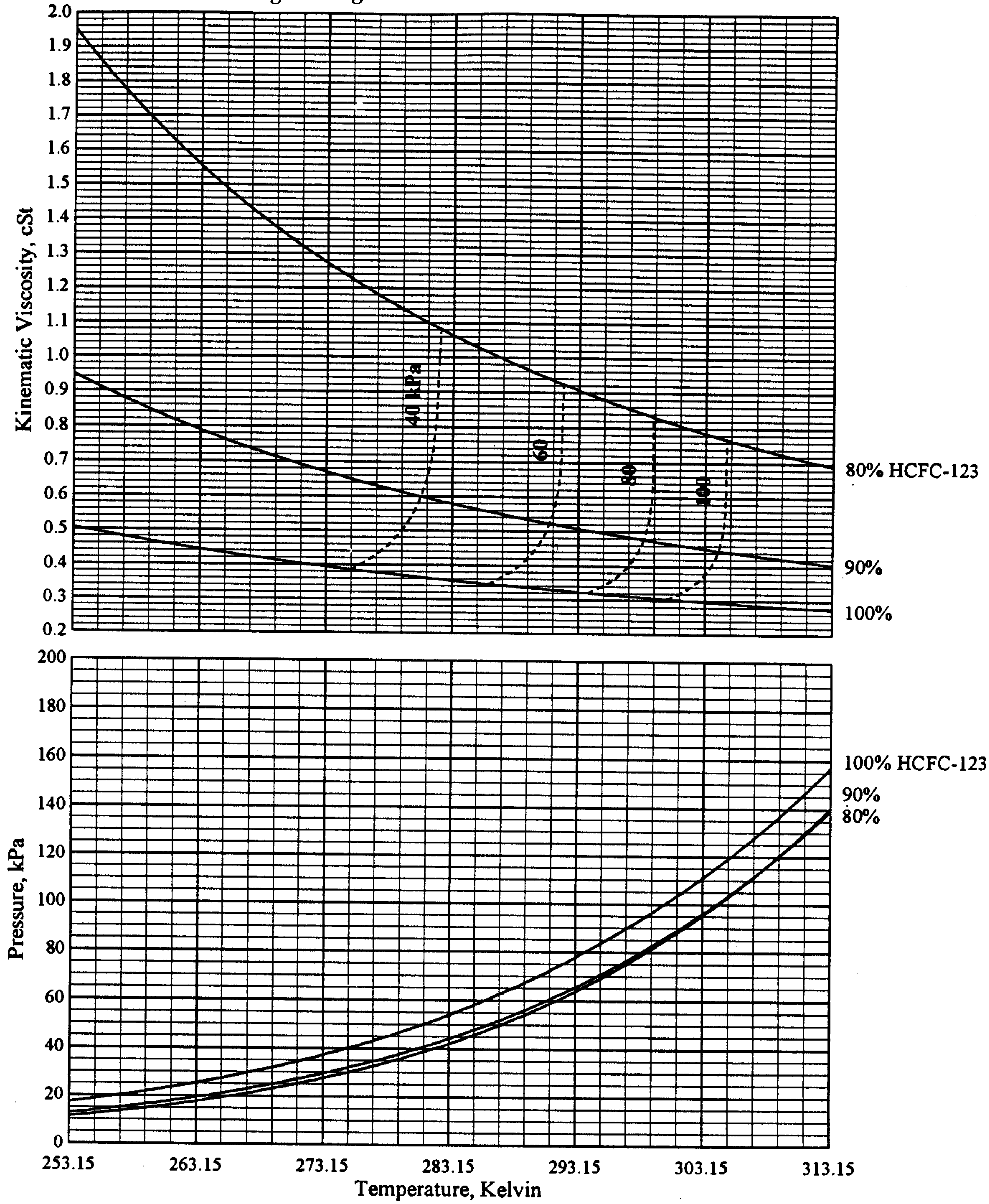


Table 15-1: Viscosity, Solubility and Density Parameters
HCFC-123/ISO 32 Alkylbenzene
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.10988E+1	-2.09648E+2	1.01516	1.04087E+1
a_2	-4.39149	1.29707	-3.77438E-4	-4.10604
a_3	0	-1.97862E-3	-4.22828E-7	0
a_4	8.06781	1.06096E+4	1.67377	7.84122
a_5	-3.48403	-7.68817E+1	-7.66592E-3	-3.40212
a_6	0	1.41442E-1	1.09670E-5	0
a_7	-1.97725E+1	-3.15316E+3	-3.23207	-1.74920E+1
a_8	7.63495	2.66171E+1	2.17621E-2	6.68463
a_9	0	5.78955E-2	-3.47192E-5	0
σ	0.9997	0.9993	0.9999	0.9997

Figure 15-1: Density of HCFC-123/ISO 32 Alkylbenzene
Low Refrigerant Concentration Mixtures

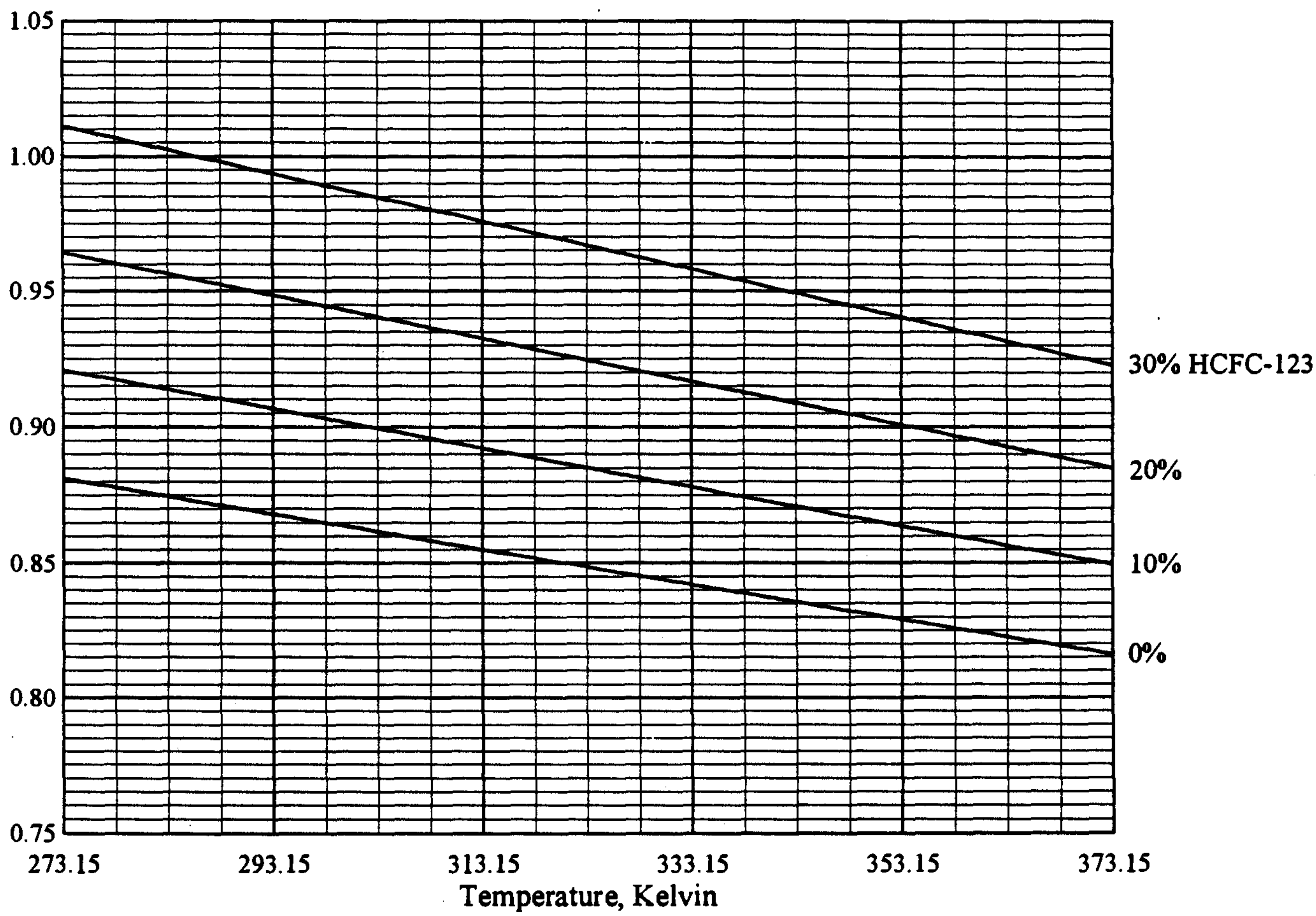


Figure 15-2: Viscosity and Solubility of HCFC-123/ISO 32 Alkylbenzene Low Refrigerant Concentration Mixtures

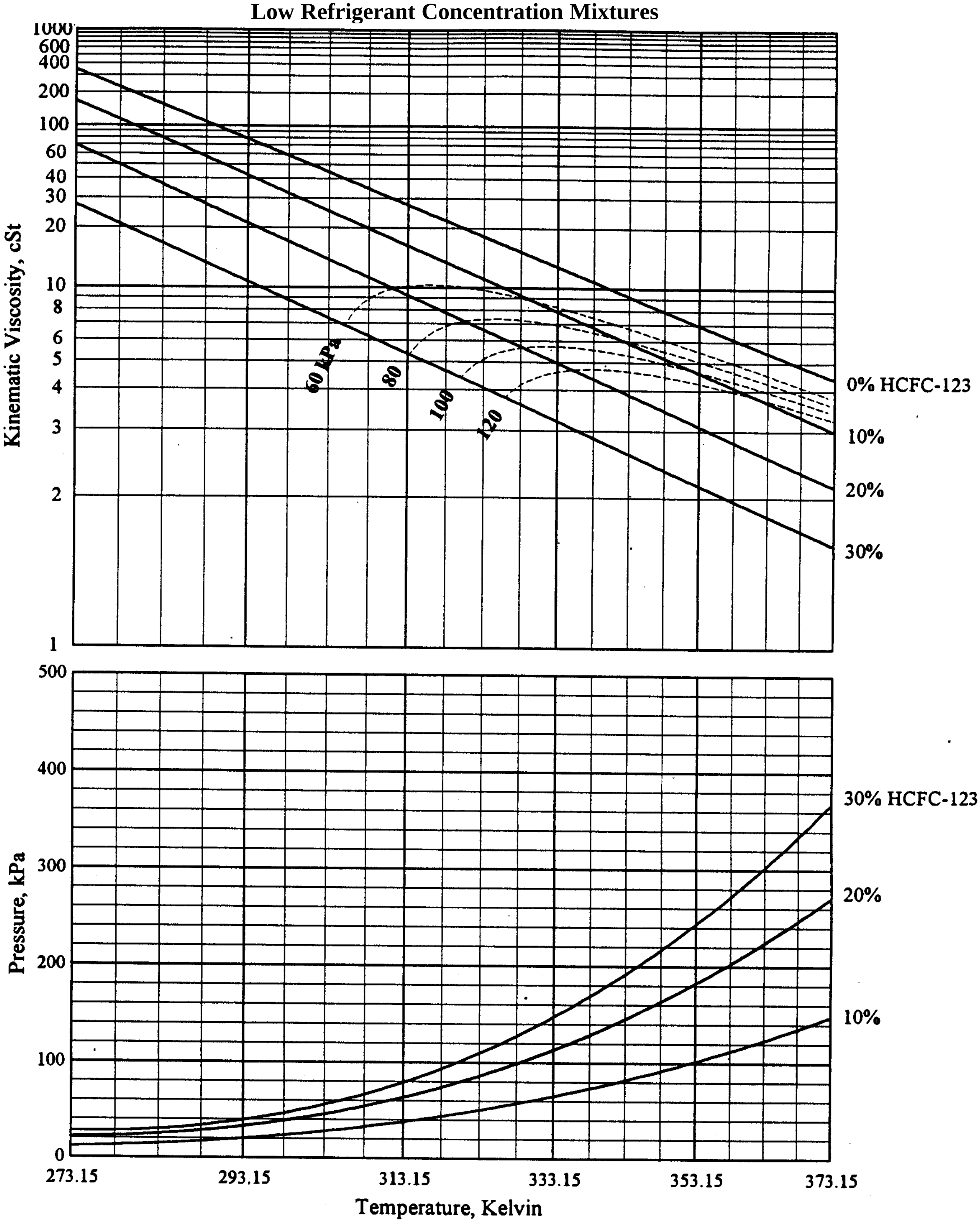


Table 15-2: Viscosity, Solubility and Density Parameters
HCFC-123/ISO 32 Alklylbenzene
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	7.55595	6.02684	1.84526E-1	1.26770
a_2	4.86370E+2	-1.42777E+3	-4.67066E-1	4.80779E+2
a_3	-4.86063E+5	8.80341E+4	3.33121	6.70419E+4
a_4	-2.05623E+1	4.85033	4.39997E-1	-6.42925
a_5	-6.53262E+2	-2.10935E+3	1.79983E-1	-3.06813E+2
a_6	1.32542E+6	1.05605E+5	-7.26803	3.39542E+4
a_7	1.16345E+1	1.84845	3.81380E-1	3.81742
a_8	3.83492E+2	-1.40681E+3	1.76394	-2.77924E+1
a_9	-8.12437E+5	3.23855E+5	3.51216	-7.05848E+4
σ	0.9997	0.9993	0.9999	0.9999

Figure 15-3: Density of HCFC-123/ISO 32 Alkylbenzene
High Refrigerant Concentration Mixtures

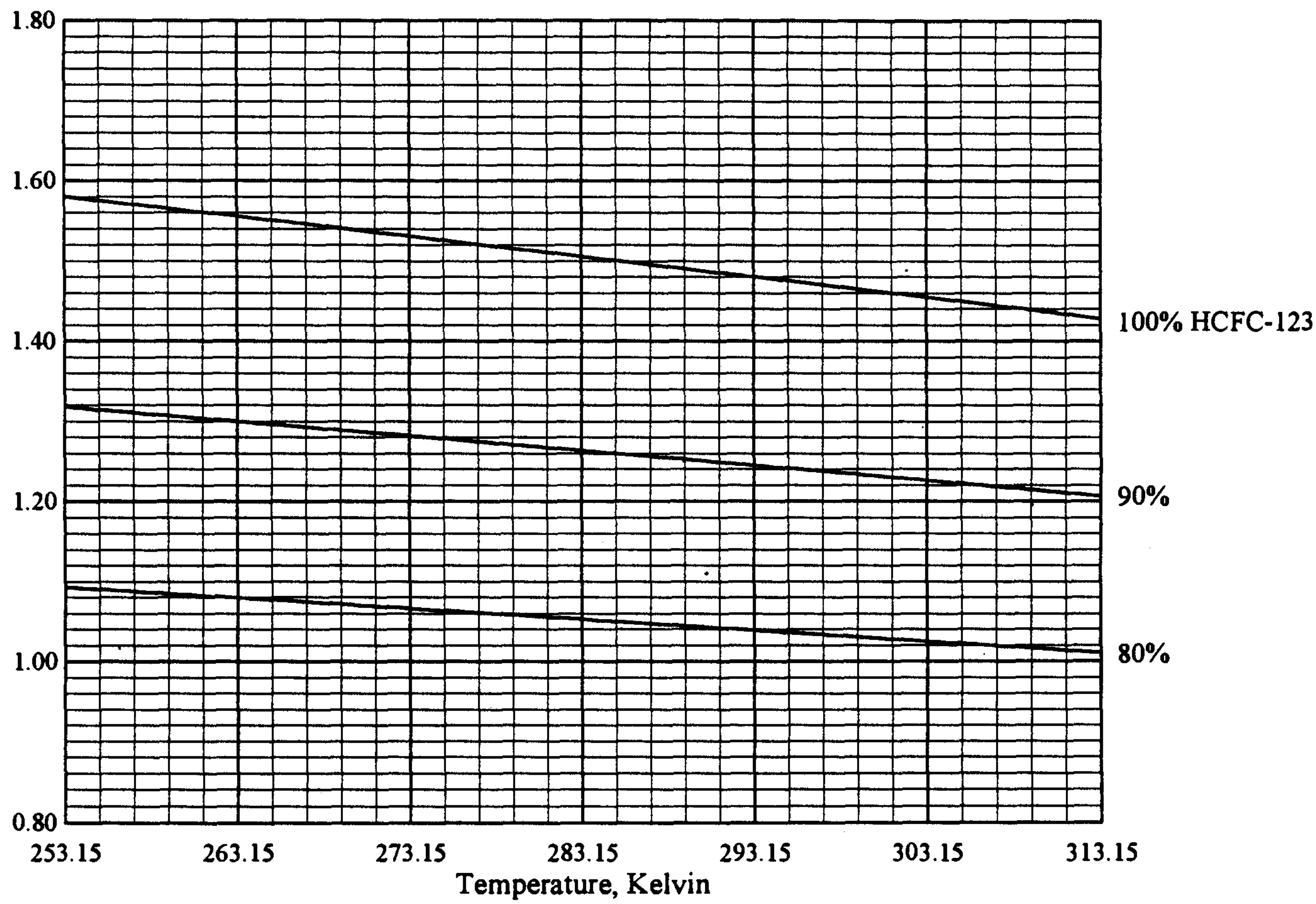


Figure 15-4: Viscosity and Solubility of HCFC-123/ISO 32 Alkylbenzene High Refrigerant Concentration Mixtures

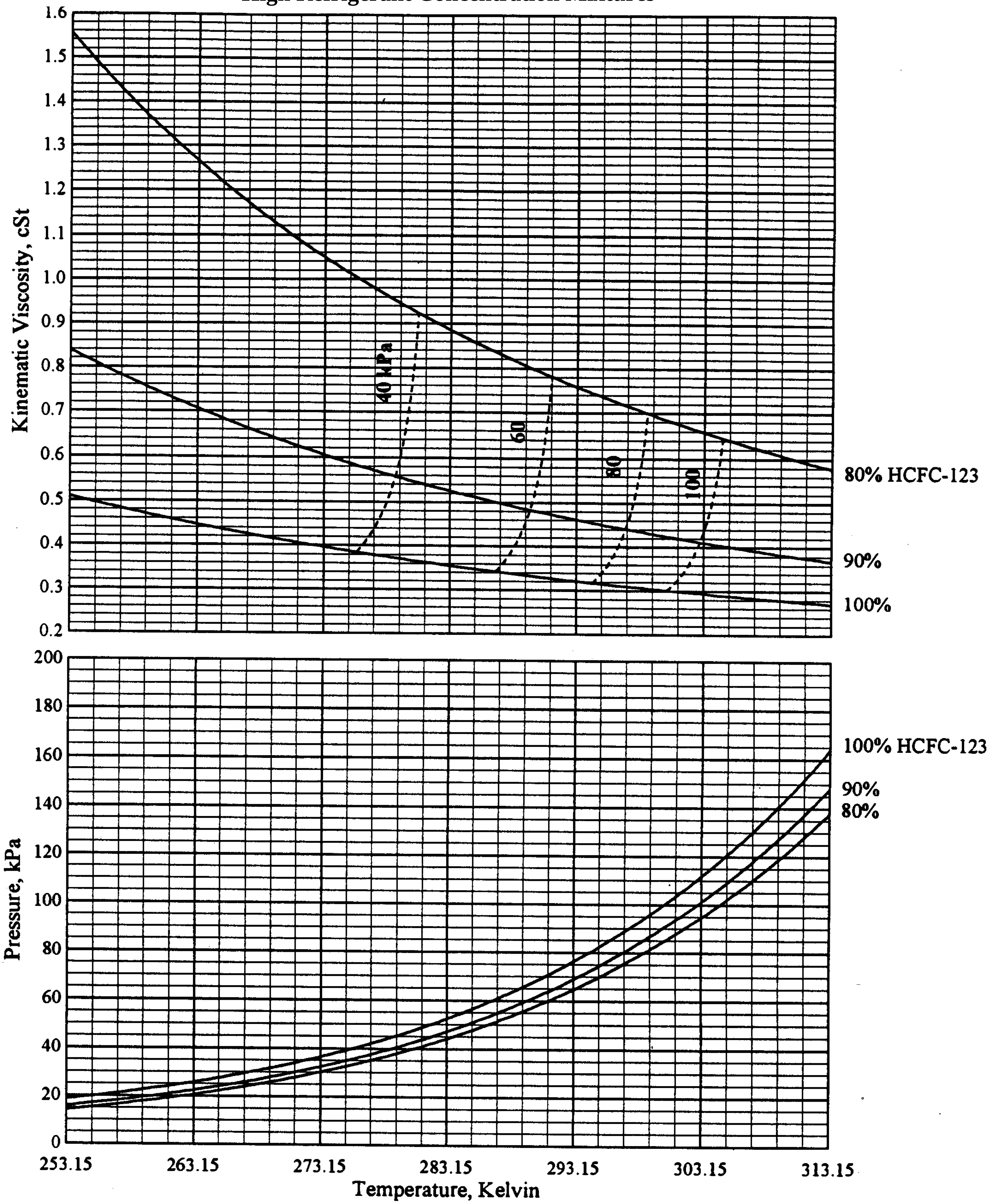


Table 16-1: Viscosity, Solubility and Density Parameters HCFC-123/ISO 68 Alkylbenzene Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.24300E+1	4.65346E+2	1.20809	1.18204E+1
a_2	-4.88787	-2.89609	-1.58795E-3	-4.63599
a_3	0	4.47475E-3	1.45792E-6	0
a_4	-1.43286E+1	3.55404E+3	-2.92800	-1.51976E+1
a_5	5.34888	-3.33544E+1	2.10154E-2	5.69248
a_6	0	7.48646E-2	-3.34477E-5	0
a_7	4.23083E+1	1.22244E+4	1.01891E+1	4.64418E+1
a_8	-1.69366E+1	-6.93139E+1	-6.19542E-2	-1.86300E+1
a_9	0	9.08685E-2	9.49459E-5	0
σ	0.9997	0.9996	0.9998	0.9996

Figure 16-1: Density of HCFC-123/ISO 68 Alkylbenzene Low Refrigerant Concentration Mixtures

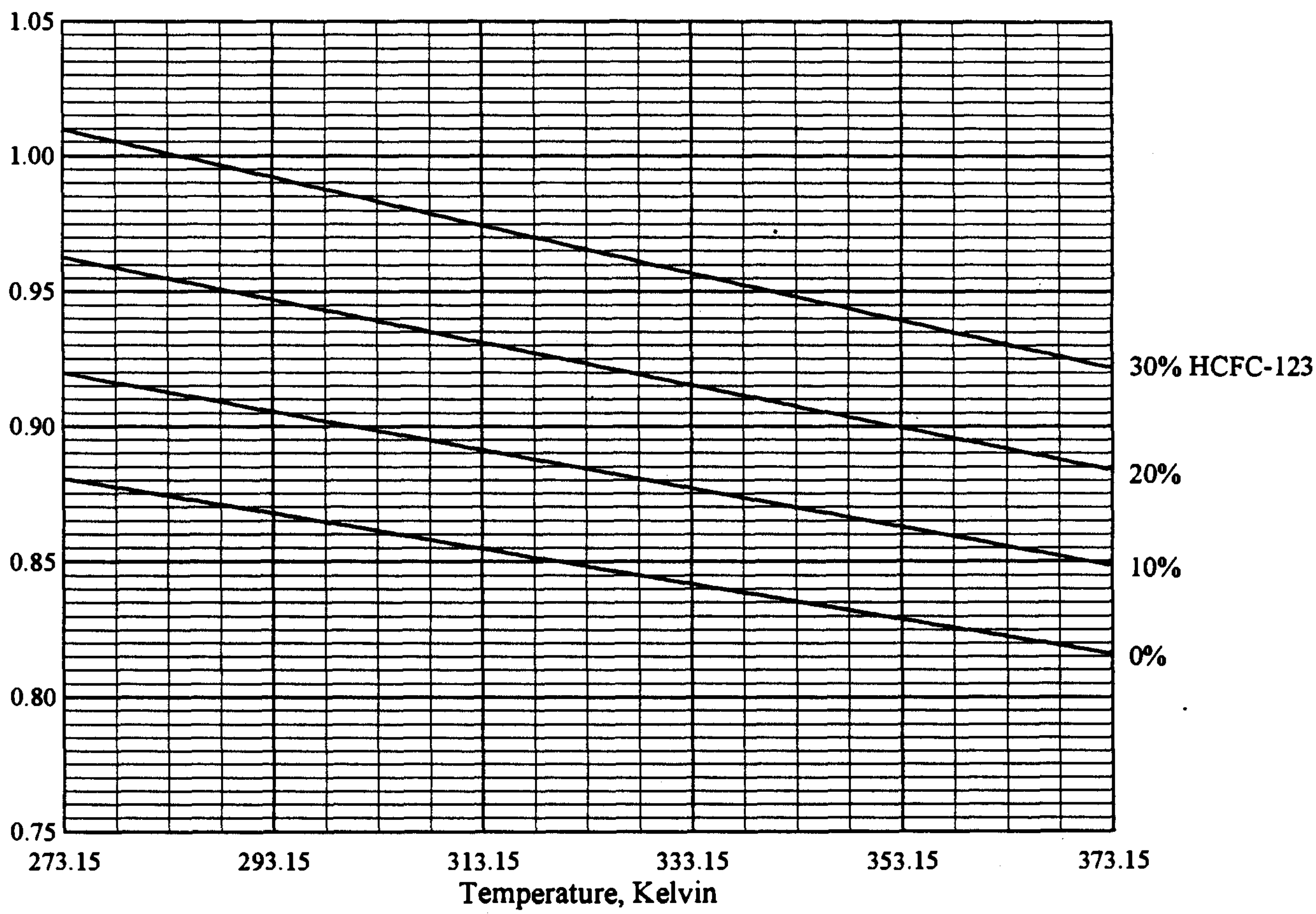


Figure 16-2: Viscosity and Solubility of HCFC-123/ISO 68 Alkylbenzene Low Refrigerant Concentration Mixtures

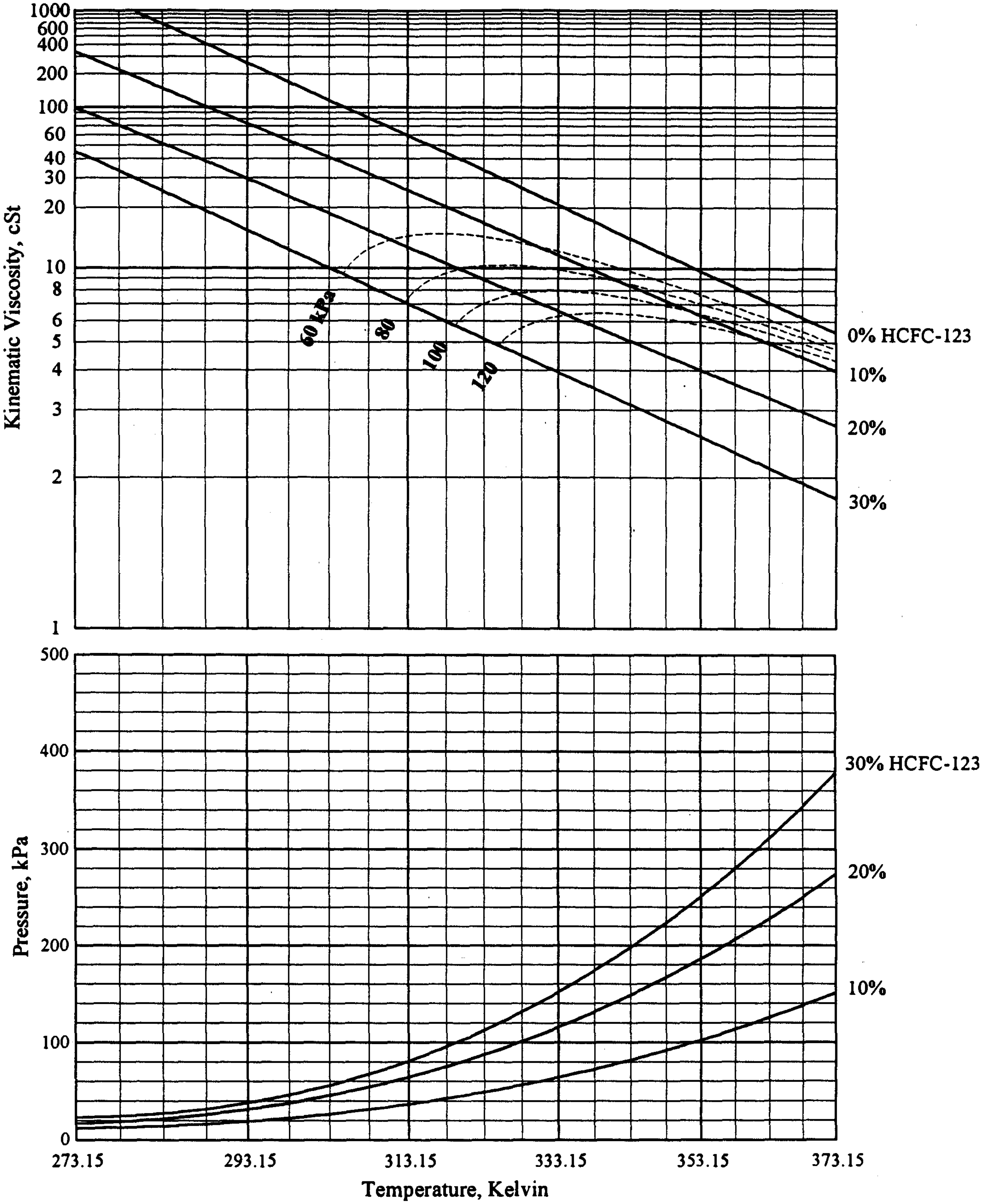


**Table 16-2: Viscosity, Solubility and Density Parameters
HCFC-123/ISO 68 Alkylbenzene
High Refrigerant Concentration Mixtures**

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	1.29462	-9.81283	2.25595E-3	2.13796
a_2	-1.44886E+2	2.15054E+3	-3.47924E-1	-2.06849E+2
a_3	.13385.E+5	2.53288E+5	5.35090	1.36778E+5
a_4	-4.30881	2.90336E+1	1.09081	-5.21685
a_5	-4.15511E+2	-4.11543E+3	-1.26643	-4.67208E+2
a_6	9.81502E+4	-1.04095E+6	-1.03841E+1	1.12069E+5
a_7	1.44534	-6.85675	-9.61061E-2	1.77537
a_8	8.79167E+2	-2.81531E+3	3.13069	8.00875E+2
a_9	-2.18196E+5	1.28780E+6	4.56680	-2.16196E+5
σ	0.9999	0.9983	0.9999	0.9999

**Figure 16-3: Density of HCFC-123/ISO 68 Alkylbenzene
High Refrigerant Concentration Mixtures**

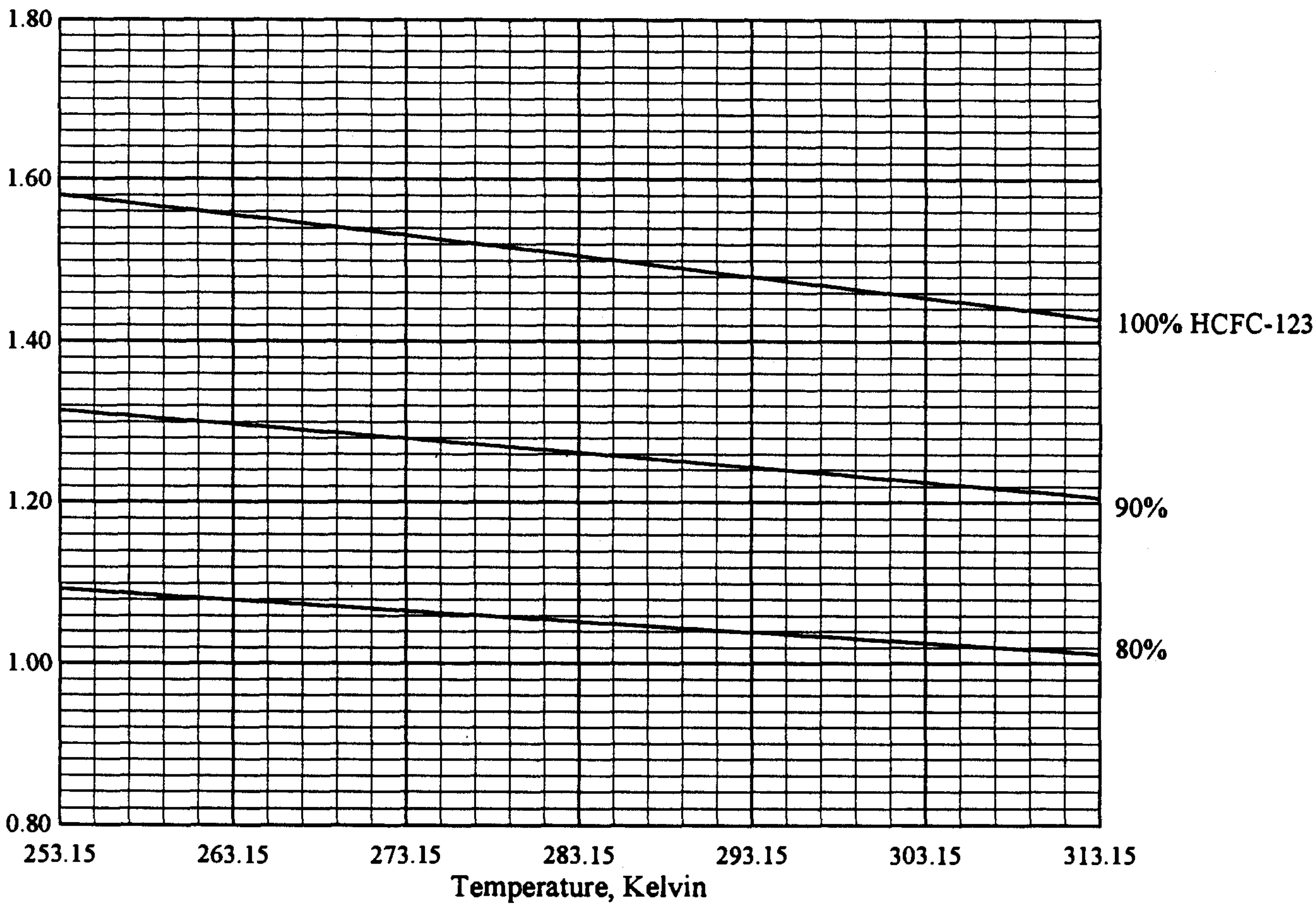


Figure 16-4: Viscosity and Solubility of HCFC-123/ISO 68 Alkylbenzene High Refrigerant Concentration Mixtures

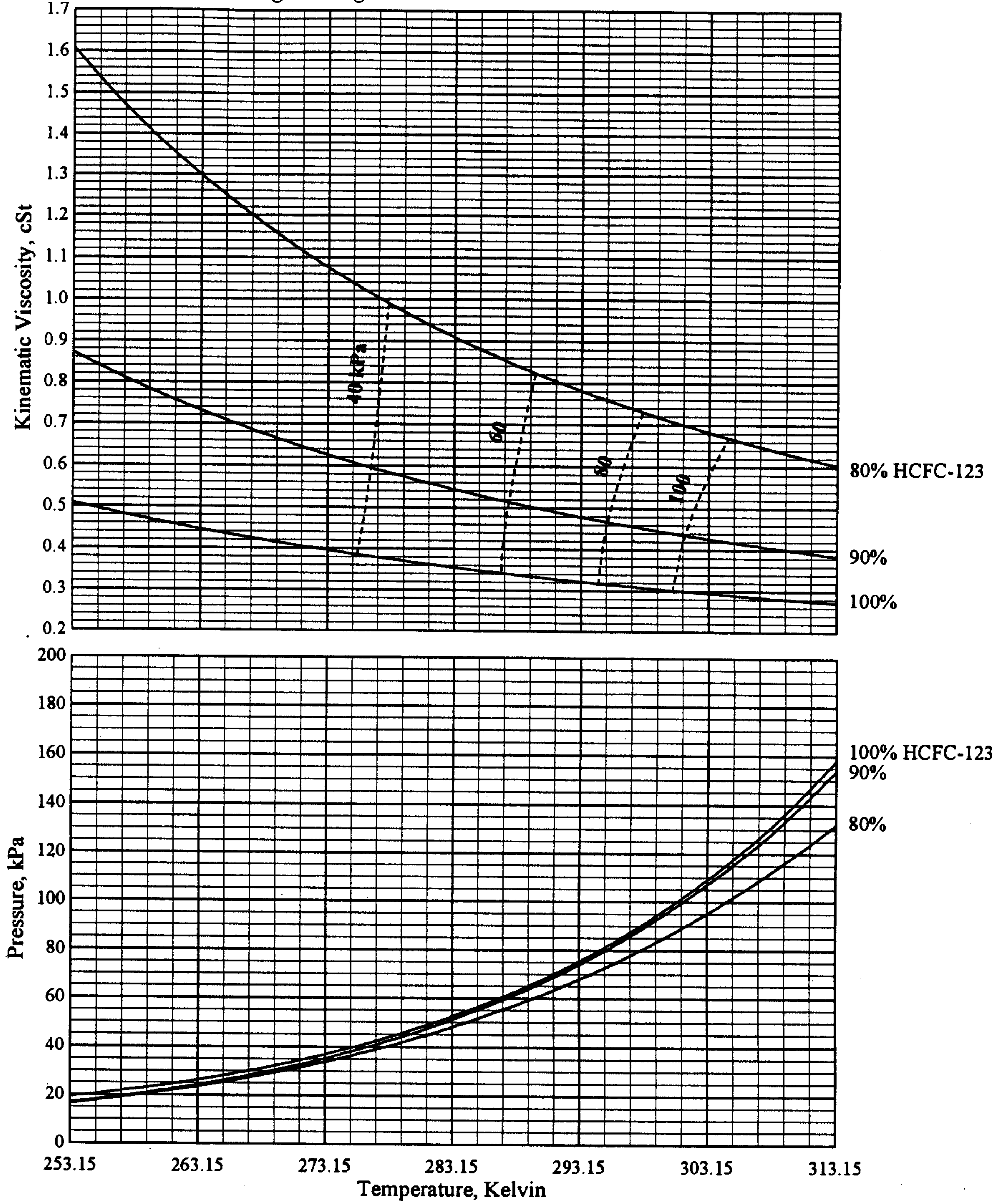


Table 17-1: Viscosity, Solubility and Density Parameters
HFC-32/ISO 22 Pentaerythritol Ester Mixed Acid #2
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.87245	-1.34099E+3	1.39387	9.69678
a_2	-3.90384	8.59852	-1.88587E-3	-3.83239
a_3	0	-1.37020E-2	1.83507E-6	0
a_4	-1.20084E+1	2.17949E+4	-1.96409E-1	-1.37496E+1
a_5	4.13421	-2.92164E+2	1.94001E-3	4.84160
a_6	0	8.27955E-1	-4.38721E-6	0
a_7	4.91275E+1	3.60638E+5	1.72030	5.13383E+1
a_8	-1.97731E+1	-2.22181E+3	-9.95843E-3	-2.07030E+1
a_9	0	3.25841	1.71798E-5	0
σ	0.9991	0.9997	0.9969	0.9991

