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SOLUBILITY, VISCOSITY AND DENSITY OF REFRIGERANT/LUBRICANT MIXTURES

Quarterly Technical Progress Report

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SOLUBILITY, VISCOSITY AND DENSITY OF REFRIGERANT/LUBRICANT MIXTURES

ABSTRACT

This report presents results on low refrigerant concentration (70, 80, 90 and 100 weight percent lubricant) mixtures of the following fluids:

- CFC-12/ISO 32 naphthenic mineral oil
- HCFC-22/ISO 32 naphthenic mineral oil
- HFC-134a/ISO 32 pentaerythritol ester mixed acid.

These data have been reduced to engineering form and are presented in the form of a Daniel Chart[1]. Scatter diagrams are given for the first fluid listed above, with the intent of illustrating the quality of data as well as providing the rationale for selecting the particular functional forms chosen to represent the experimental data. Equations are given along with statistical measures of goodness of fit.

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. Low refrigerant concentrations are generally to be measured over 0 to 100°C, with the exception of HFC-32, 125 and 143a, which are to be measured over zero Celsius to slightly below the critical temperature. The experimental data are to be graphically reported in the Daniel Chart format, and mathematical relationships are to be derived.

The entire process of measurement, data reduction, mathematical modeling and plotting has been essentially completed for the low refrigerant concentrations on fluids 1, 3 and 6 (Table 1) and is reported here. Measurements have been completed on several other working fluids and data reduction is in progress. Substantial efforts were directed toward establishment of experimental facilities, software development and organizational/administrative activities.

[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 To Be Studied

Refrigerant/Lubricant	Low Refrigerant Concentrations[1] Temp. Range, C	High Refrigerant Concentrations[2] Temp. Range, C
1. CFC-12/ISO 32 MO[3]	0 to 100	-40 to +40
2. 12/ISO 100 MO	0 to 100	-40 to +40
3. HCFC-22/ISO 32 MO	0 to 100	-40 to +40
4. HFC-134a/ISO 68 PAG[4]	0 to 100	-40 to +40
5. 134a/ISO 22 POE-MA[5]	0 to 100	-40 to +40
6. 134a/ISO 32 POE-MA	0 to 100	-40 to +40
7. 134a/ISO 68 POE-MA	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-BA	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 HCFC-123/ISO 32 MO	0 to 100	-20 to +40
14. 123/ISO 100 MO	0 to 100	-20 to +40
15. 123/ISO 32 AB[7]	0 to 100	-20 to +40
16. 123/ISO 68 AB	0 to 100	-20 to +40
17. HFC-32/ISO 22 POE-MA	0 to 75	-50 to +40
18. 32/ISO 68 POE-MA	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. HFC-125/ISO 22 POE-MA	0 to 65	-40 to +40
22. 125/ISO 68 POE-MA	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. HFC-152a/ISO 32 AB	0 to 100	-40 to +40
26. 152a/ISO 68 AB	0 to 100	-40 to +40
27. 152a/ISO 22 POE-MA	0 to 100	-40 to +40
28. 152a/ISO 100 POE-MA	0 to 100	-40 to +40
29. HFC-143a/ISO 22 POE-MA	0 to 70	-45 to +40
30. 143a/ISO 68 POE-MA	0 to 70	-45 to +40
31. 143a/ISO 32 POE-BA	0 to 70	-45 to +40
32. 143a/ISO 100 POE-MA	0 to 70	-45 to +40
33. HCFC-124/ISO 32 AB	0 to 100	-40 to +40
34. 124/ISO 68 AB	0 to 100	-40 to +40
35. HCFC-142b/ISO 32 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]Penta Erythritol Ester Mixed Acid
[6]Penta Erythritol Ester Branched Acid
[7]Alkylbenzene

SIGNIFICANT RESULTS

INTRODUCTION

Experimental data is presented in the form of mathematical models and two charts, the first giving the viscosity and pressure as functions of temperature and composition (Daniel Chart), the second giving the density. On the upper portion of the Daniel Chart are isobaric viscosity curves which have been numerically generated from the measured data, together with the knowledge that these fluid systems have two degrees of freedom and the assumption that linear interpolation between measured curves is valid.

CFC-12/ISO 32 MINERAL OIL

This fluid has been arbitrarily chosen as a representative case to illustrate the quality of data, corrections applied to the raw data, and the numerical modeling process.