Figure 17-1: Density of HFC-32/ISO 22 Pentaerythritol Ester Mixed Acid #2
Low Refrigerant Concentrations

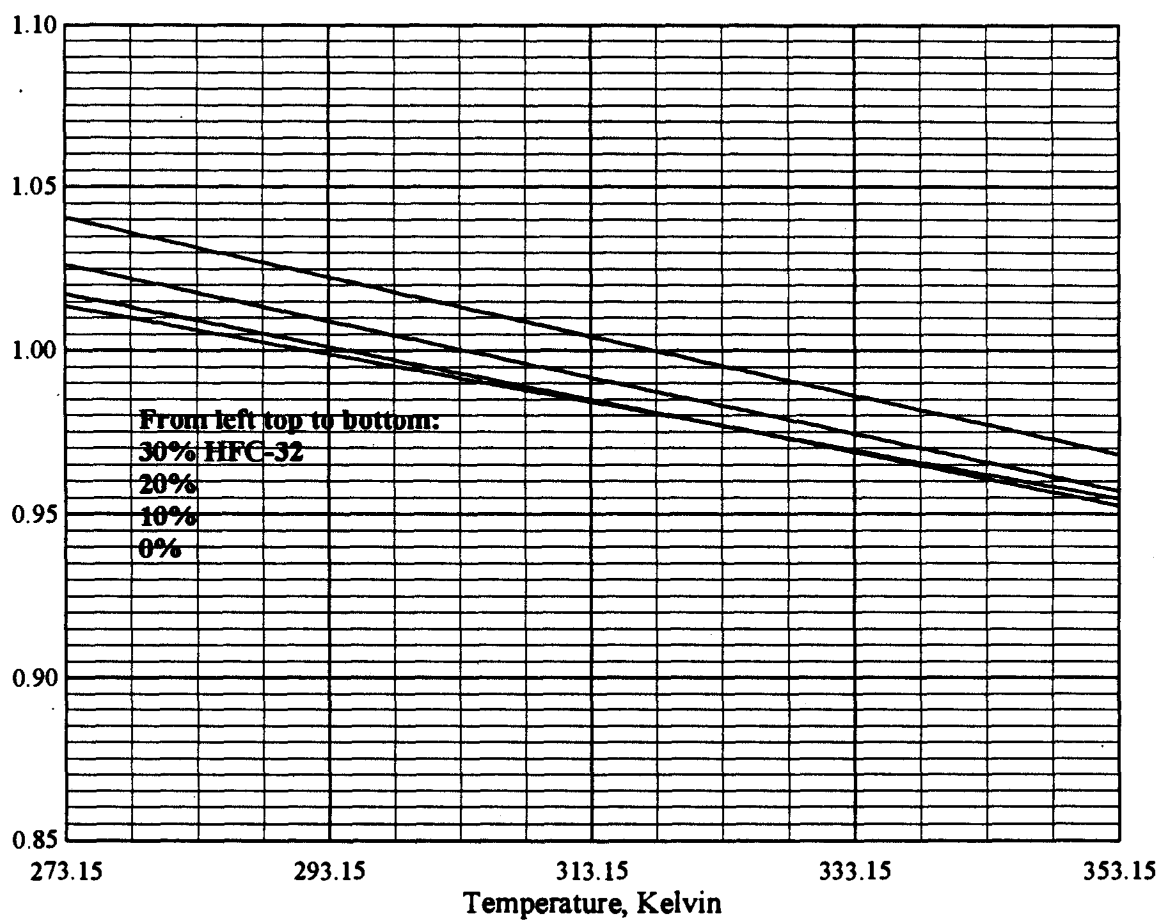


Figure 17-2: Viscosity and Solubility of HFC-32/ISO 22 Pentaerythritol Ester Mixed Acid #2 Low Refrigerant Concentration Mixtures

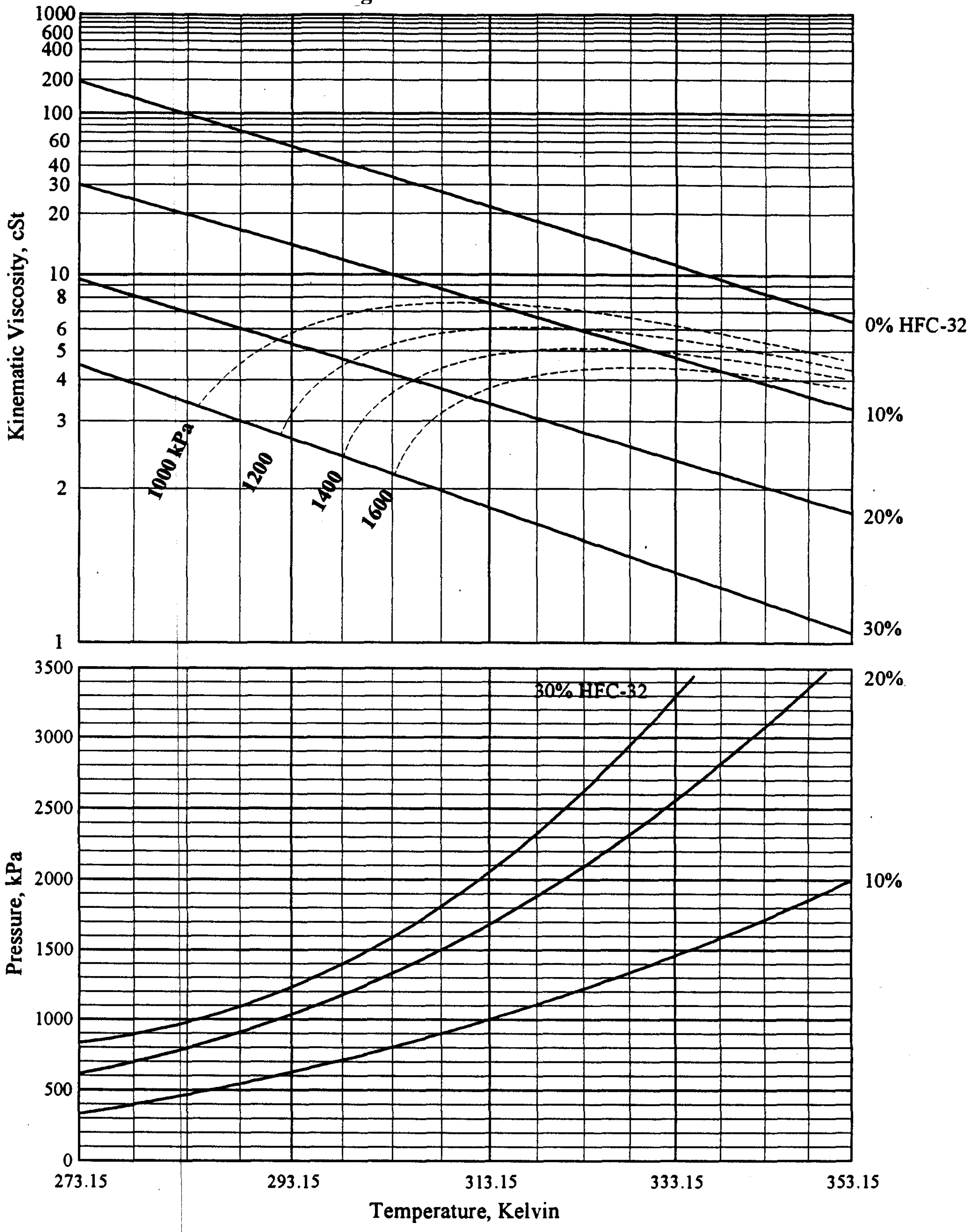


Table 17-2: Viscosity, Solubility and Density Parameters HFC-32/ISO 22 Pentaerythritol Ester Mixed Acid #2 High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-3.03935E-1	2.95908	-8.33003E-1	1.35473E-1
a_2	8.32277E+2	-7.69517E+1	4.96956E-1	5.42352E+2
a_3	-8.78588E+4	3.43721E+3	1.02227E+1	4.00490E+4
a_4	-3.00139	6.32210	3.72673	-2.18744
a_5	-6.27766E+2	-1.08660E+3	-8.44969	-8.27790E+2
a_6	1.15636E+5	-1.49878E+5	-6.02082	-3.05226E+4
a_7	1.69930E-1	-1.36859	-2.18662	9.85453E-2
a_8	6.55945E+2	-5.06637E+2	9.86595	6.03911E+2
a_9	-9.38337E+4	2.26515E+5	-5.67922	-1.75238E+4
σ	0.9996	0.9998	0.9999	0.9997

Figure 17-3: Density of HFC-32/ISO 22 Pentaerythritol Ester Mixed Acid #2 High Refrigerant Concentration Mixtures

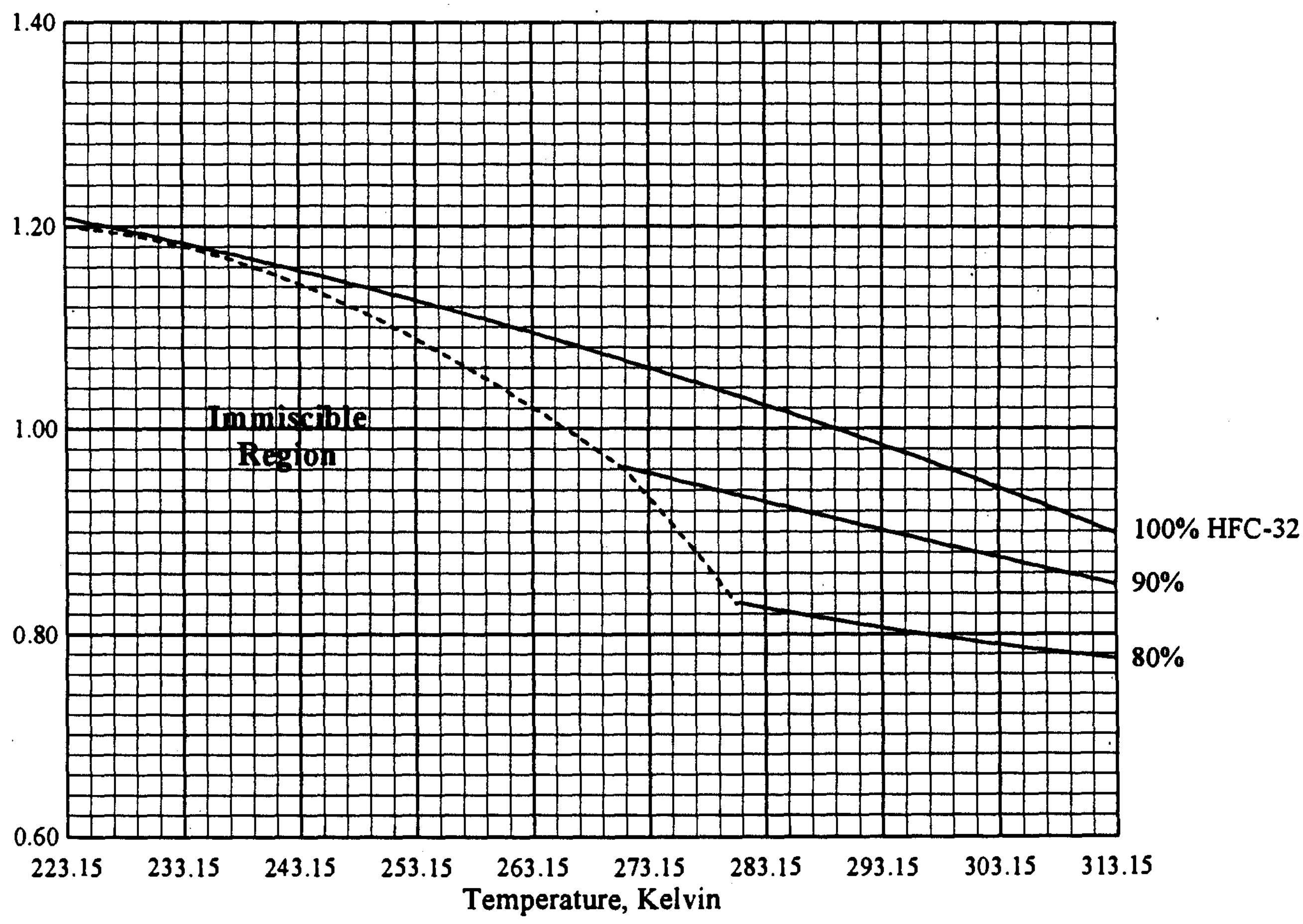


Figure 17-4: Viscosity and Solubility of HFC-32/ISO 22 Pentaerythritol Ester Mixed Acid #2 High Refrigerant Concentration Mixtures

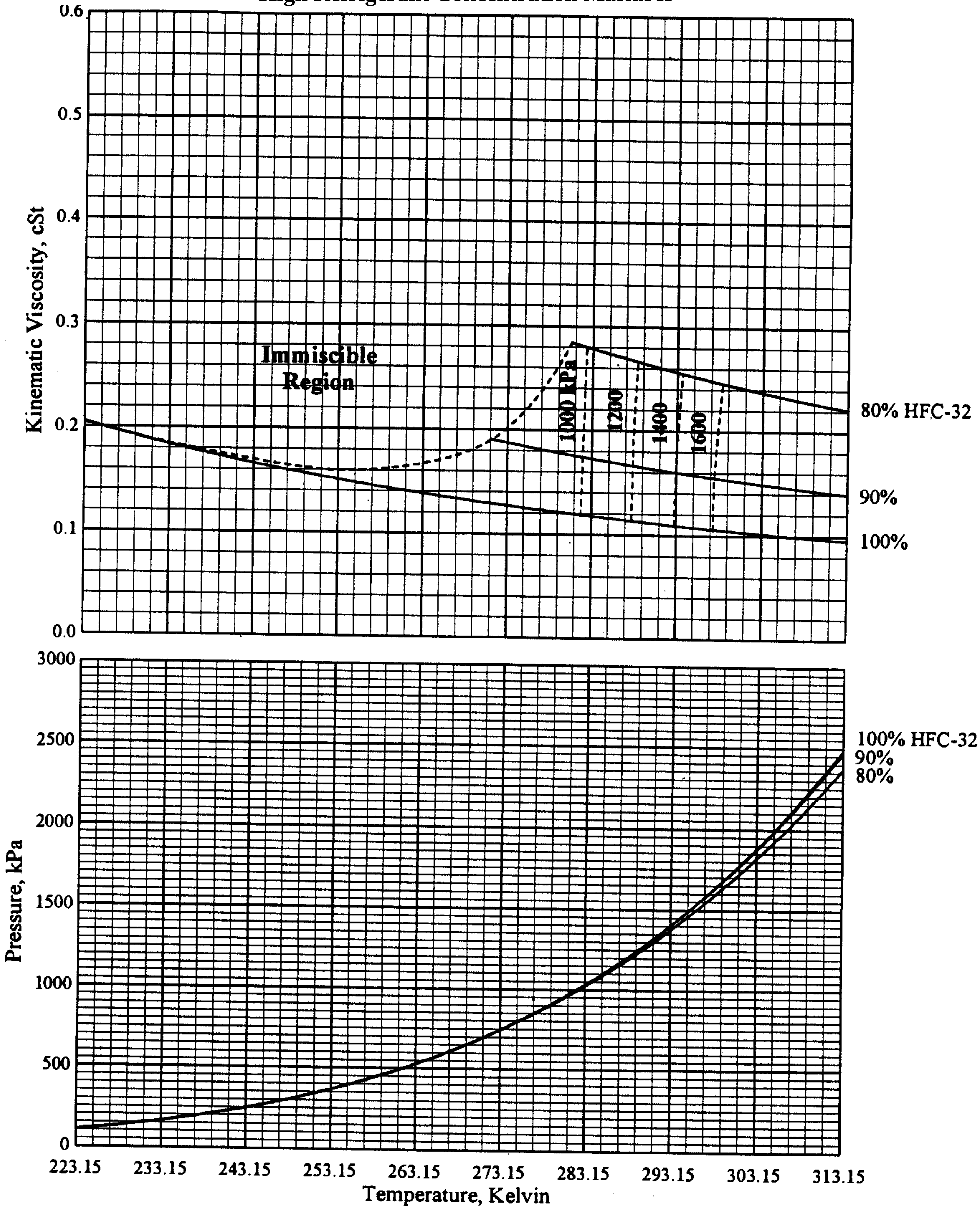


Table 18-1: Viscosity, Solubility and Density Parameters HFC-32/ISO 68 Pentaerythritol Ester Mixed Acid #2 Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	8.82885	5.23901E+2	1.24465	8.73084
a_2	-3.43072	-4.07248	-1.13150E-3	-3.38970
a_3	0	8.03095E-3	7.00018E-7	0
a_4	1.83410	1.17981E+4	6.10257E-1	-1.70416
a_5	-1.43467	-2.41853E+2	-2.39920E-3	-1.11362E-2
a_6	0	7.72624E-1	2.34237E-6	0
a_7	4.07074	5.99182E+4	-3.83439E-1	1.22241E+1
a_8	-1.41363	-9.18687E+1	2.82150E-3	-4.69226
a_9	0	-5.20589E-1	-5.93677E-6	0
σ	0.9998	0.9959	0.9998	0.9998

Figure 18-1: Density of HFC-32/ISO 68 Pentaerythritol Ester Mixed Acid #2 Low Refrigerant Concentrations

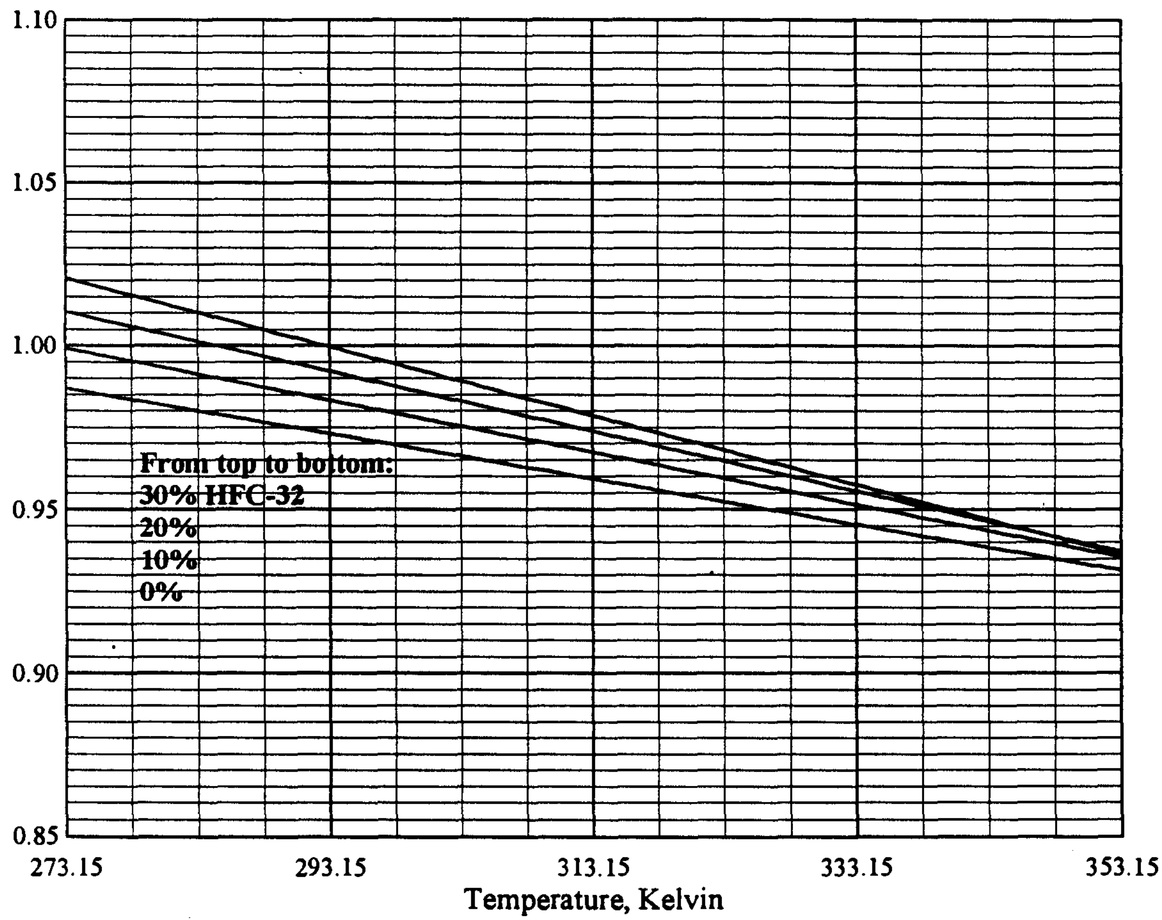


Figure 18-2: Viscosity and Solubility of HFC-32/ISO 68 Pentaerythritol Ester Mixed Acid #2 Low Refrigerant Concentration Mixtures

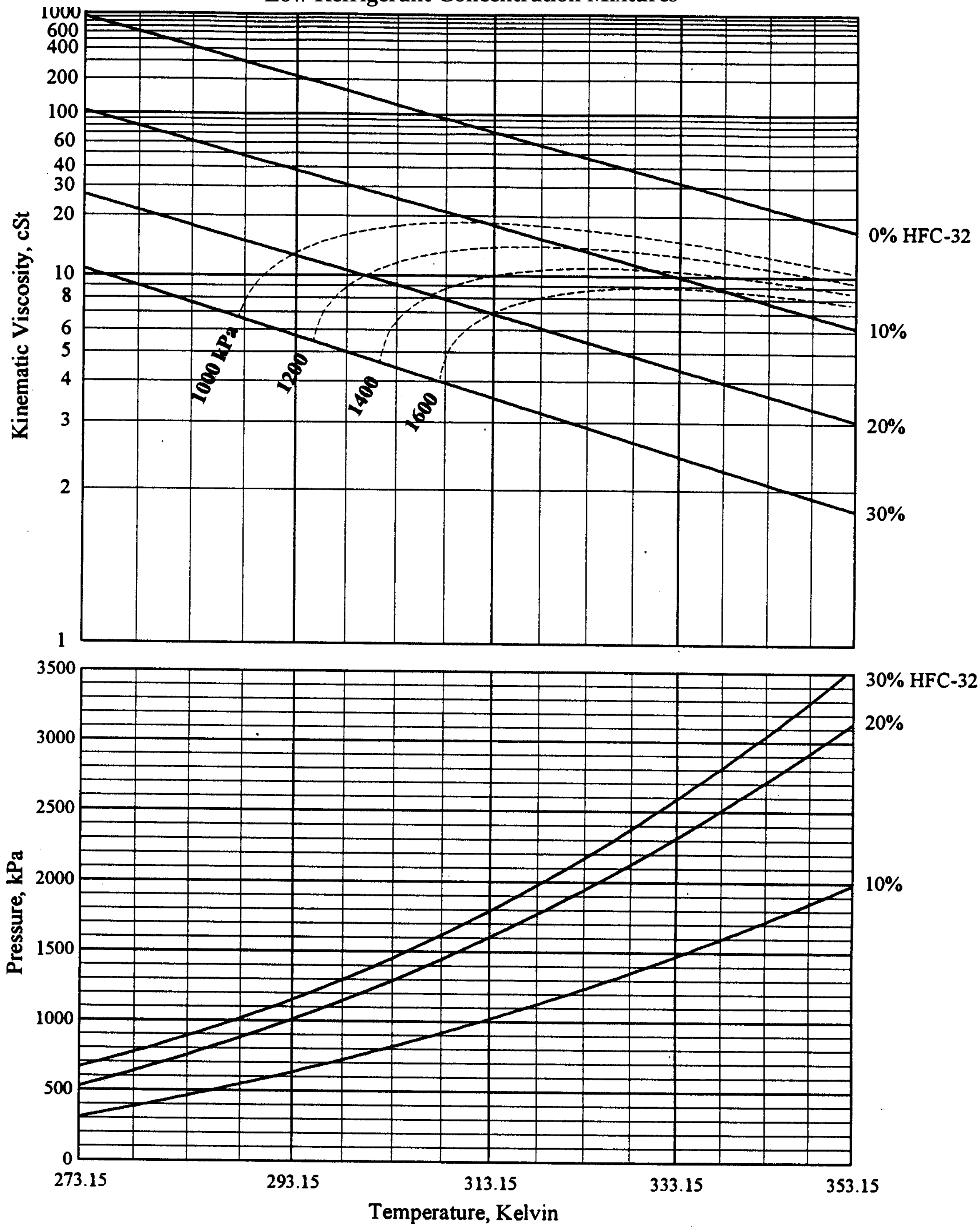


Table 19-1: Viscosity, Solubility and Density Parameters
HFC-32/ISO 32 Pentaerythritol Ester Branched Acid
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.24330	-2.02674E+3	1.49896	9.11767
a_2	-3.63313	1.29657E+1	-2.30995E-3	-3.58348
a_3	0	-2.06287E-2	2.46107E-6	0
a_4	3.95553	1.55968E+3	-1.94304	3.31771
a_5	-2.19602	-1.63428E+2	1.38109E-2	-1.94054
a_6	0	6.15149E-1	-2.40889E-5	0
a_7	-8.54932	3.13289E+5	-3.37963	-9.84240
a_8	3.15935	-1.87972E+3	2.23004E-2	3.64609
a_9	0	2.66387	-3.50548E-5	0
σ	0.9997	0.9997	0.9945	0.9997

Figure 19-1: Density of HFC-32/ISO 32 Pentaerythritol Ester Branched Acid
Low Refrigerant Concentrations

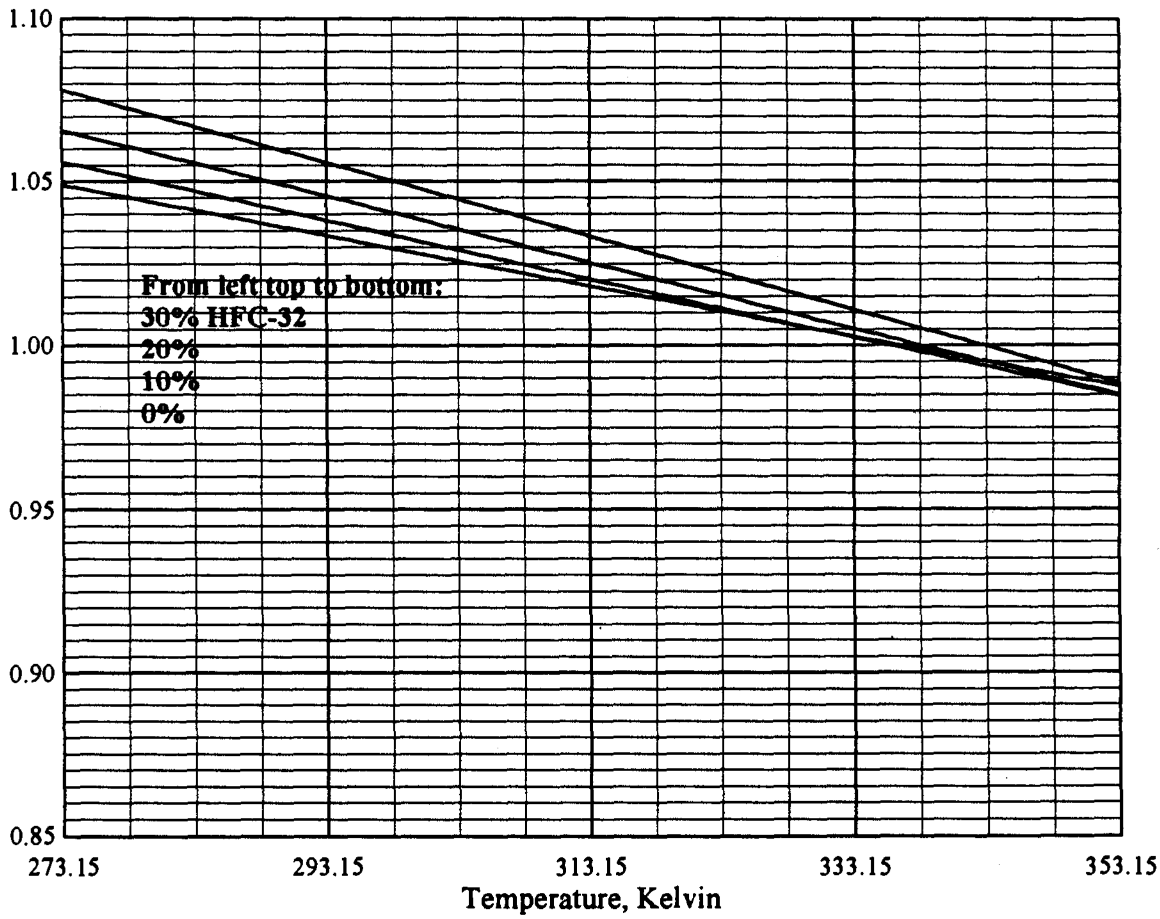


Figure 19-2: Viscosity and Solubility of HFC-32/ISO 32 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

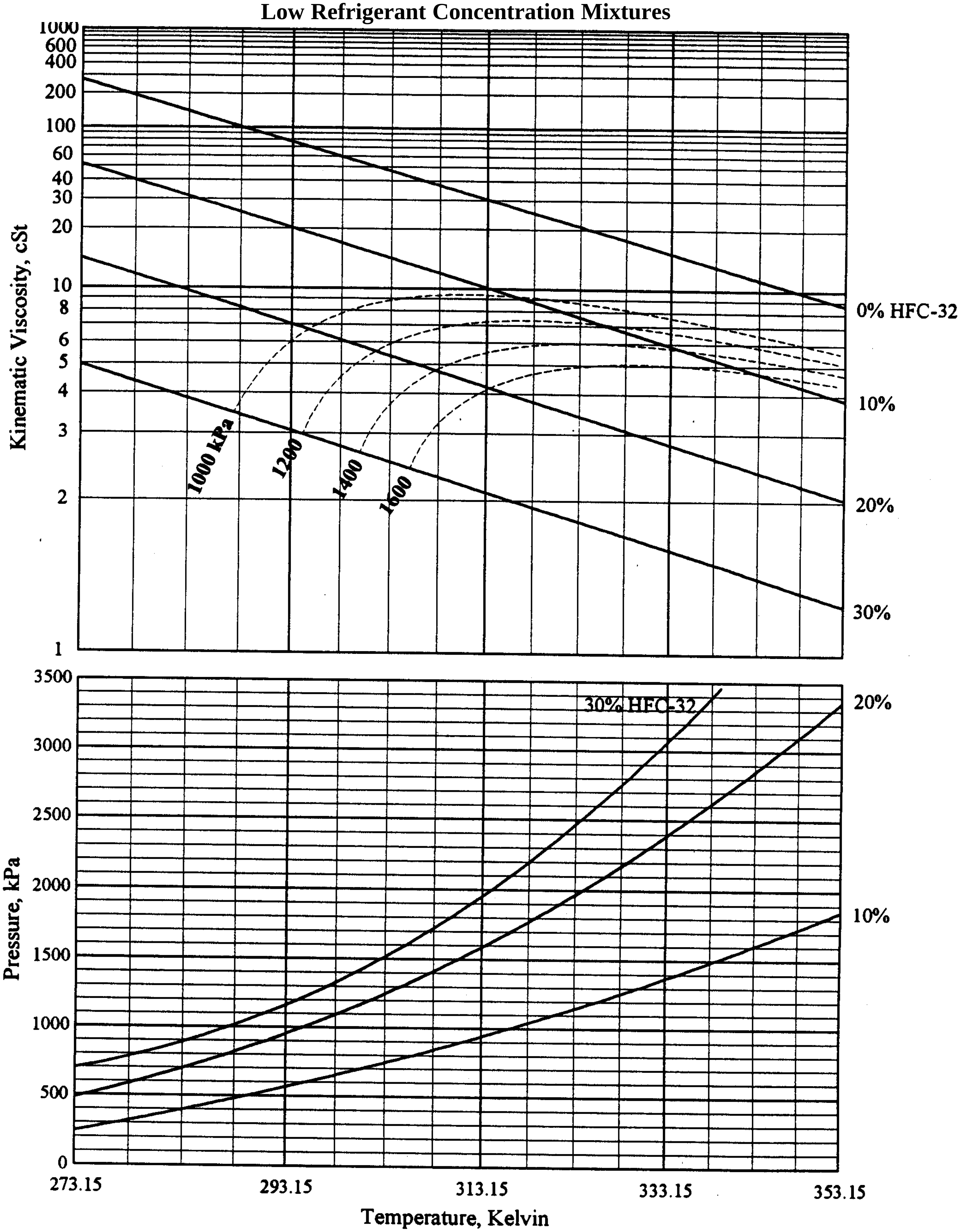


Table 19-2: Viscosity, Solubility and Density Parameters
HFC-32/ISO 32 Pentaerythritol Ester Branched Acid
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-1.30558E+1	1.98219	-3.37933E-1	-1.10440E+1
a_2	3.19522E+3	1.73333E+3	-3.12411	2.66373E+3
a_3	-6.33784E+4	-4.18158E+5	1.30807E+1	-8.50456E+3
a_4	2.13747E+1	2.53097	2.24065	1.91332E+1
a_5	-3.88704E+3	-1.82415E+3	4.50141	-3.63339E+3
a_6	-1.66884E+5	3.35467E+5	-2.53989E+1	-1.66433E+5
a_7	-1.04992E+1	4.30442	-1.19832	-9.16813
a_8	1.05699E+3	-2.06296E+3	5.57469E-1	8.35433E+2
a_9	2.27628E+5	2.26935E+5	1.08015E+1	2.24808E+5
σ	0.9970	0.9996	0.9999	0.9977

Figure 19-3: Density of HFC-32/ISO 32 Pentaerythritol Ester Branched Acid
High Refrigerant Concentration Mixtures

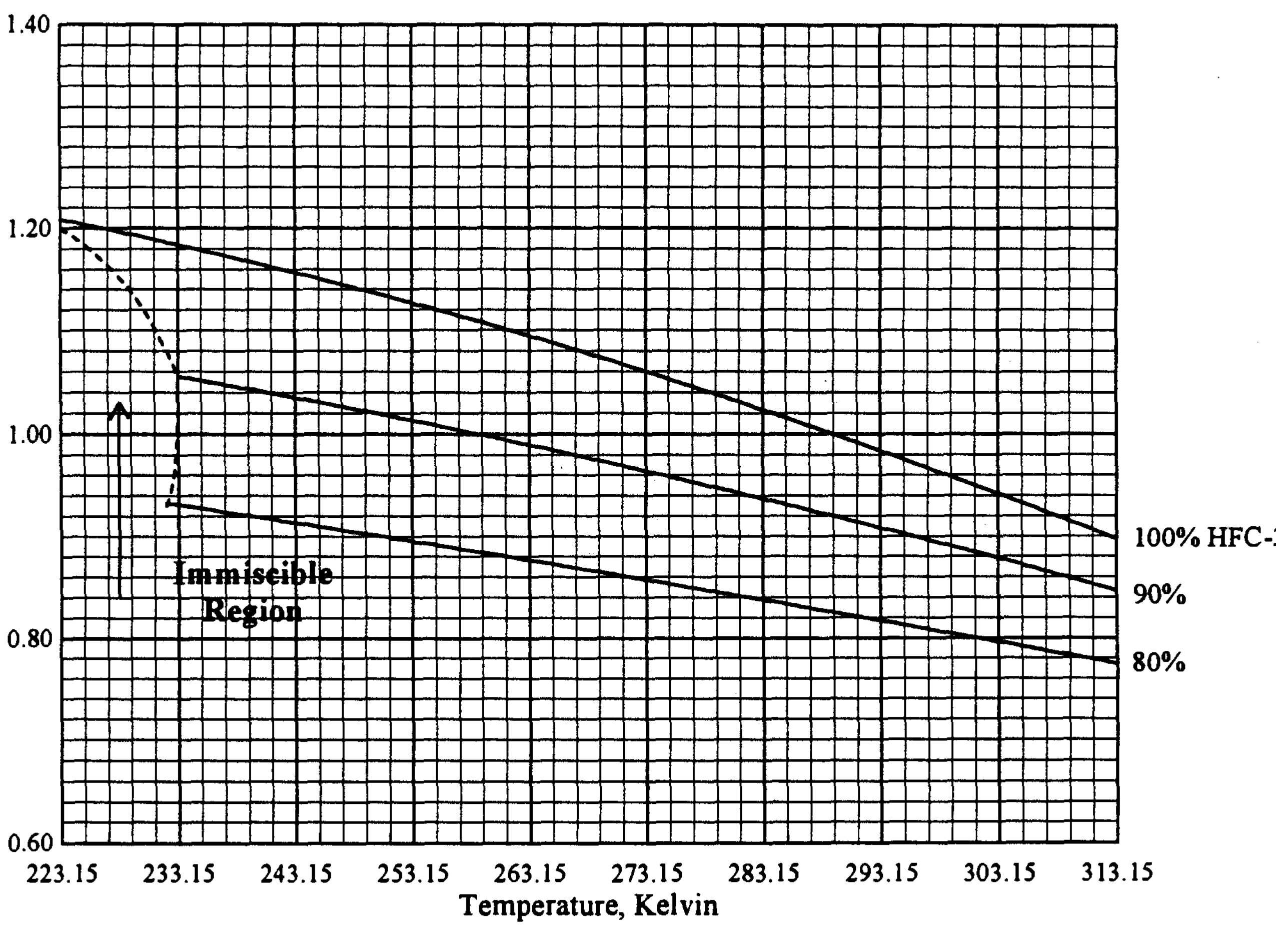


Figure 19-4: Viscosity and Solubility of HFC-32/ISO 32 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

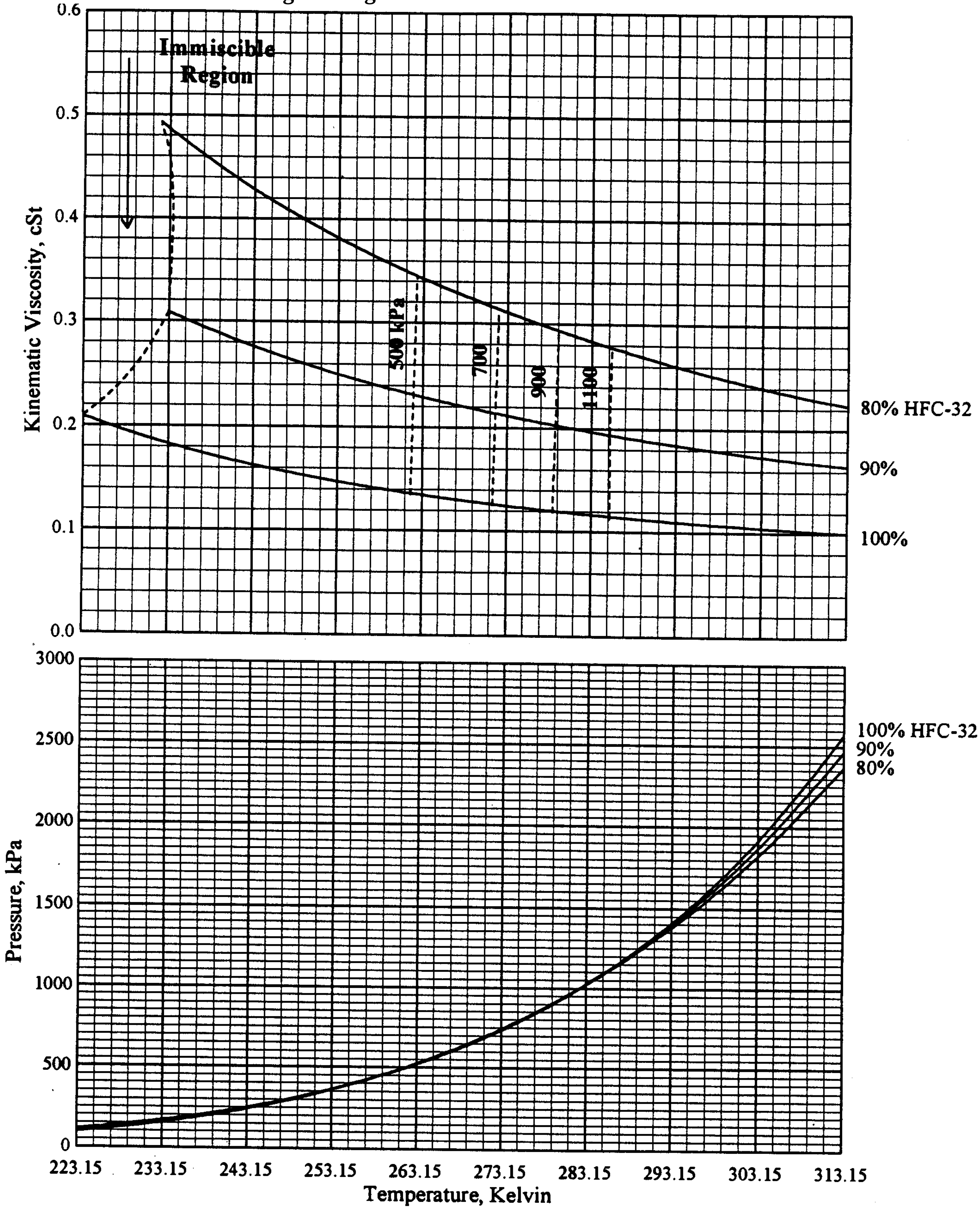


**Table 20-1: Viscosity, Solubility and Density Parameters
HFC-32/ISO 100 Pentaerythritol Ester Branched Acid
Low Refrigerant Concentration Mixtures**

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	8.34664	1.58364E+3	1.27197	8.25738
a_2	-3.22184	-1.03469E+1	-7.05062E-4	-3.18736
a_3	0	1.68581E-2	-1.04348E-7	0
a_4	-5.29595	5.52276E+4	3.66137	-5.40106
a_5	1.56092	-5.33025E+2	-2.24041E-2	1.59731
a_6	0	1.25416	3.43784E-5	0
a_7	3.42788E+1	8.53957E+4	-1.13921E+1	3.28096E+1
a_8	-1.39609E+1	-3.41479E+2	7.33225E-2	-1.33800E+1
a_9	0	6.71700E-2	-1.18131E-4	0
σ	0.9998	0.9998	0.9996	0.9998

**Figure 20-1: Density of HFC-32/ISO 100 Pentaerythritol Ester Branched Acid
Low Refrigerant Concentrations**

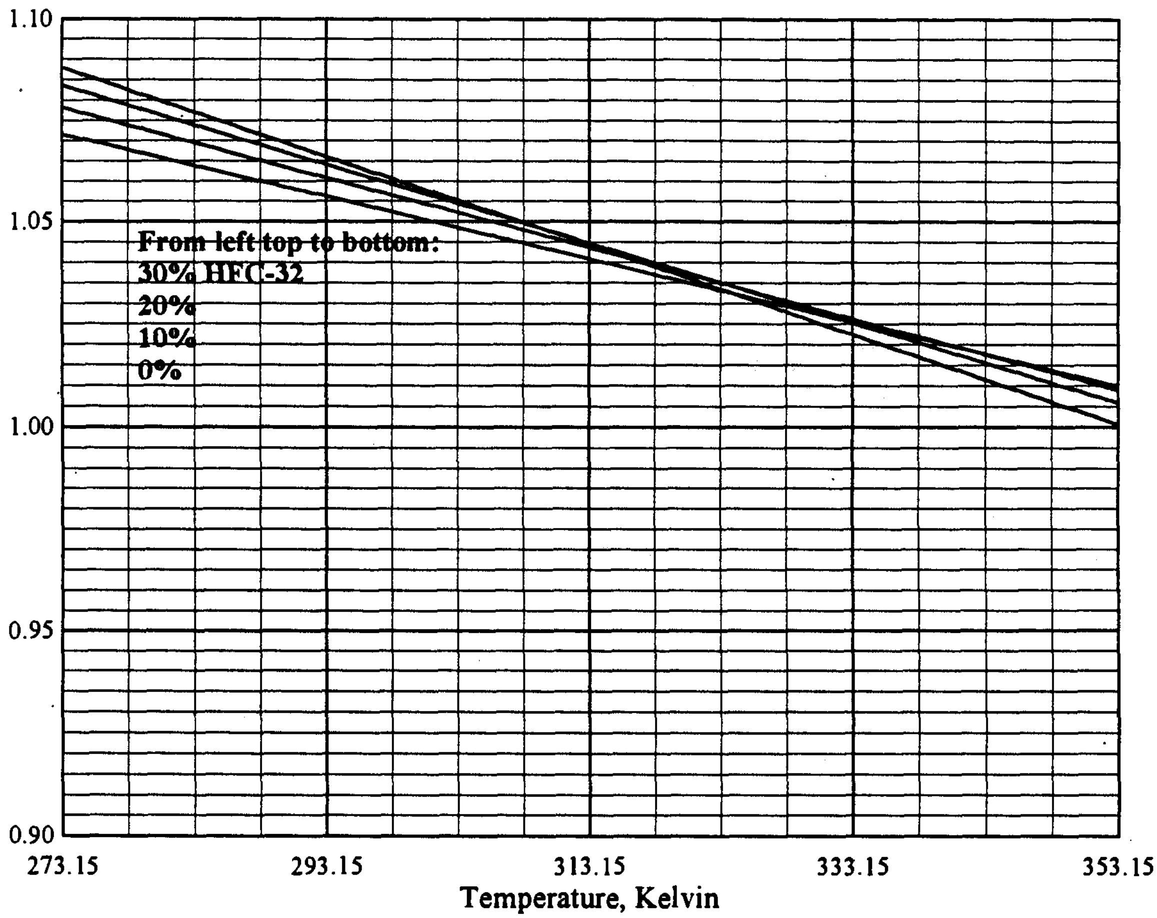


Figure 20-2: Viscosity and Solubility of HFC-32/ISO 100 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

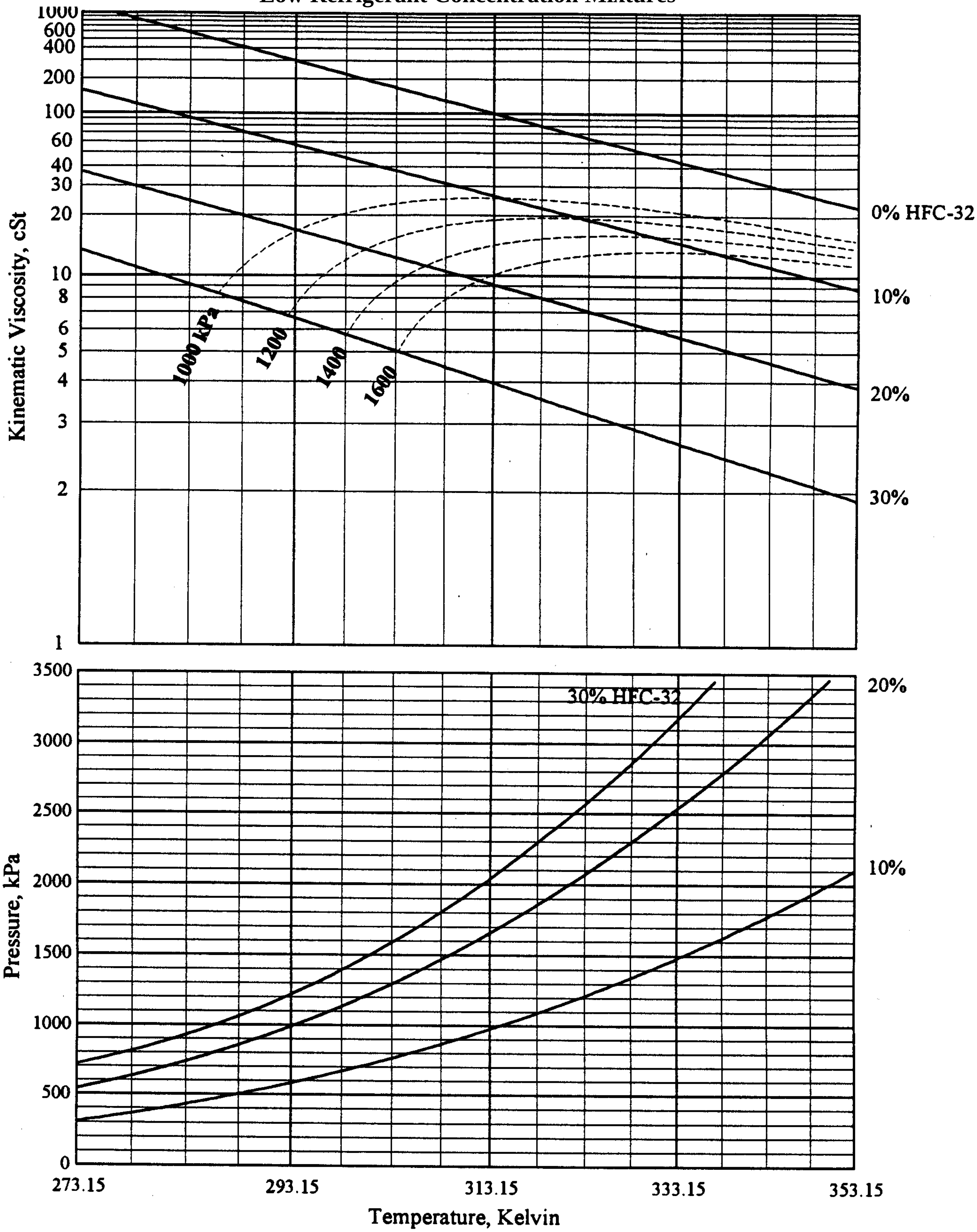


Table 21-1: Viscosity, Solubility and Density Parameters HFC-125/ISO 22 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.11565	9.33174E+3	1.22636	8.92634
a_2	-3.59907	-6.19656E+1	-8.50474E-4	-3.52182
a_3	0	1.03249E-1	1.68863E-7	0
a_4	4.58187	-8.08004E+3	-1.41881	4.90965
a_5	-2.12173	-4.96284E+1	1.17277E-2	-2.26321
a_6	0	2.93804E-1	-2.02203E-5	0
a_7	-1.30798E+1	1.23623E+5	1.03996E+1	-1.30769E+1
a_8	4.95383	-7.02891E+2	-6.78810E-2	4.90564
a_9	0	9.45651E-1	1.11865E-4	0
σ	0.9994	0.9998	0.9995	0.9994

Figure 21-1: Density of HFC-125/ISO 22 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentrations

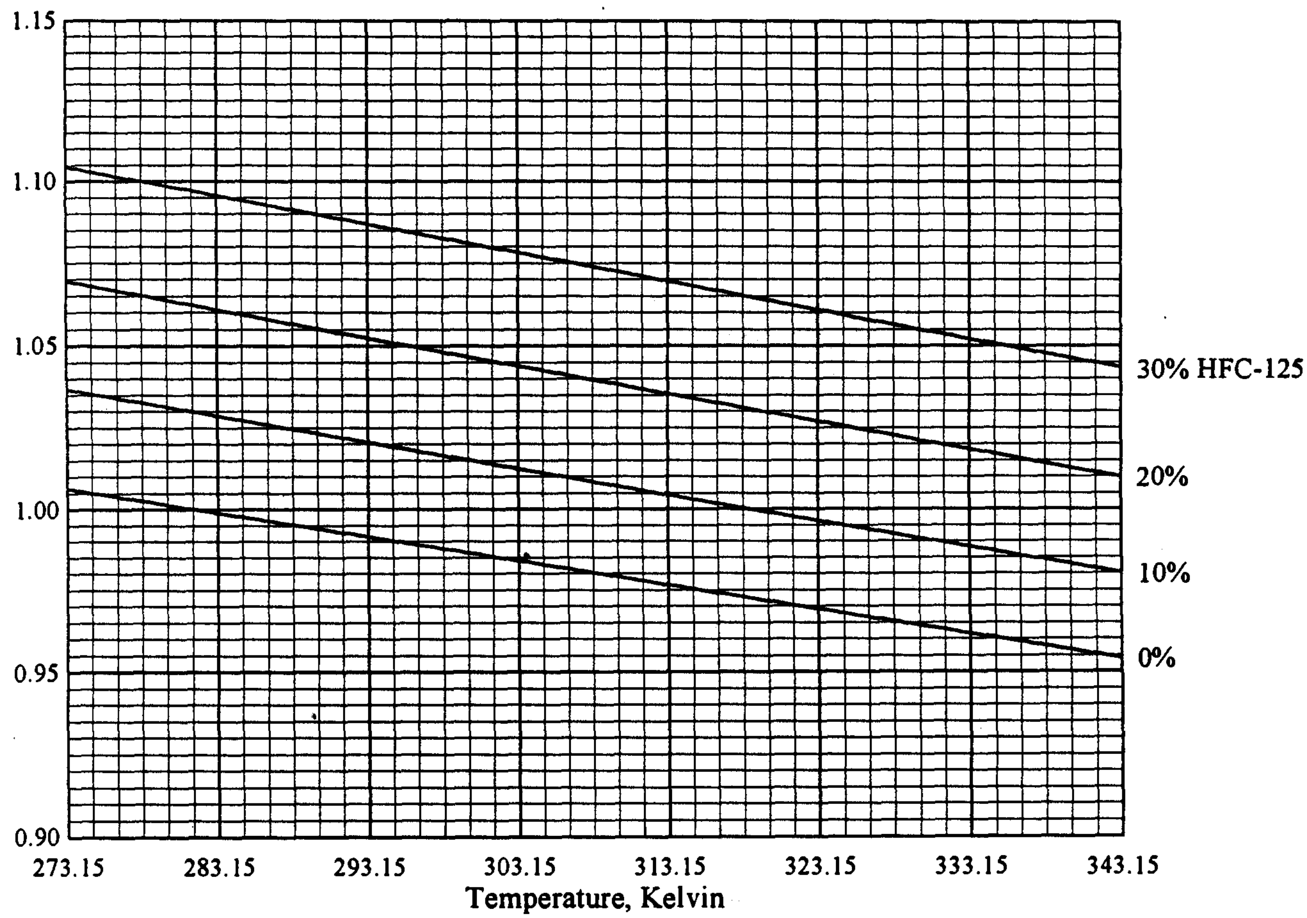


Figure 21-2: Viscosity and Solubility of HFC-125/ISO 22 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

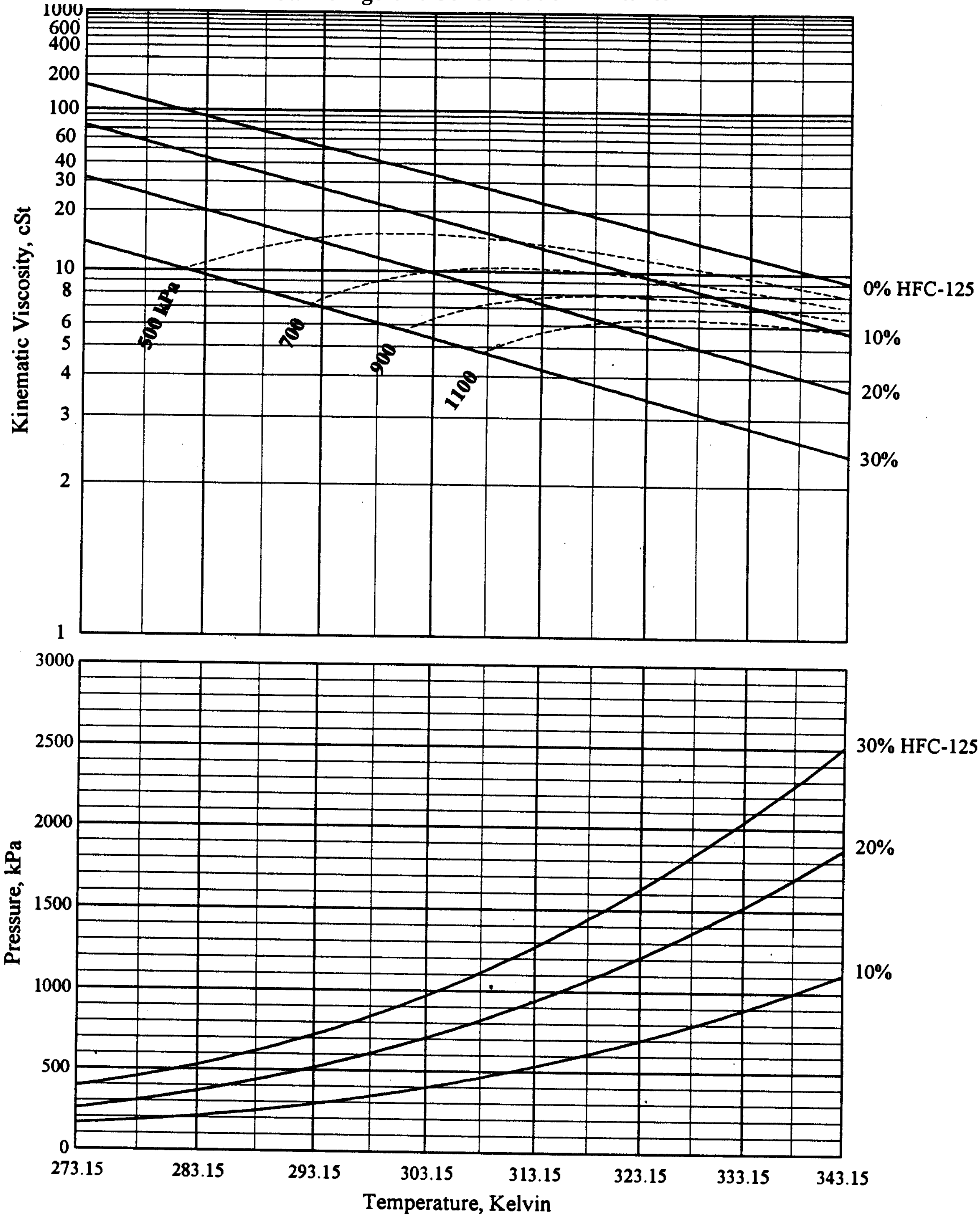


Table 21-2: Viscosity, Solubility and Density Parameters HFC-125/ISO 22 Pentaerythritol Ester Mixed Acid #1 High Refrigerant Concentration Mixtures

Coefficient	Kinematic Viscosity (eq. 9)	Vapor Pressure (eq. 10)	Density (eq. 11)
a_1	-1.43664	6.71867	5.55504E-1
a_2	1.31143E+2	-1.10275E+3	1.04165E-2
a_3	1.44370E+4	1.04402E+4	-2.77208E-5
σ_{100}	0.9985	0.9999	0.9994
a_4	-1.00707E-1	6.38232	1.30209
a_5	-5.90807E+2	-9.26526E+2	3.51020E-3
a_6	1.26571E+5	-1.36115E+4	-1.27537E-5
σ_{90}	0.9991	0.9999	0.9999
a_7	9.73358E-1	6.49932	1.47210
a_8	-1.02844E+3	-9.86559E+2	1.25430E-3
a_9	1.89626E+5	-6.81948E+3	-7.23471E-6
σ_{80}	0.9993	0.9999	0.9999

Figure 21-3: Density of HFC-125/ISO 22 Pentaerythritol Ester Mixed Acid #1 High Refrigerant Concentration Mixtures

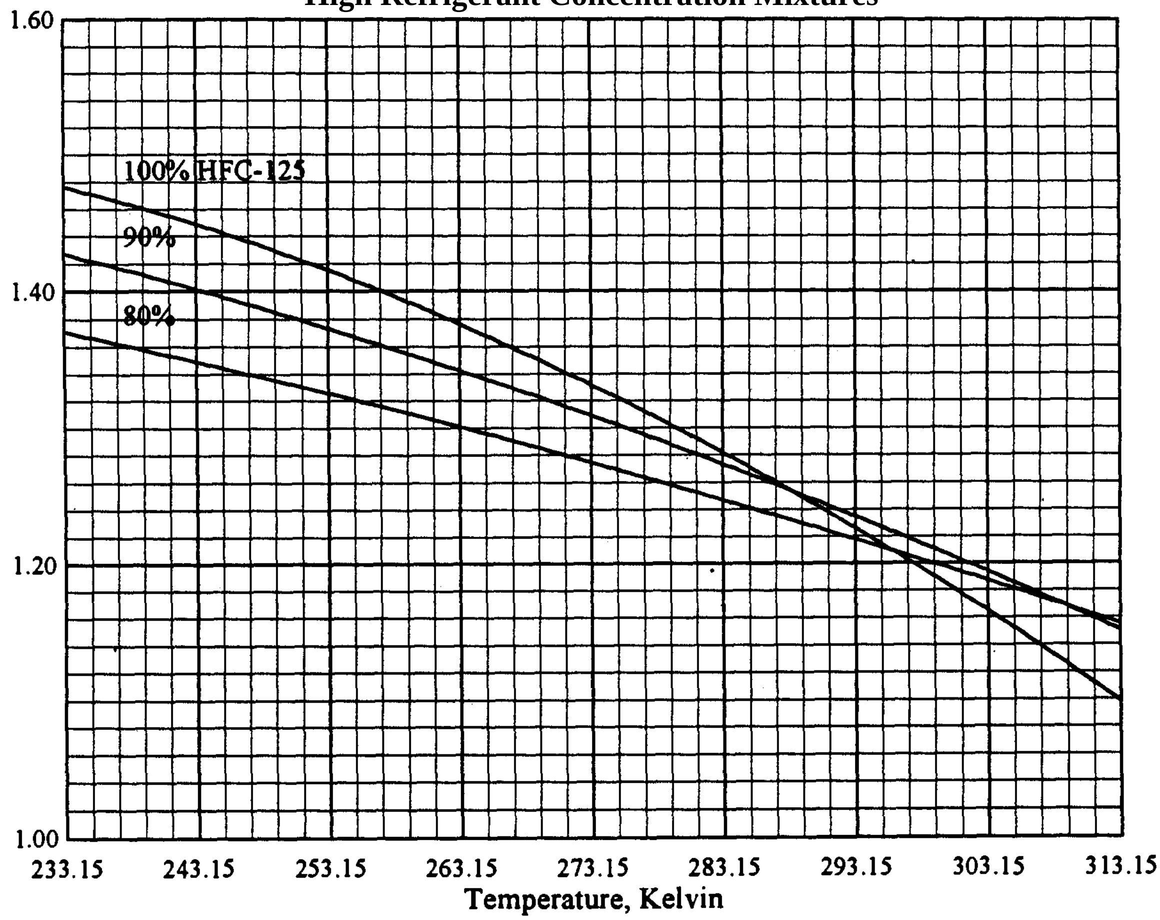


Figure 21-4: Viscosity and Solubility of HFC-125/ISO 22 Pentaerythritol Ester Mixed Acid #1 High Refrigerant Concentration Mixtures

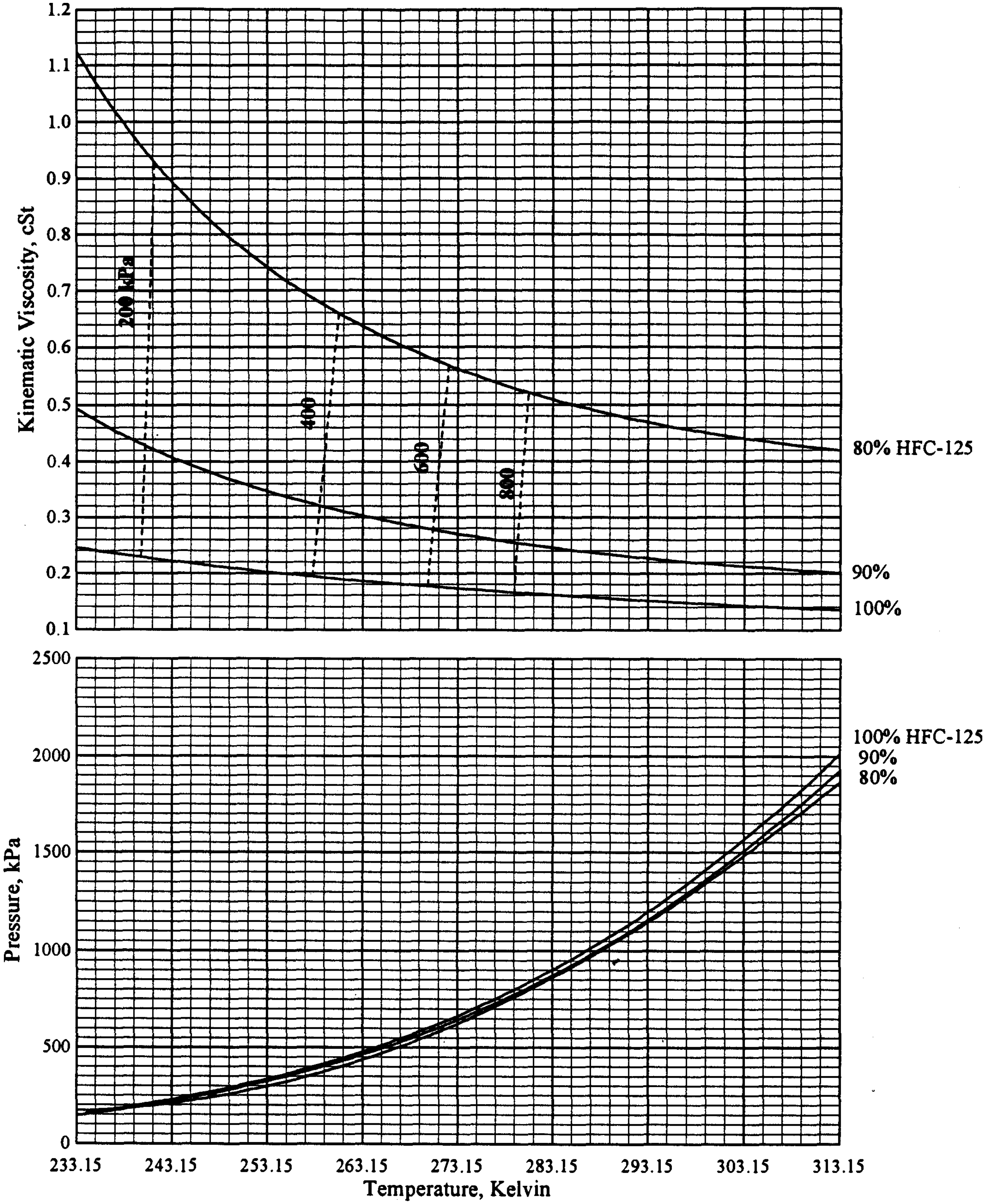


**Table 22-1: Viscosity, Solubility and Density Parameters
HFC-125/ISO 68 Pentaerythritol Ester Mixed Acid #2
Low Refrigerant Concentration Mixtures**

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	8.81454	2.01910E+3	1.24309	8.62420
a_2	-3.42524	-1.25159E+1	-1.12000E-3	-3.34716
a_3	0	1.92469E-2	6.81958E-7	0
a_4	1.16560E+1	6.00305E+4	3.55645E-1	1.14890E+1
a_5	-4.93647	-5.19229E+2	4.47903E-4	-4.87541
a_6	0	1.11454	-2.31872E-6	0
a_7	-3.61003E+1	-5.30431E+4	-1.69843	-3.42108E+1
a_8	1.40966E+1	4.86166E+2	1.11536E-2	1.32973E+1
a_9	0	-1.07753	-1.64462E-5	0
σ	0.9994	0.9995	0.9997	0.9995

**Figure 22-1: Density of HFC-125/ISO 68 Pentaerythritol Ester Mixed Acid #2
Low Refrigerant Concentrations**

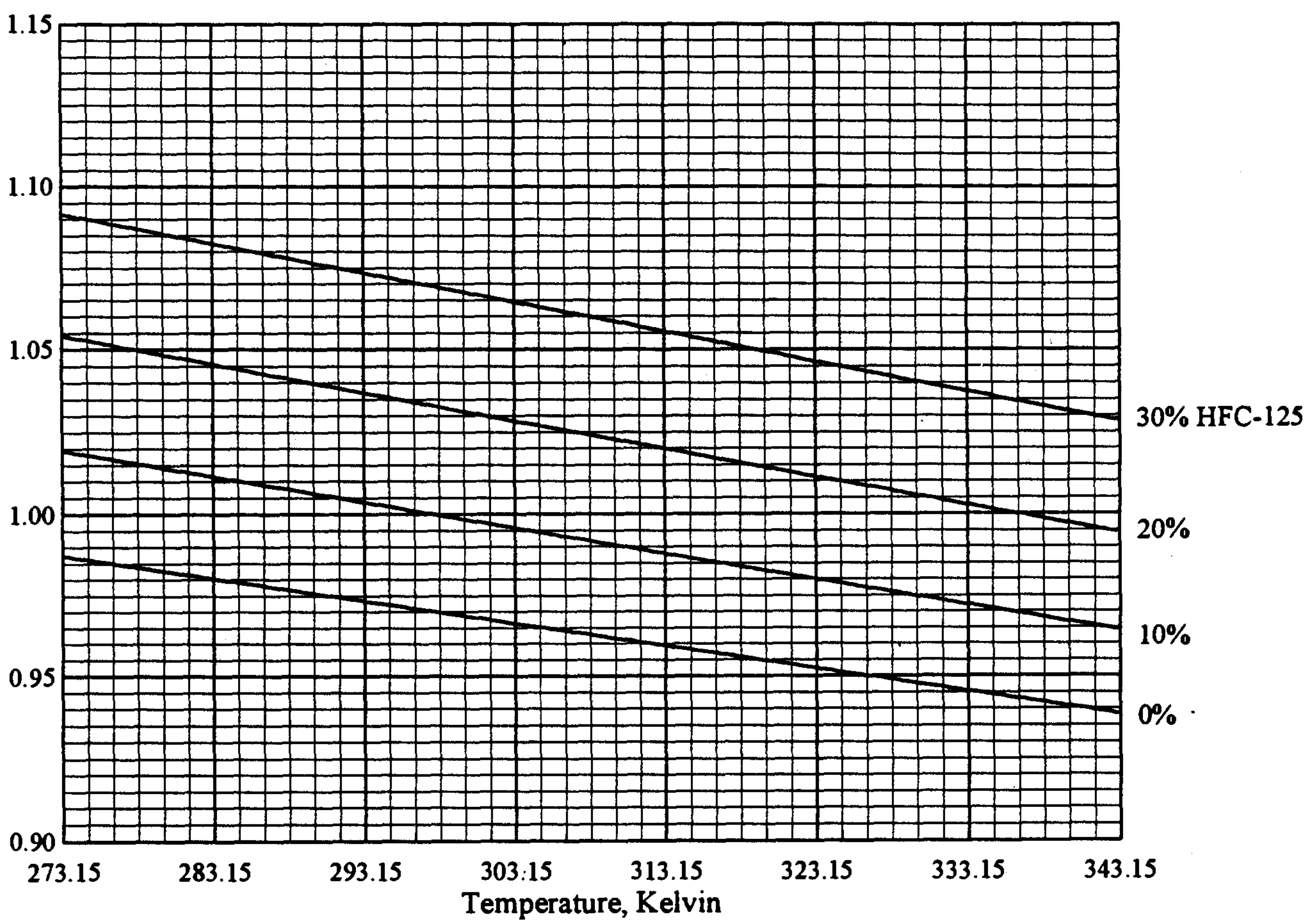


Figure 22-2: Viscosity and Solubility of HFC-125/ISO 68 Pentaerythritol Ester Mixed Acid #2 Low Refrigerant Concentration Mixtures

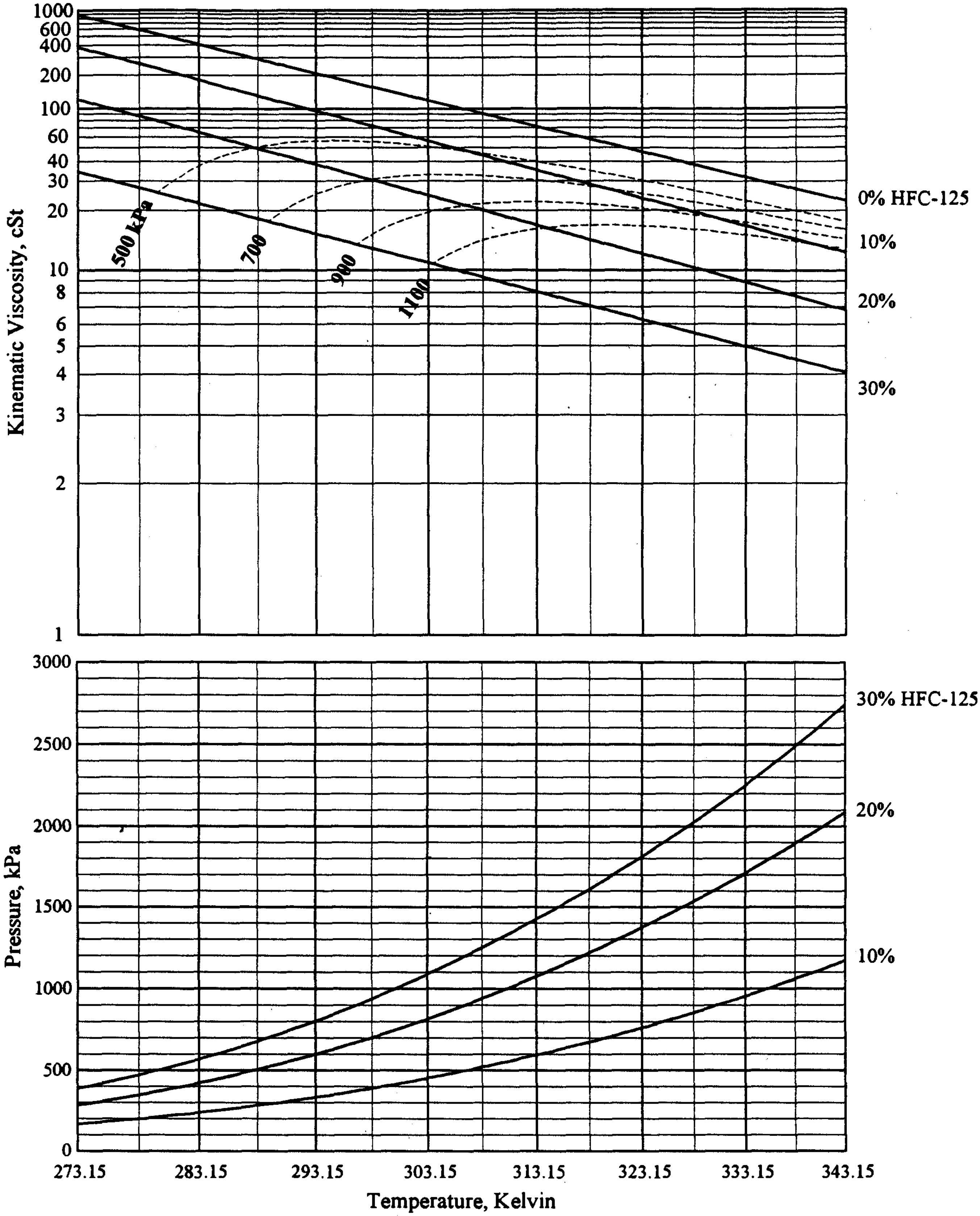


Table 22-2: Viscosity, Solubility and Density Parameters HFC-125/ISO 68 Pentaerythritol Ester Mixed Acid #2 High Refrigerant Concentration Mixtures

Coefficient	Kinematic Viscosity (eq. 9)	Vapor Pressure (eq. 10)	Density (eq. 11)
a_1	-1.43664	6.71867	5.55504E-1
a_2	1.31143E+2	-1.10275E+3	1.04165E-2
a_3	1.44370E+4	1.04402E+4	-2.77208E-5
σ_{100}	0.9985	0.9999	0.9994
a_4	-5.86618E-2	6.42789	1.05112
a_5	-5.63200E+2	-9.52139E+2	5.26636E+3
a_6	1.19813E+5	-9.63556E+3	-1.58627E-5
σ_{90}	0.9998	0.9999	0.9994
a_7	1.64273	6.69251	1.46583
a_8	-1.33799E+3	-1.09769E+3	1.66027E-3
a_9	2.29988E+5	9.75143E+3	-8.26358E-6
σ_{80}	0.9994	0.9999	0.9995

Figure 22-3: Density of HFC-125/ISO 68 Pentaerythritol Ester Mixed Acid #2 High Refrigerant Concentration Mixtures