Viscosity and Pressure

Figure 1 gives the experimental dynamic viscosity and vapor pressure data points, shown superimposed over the best fit regression curves. For viscosity, the functional form chosen is the Walther equation,

$$\log\{\log(\mu + 0.7) = A + B \cdot \log(T) \qquad (1)$$

where

log = logarithm to the base 10
μ = dynamic viscosity, centipoise
A, B = constants found by least squares regression
T = temperature, Kelvin.

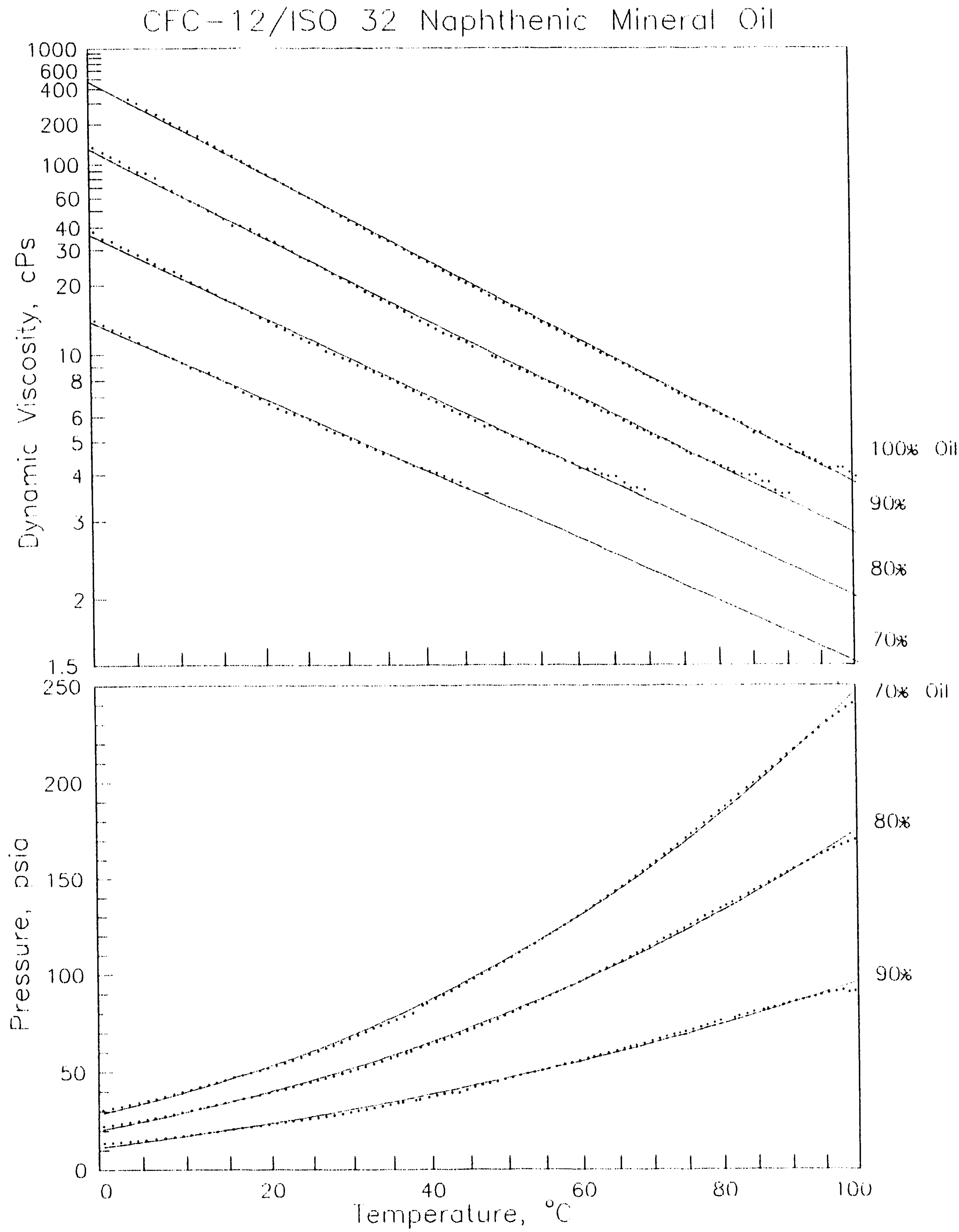
Table 2 gives the values of A, B and the correlation coefficient for each of the mixtures.