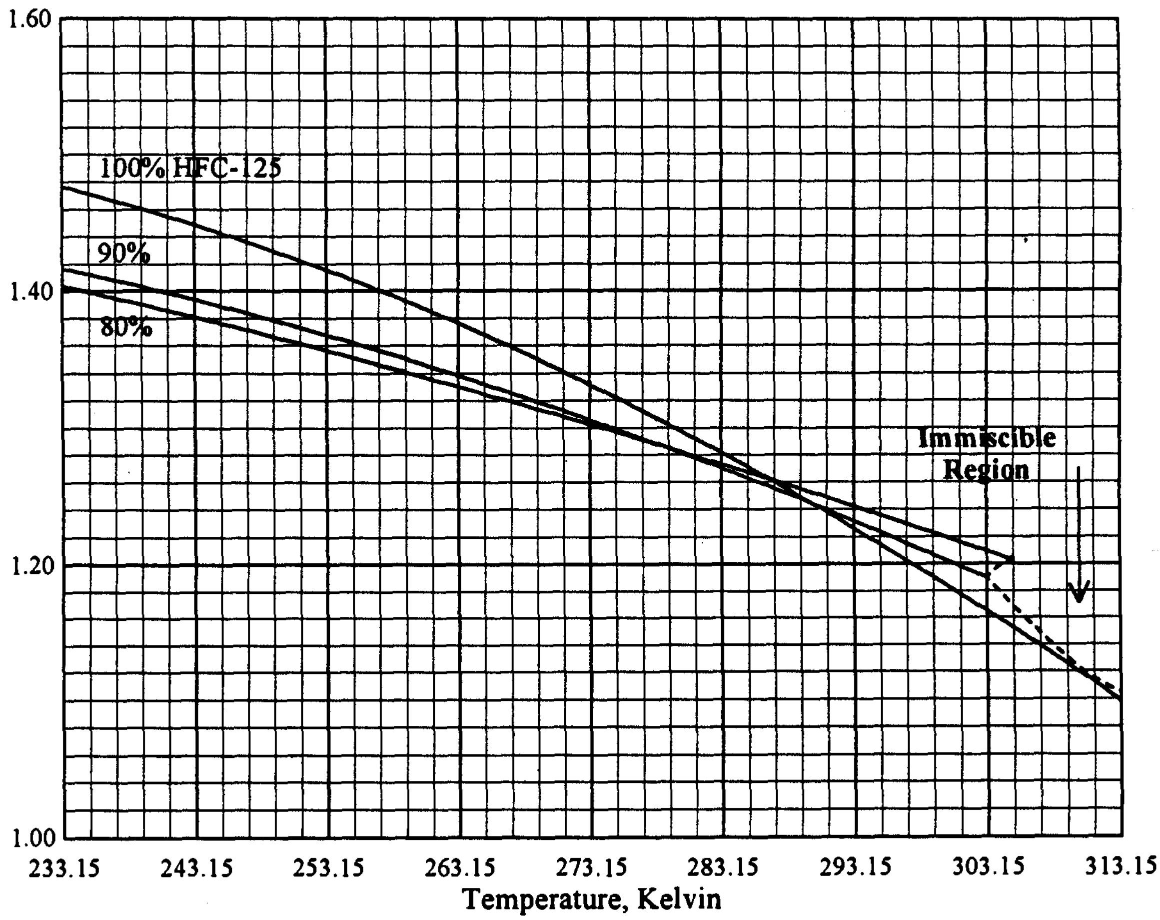


Figure 22-4: Viscosity and Solubility of HFC-125/ISO 68 Pentaerythritol Ester Mixed Acid #2 High Refrigerant Concentration Mixtures

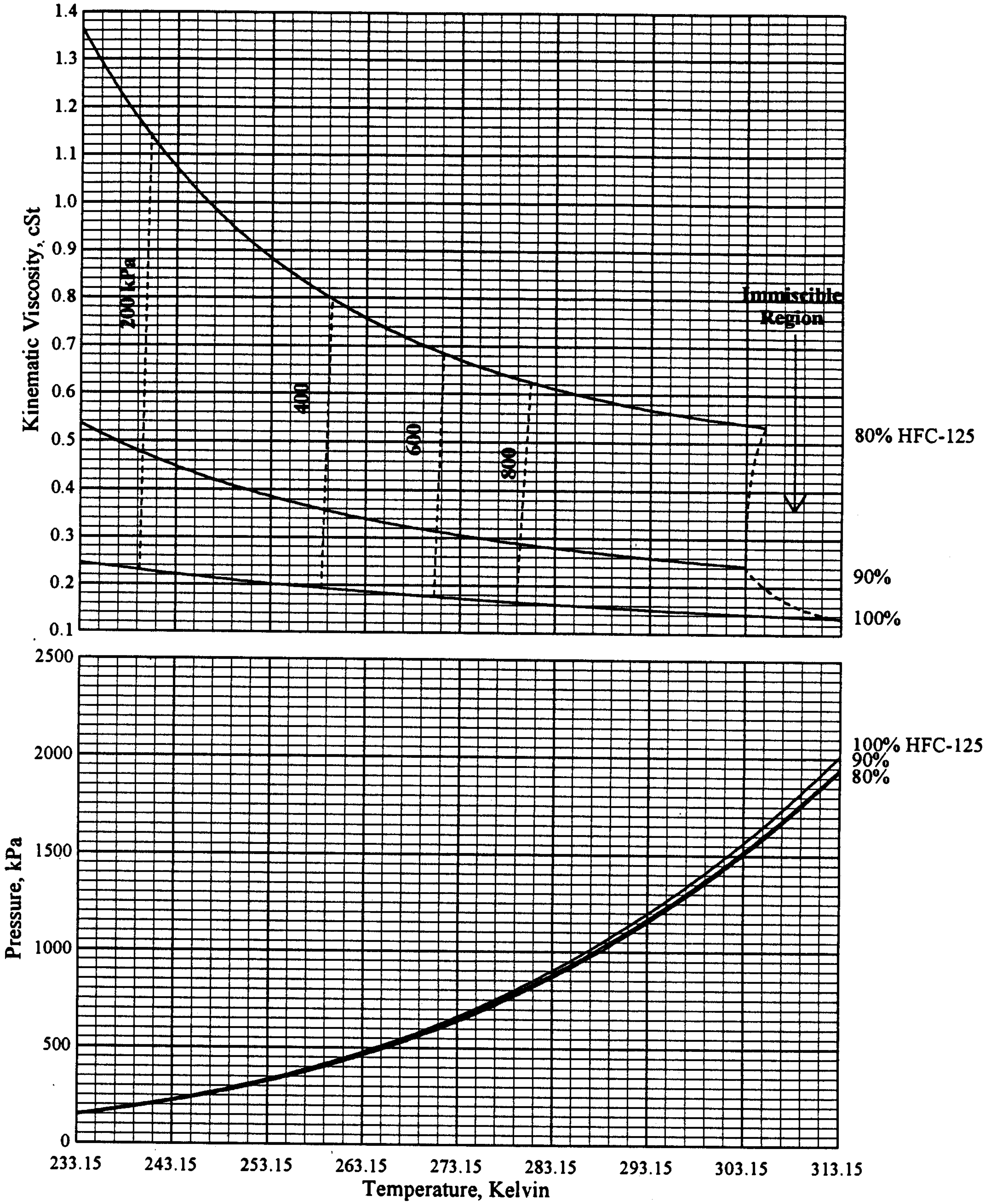


Table 23-1: Viscosity, Solubility and Density Parameters
HFC-125/ISO 32 Pentaerythritol Ester Branched Acid
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.11492	1.01710E+4	1.16909	8.96733
a_2	-3.58088	-6.64601E+1	-1.79173E-4	-3.52240
a_3	0	1.08115E-1	-9.64680E-7	0
a_4	1.14713E+1	-7.96440E+4	3.08703	1.18293E+1
a_5	-4.90376	4.28531E+2	-1.73262E-2	-5.05910
a_6	0	-4.97952E-1	2.64659E-5	0
a_7	-3.80414E+1	3.30692E+5	1.21497	-3.72677E+1
a_8	1.48515E+1	-2.07769E+3	-8.76281E-3	1.44909E+1
a_9	0	3.19927	1.61212E-5	0
σ	0.9983	0.9987	0.999574	0.9984

Figure 23-1: Density of HFC-125/ISO 32 Pentaerythritol Ester Branched Acid
Low Refrigerant Concentrations

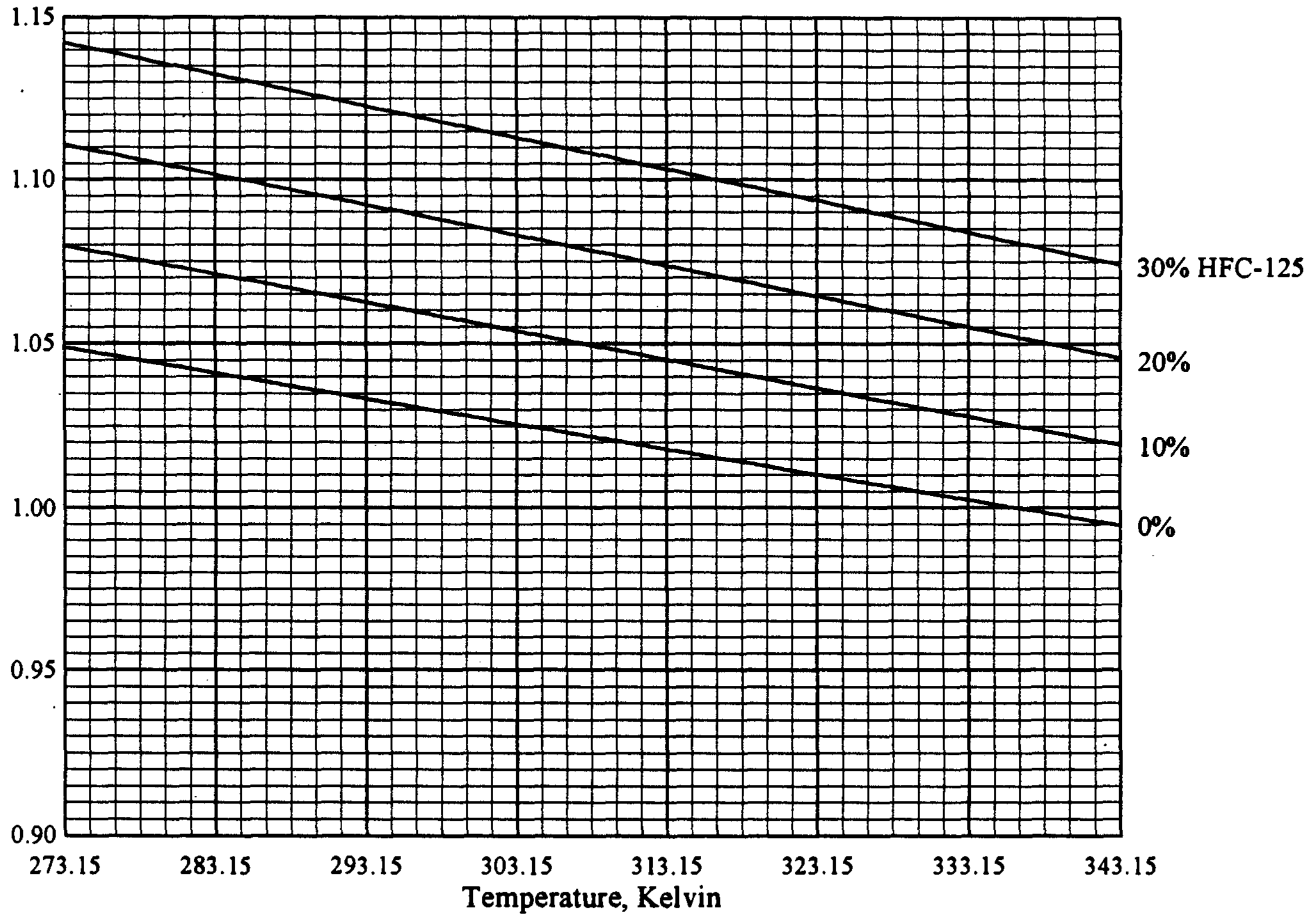


Figure 23-2: Viscosity and Solubility of HFC-125/ISO 32 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

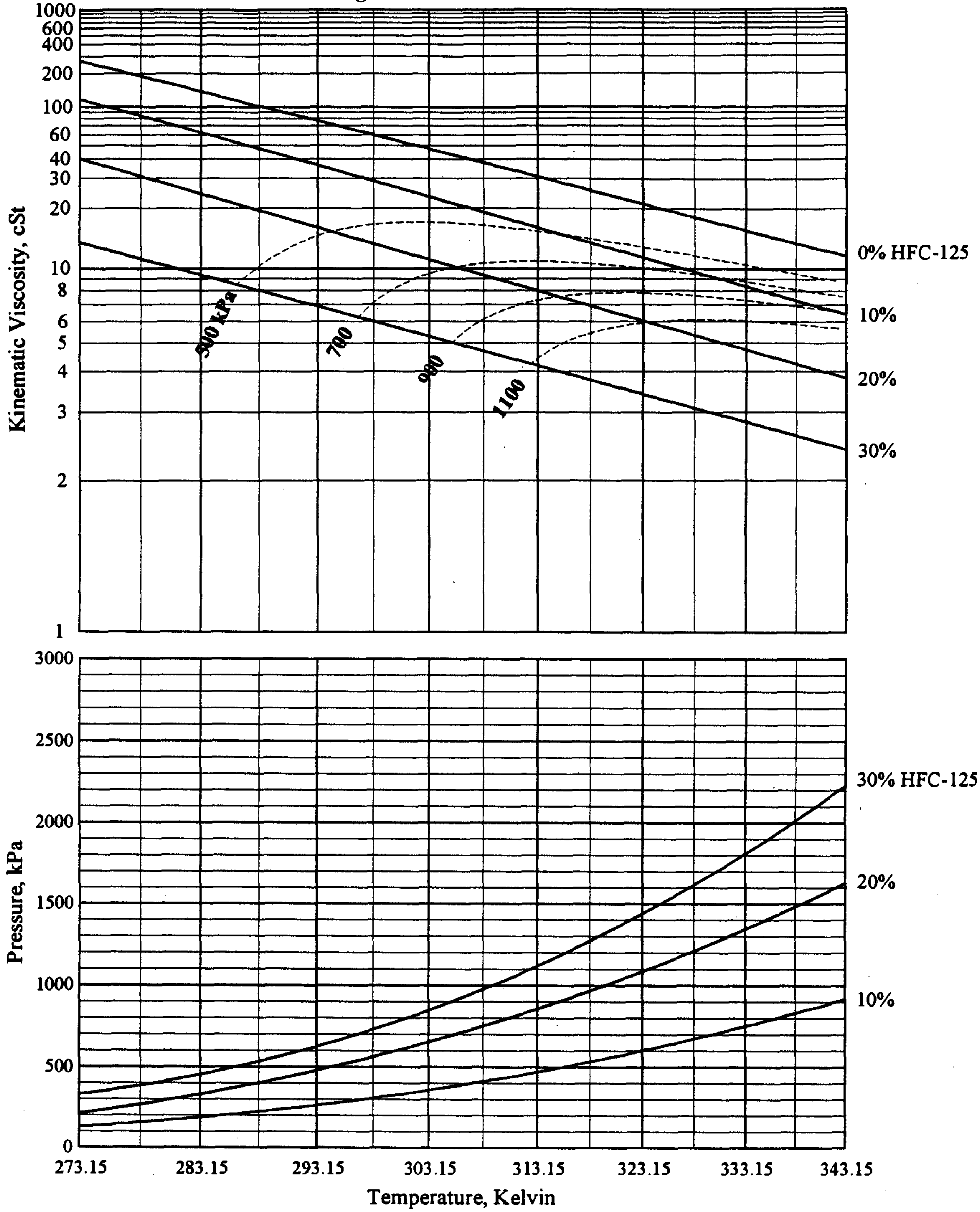


Table 23-2: Viscosity, Solubility and Density Parameters
HFC-125/ISO 32 Pentaerythritol Ester Branched Acid
High Refrigerant Concentration Mixtures

Coefficient	Kinematic Viscosity (eq. 9)	Vapor Pressure (eq. 10)	Density (eq. 11)
a_1	-1.43664	6.71867	5.55504E-1
a_2	1.31143E+2	-1.10275E+3	1.04165E-2
a_3	1.44370E+4	1.04402E+4	-2.77208E-5
σ_{100}	0.9985	0.9999	0.9994
a_4	-6.05623E-1	6.60126	1.45139
a_5	-3.28178E+2	-1.05826E+3	2.70711E-3
a_6	9.2055E+4	5.89946E+3	-1.17321E-5
σ_{90}	0.9997	0.9999	0.9996
a_7	3.41583E-1	6.17341	1.70126
a_8	-6.96745E+2	-7.92434E+2	-3.57003E-4
a_9	1.45902E+5	-3.75301E+4	-4.09883E-6
σ_{80}	0.9998	0.9999	0.9999

Figure 23-3: Density of HFC-125/ISO 32 Pentaerythritol Ester Branched Acid
High Refrigerant Concentration Mixtures

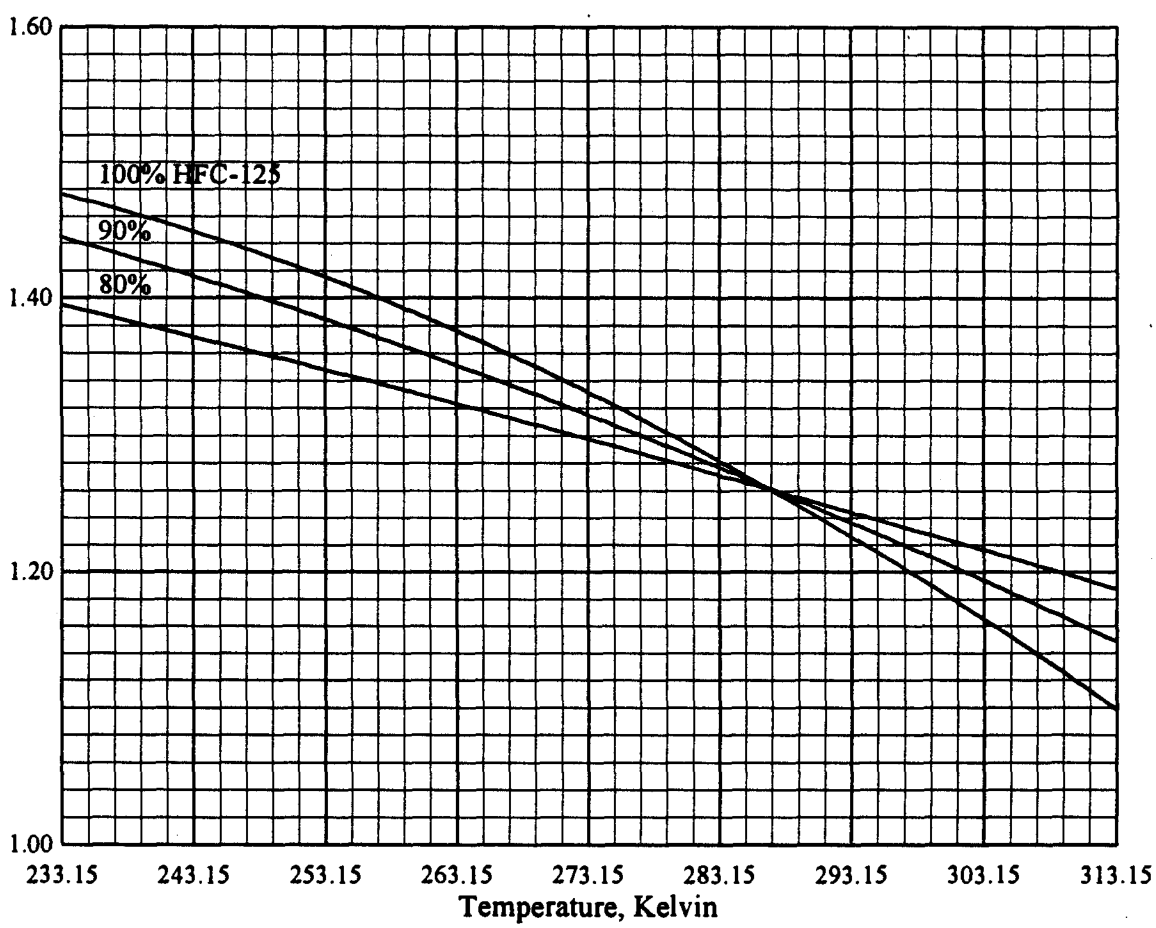


Figure 23-4: Viscosity and Solubility of HFC-125/ISO 32 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

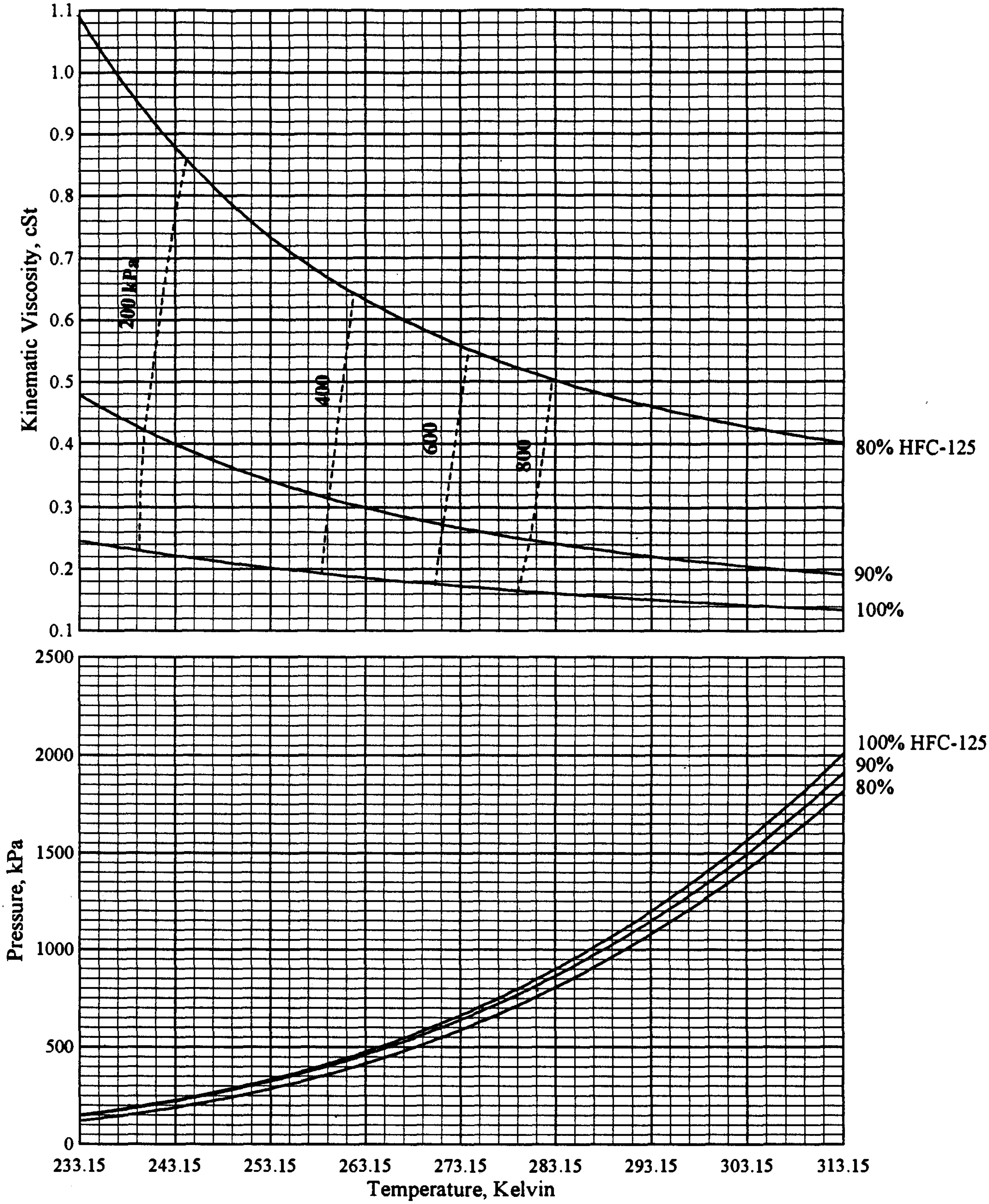


Table 24-1: Viscosity, Solubility and Density Parameters HFC-125/ISO 100 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	8.41066	1.82085E+3	1.28679	8.31131
a_2	-3.24772	-1.78385E+1	-7.94027E-4	-3.20924
a_3	0	4.04727E-2	2.99176E-8	0
a_4	-1.18482E+1	9.01506E+4	1.70047	-1.12412E+1
a_5	4.41652	-5.61147E+2	-8.20354E-3	4.16204
a_6	0	8.86526E-1	1.14527E-5	0
a_7	4.31096E+1	-6.73741E+4	-8.17055E-1	4.26821E+1
a_8	-1.74872E+1	8.66479E+1	3.36529E-3	-1.73510E+1
a_9	0	4.99831E-1	-1.99056E-6	0
σ	0.9988	0.9985	0.9999	0.998773

Figure 24-1: Density of HFC-125/ISO 100 Pentaerythritol Ester Branched Acid Low Refrigerant Concentrations

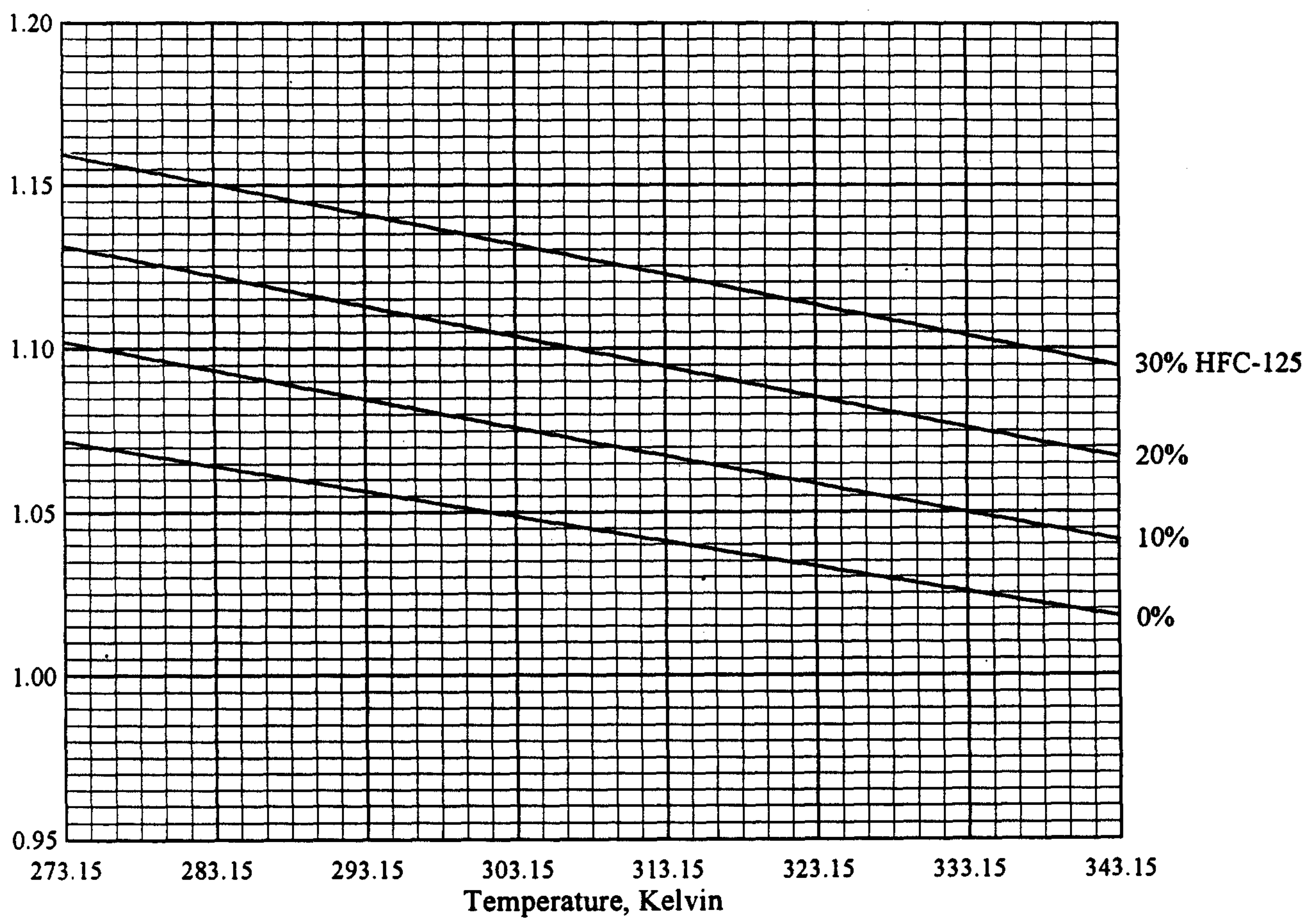


Figure 24-2: Viscosity and Solubility of HFC-125/ISO 100 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

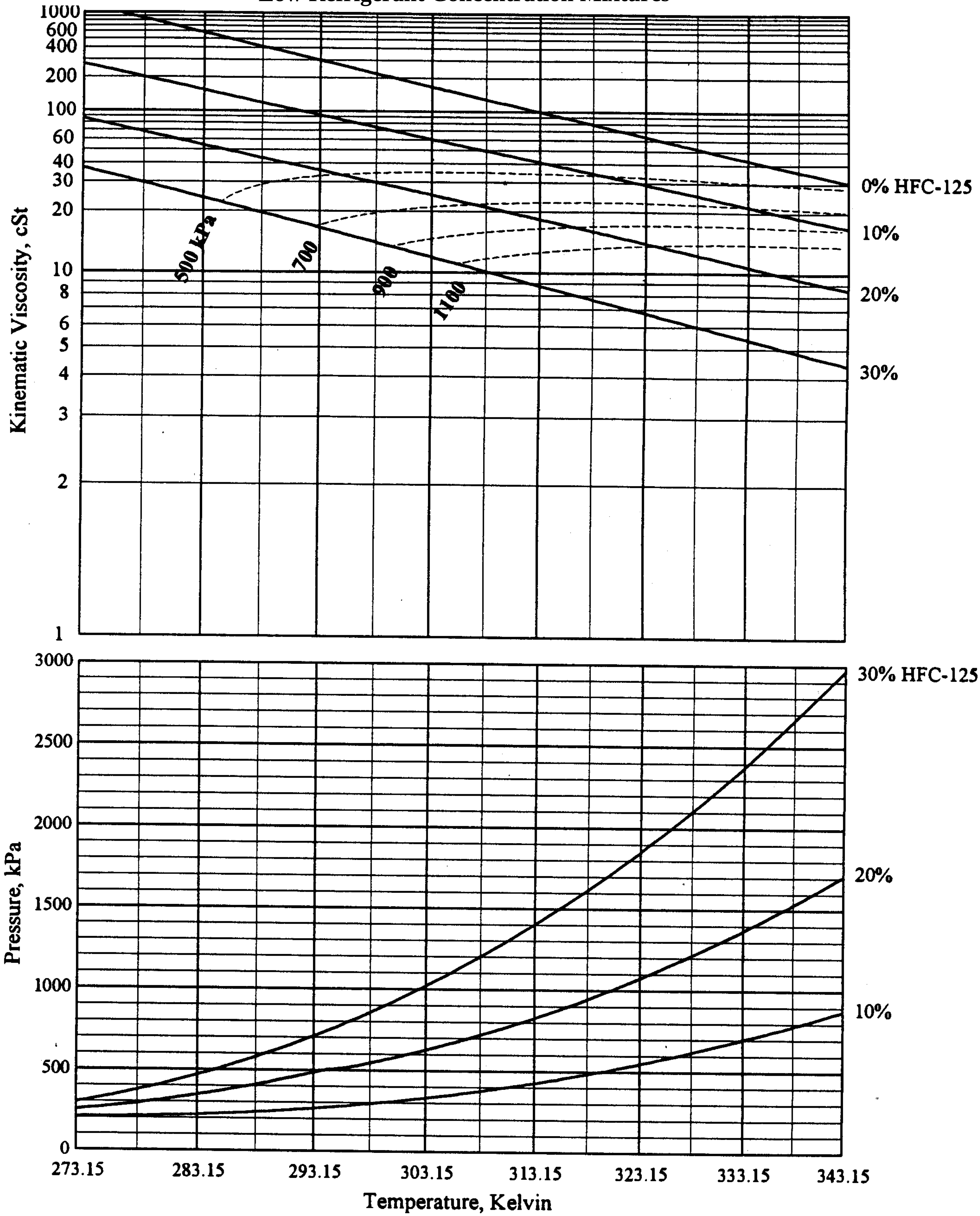


Table 24-2: Viscosity, Solubility and Density Parameters HFC-125/ISO 100 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

Coefficient	Kinematic Viscosity (eq. 9)	Vapor Pressure (eq. 10)	Density (eq. 11)
a_1	-1.43664	6.71867	5.55504E-1
a_2	1.31143E+2	-1.10275E+3	1.04165E-2
a_3	1.44370E+4	1.04402E+4	-2.77208E-5
σ_{100}	0.9985	0.9999	0.9994
a_4	-5.50468E-1	6.60308	1.27430
a_5	-3.12442E+2	-1.05201E+3	4.01717E-3
a_6	8.96815E+4	4.13843E+3	-1.40213E-5
σ_{90}	0.9995	0.9999	0.9997
a_7	8.91295E-1	6.14183	1.48181
a_8	-9.36544E+2	-7.61257E+2	1.37782E-3
a_9	1.79470E+5	-4.36639E+4	-7.37297E-6
σ_{80}	0.9995	0.9999	0.9999

Figure 24-3: Density of HFC-125/ISO 100 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

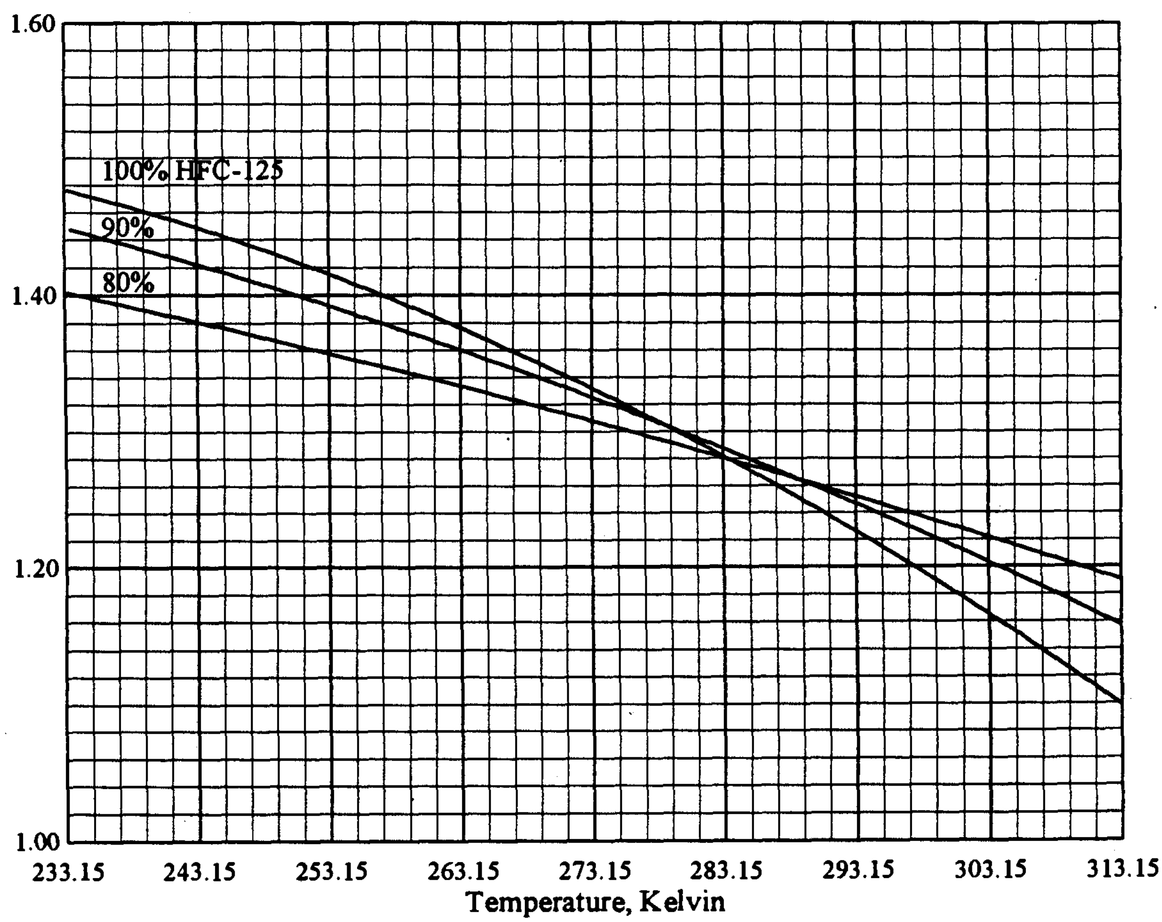


Figure 24-4: Viscosity and Solubility of HFC-125/ISO 100 Pentaerythritol Ester Branched Acid High Refrigerant Concentration Mixtures

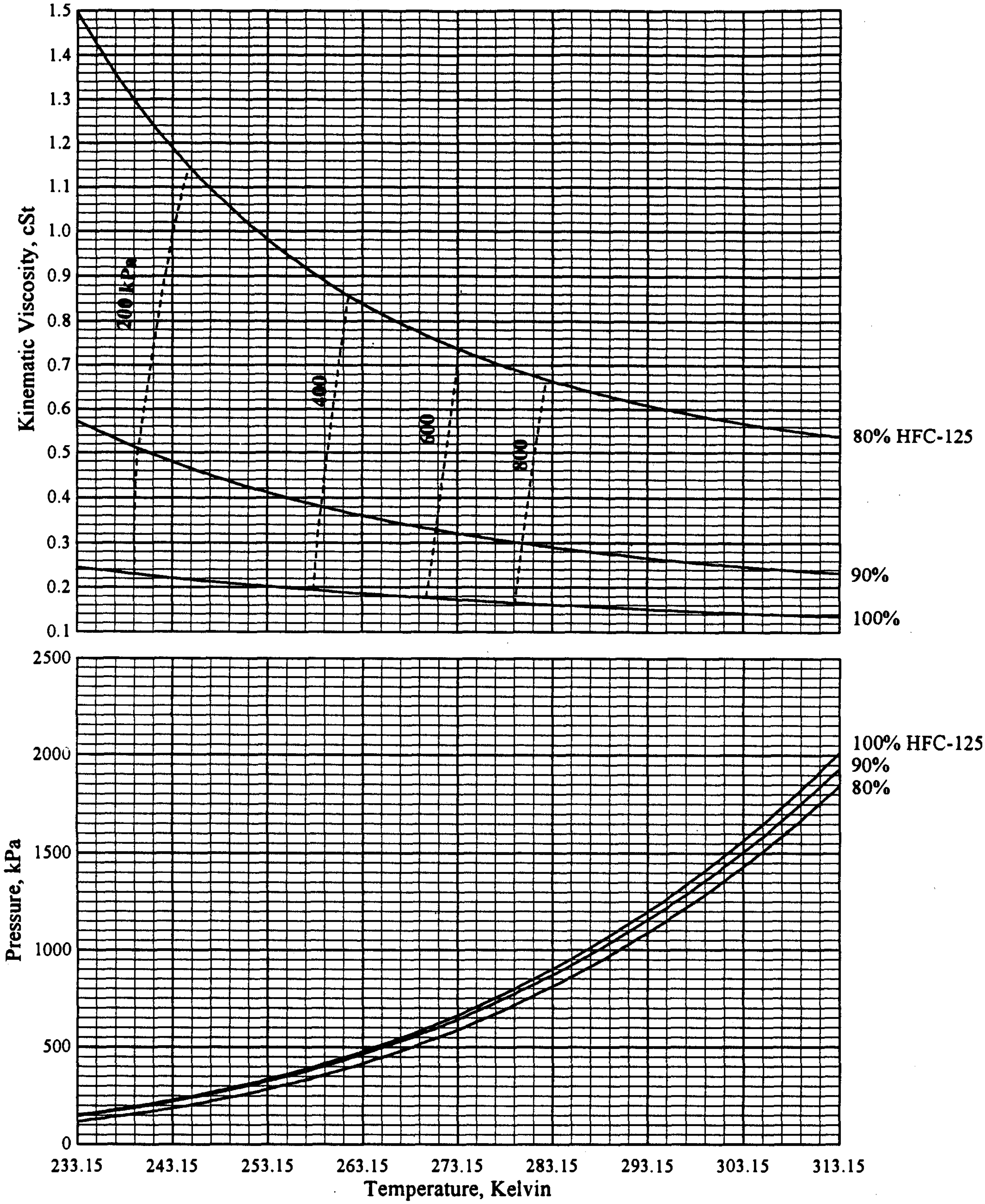


Table 25-1: Viscosity, Solubility and Density Parameters
HFC-152a/ISO 32 Alkylbenzene
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.12969E+1	-4.26255E+2	1.15489	1.05515E+1
a_2	-4.47052	2.26005	-1.24459E-3	-4.16305
a_3	0	1.72989E-4	9.10168E-7	0
a_4	7.41136	8.50038E+3	-1.06396	5.14353
a_5	-3.82419	-1.55322E+2	7.70704E-3	-2.87785
a_6	0	4.41761E-1	-1.28355E-5	0
a_7	-1.30187E+1	1.52723E+5	4.87092	-1.11382E+1
a_8	6.48918	-8.25552E+2	-3.00483E-2	5.67734
a_9	0	1.03344	4.53412E-5	0
σ	0.9998	0.9999	0.9996	0.9998

Figure 25-1: Density of HFC-152a/ISO 32 Alkylbenzene
Low Refrigerant Concentration Mixtures

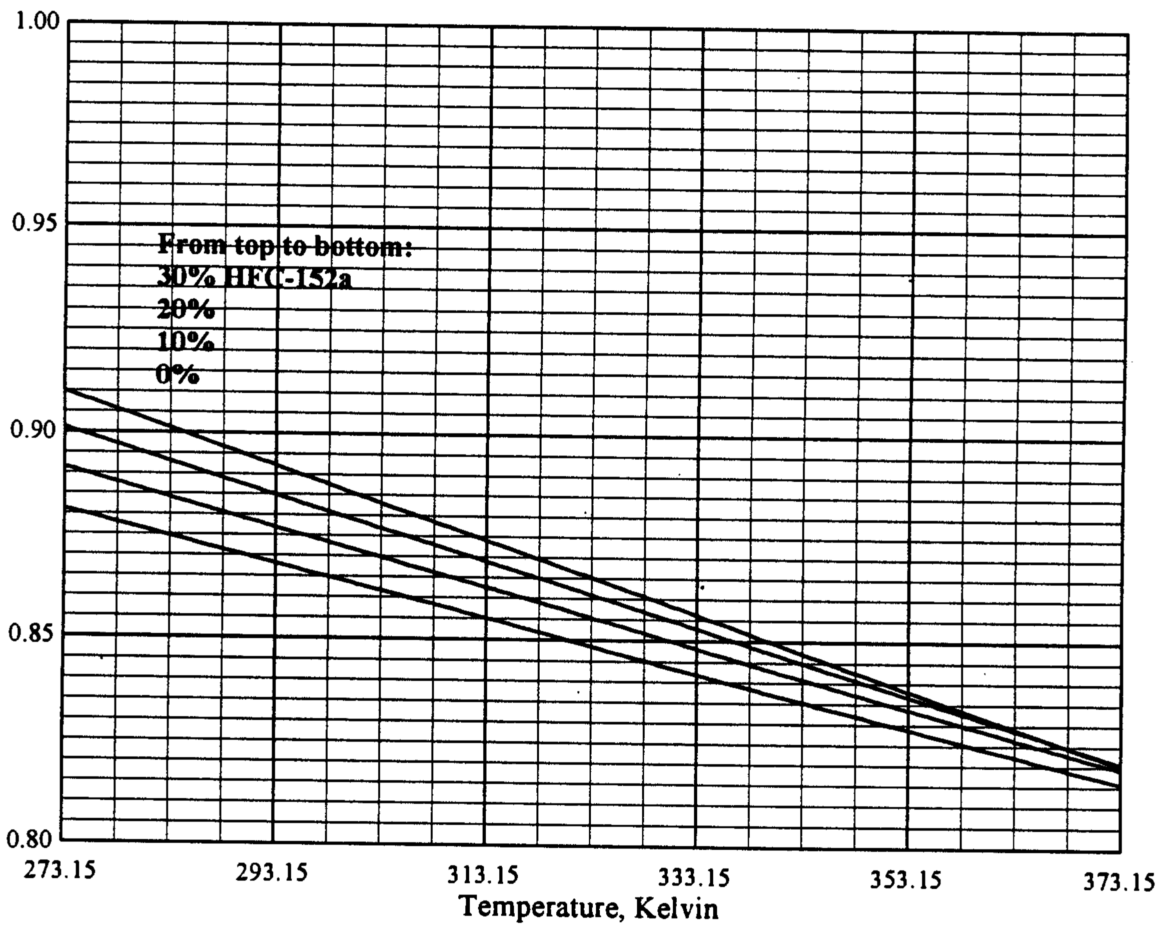


Figure 25-2: Viscosity and Solubility of HFC-152a/ISO 32 Alkylbenzene Low Refrigerant Concentration Mixtures

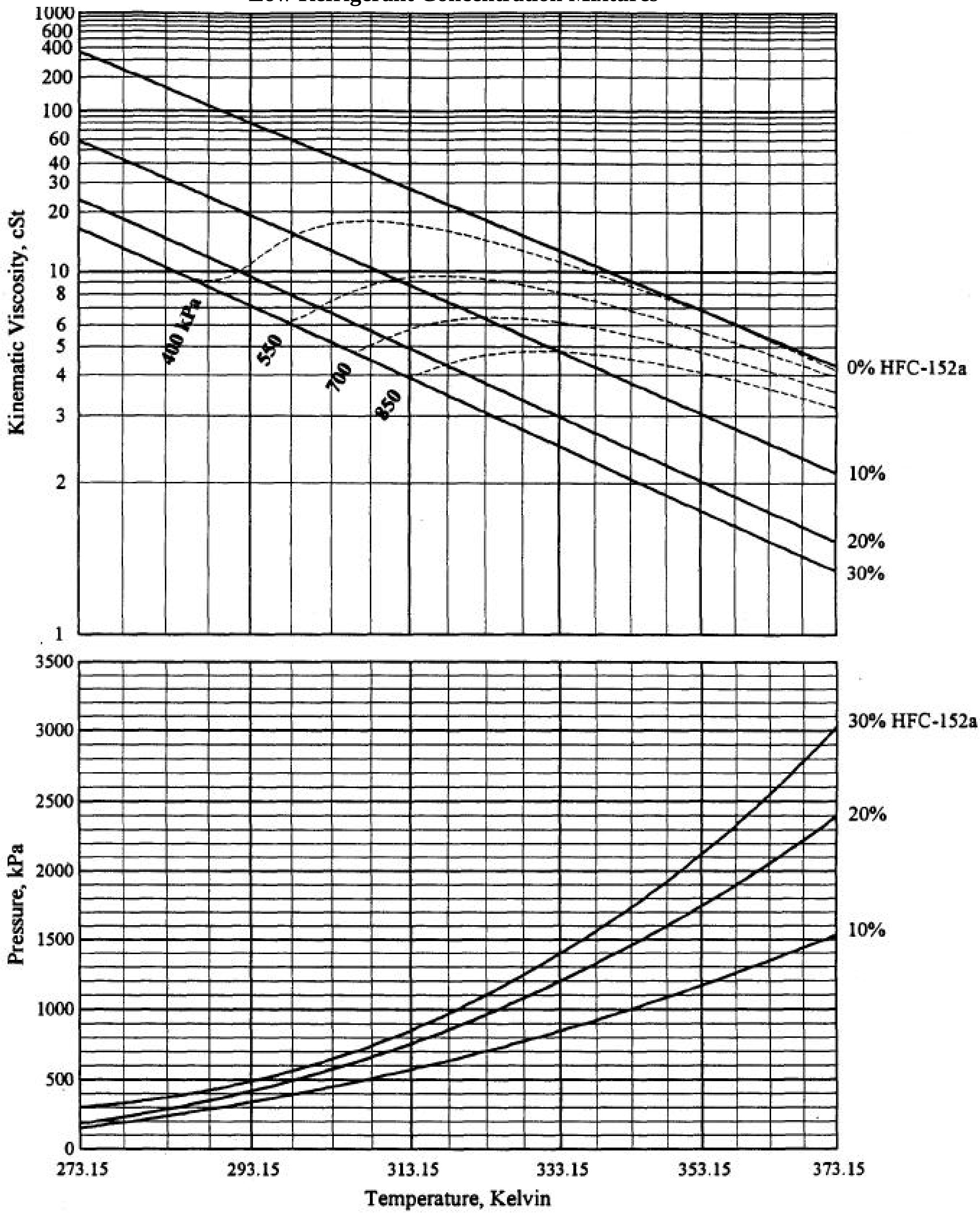


Table 26-1: Viscosity, Solubility and Density Parameters
HFC-152a/ISO 68 Alkylbenzene
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.19675E+1	1.09347E+3	1.05182	1.13194E+1
a_2	-4.70394	-6.83233	-6.14979E-4	-4.43675
a_3	0	1.07054E-2	-4.36432E-8	0
a_4	8.22647	-5.48908E+3	-9.40705E-2	6.34432
a_5	-4.20618	-7.64934E+1	1.79353E-3	-3.41681
a_6	0	3.68902E-1	-4.09246E-6	0
a_7	-2.90175E+1	1.82422E+5	2.36326	-2.89083E+1
a_8	1.29266E+1	-9.79742E+2	-1.47500E-2	1.28381E+1
a_9	0	1.13944	2.24327E-5	0
σ	0.999412	0.9992	0.9999	0.9992

Figure 26-1: Density of HFC-152a/ISO 68 Alkylbenzene
Low Refrigerant Concentration Mixtures

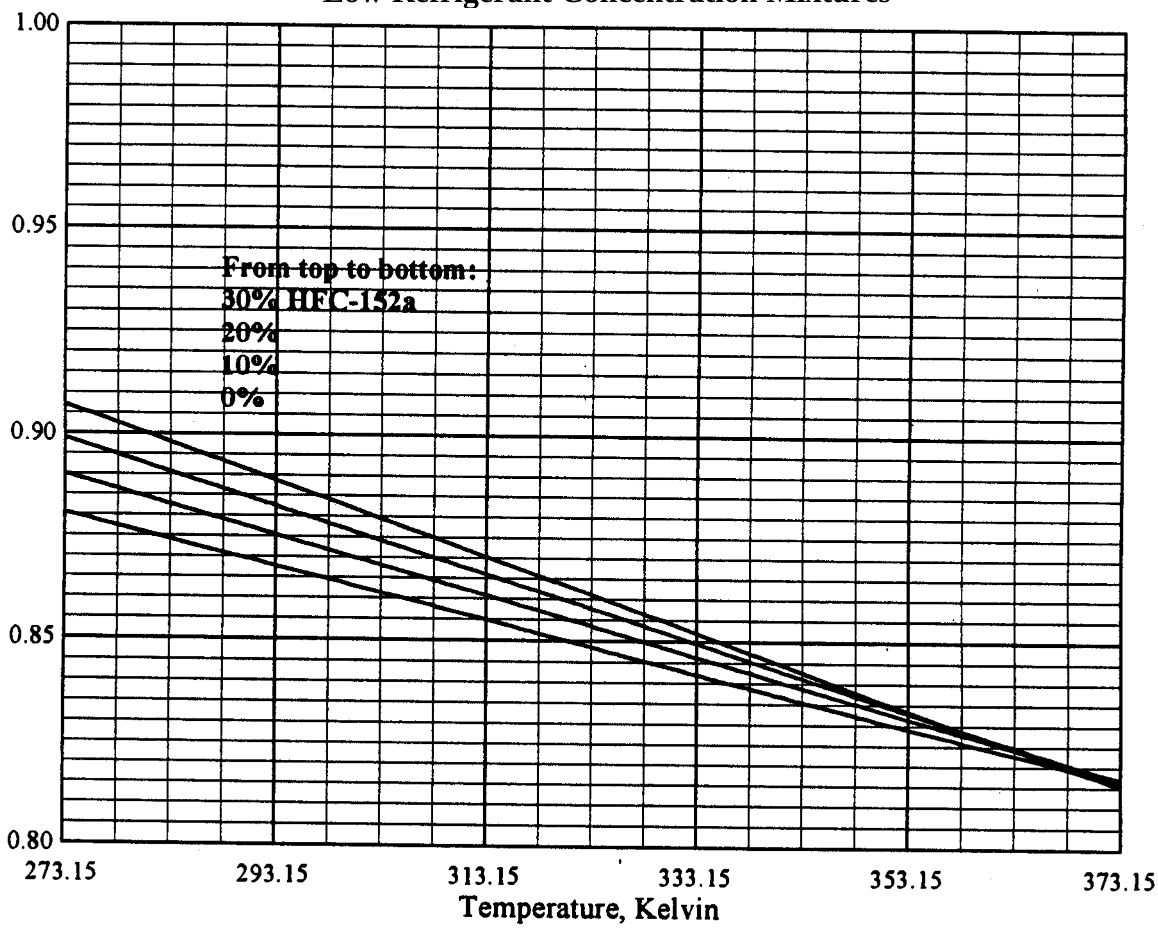


Figure 26-2: Viscosity and Solubility of HFC-152a/ISO 68 Alkylbenzene Low Refrigerant Concentration Mixtures

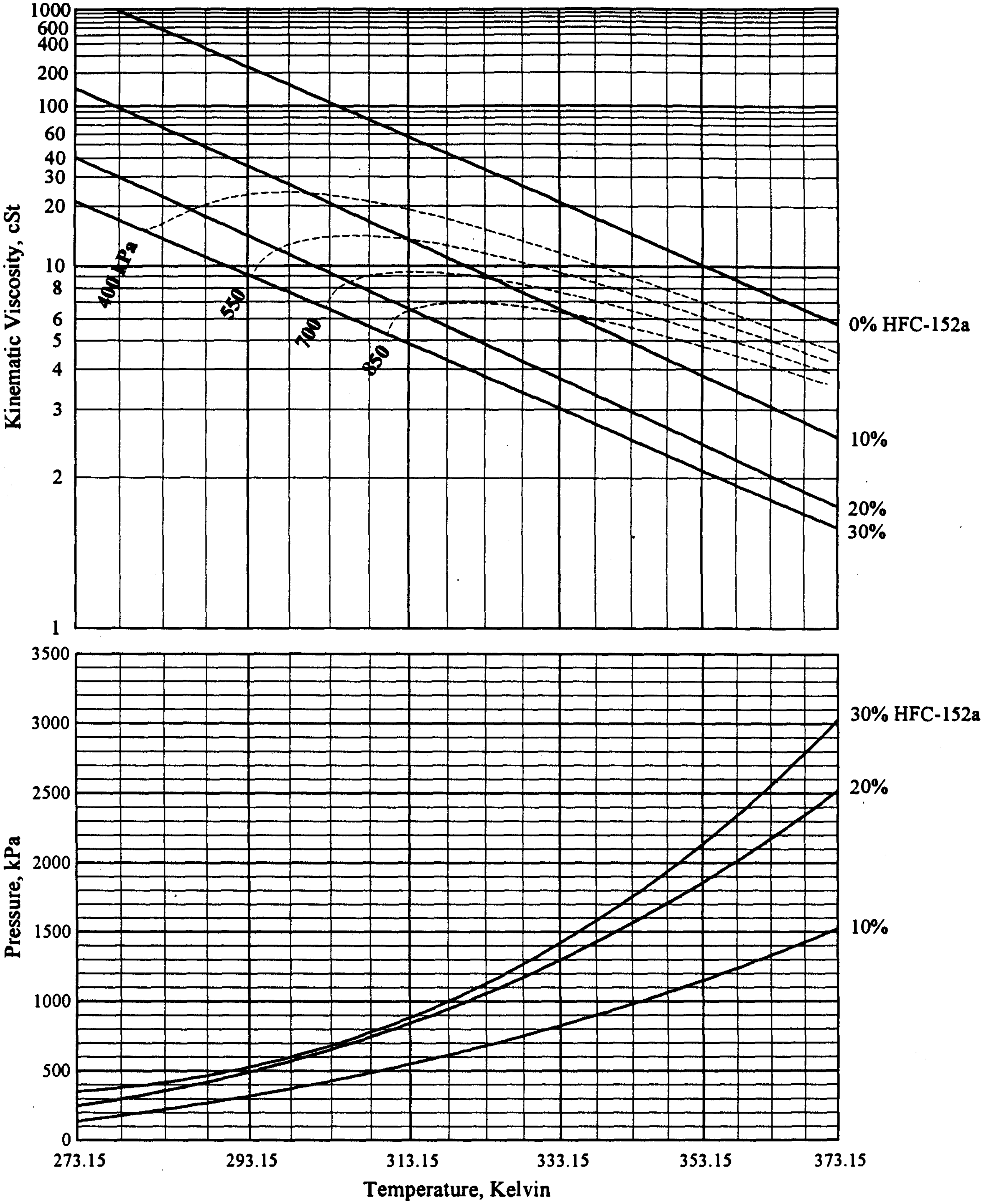


Table 27-1: Viscosity, Solubility and Density Parameters HFC-152a/ISO 22 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.34831	2.08407E+3	1.21524	9.08856
a_2	-3.69409	-1.37514E+1	-7.76844E-4	-3.58823
a_3	0	2.30728E-2	5.08831E-8	0
a_4	-9.75187E-1	-7.28207E+3	3.92383E-1	-3.05687
a_5	-1.71883E-1	-3.16923E+1	-1.76011E-3	6.66697E-1
a_6	0	2.17743E-1	1.22764E-6	0
a_7	8.32495	1.62326E+5	-1.40893E-2	9.54594
a_8	-3.46694	-9.38255E+2	-9.13855E-4	-3.93330
a_9	0	1.27630	3.11003E-6	0
σ	0.9995	0.9999	0.9999	0.9996

Figure 27-1: Density of HFC-152a/ISO 22 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

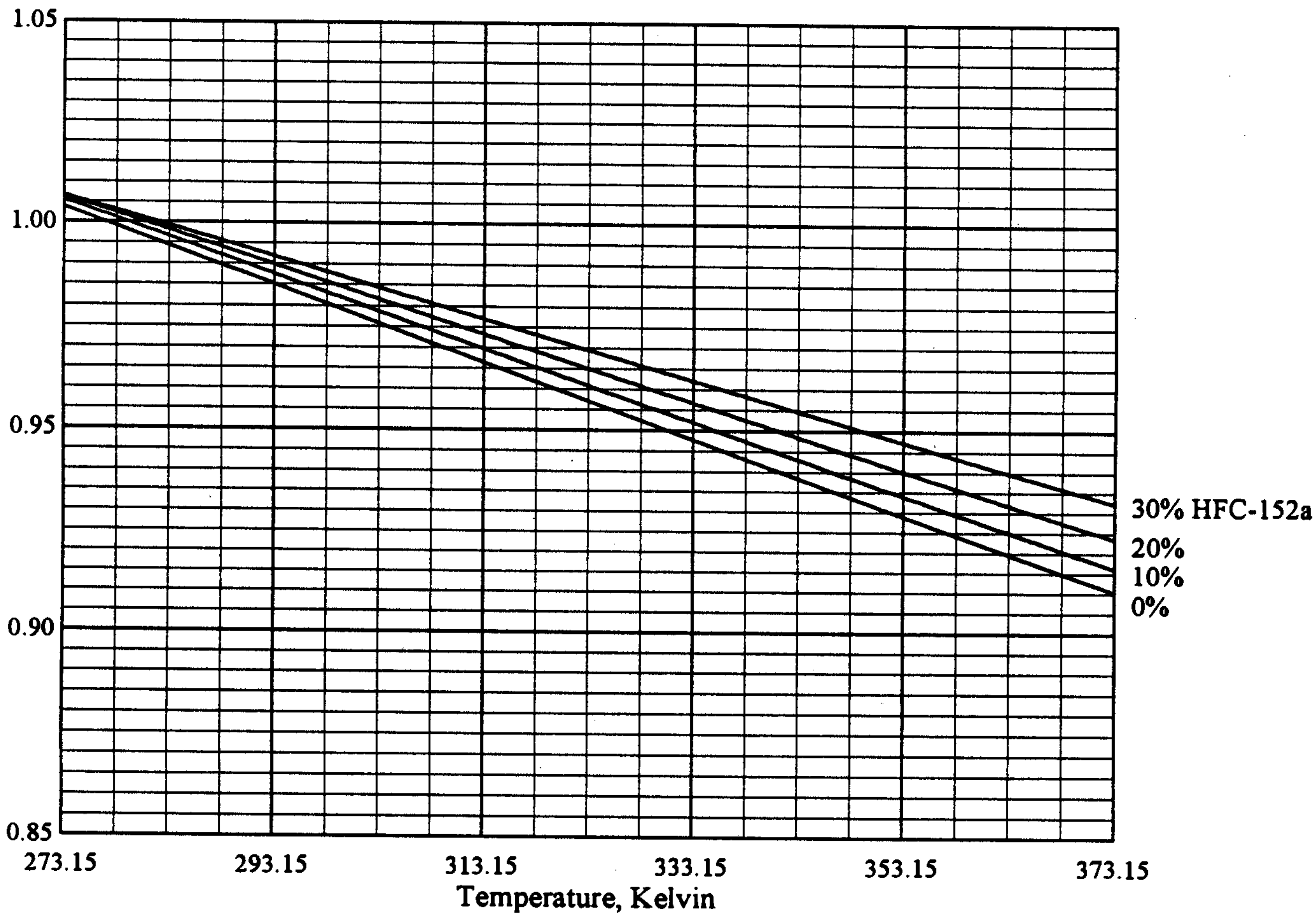


Figure 27-2: Viscosity and Solubility of HFC-152a/ISO 22 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

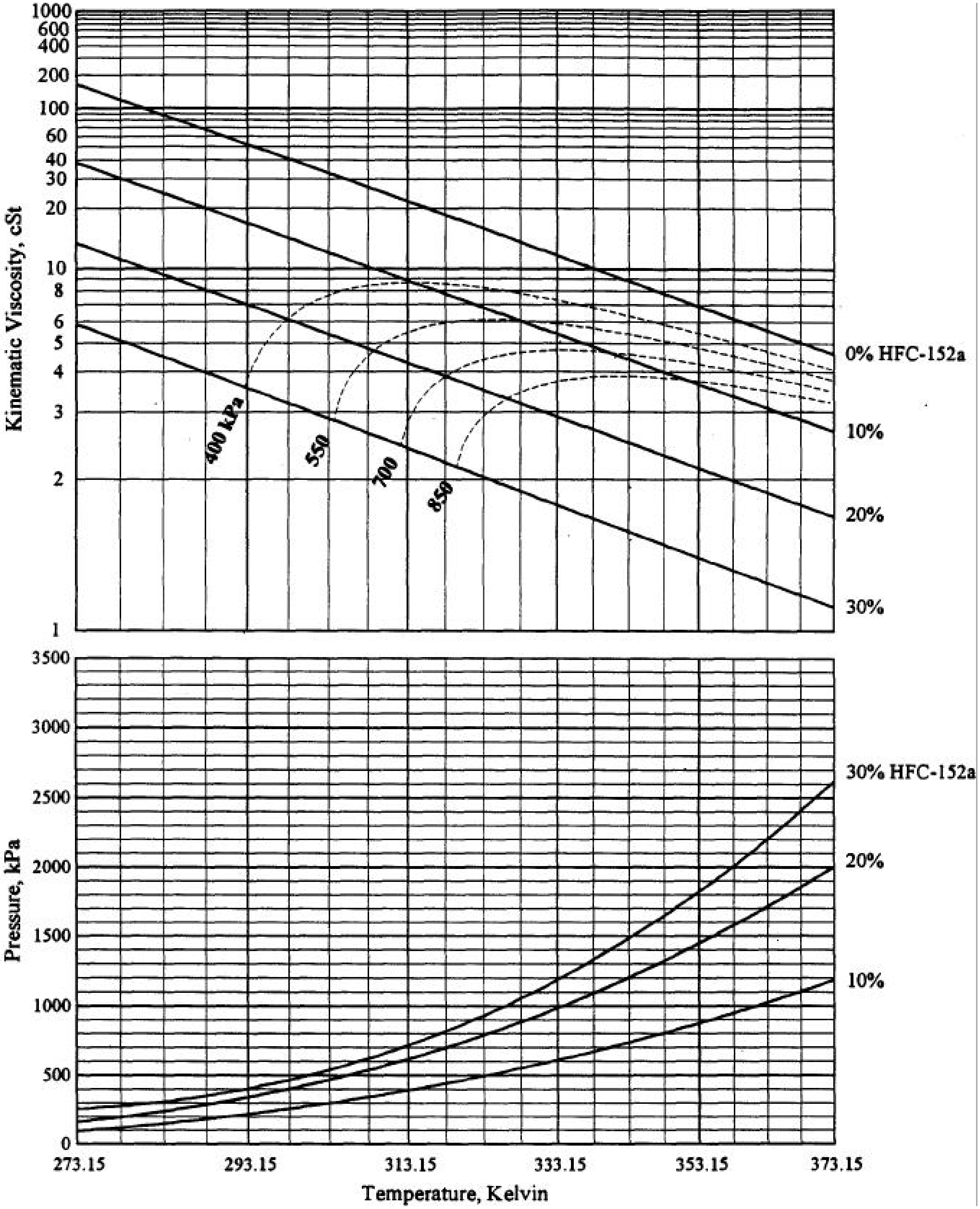


Table 27-2: Viscosity, Solubility and Density Parameters
HFC-152a/ISO 22 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

Coefficient	Kinematic Viscosity (eq. 9)	Vapor Pressure (eq. 10)	Density (eq. 11)
a_1	-9.61738E-1	6.09749	1.28265
a_2	07.87807E+1	-8.45205E+2	-1.90754E-5
a_3	4.50588E+4	-4.35412E+4	-4.21920E-6
σ_{100}	0.9999	0.9999	0.9998
a_4	-1.45786	7.45276	1.31553
a_5	1.44591E+2	-1.62786E+3	-4.53452E-4
a_6	2.84880E+4	6.83450E+4	-2.97266E-6
σ_{90}	0.9998	0.9996	0.9999
a_7	-1.22347	7.47852	1.32687
a_8	8.89346E+1	-1.63906E+3	-7.17882E-4
a_9	4.06046E+4	6.86623E+4	-2.06707E-6
σ_{80}	0.9999	0.9996	0.9999

Figure 27-3: Density of HFC-152a/ISO 22 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

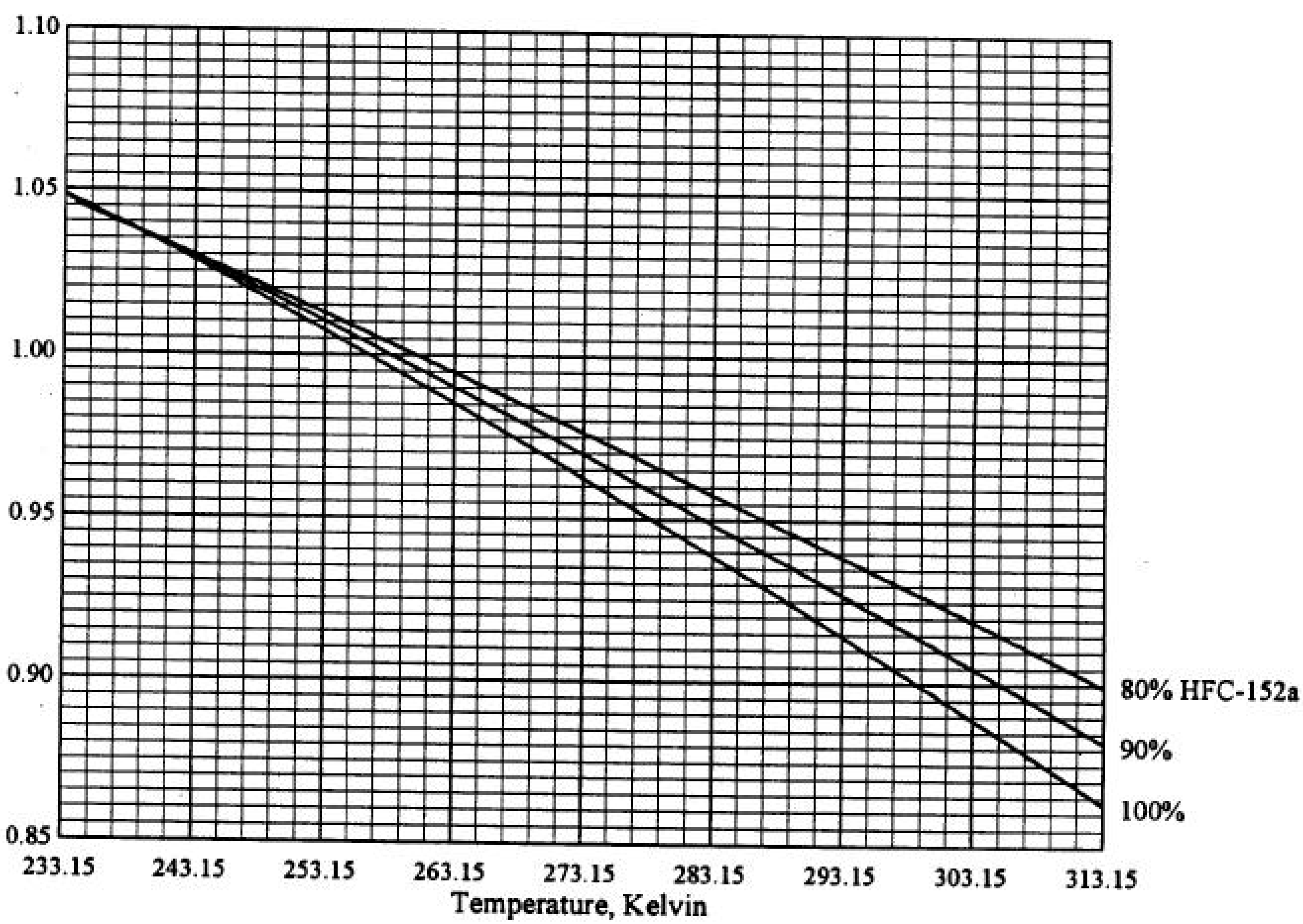


Figure 27-4: Viscosity and Solubility of HFC-152a/ISO 22 Pentaerythritol Ester Mixed Acid #1 High Refrigerant Concentration Mixtures

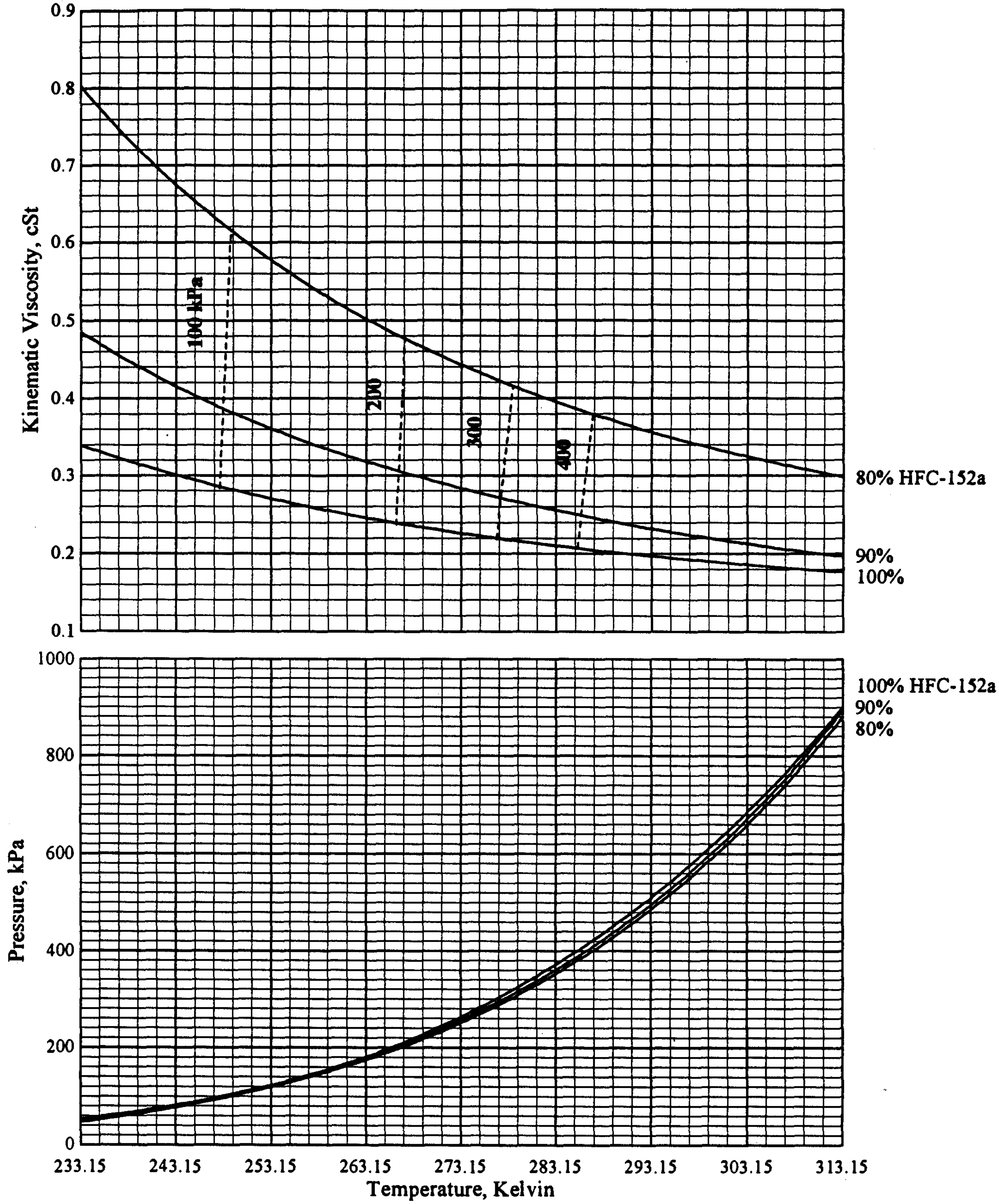


Table 28-1: Viscosity, Solubility and Density Parameters HFC-152a/ISO 68 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.00502E+1	1.34075E+3	1.29635	9.75432
a_2	-3.92525	-8.41681	-1.47106E-3	-3.80427
a_3	0	1.31424E-2	1.18369E-6	0
a_4	2.38182	1.51869E+4	-1.37488	1.20647
a_5	-1.64650	-1.84082E+2	9.62094E-3	-1.16896
a_6	0	4.80921E-1	-1.62914E-5	0
a_7	-1.07135E+1	7.85982E+4	5.47544	-1.15568E+1
a_8	4.28814	-3.79699E+2	-3.63990E-2	4.64500
a_9	0	3.33963E-1	5.90968E-5	0
s	0.9997	0.9998	0.9992	0.9998

Figure 28-1: Density of HFC-152a/ISO 68 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

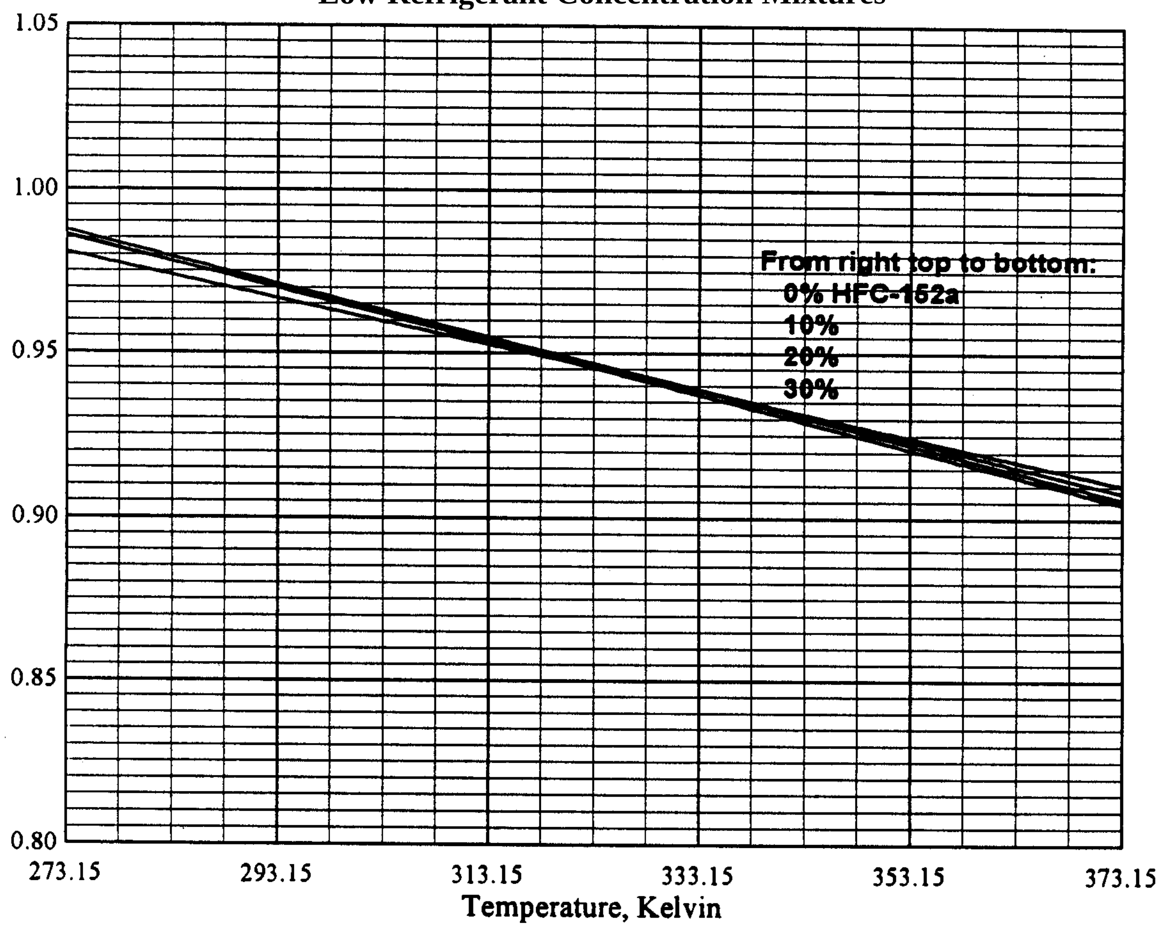


Figure 28-2: Viscosity and Solubility of HFC-152a/ISO 68 Pentaerythritol Ester Mixed Acid #1 Low Refrigerant Concentration Mixtures