Table 2: Dynamic Viscosity Parameters
CFC-12/ISO 32 Mineral Oil

Composition	A	B	Correlation Coefficient
100% Oil	11.40495	-4.50591	0.999
90%	10.89065	-4.33684	0.999
80%	10.19943	-4.10609	0.999
70%	9.47597	-3.86349	0.999

The experimental data spans the entire temperature range of interest, and spans the viscosity range of 3.5 to 350 centipoise. Below or above this value, it is necessary to change the moving element (bobbin) in the viscometer, which requires recalibration of the instrument, charging the vessel with the same mixture and running the experiment again. Efficiency in making the large number of measurements required by this program is improved by minimizing the number of bobbin changes, which is accomplished by experimentally determining viscosity for a number of fluids falling within the range of one bobbin (3.5 to 350 cps), followed by further measurements as necessary later in the program. For this reason, the viscosity data reported here is subject to revision at a later date when the measurements on the 70% mixtures below 3.5 centipoise have been completed.

Figure 1


CFC-12/ISO 32 Naphthenic Mineral Oil
Dynamic Viscosity, cPs
1000
600
400
200
100
60
40
30
20
10
8
6
5
4
3
2
1.5
100% Oil
90%
80%
70%
Pressure, psia
250
200
150
100
50
0
70% Oil
80%
90%
0
20
40
60
80
100
Temperature, °C

Pressure data and best fit quadratic polynomials are also shown in Figure 1. These curves are of the form

$$P = a + b \cdot T + c \cdot T^2 \qquad (2)$$

where

P = pressure, psia
T = temperature, Celsius
a, b, c = constants found by least squares regression.

Table 3 gives the values of the constants as well as the correlation coefficient for these mixtures.

Table 3: Vapor Pressure Parameters
CFC-12/ISO 32 Mineral Oil

Mixture	a	b	c	Correlation Coefficient
90% Oil	11.350	0.580	0.00269	0.999
80%	20.314	0.861	0.00689	0.999
70%	28.640	1.004	0.00118	0.999

Density

Raw (uncorrected) density data is given in Figure 2, along with the best fit lines. Density parameters are given in Table 4, and the best fit lines are of the form

$$\rho = \alpha + \beta \cdot T \qquad (3)$$

where

ρ = density, g/cc
α, β = constants found by least squares regression
T = temperature, Celsius.

Table 4: Density Parameters
CFC-12/ISO 32 Mineral Oil

Mixture	α	β	Correlation Coefficient
100% Oil	0.9180	-0.0006319	0.999
90%	0.9544	-0.0006785	0.999
80%	0.9911	-0.0007590	0.999
70%	1.0357	-0.0008696	0.999

Corrections to the raw density data are necessary due to the varying solubility and size of the vapor space as the density bulb is thermally cycled, thereby changing the mass of refrigerant in the liquid phase. This is accomplished by using the measured pressure data and the ideal gas law to calculate the amount of refrigerant in the vapor phase and subtracting this from the total charge, thus arriving at the amount in the liquid phase and the true composition. Table 5 gives selected results of these calculations for the (worst case) 70% lubricant mixture; it can be seen that these variations are slight, on the order of a few tenths of one percent, but these data will be taken into account for two-variable modeling to be conducted later in this program.