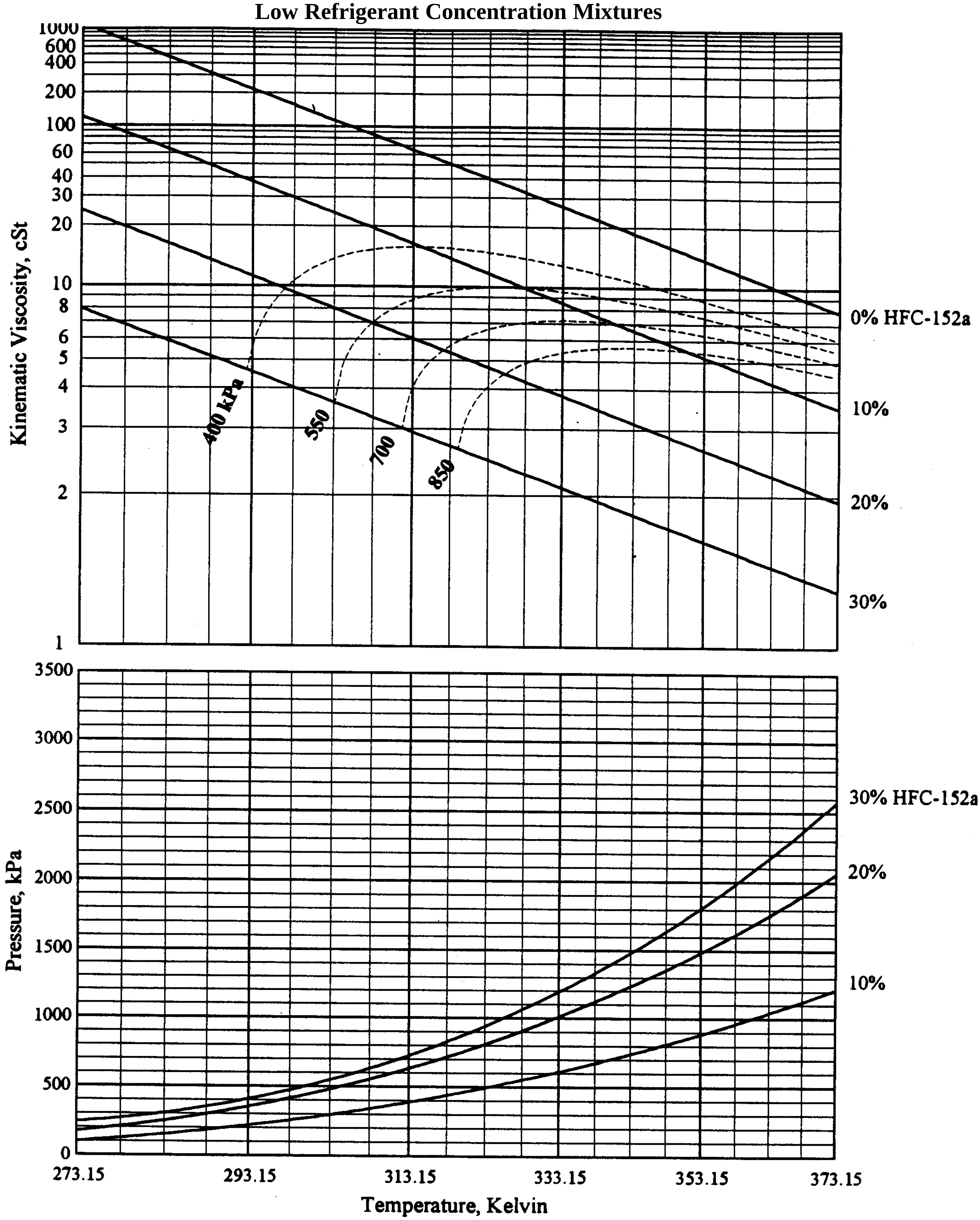


Table 28-2: Viscosity, Solubility and Density Parameters
HFC-152a/ISO 68 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

Coefficient	Kinematic Viscosity (eq. 9)	Vapor Pressure (eq. 10)	Density (eq. 11)
a_1	-9.61738E-1	6.09749	1.28265
a_2	07.87807E+1	-8.45205E+2	-1.90754E-5
a_3	4.50588E+4	-4.35412E+4	-4.21920E-6
σ_{100}	0.9999	0.9999	0.9998
a_4	-9.56879E-1	7.26541	1.24398
a_5	-7.03968E+1	-1.51501E+3	2.08355E-5
a_6	5.18251E+4	5.12258E+4	-3.76891E-6
σ_{90}	0.9991	0.9995	0.9999
a_7	-1.28532	7.21459	1.29589
a_8	1.31797E+2	-1.47977E+3	-5.42068E-4
a_9	3.35145E+4	4.43555E+4	-2.32717E-6
σ_{80}	0.9999	0.9995	0.9999

Figure 28-3: Density of HFC-152a/ISO 68 Pentaerythritol Ester Mixed Acid #1
High Refrigerant Concentration Mixtures

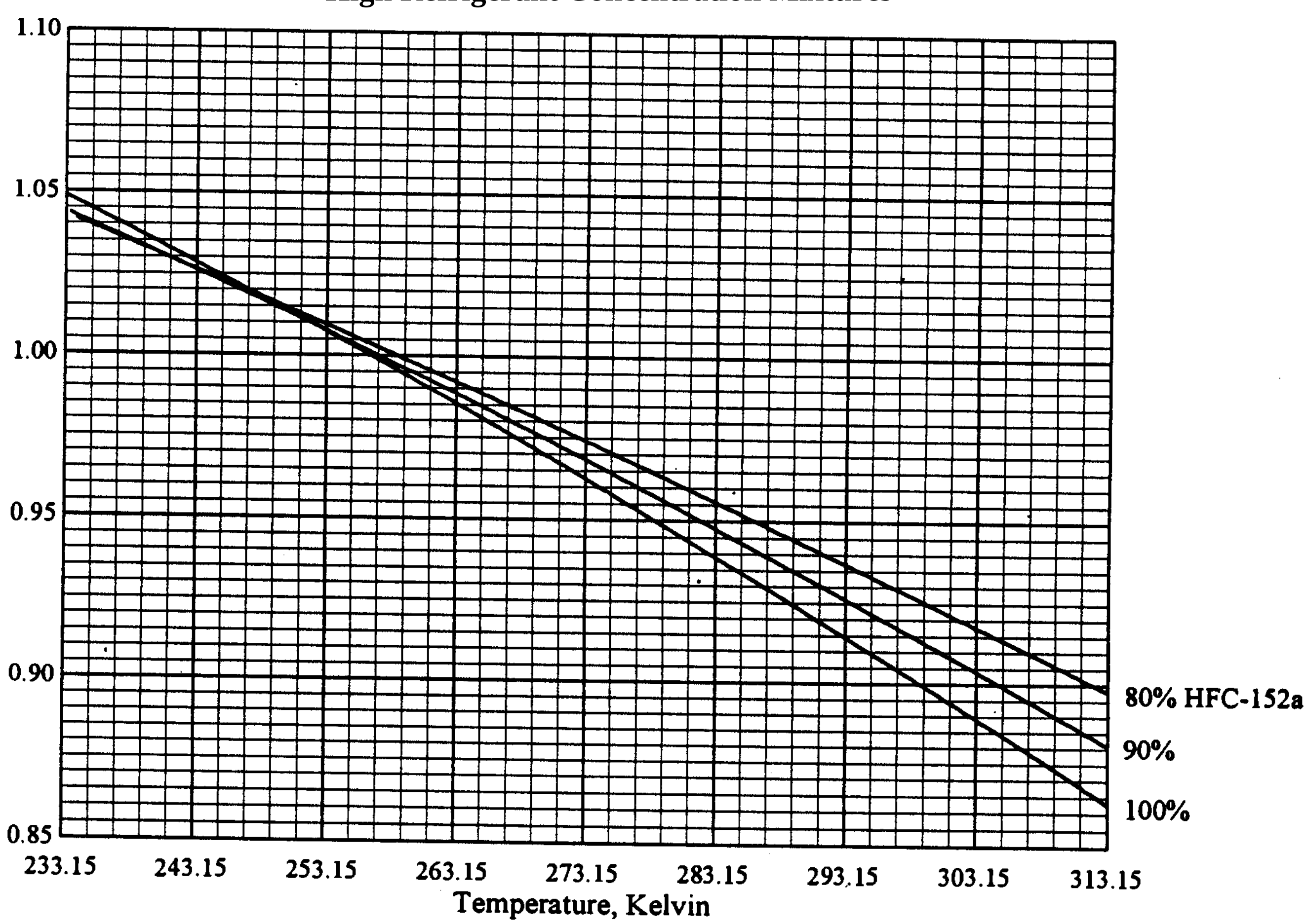


Figure 28-4: Viscosity and Solubility of HFC-152a/ISO 68 Pentaerythritol Ester Mixed Acid #1 High Refrigerant Concentration Mixtures

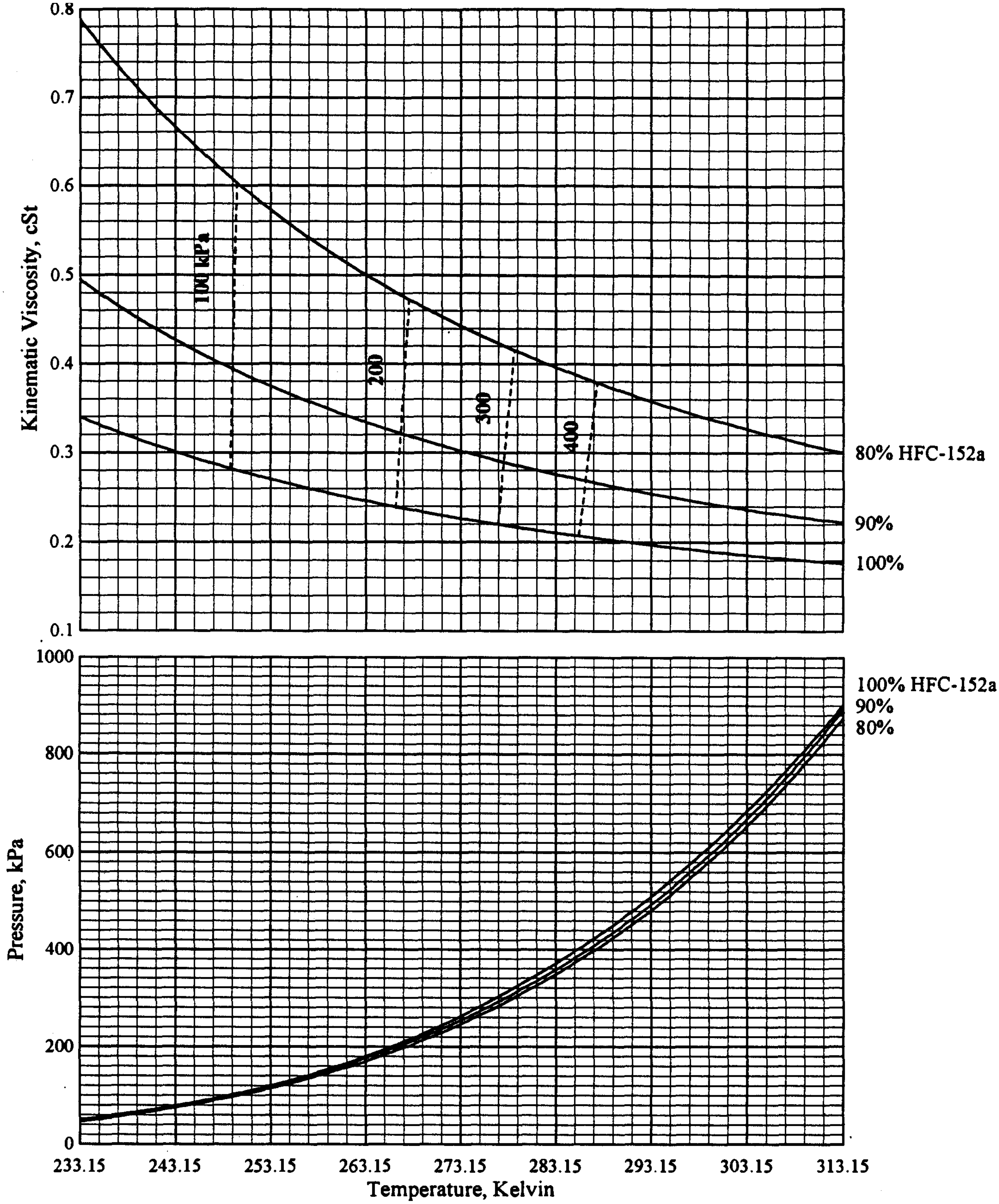


Table 29-1: Viscosity, Solubility and Density Parameters
HFC-143a/ISO 22 Pentaerythritol Ester Mixed Acid #2
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	8.70907	1.55440E+4	1.15129	8.57249
a_2	-3.43602	-1.00000E+2	-3.56515E-4	-3.38037
a_3	0	1.60348E-1	-5.43603E-7	0
a_4	6.83488	-3.97046E+4	2.38394	3.34158
a_5	-3.33965	1.07547E+2	-1.23216E-2	-1.93524
a_6	0	1.64293E-1	1.54428E-5	0
a_7	-2.25721E+1	8.14263E+4	-2.05536	-1.13610E+1
a_8	9.39030	-3.28549E+2	5.05033E-3	4.86169
a_9	0	7.63833E-2	5.88808E-6	0
σ	0.9991	0.9995	0.9986	0.9993

Figure 29-1: Density of HFC-143a/ISO 22 Pentaerythritol Ester Mixed Acid #2
Low Refrigerant Concentrations

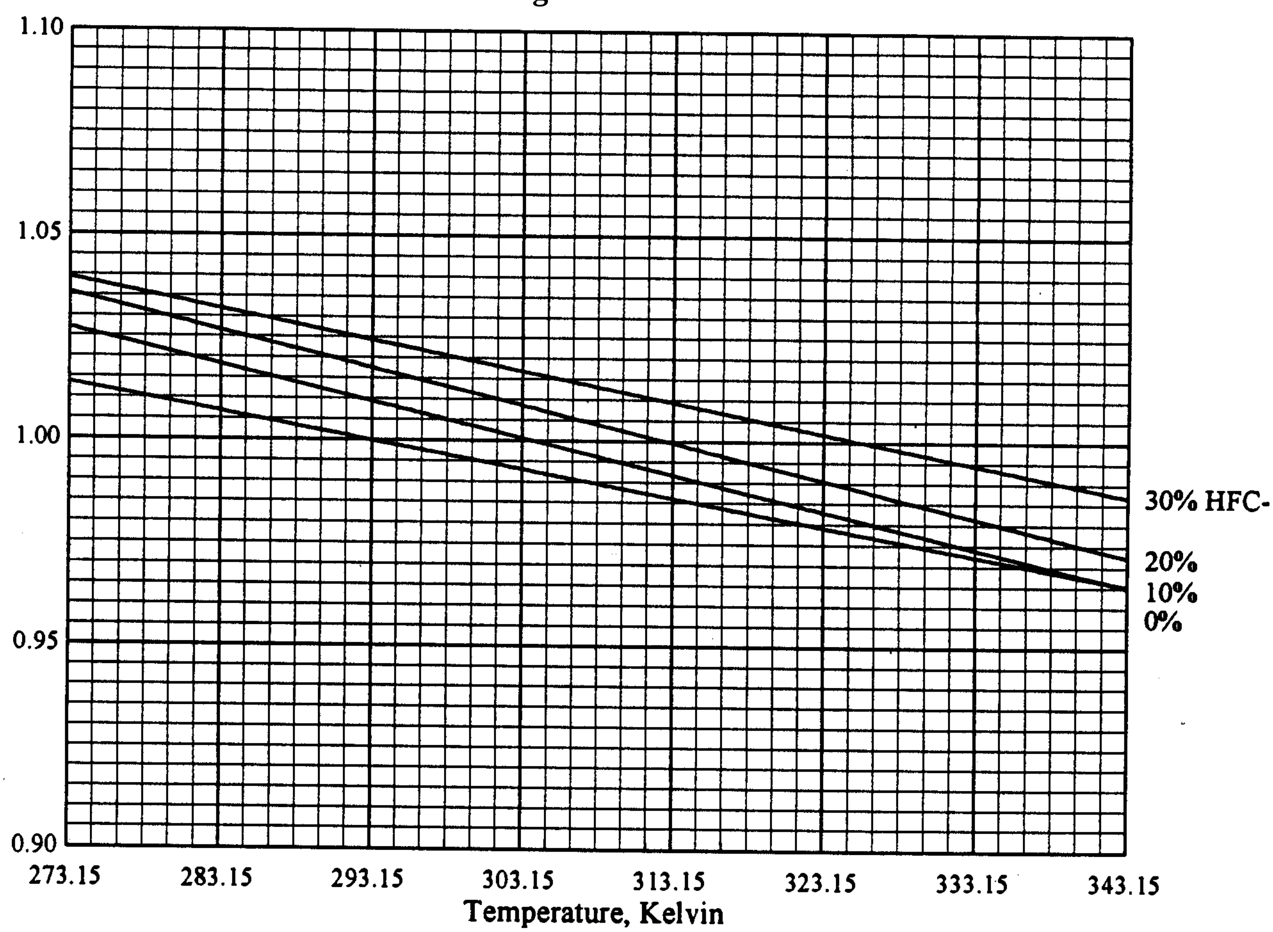


Figure 29-2: Viscosity and Solubility of HFC-143a/ISO 22 Pentaerythritol Ester Mixed Acid #2 Low Refrigerant Concentration Mixtures

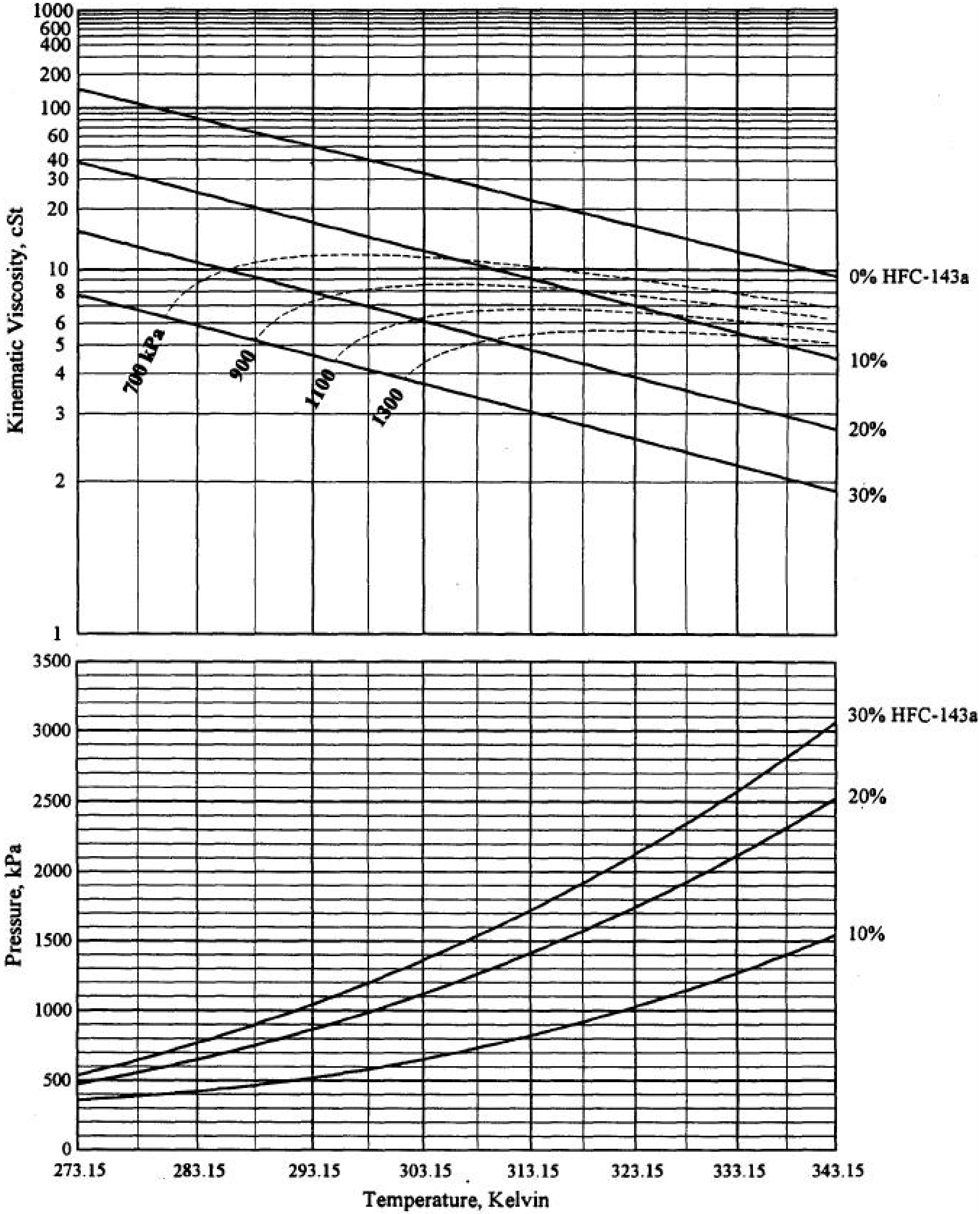


Table 30-1: Viscosity, Solubility and Density Parameters
HFC-143a/ISO 68 Pentaerythritol Ester Mixed Acid #2
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	8.42333	2.31004E+4	1.13389	8.24160
a_2	-3.26823	-1.51362E+2	-0.424932E-4	-3.19359
a_3	0	2.47217E-1	-0.419997E-7	0
a_4	1.92187E+1	1.17909E+4	4.13966	1.82009E+1
a_5	-8.17957	-2.32517E+2	-0.239383E-2	-7.77015
a_6	0	7.27220E-1	0.351647E-5	0
a_7	-5.55205E+1	-1.20239E+5	-6.99448	-5.21213E+1
a_8	2.25800E+1	9.91826E+2	0.373716E-2	2.11973E+1
a_9	0	-2.07634	-0.471951E-5	0
σ	0.9990	0.9983	0.9984	0.9990

Figure 30-1: Density of HFC-143a/IS0 68 Pentaerythritol Ester Mixed Acid #2
Low Refrigerant Concentrations

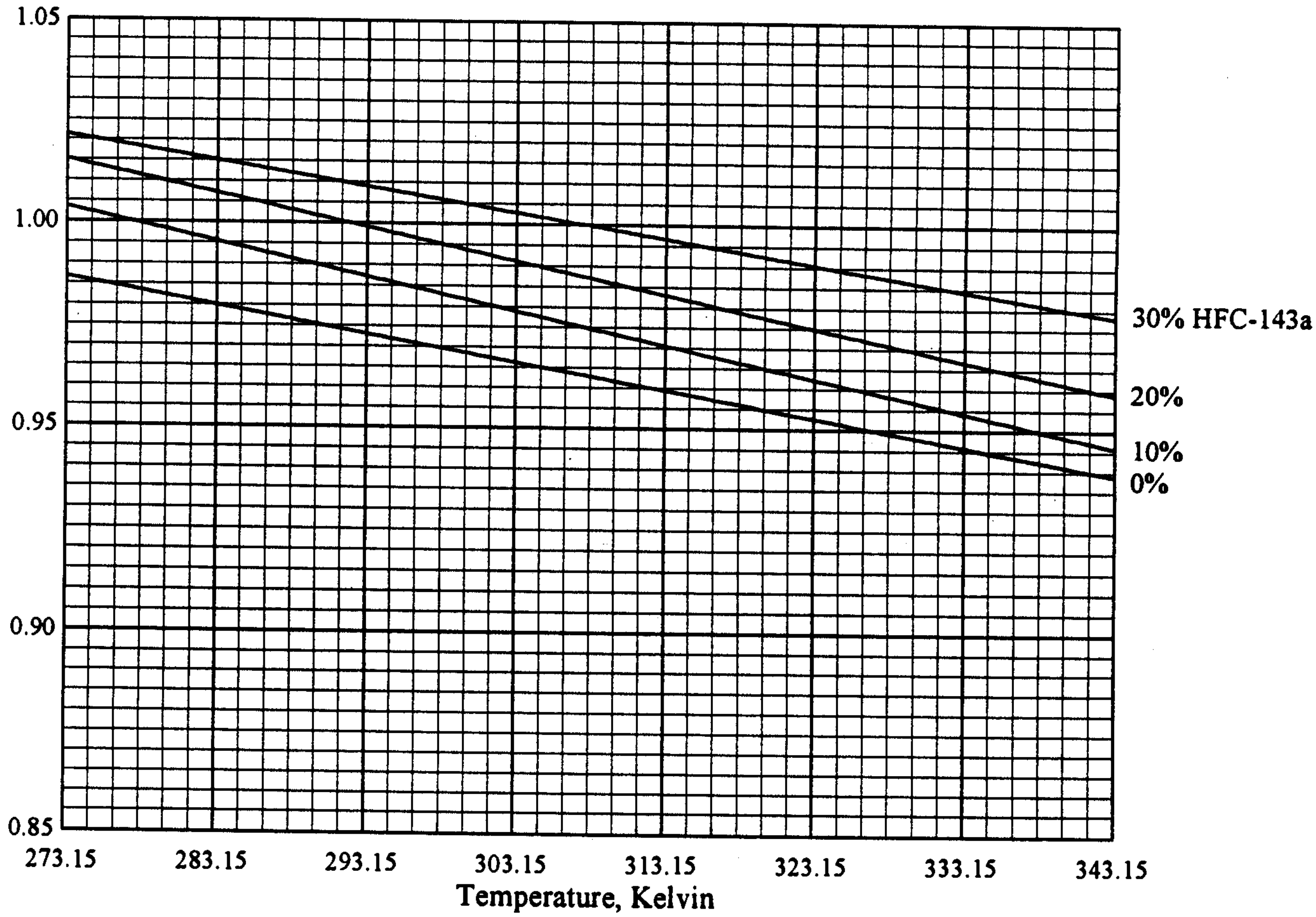


Figure 30-2: Viscosity and Solubility of HFC-143a/ISO 68 Pentaerythritol Ester Mixed Acid #2 Low Refrigerant Concentration Mixtures

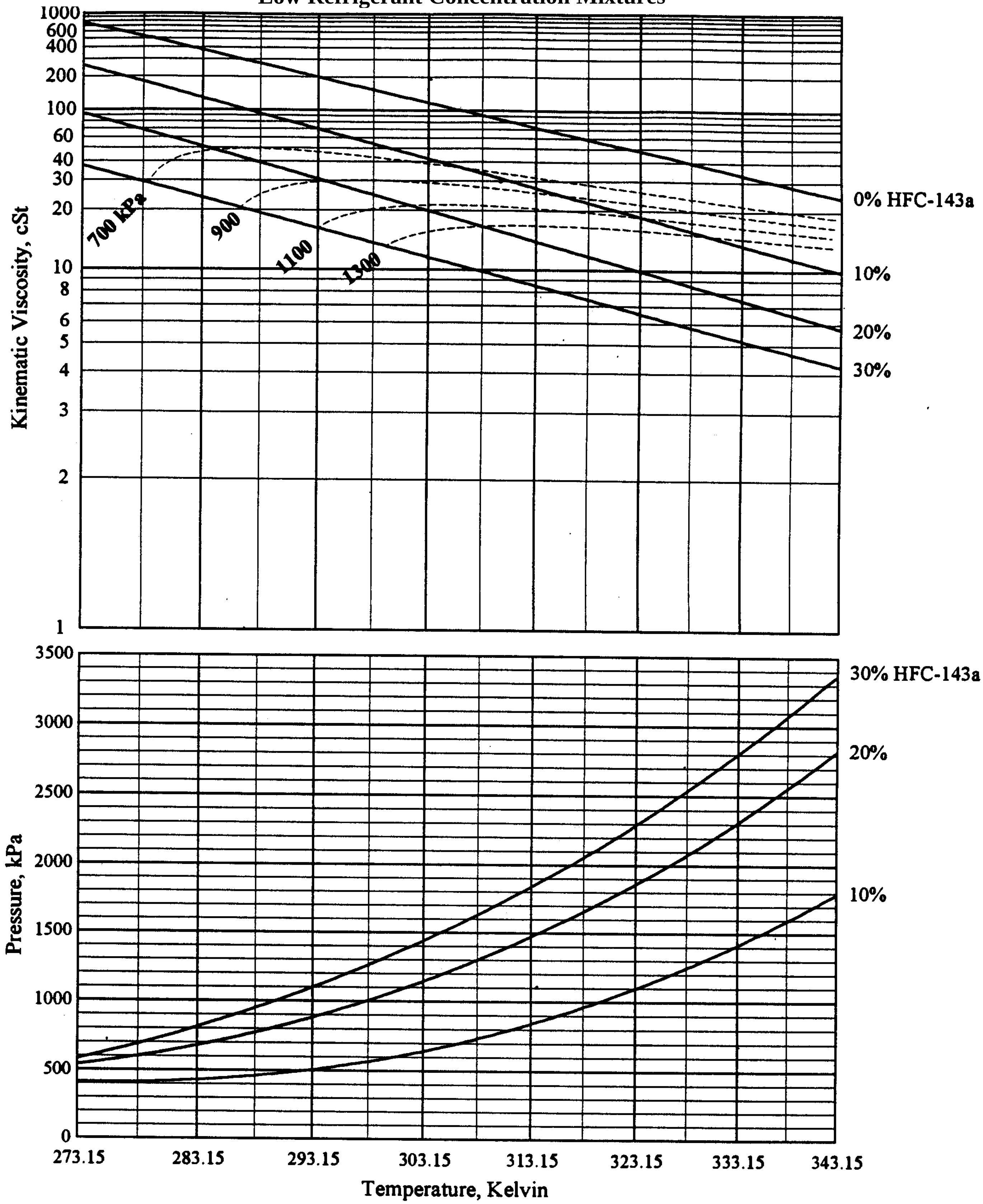


Table 31-1: Viscosity, Solubility and Density Parameters HFC-143a/ISO 32 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	9.91137	2.10608E+3	1.49868	9.79374
a_2	-3.90158	-1.39129E+1	-2.30159E-3	-3.85512
a_3	0	2.29279E-2	2.43288E-6	0
a_4	-13.9374E+1	8.57706E+4	6.02706	-1.47764E+1
a_5	5.22368	-6.97759E+2	-3.60189E-2	5.55615
a_6	0	1.44812	5.44274E-5	0
a_7	144.474E+2	-3.50224E+4	-2.02656E+1	1.47964E+2
a_8	-59.1881E+1	3.95537E+2	1.22895E-1	-6.06214E+1
a_9	0	-1.03526	-1.85984E-4	0
σ	0.9997	0.9997	0.9986	0.9997

Figure 31-1: Density of HFC-143a/ISO 32 Pentaerythritol Ester Branched Acid Low Refrigerant Concentrations

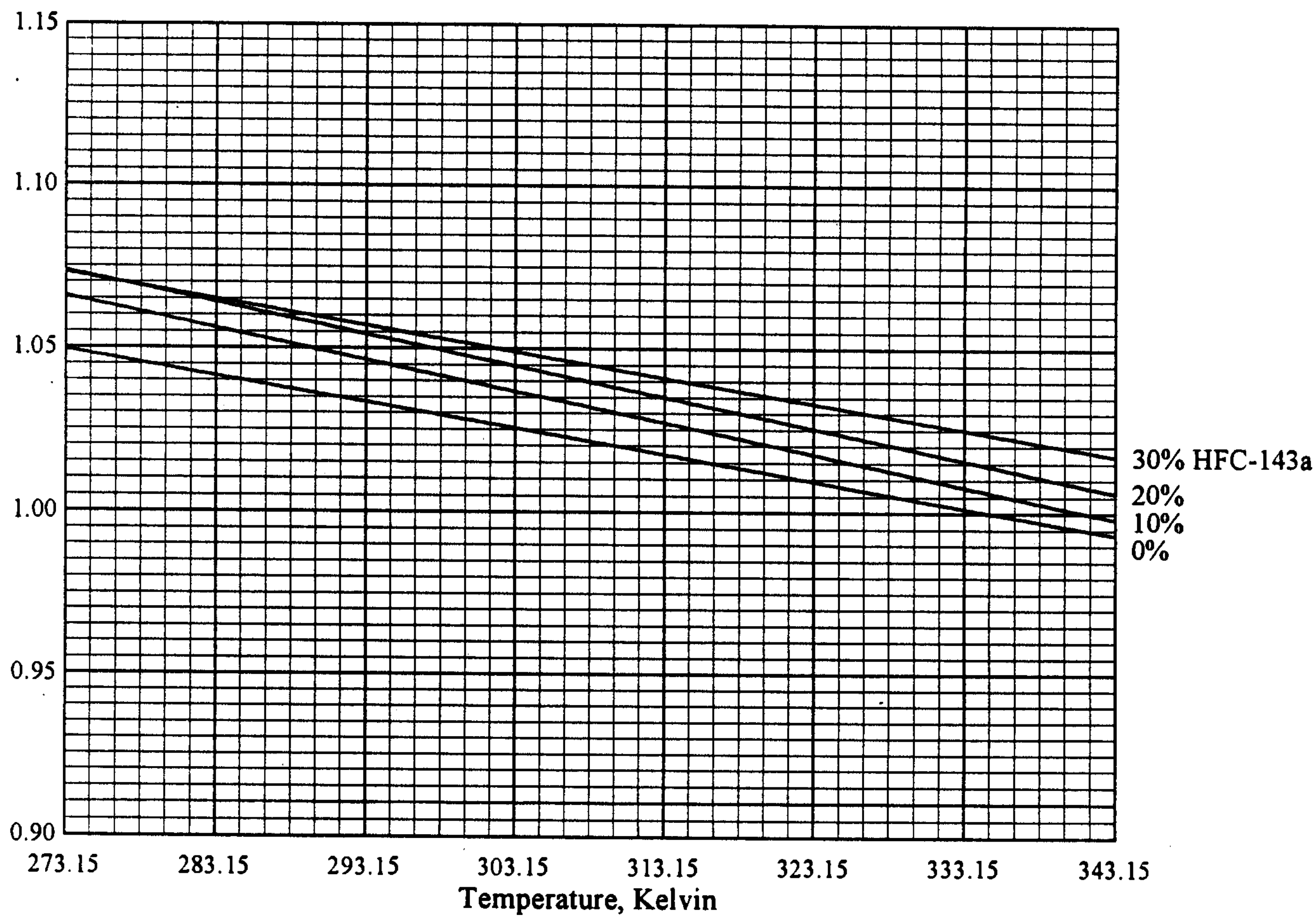


Figure 31-2: Viscosity and Solubility of HFC-143a/ISO 32 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

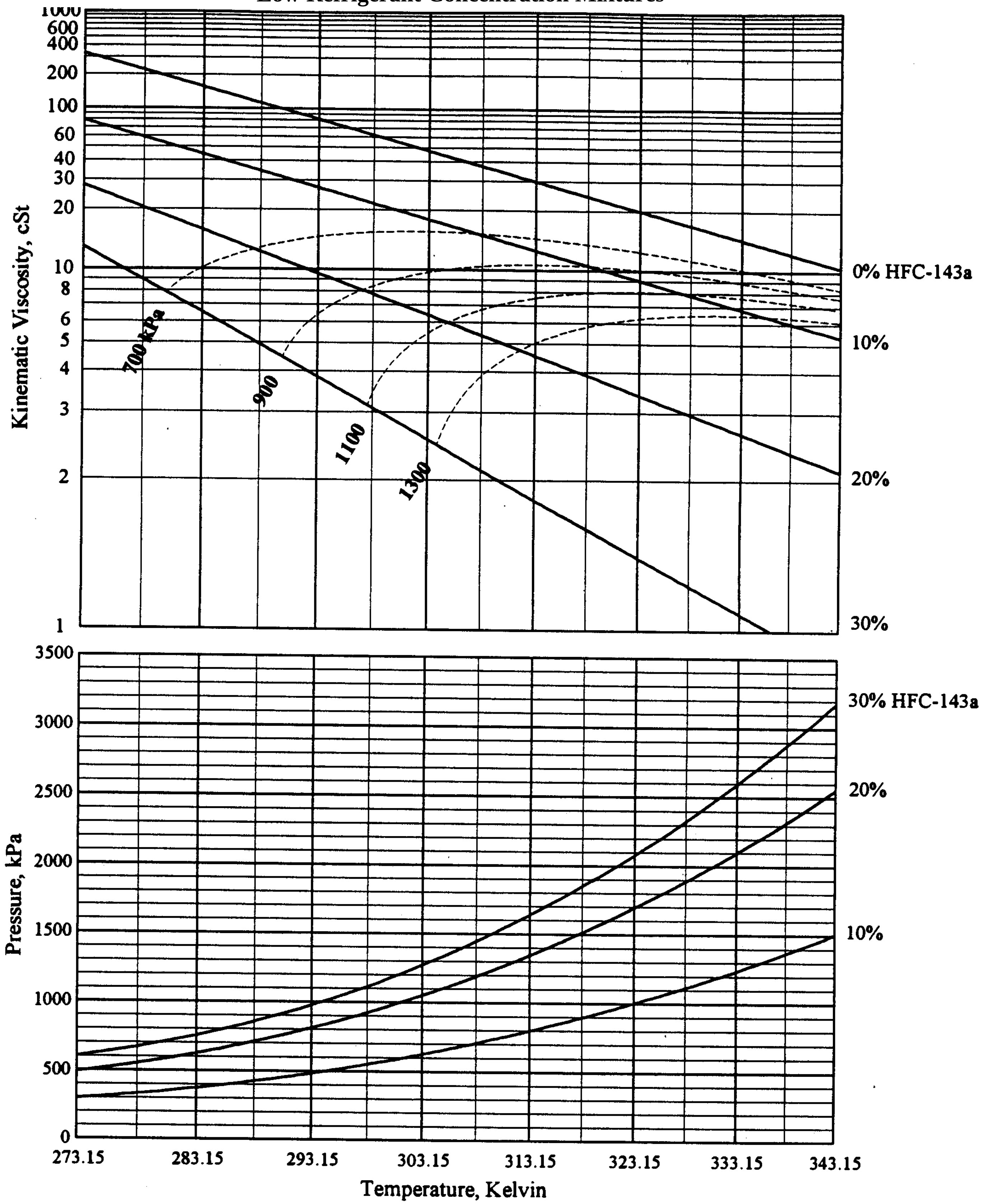


Table 32-1: Viscosity, Solubility and Density Parameters HFC-143a/ISO 100 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	8.13798	1.21903E+4	1.22160	8.05163
a_2	-3.13869	-7.90886E+1	-3.84463E-4	-3.10540
a_3	0	1.27867E-1	-6.02926E-7	0
a_4	3.04238E+1	-8.69998E+4	-1.83435	3.01433E+1
a_5	-1.28972E+1	4.47799E+2	1.47001E-2	-1.27907E+1
a_6	0	-4.44506E-1	-2.78500E-5	0
a_7	-4.65286E+1	5.30032E+5	2.01291E+1	-4.37334E+1
a_8	1.89797E+1	-3.43937E+3	-1.39856E-1	1.78318E+1
a_9	0	5.46602	2.42034E-4	0
σ	0.9996	0.9977	0.9956	0.9995

Figure 32-1: Density of HFC-143a/ISO 100 Pentaerythritol Ester Branched Acid Low Refrigerant Concentrations

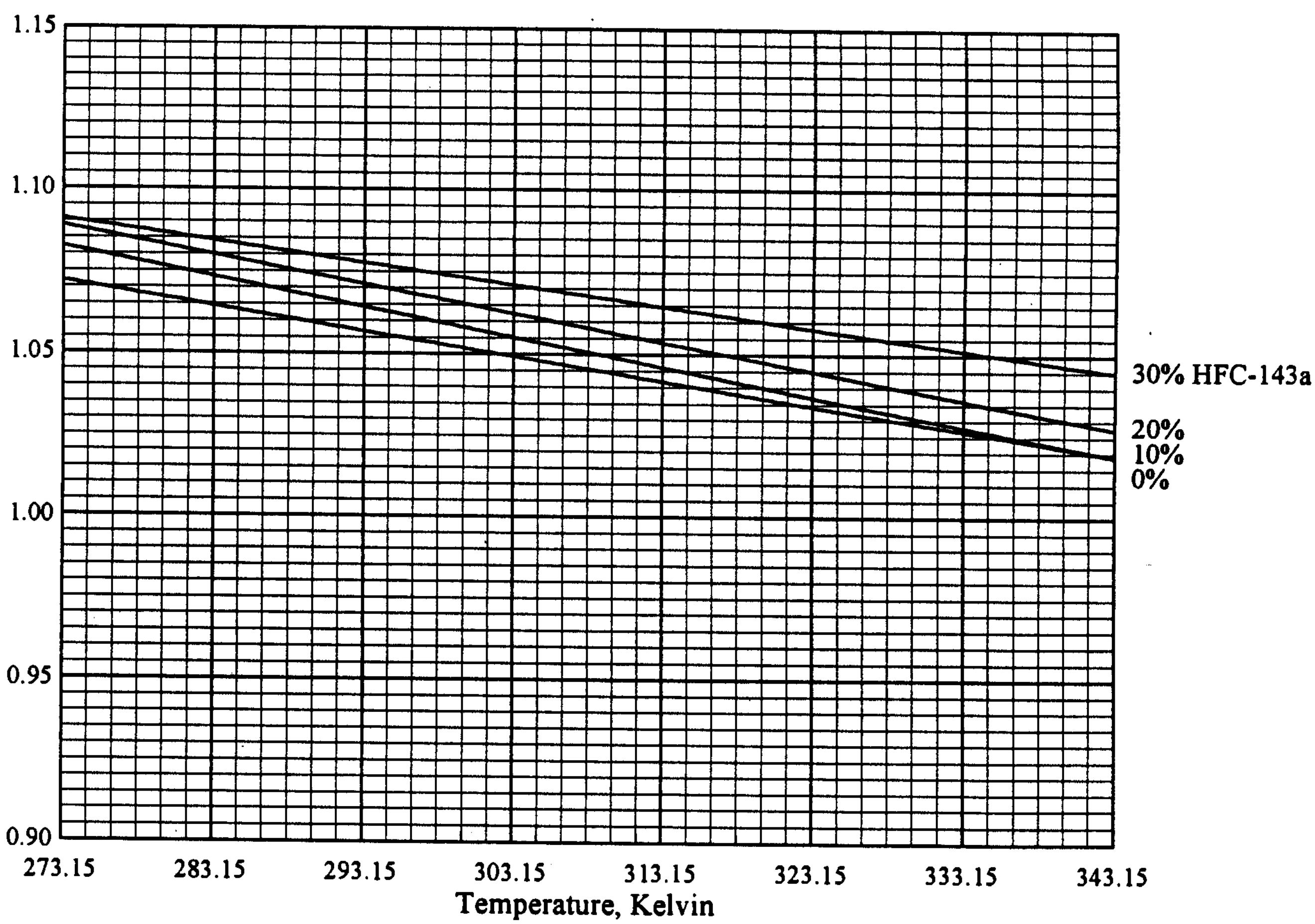


Figure 32-2: Viscosity and Solubility of HFC-143a/ISO 100 Pentaerythritol Ester Branched Acid Low Refrigerant Concentration Mixtures

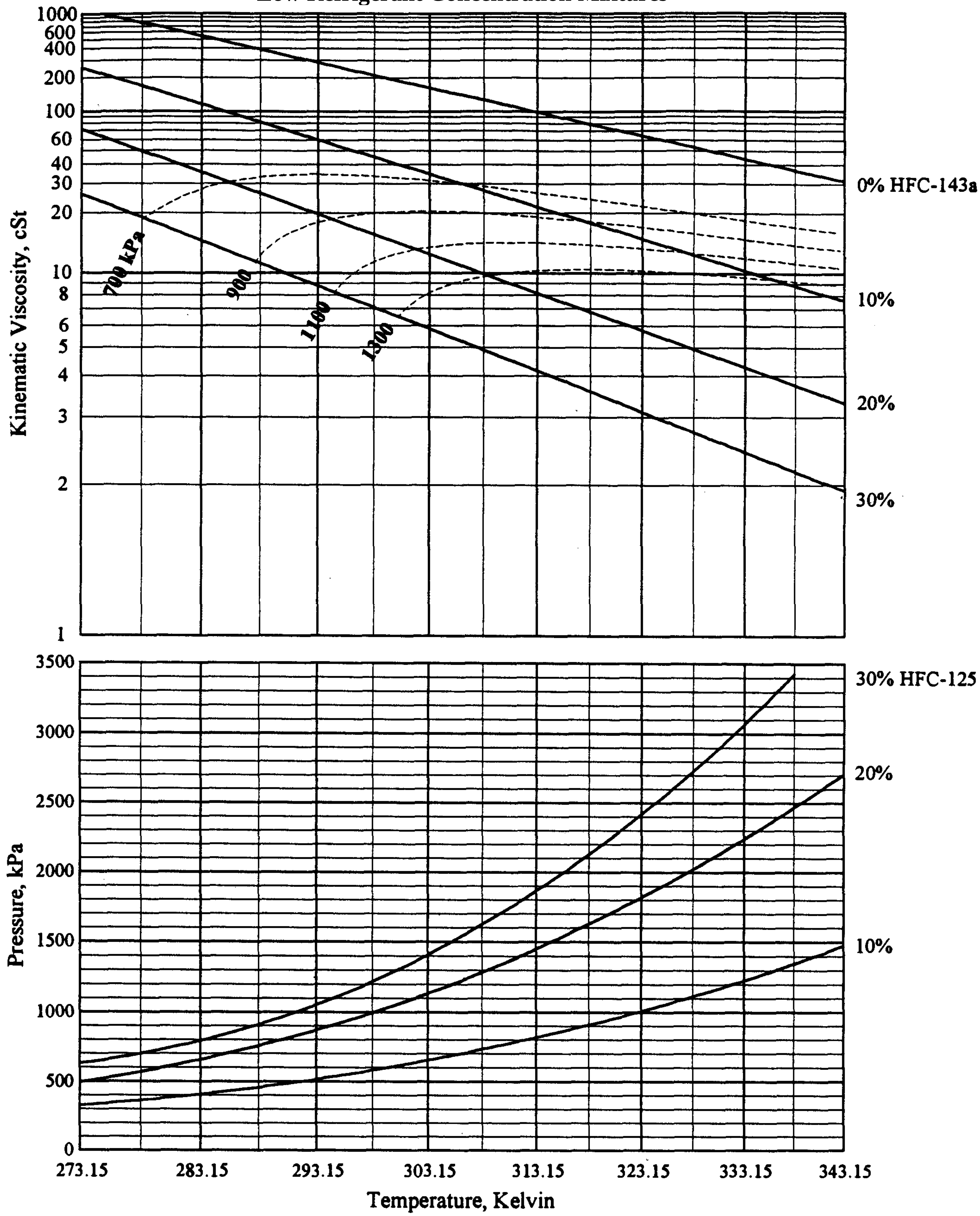


Table 33-1: Viscosity, Solubility and Density Parameters
HCFC-124/ISO 32 Alkylbenzene
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.17196E+1	5.69555E+2	1.01585	1.09631E+1
a_2	-4.63855	-3.54954	-3.82592E-4	-4.32666
a_3	0	5.49783E-3	-4.14279E-7	0
a_4	-1.14674E+1	2.30823E+4	1.75319	-1.09298E+1
a_5	4.08853	-1.90958E+2	-8.07066E-3	3.87616
a_6	0	3.96815E-1	1.11027E-5	0
a_7	2.45761E+1	-2.72026E+4	-3.78158	2.45076E+1
a_8	-9.36660	2.22581E+2	2.44315E-2	-9.39999
a_9	0	-4.59567E-1	-3.77985E-5	0
σ	0.9994	0.9998	0.9999	0.9993

Figure 33-1: Density of HCFC-124/ISO 32 Alkylbenzene
Low Refrigerant Concentration Mixtures

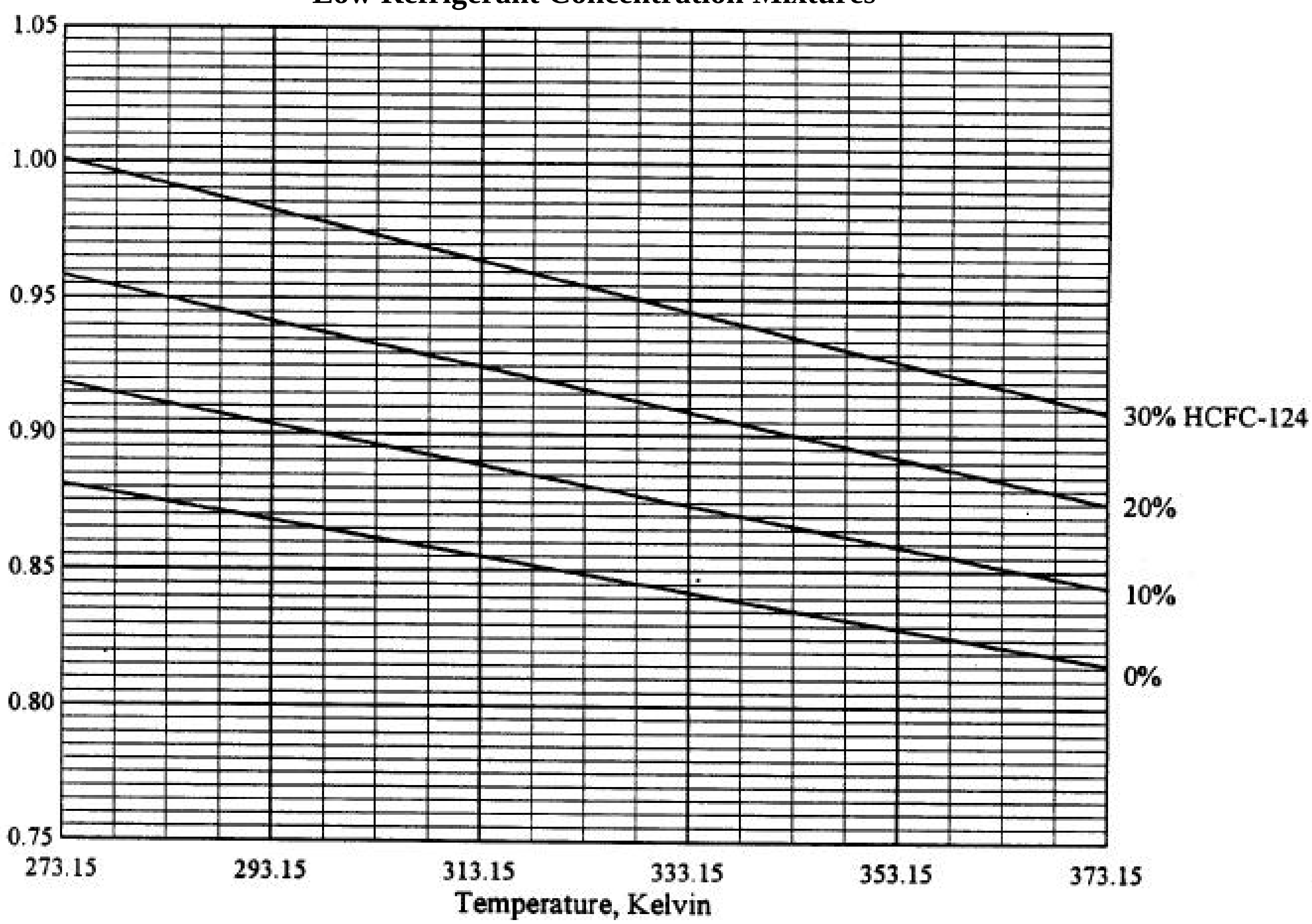


Figure 33-2: Viscosity and Solubility. of HCFC-124/ISO 32 Alkylbenzene Low Refrigerant Concentration Mixtures

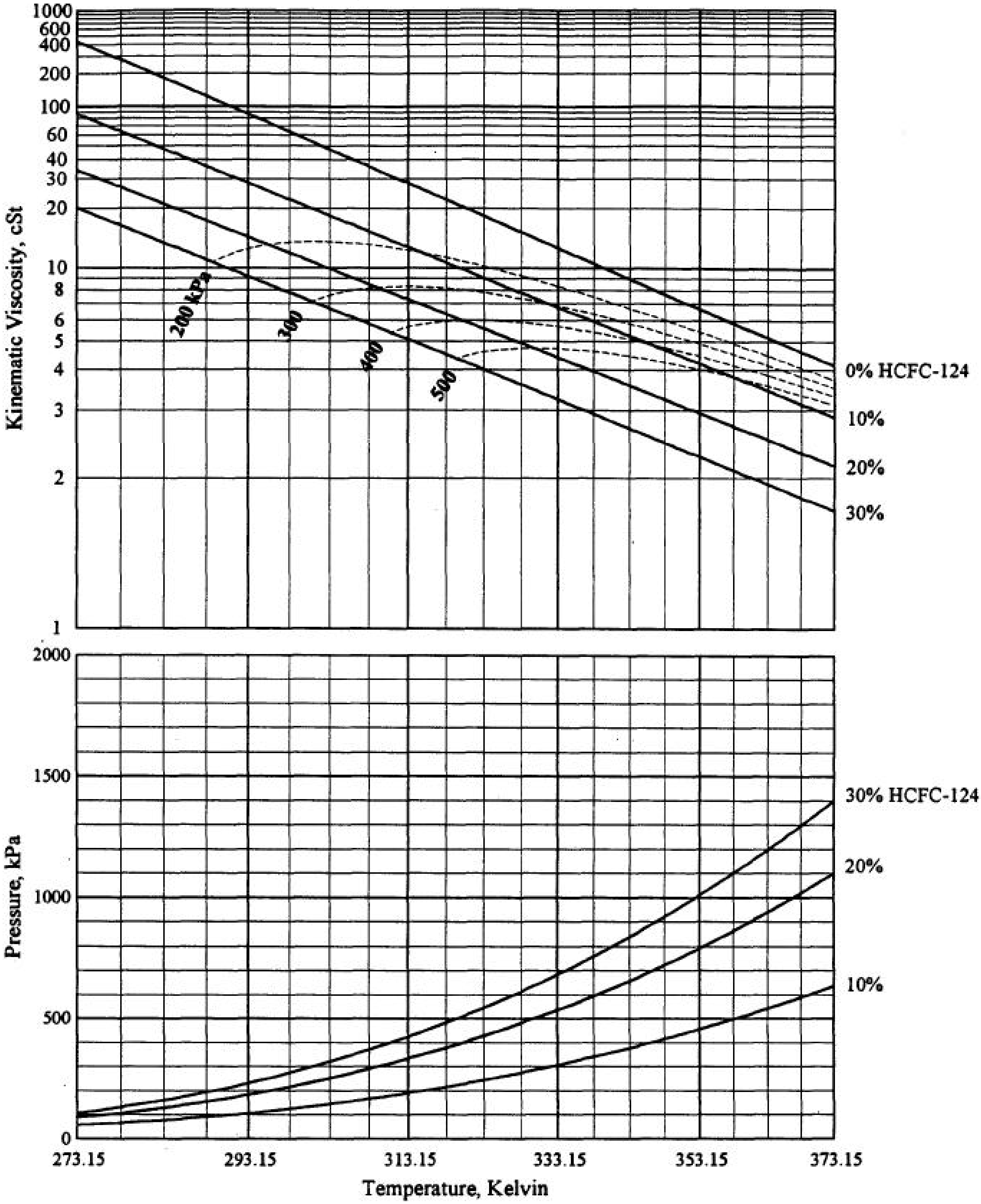


Table 33-2: Viscosity, Solubility and Density Parameters
HCFC-124/ISO 32 Alkylbenzene
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-3.68647	2.71182	-1.49260E-1	-5.41492
a_2	3.21173E+3	2.18481E+2	-5.78507E-1	4.19273E+3
a_3	-3.19486E+5	-1.51604E+5	4.35960	-3.97399E+5
a_4	-5.89869	4.00013	1.54625	-5.16263
a_5	-1.16627E+3	-9.07666E+2	-1.41707	-1.33426E+3
a_6	2.07867E+5	6.37526E+4	-6.86982	1.06022E+5
a_7	7.45226	2.93444	-4.19460E-1	9.26341
a_8	-1.50833E+3	-2.22936E+3	3.74450	-2.78201E+3
a_9	8.97192E+4	3.29984E+5	1.64363	3.22314E+5
σ	0.9928	0.9989	0.9999	0.9937

Figure 33-3: Density of HCFC-124/ISO 32 Alkylbenzene
High Refrigerant Concentration Mixtures

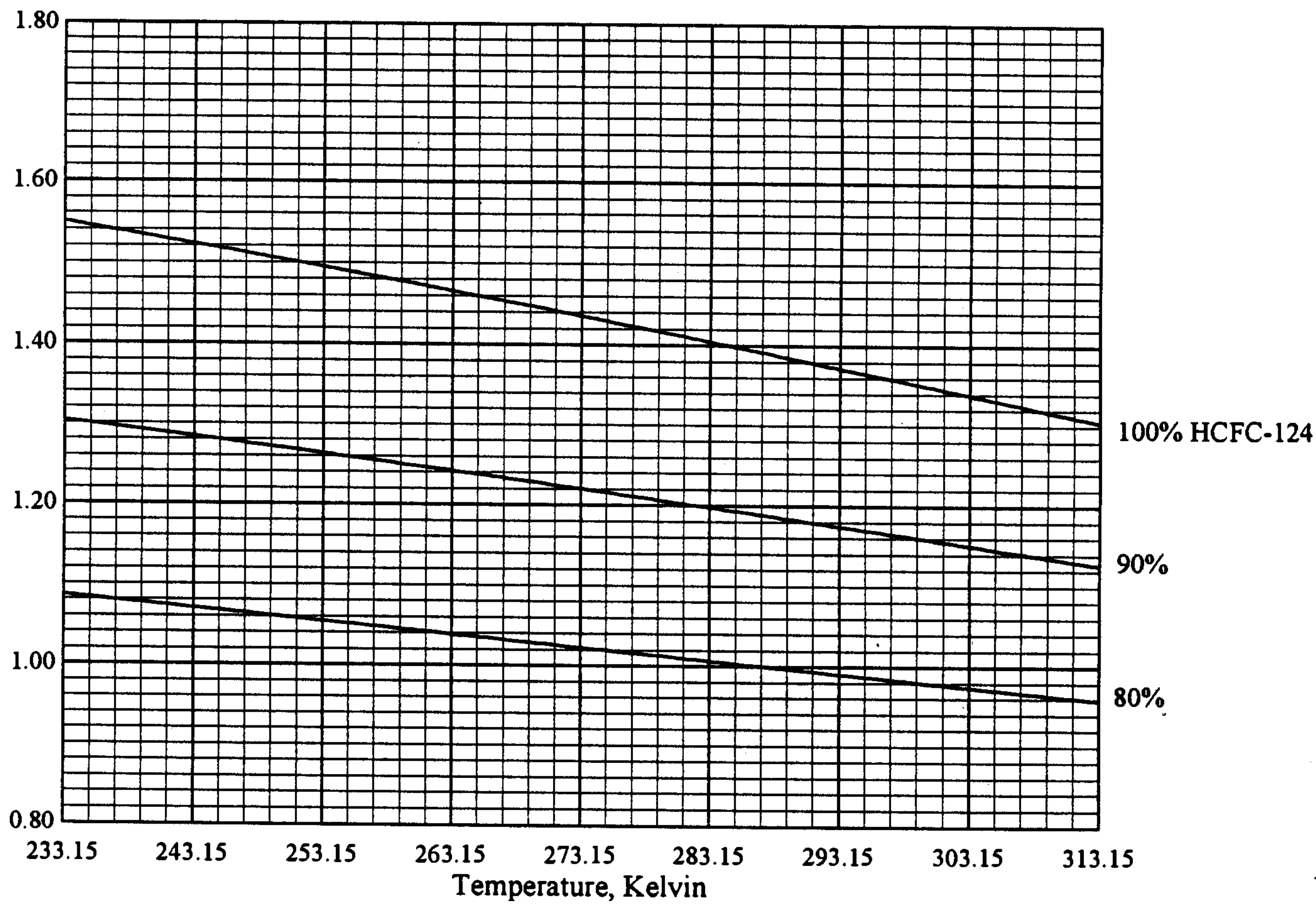


Figure 33-4: Viscosity and Solubility of HCFC-124/ISO 32 Alkylbenzene High Refrigerant Concentration Mixtures

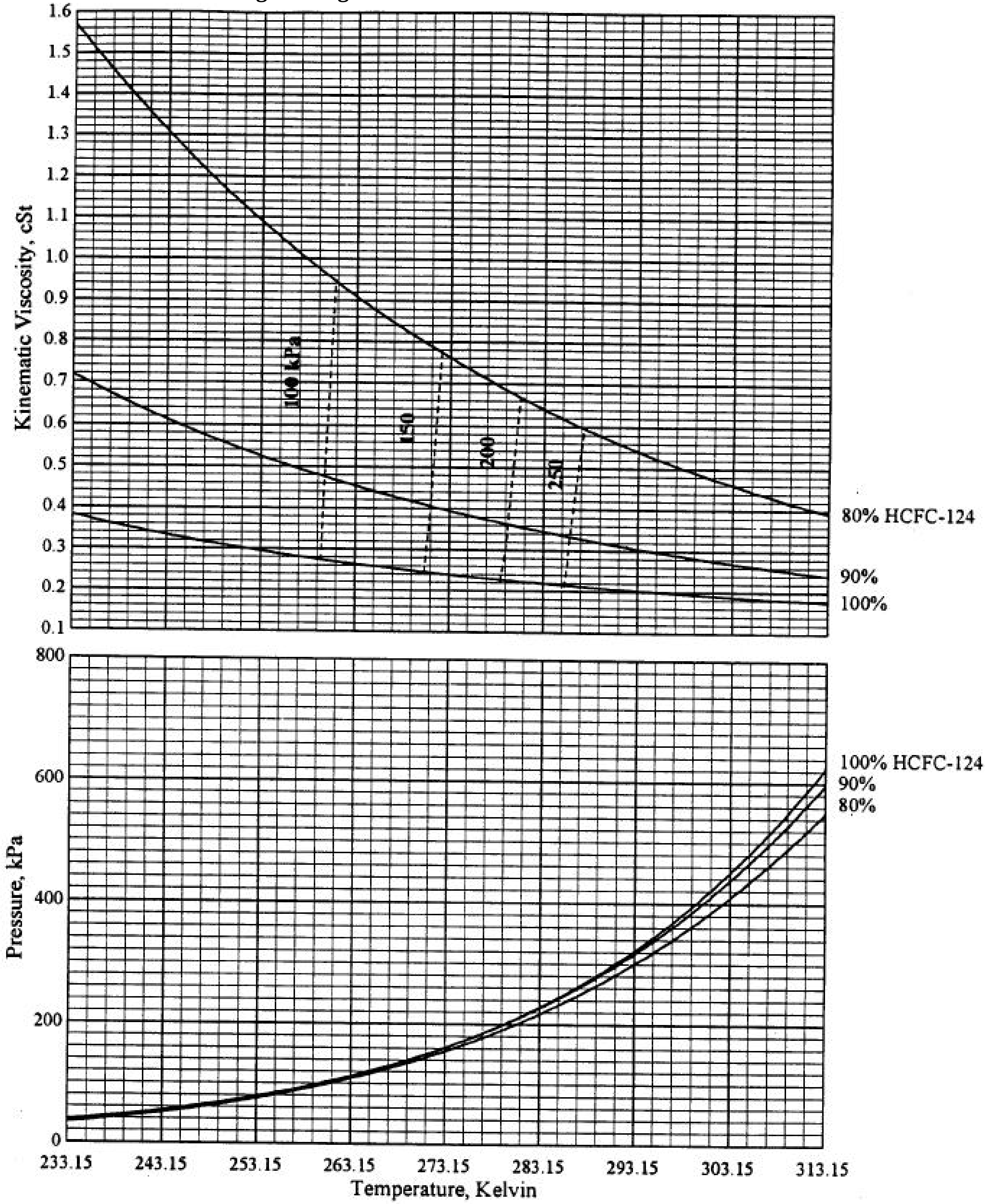


Table 34-1: Viscosity, Solubility and Density Parameters
HCFC-124/ISO 68 Alkylbenzene
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.19562E+1	-1.71810E+3	1.04991	1.13318E+1
a_2	-4.69902	1.06869E+1	-6.06989E-4	-4.44123
a_3	0	-1.64774E-2	-5.33500E-8	0
a_4	4.37528E-1	3.92469E+4	8.54644E-1	-4.25099E-1
a_5	-6.54286E-1	-2.89757E+2	-2.58944E-3	-3.05002E-1
a_6	0	5.47077E-1	2.77345E-6	0
a_7	-3.46598	-4.21188E+4	-8.79548E-1	-6.14676E-1
a_8	1.41764	3.06231E+2	6.71449E-3	2.24443E-1
a_9	0	-5.75102E-1	-1.07696E-5	0
σ	0.9998	0.9998	0.9999	0.9998

Figure 34-1: Density of HCFC-124/ISO 68 Alkylbenzene
Low Refrigerant Concentration Mixtures

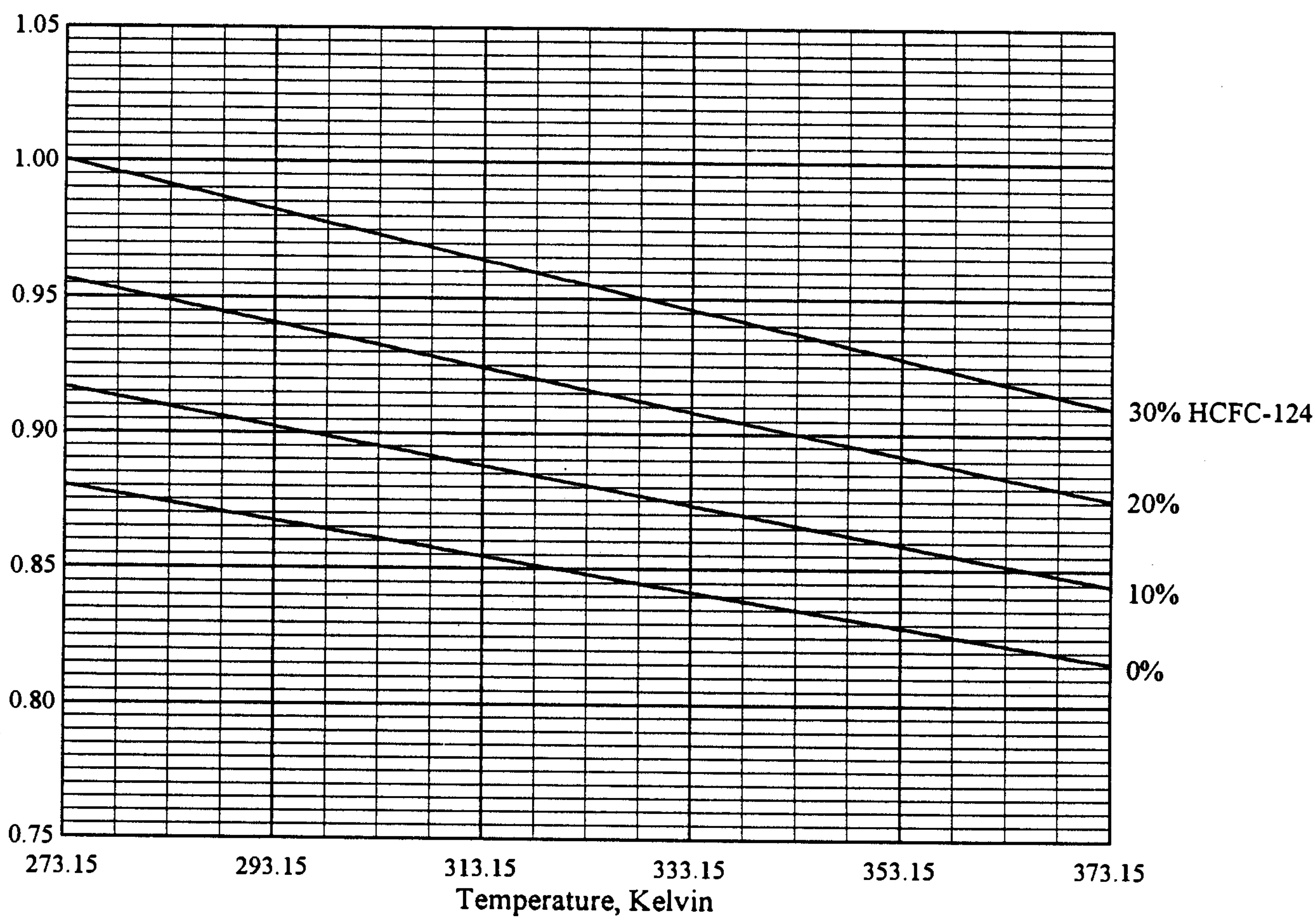


Figure 34-2: Viscosity and Solubility of HCFC-124/ISO 68 Alkylbenzene Low Refrigerant Concentration Mixtures

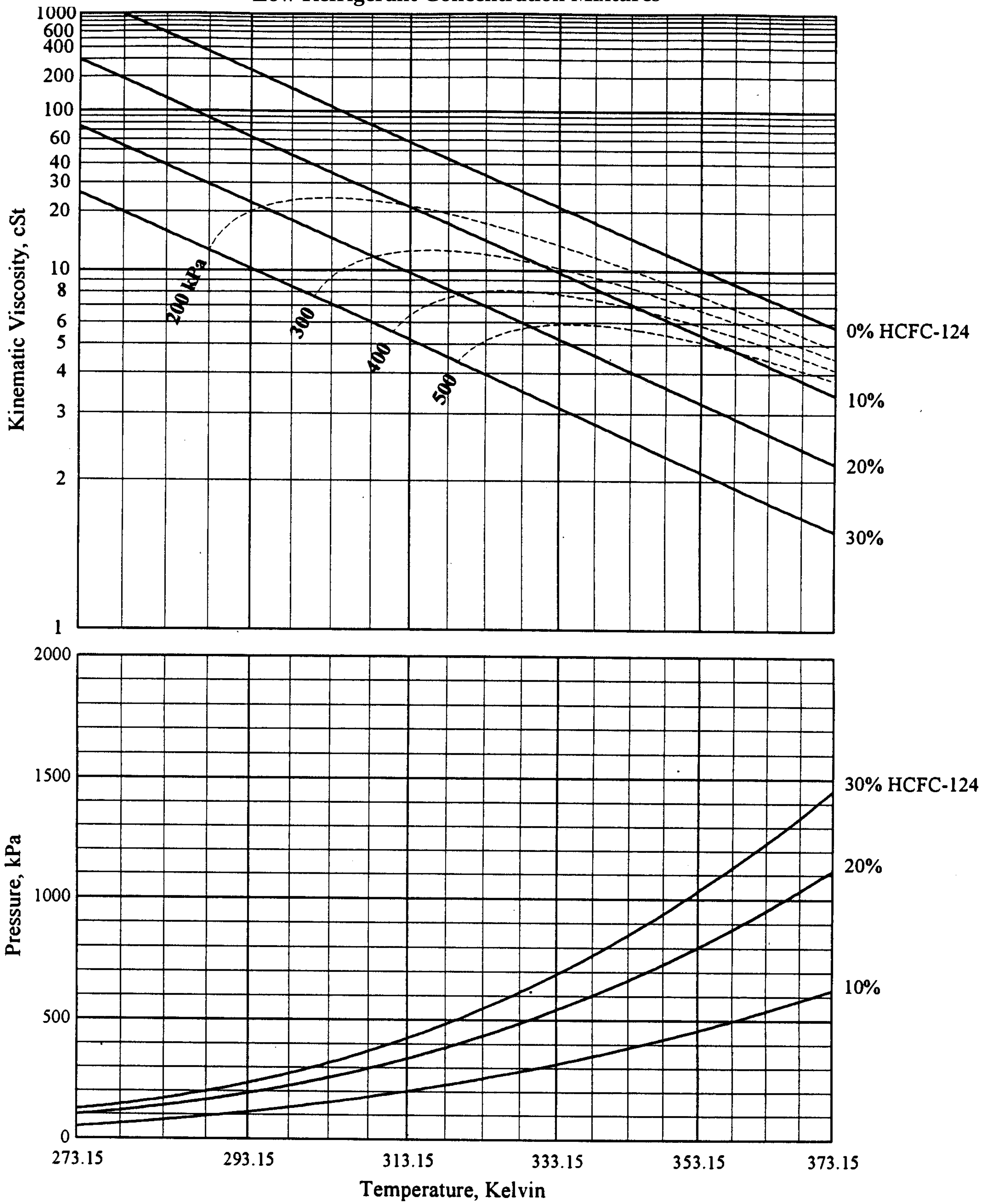


Table 34-2: Viscosity, Solubility and Density Parameters
HCFC-124/ISO 68 Alkylbenzene
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-1.03553E+1	5.17313	7.75844E-2	-4.36732
a_2	5.94105E+3	-8.17737E+2	-3.62939	4.69356E+3
a_3	-6.47955E+5	-5.46019E+4	1.19036E+1	-6.91169E+5
a_4	2.33540	3.18491	1.02449	-9.67510
a_5	-3.63921E+3	-1.12347E+3	5.49793	-1.27260E+3
a_6	4.61556E+5	1.87118E+5	-2.39830E+1	6.11606E+5
a_7	6.72439	7.64692E-1	-1.14947E-1	1.31556E+1
a_8	-2.20705E+3	-6.93847E+2	-1.93096E-1	-3.55792E+3
a_9	2.22348E+5	7.15390E+4	1.13432E+1	1.36727E+5
σ	0.9929	0.9992	0.9999	0.9936

Figure 34-3: Density of HCFC-124/ISO 68 Alkylbenzene
High Refrigerant Concentration Mixtures

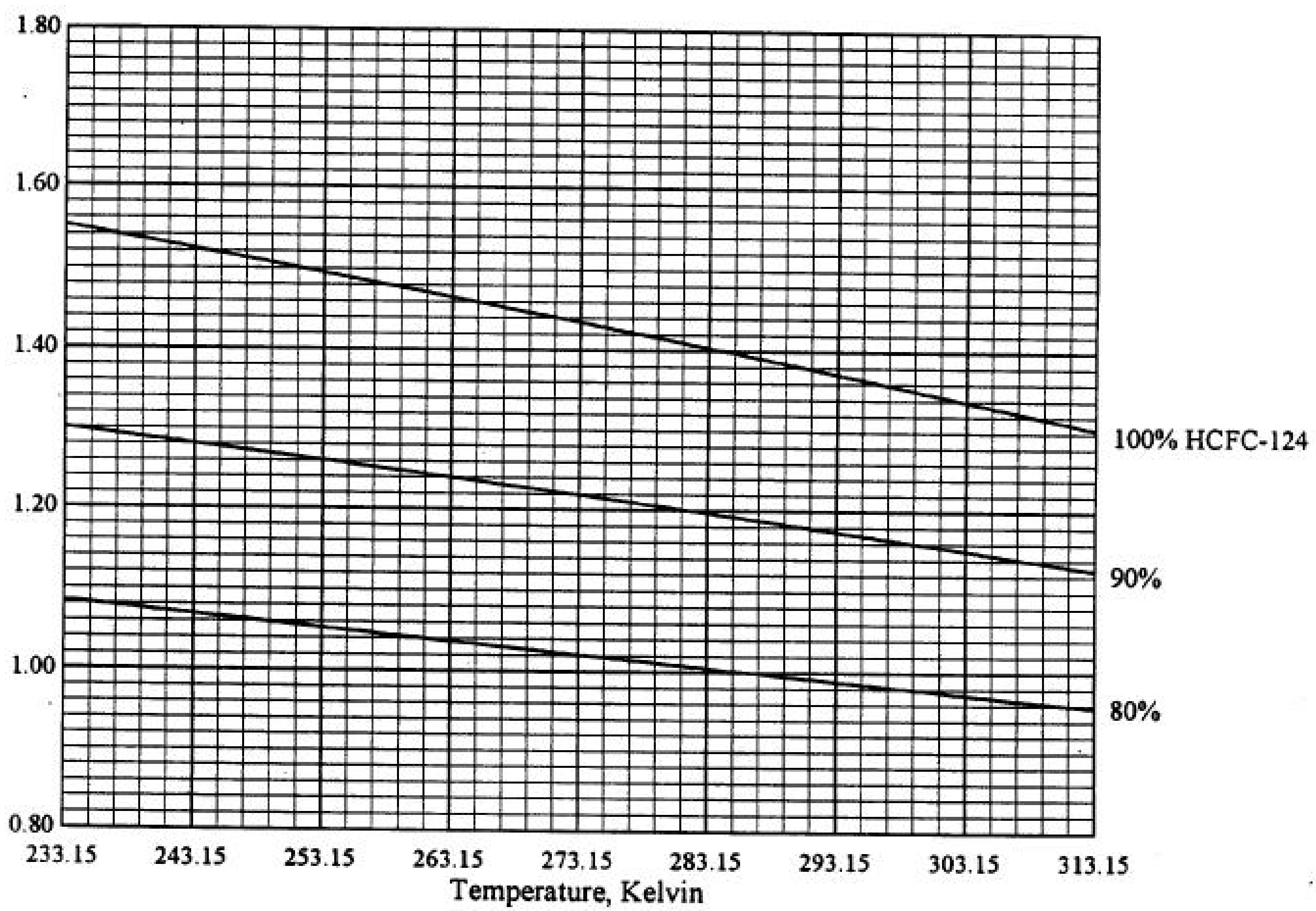


Figure 34-4: Viscosity and Solubility of HCFC-124/ISO 68 Alkylbenzene High Refrigerant Concentration Mixtures

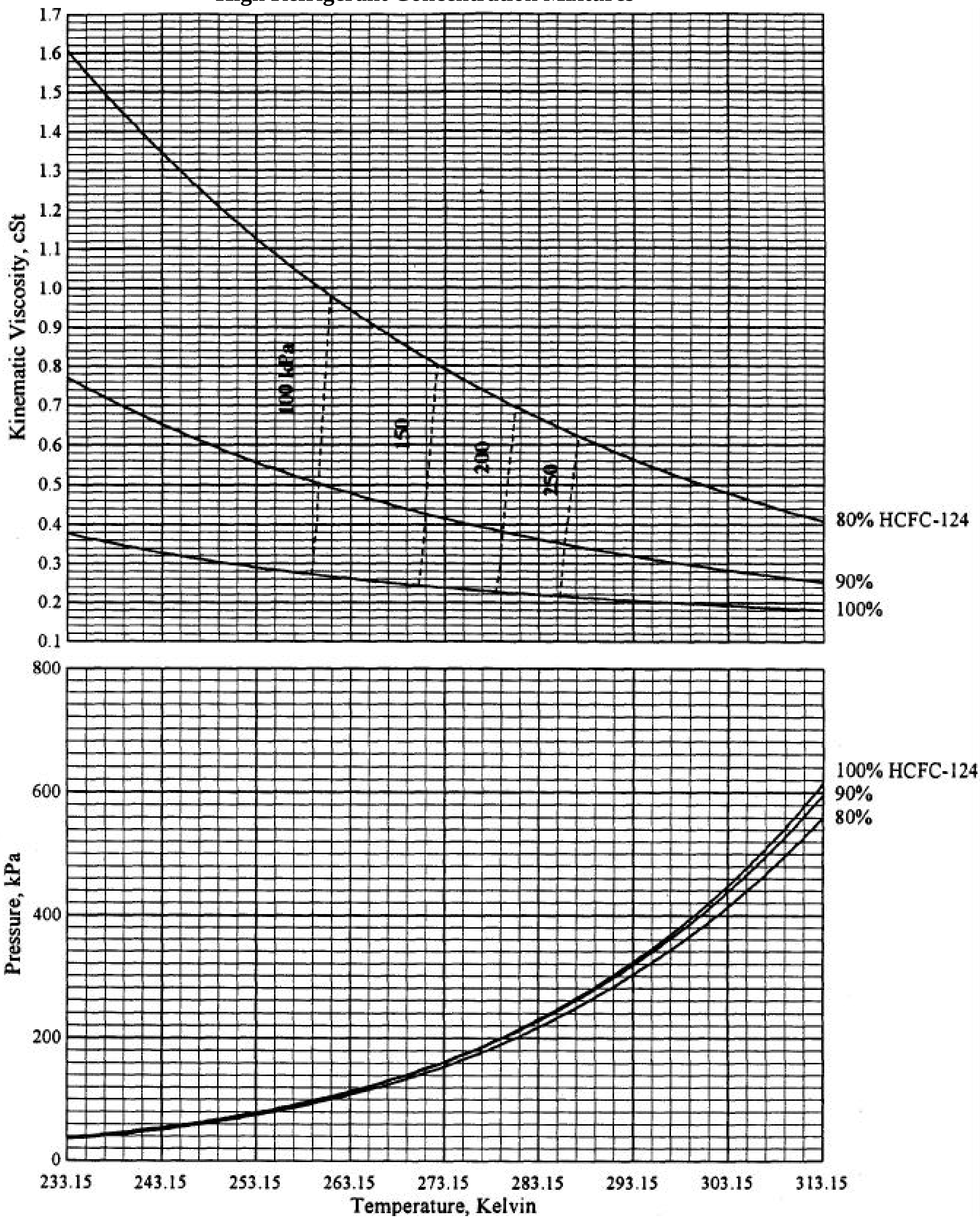


Table 35-1: Viscosity, Solubility and Density Parameters
HCFC-142b/ISO 32 Alkylbenzene
Low Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 1)	Vapor Pressure (eq. 2)	Density (eq. 3)	Kinematic Viscosity (eq. 4)
a_1	1.17197E+1	7.55421E+2	1.17623	1.09894E+1
a_2	-4.63943	-4.77619	-1.37786E-3	-4.33789
a_3	0	7.51096E-3	1.11756E-6	0
a_4	9.41932E-1	-3.03250E+3	-2.24872	1.14148E-1
a_5	-8.66930E-1	-1.84898E+1	1.58086E-2	-5.23223E-1
a_6	0	1.11425E-1	-2.54032E-5	0
a_7	-5.79510	7.74769E+4	8.24809	-5.71619
a_8	2.24228	-4.51188E+2	-5.00915E-2	2.18041
a_9	0	6.20184E-1	7.63598E-5	0
σ	0.9998	0.9995	0.9998	0.9998

Figure 35-1: Density of HCFC-142b/ISO 32 Alkylbenzene
Low Refrigerant Concentration Mixtures

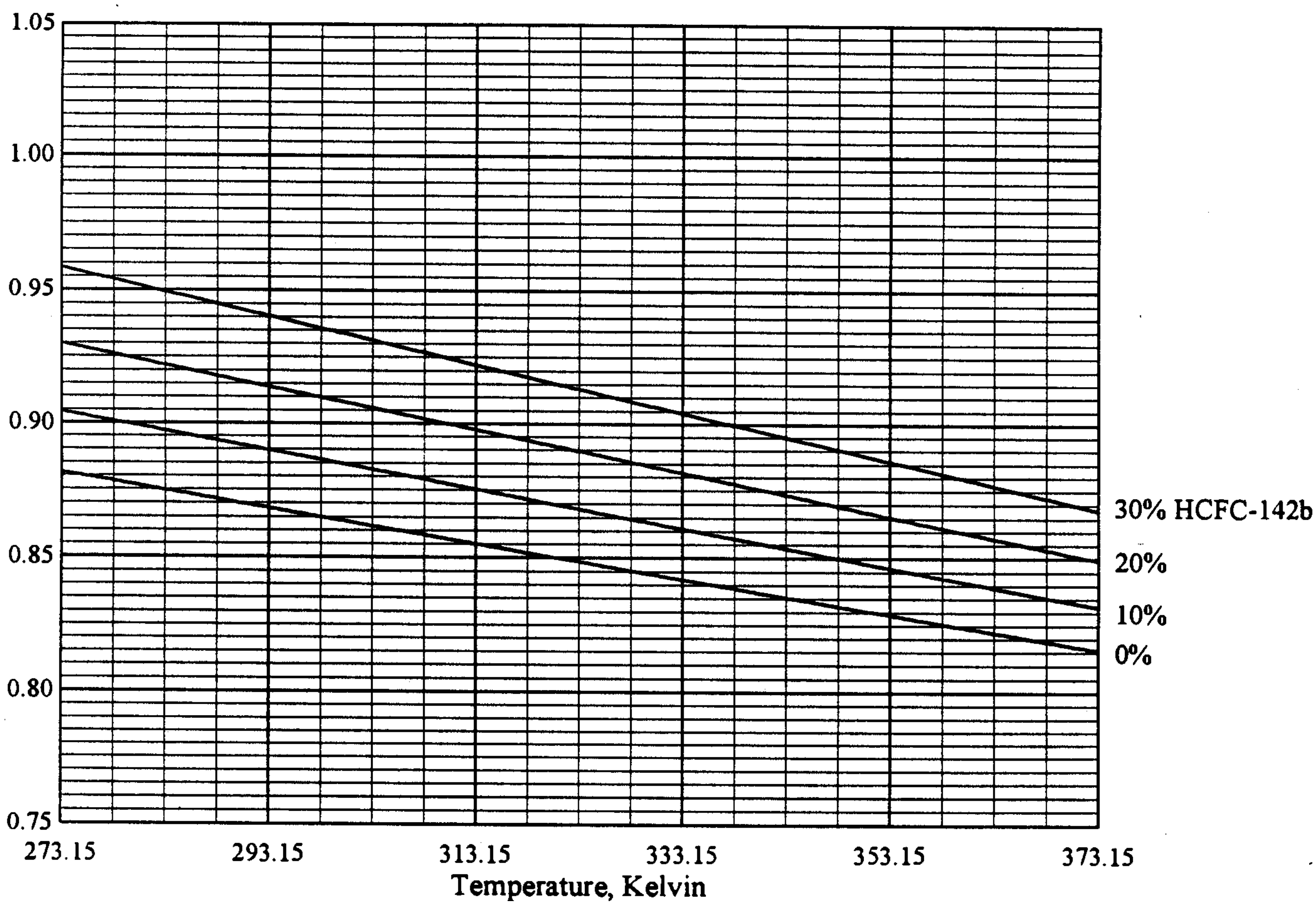


Figure 35-2: Viscosity and Solubility of HCFC-142b/ISO 32 Alkylbenzene Low Refrigerant Concentration Mixtures

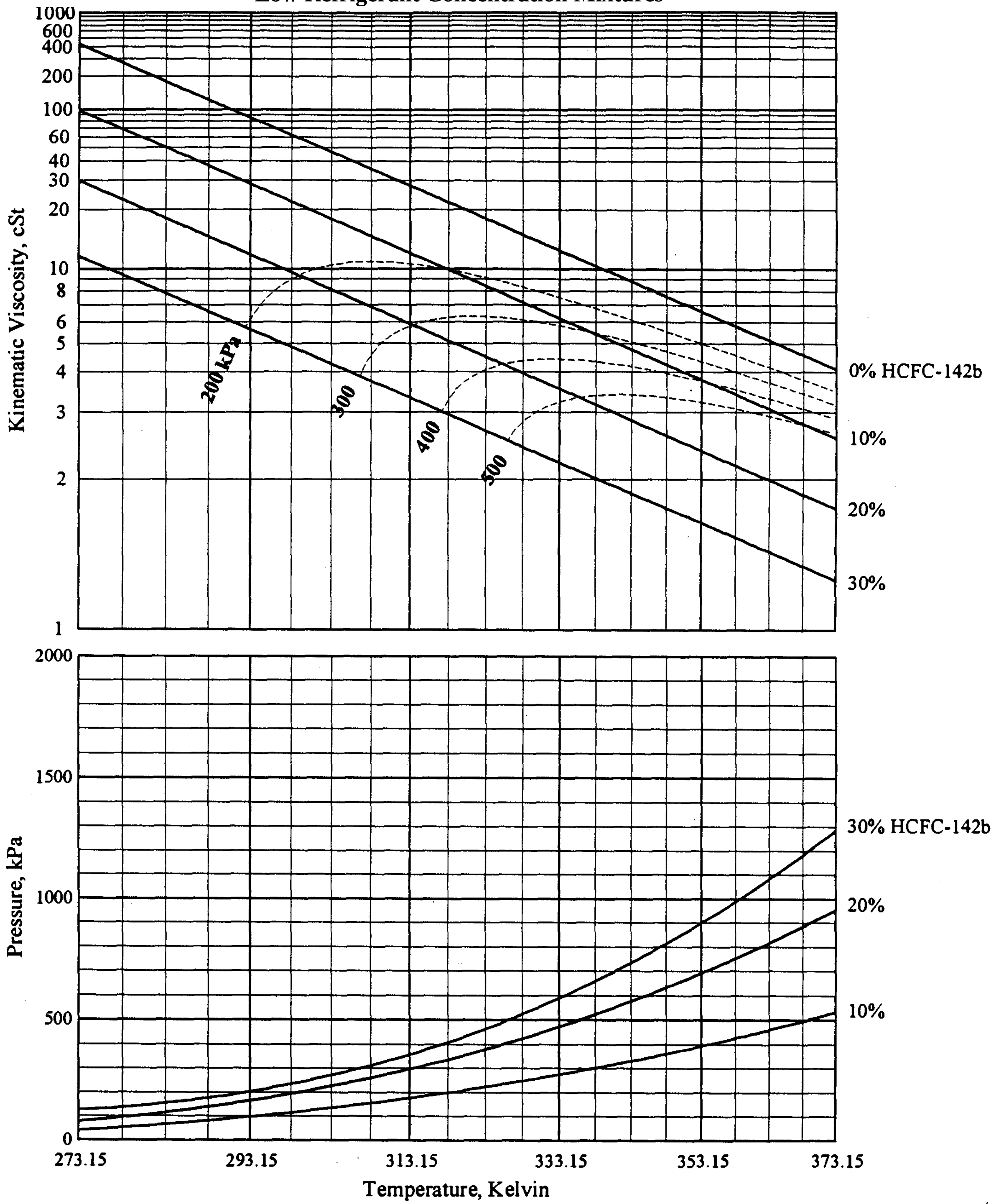


Table 35-2: Viscosity, Solubility and Density Parameters
HCFC-142b/ISO 32 Alkylbenzene
High Refrigerant Concentration Mixtures

Coefficient	Dynamic Viscosity (eq. 5)	Vapor Pressure (eq. 6)	Density (eq. 7)	Kinematic Viscosity (eq. 8)
a_1	-5.58931E-2	6.36886	2.07745E-1	3.58548
a_2	2.33601E+2	-9.08382E+2	-9.62290E-1	2.41034E+2
a_3	1.92922E+5	2.03389E+4	1.39699	-1.12071E+4
a_4	-1.38159E+1	6.01946E-1	7.11933E-1	-1.52732E+1
a_5	5.43446E+3	-1.05041E+3	4.49288E-1	2.16038E+3
a_6	-9.99033E+5	4.93648E+4	-1.17755	-1.10610E+5
a_7	1.31479E+1	1.26072E-2	-1.28097E-1	1.09577E+1
a_8	-5.90696E+3	4.66636E+2	1.85385	-2.60573E+3
a_9	8.85587E+5	-1.98616E+4	-8.16088E-1	1.87578E+5
σ	0.9991	0.9999	0.9999	0.9998

Figure 35-3: Density of HCFC-142b/ISO 32 Alkylbenzene
High Refrigerant Concentration Mixtures

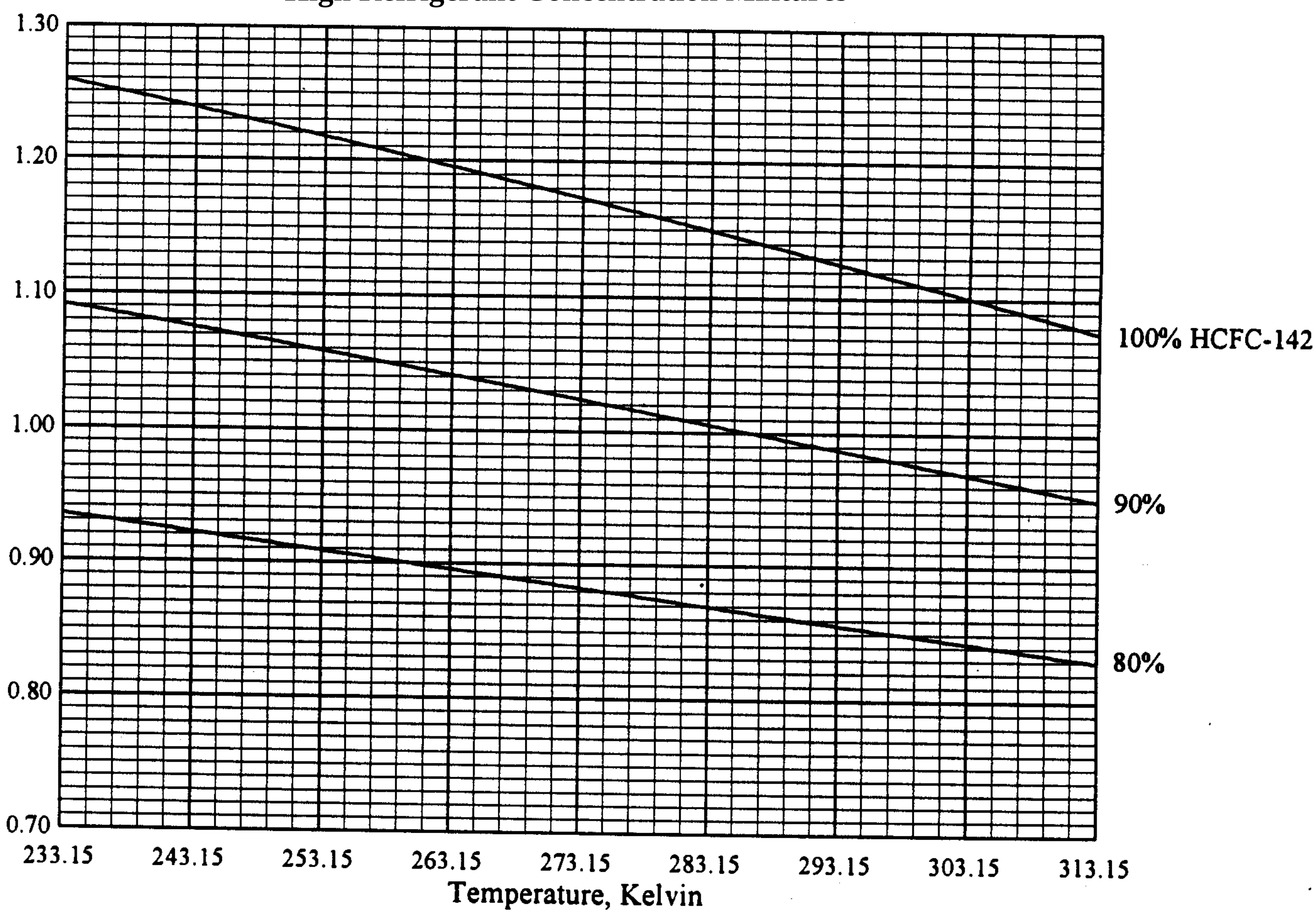
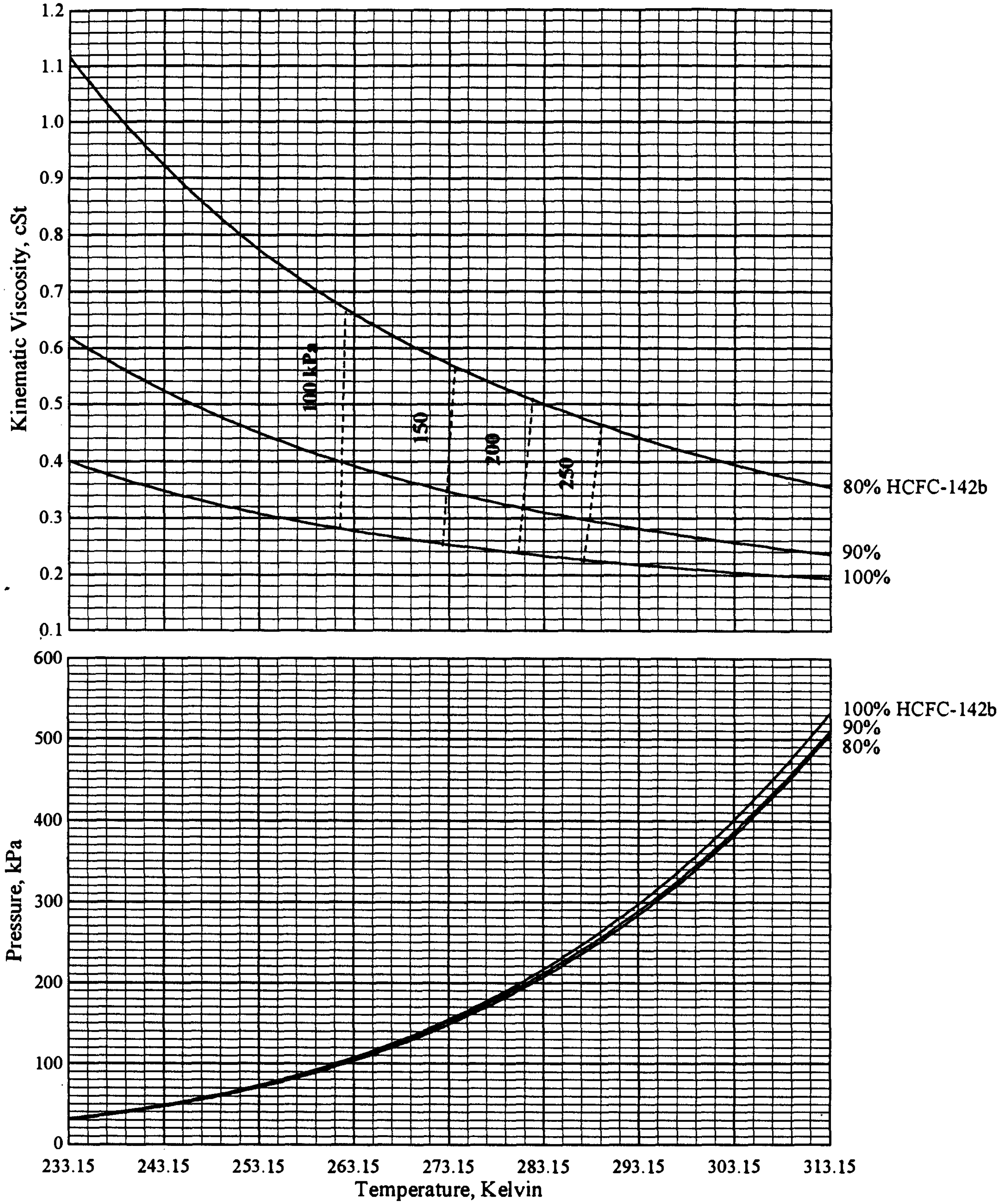


Figure 35-4: Viscosity and Solubility of HCFC-142b/ISO 32 Alkylbenzene High Refrigerant Concentration Mixtures



APPENDIX A

Experimental Technique

Low Refrigerant Concentration Mixtures

The theoretical basis for the following development lies in application of the Gibbs Phase Rule, which will show that the two component fluid systems under study here, for all practical purposes, have two degrees of freedom. Thus, if temperature and density in one vessel is known, composition is also known; likewise, if temperature and pressure in another vessel is known, composition in that vessel is known as well. Although it may not be readily apparent what these compositions are, the point to be made is that they are fixed and can be found to any desired degree of accuracy.

In the method employed here, viscosity, vapor pressure and density are measured in three separate vessels. Fluids for viscosity and vapor pressure are housed in identical 300 ml stainless steel bombs; fluids for density measurements are charged into a glass bulb with a long neck which is equipped with a scribe mark for the purpose of measuring the volume occupied by the known mass of liquid in the bulb. These vessels are depicted conceptually in Figure A-1.

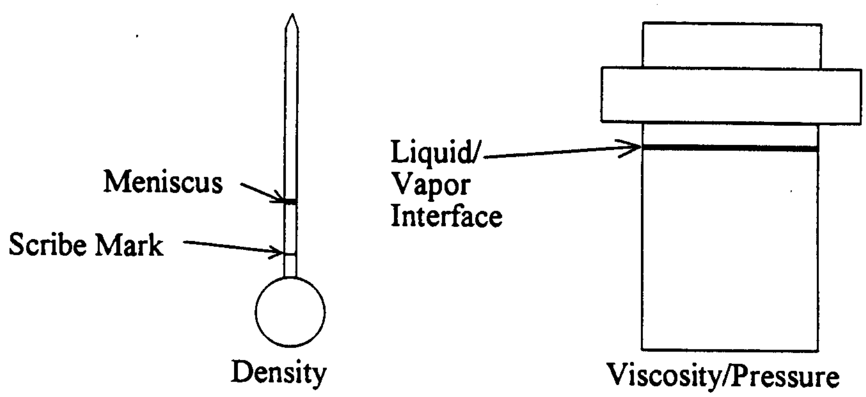


Figure A-1: Density Bulb and Viscosity/Pressure Vessels (lubricant rich mixtures)

Density is measured by determining the volume occupied by the liquid as given by readings of meniscus height (w.r.t. scribe mark). Pressure is measured by a variable capacitance transducer, accuracy 3.8 kPa, and viscosity is measured by an electromagnetic device, accuracy 2% of reading. Temperature is measured by type K thermocouples in the vapor pressure vessel and by a 4-wire resistance temperature device (RTD) integral to the viscometer. Reference 2 describes this equipment and the technique in more detail.

Since there exists a free volume above the liquid, a portion of the refrigerant charge will occupy this free volume, the amount of which depends on the gas density. The composition of the liquid consequently changes as the temperature is varied by thermally cycling the vessels. Care is taken in charging these vessels to minimize the free volume consistent with safety requirements so that shifts in composition from the "as charged" condition are small.

After charging the vessels, pressure, density and viscosity are experimentally determined as a function of temperature. The "as charged" composition, which is determined to within 0.0015 mass fraction, serves as a boundary condition for an iterative computer program. This program is used to find the composition of the liquid phase over the entire experimental measurement range; the algorithm and program are described below.

[2]Spauschus, H. O. and Henderson, D. R., "New Methods of Determining Viscosity and Pressure of Refrigerant/Lubricant Mixtures," Proceedings of the 1990 ASHRAE-Purdue CFC Conference, Purdue University, West Lafayette, IN, 1990.

Notation:

$P_n(T)$ = pressure as a function of temperature at the "as charged" composition
(n = nominal refrigerant mass fraction, i.e. 0.1, 0.2, 0.3)
$\rho_n(T)$ = density as a function of temperature at the "as charged" composition
$P(T,\omega)$ = pressure as a function of temperature and composition
(ω = refrigerant mass fraction)
$\rho(T,\omega)$ = density
$\eta(T,\omega)$ = absolute viscosity
$\nu(T,\omega)$ = kinematic viscosity
m_o = mass of oil
m_r = mass of refrigerant

Algorithm:

1. Find $P_n(T)$; use $P_n(T)$ and measured density to calculate composition in density bulbs at each temperature point.
2. Find $\rho_n(T)$; use $\rho_n(T)$ and measured pressure to calculate composition in pressure bomb at each temperature point.

At this point, data files consisting of the ordered triples temperature, pressure, composition and temperature, density, composition are constructed, where composition is a refined initial guess based on the measured data.

3. Find $P(T,\omega)$.
4. Use $P(T,\omega)$ to refine density bulb compositions.
5. Find $\rho(T,\omega)$.
6. Use $\rho(T,\omega)$ to refine pressure compositions.
7. Repeat steps 3 through 6 until the composition change at any measurement point is less than 0.00001 mass fraction refrigerant.
8. Using final $P(T,\omega)$ and $\rho(T,\omega)$ perform calculations on viscosity vessel until composition change at any measurement point is less than 0.00001 mass fraction refrigerant.
9. Find $\eta(T,\omega)$.
10. Construct a data file containing the ordered triples temperature, kinematic viscosity, composition.
11. Find $\nu(T,\omega)$.
12. Plot $P(T,\omega)$ and $\nu(T,\omega)$ for constant ω on the Daniel Chart.
13. Plot $\rho(T,\omega)$ for constant ω.

Method for calculating composition:

1. Use density and mass of liquid to determine volume occupied by liquid phase (using measured density takes volume change on mixing into account).
2. Subtract from total volume to obtain vapor space volume.
3. Use subroutines from REFPROP 4.0, with measured temperature and pressure, to find molar volume of refrigerant gas.
4. Subtract mass of refrigerant gas from amount charged to obtain composition.

Factors which cause shifts in composition to be larger are higher liquid density and higher vapor pressure at lower solution temperatures. As a specific example, HCFC-22 with ISO 32 naphthenic mineral will be examined in detail.

"As charged" composition of the density bulbs and pressure bombs are given below in Table A-1. Oil and refrigerant amounts are given in grams.

	Density bulbs			Pressure bombs		
n	m_o	m_r	ω	m_o	m_r	ω
0.3	10.078	4.319	0.3000	141.2	60.6	0.3003
0.2	11.455	2.864	0.2000	160.3	40.0	0.1997
0.1	12.679	1.409	0.1000	180.1	20.0	0.09995

Table A-1: "As Charged" Compositions

Results of the calculations are given in Table A-2, which shows the refined initial estimates, and Table A-3 which gives the compositions after completion of iterations.

Temp, C	Density Bulb Compositions			Pressure Bomb Compositions		
	n=0.3	n=0.2	n=0.1	n=0.3	n=0.2	n=0.1
0	0.2972	0.1976	0.09902	0.2922	0.1929	0.09581
20	0.2955	0.1960	0.09849	0.2871	0.1890	0.09359
40	0.2944	0.1951	0.09840	0.2797	0.1837	0.09085
60	0.2935	0.1944	0.09868	0.2704	0.1778	0.08755
80	0.2938	0.1948	0.09935	0.2603	0.1724	0.08498
100	0.2943	0.1955	0.09985	0.2534	0.1693	0.08393

Table A-2: Density Bulb and Pressure Bomb Compositions After Algorithm Steps 1 and 2

Temp, C	Density Bulb Compositions			Pressure Bomb Compositions		
	n=0.3	n=0.2	n=0.1	n=0.3	n=0.2	n=0.1
0	0.2970	0.1974	0.09905	0.2922	0.1929	0.09581
20	0.2954	0.1958	0.09847	0.2871	0.1890	0.09359
40	0.2942	0.1948	0.09830	0.2798	0.1838	0.09089
60	0.2931	0.1938	0.09856	0.2709	0.1780	0.08756
80	0.2931	0.1941	0.09927	0.2612	0.1727	0.08509
100	0.2936	0.1956	0.09981	0.2544	0.1697	0.08405

Table A-3: Density Bulb and Pressure Bomb Compositions After Completion of the Iterations

It can be seen that larger composition shifts are observed in the pressure bombs than in the density bulbs; this is due to the fact that the liquid phase occupies the long, narrow neck of the density bulb, and changes in the height of the liquid phase as the temperature is elevated are large. This causes smaller vapor space volume, which tends to counter the effects of increased pressure; in fact, at the higher temperatures the effect of decreasing vapor space dominates.

Comparison of Tables A-2 and A-3 show that the iteration quickly converges. After the first two steps of the algorithm, the composition is within 0.1 mass fraction of the true composition, and the convergence criteria is satisfied in two iterations of algorithm steps 3 through 7.

The value used for the specific volume of the refrigerant gas in the vapor space is obviously important, and subroutine VIT from REFPROP has been extracted and used for this purpose. The limitations of REFPROP in representing refrigerant properties near the critical point are recognized, and for the "worst case" composition shift in this data set, the value 8.523 cc/g was obtained for HCFC-22 at the measured thermodynamic condition of 100°C and 3,113 kPa. This compares very favorably with pressure-enthalpy diagrams published by ASHRAE and DuPont.

Having at this point an excellent representation of the pressure-volume-temperature behavior, calculations for the viscosity bomb proceed in a similar iterative fashion, also reaching convergence in two iterations for this fluid. The free volume of the viscosity bomb (as compared to the pressure bomb) is generally lower, which results in smaller composition shifts, as illustrated in Table A-4 (compare with Table A-3).

Temp, C	Viscosity Bomb Compositions		
	n=0.3	n=0.2	n=0.1
0	0.2961	0.1968	0.1040
20	0.2927	0.1946	0.1031
40	0.2890	0.1925	0.1022
60	0.2849	0.1902	0.1012
80	0.2809	0.1880	0.1004
100	0.2773	0.1862	0.09968

Table A-4: Viscosity Bomb Compositions After Completion of the Iterations

Two data files consisting of the ordered triples temperature, absolute viscosity, composition and temperature, kinematic viscosity, composition are now constructed and are used to find these viscosities as a function of temperature and composition. Regression constants and statistical measures of goodness of fit are calculated, and curves of constant composition are plotted from these equations.

Isobaric viscosity curves are generated algebraically, using the assumptions that interpolation between measured curves is valid, the fluid has two degrees of freedom and the vapor pressure of the neat oil is identically zero over the temperature range of interest. These curves are plotted on the upper portion of the Daniel Chart.

High Refrigerant Concentration Mixtures

Glass capillary viscometers were employed for these low viscosity, refrigerant rich mixtures. The viscometers were fabricated after the design of Shankland[3] and are depicted in Figure A-2. Calibration was accomplished by measuring the flow times at various temperatures for diethyl ether, CFC- 12 and methanol, so that each was applicable to a viscosity range of 0.1 to 2 centistokes. The instruments were thermally equillabrated in a programmable air bath, and it was found experimentally that equilibrium was reached in fifteen minutes after a temperature change of 10°C, as evidenced by no measurable temperature difference between the top and bottom of any viscometer or between the four instruments.

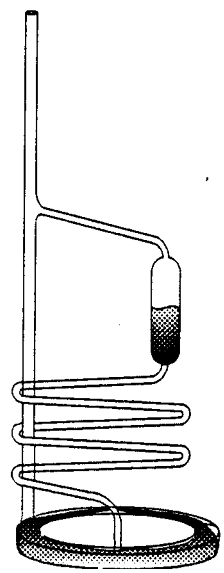


Figure A-2: Glass Capillary Viscometer

Vapor pressure of these mixtures was determined by differential from the neat refrigerant, since the pressure reduction caused by the presence of the oil was found to be small. Identical 300 ml test bombs were charged with neat refrigerant, 10 and 20 weight percent oil and were thermally cycled at a very slow rate (0.15°C/minute) in the programmable air bath. Temperature was measured by three wire resistance temperature devices (RTDs), and pressure was measured by means of a variable capacitance transducer with an accuracy of 0.379 kPad (0.055 psid). Temperature/pressure difference data points were recorded by computer at one minute intervals, which were averaged at one degree intervals prior to performing linear regression.

Density was measured in the same manner as described previously for low refrigerant concentration mixtures. Corrections for vapor space in the viscometers, pressure vessels and density bulbs were made as discussed above.

[3]Shankland, I. R., Basu, R. S. and Wilson, D. P., "Thermal Conductivity and Viscosity of a New Stratospherically Save Refrigerant-1,1,1,2Tetrafluoroethane(R-134a)," CFCs: Time of Transition, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA 1989.

APPENDIX B

Lubricant Purity

Moisture, total acid number, iron content and copper content have been measured for the lubricants reported in this study. Table B-1 below gives these results. The intent of these measurements is to verify purity of the lubricants prior to study of the viscosity, solubility and density characteristics when mixed with various refrigerants; impurities of the order shown below have negligible effects on these properties.

Lubricant	Moisture, ppm	Total Acid Nuamber mg KOH/g oil	Fe, ppm	Cu, ppm
ISO 32 Naphthenic Mineral Oil	31	0.02	< 1	< 1
ISO 100 Naphthenic Mineral Oil	42	0.03	< 1	< 1
ISO 68 Polyalkylene Glycol	230	< 0.01	< 1	< 1
ISO 22 Pentaerythritol Ester Mixed Acid #1	35	<0.01	< 1	< 1
ISO 22 Pentaerythritol Ester Mixed Acid #2	86	0.08	< 1	< 1
ISO 32 Pentaerythritol Ester Mixed Acid #1	35	< 0.01	< 1	< 1
ISO 32 Pentaerythritol Ester Mixed Acid #2	64	0.04	< 1	< 1
ISO 68 Pentaerythritol Ester Mixed Acid #1	77	0.04	< 1	< 1
ISO 68 Pentaerythritol Ester Mixed Acid #2	96	< 0.01	< 1	< 1
ISO 100 Pentaerythritol Ester Mixed Acid #1	80	0.06	< 1	< 1
ISO 22 Pentaerythritol Ester Branched Acid	91	< 0.01	< 1	< 1
ISO 32 Pentaerythritol Ester Branched Acid	51	< 0.01	< 1	< 1
ISO 68 Pentaerythritol Ester Branched Acid	45	< 0.01	< 1	< 1
ISO 100 Pentaerythritol Ester Branched Acid	59	< 0.01	< 1	< 1
ISO 32 Alkylbenzene	29	0.01	< 1	< 1
ISO 68 Alkylbenzene	29	0.04	4	< 1

Table B-1: Lubricant Purity

APPENDIX C

Commercial Identification

Lubricants tested are commercially available and are:

ISO 32 Naphthenic Mineral Oil	Witco Suniso 3GS
ISO 100 Naphthenic Mineral Oil	Witco Sunios 5GS
ISO 68 Polyalkylene Glycol	ICI Emkarox DGLP 103
ISO 22 Pentaerythritol Ester Mixed Acid #1	Mobil Arctic EAL 22
ISO 22 Pentaerythritol Ester Mixed Acid #2	Castrol Icematic SW 22
ISO 32 Pentaerythritol Ester Mixed Acid #1	Mobil Arctic EAL 32
ISO 32 Pentaerythritol Ester Mixed Acid #2	Castrol Icematic SW 32
ISO 68 Pentaerythritol Ester Mixed Acid #1	Castrol Icematic SW 68
ISO 68 Pentaerythritol Ester Mixed Acid #2	ICI Emkarate RL-375
ISO 100 Pentaerythritol Ester Mixed Acid	Castrol Icematic SW 100
ISO 22 Pentaerythritol Ester Branched Acid	Henkel, Emery Group 2966A
ISO 32 Pentaerythritol Ester Branched Acid	Henkel, Emery Group 2968A
ISO 68 Pentaerythritol Ester Branched Acid	Henkel, Emery Group 2942A
ISO 100 Pentaerythritol Ester Branched Acid	Henkel, Emery Group 2928A
ISO 32 Alkylbenzene	Shrieve Chemical Zerol 150
ISO 68 Alkylbenzene	Shrieve Chemical Zerol 300