Figure 2

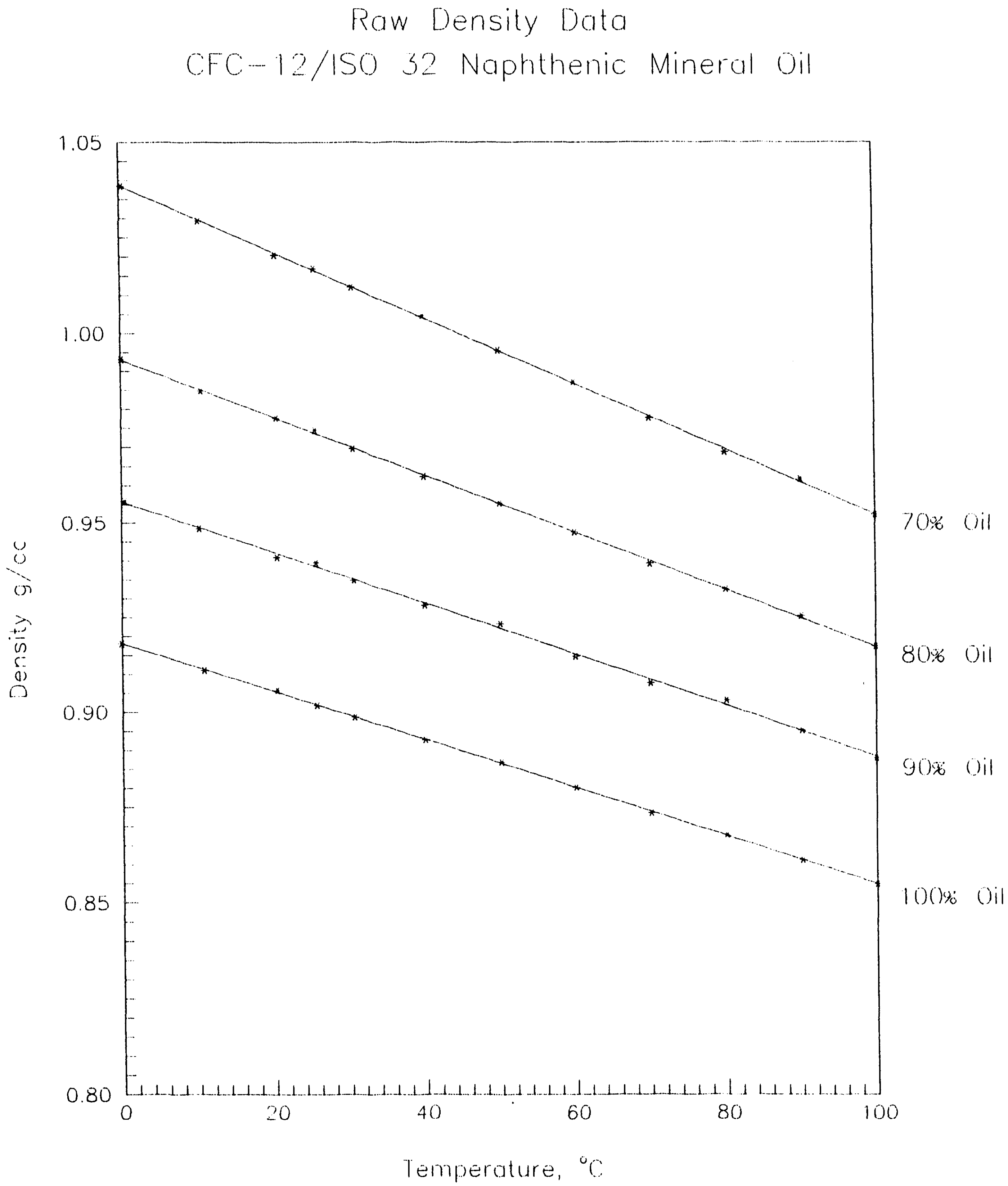

Raw Density Data
CFC-12/ISO 32 Naphthenic Mineral Oil
1.05
1.00
0.95
0.90
0.85
0.80
Density g/cc
0
20
40
60
80
100
Temperature, °C
70% Oil
80% Oil
90% Oil
100% Oil

Table 5: Corrections to Density due to Thermal Cycling
CFC-12/ISO 32 Mineral Oil at 70 Weight Percent Oil

Temperature Celsius	Measured Density, g/cc	Corrected Density, g/cc	True Composition, %Oil
0.5	1.0385	1.0361	70.16
20.4	1.0205	1.0170	70.24
40.0	1.0046	1.0003	70.30
60.0	0.9871	0.9826	70.32
80.0	0.9685	0.9645	70.29
100.0	0.9513	0.9494	70.20

True composition is also calculated for the viscosity and pressure data. Table 6 gives selected results of these calculations for the 70% mixture of CFC-12/ISO 32 mineral oil; these composition variations are also small.

Table 6: Changes in Composition for Viscosity and Pressure due to Thermal Cycling
CFC-12/ISO 32 Mineral Oil at 70 Weight Percent Oil

Temperature Celsius	True Composition, %
0	70.14
25	70.37
50	70.56
75	70.71
100	70.83

The completed Daniel chart is given in Figure 3 and the corrected density in Figure 4. Equations for the kinematic viscosity are derived using the two point method at the extremes of temperature, i.e. 0 and 100 Celsius. Using equations (1) and (3), dynamic viscosity and density are calculated and used to obtain kinematic viscosity, and these two points are used to find A_1 and B_1 in the following:

$$\log\{\log(\nu + 0.7)\} = A_1 + B_1 \cdot \log(T) \tag{4}$$

where

log = logarithm to the base 10
ν = kinematic viscosity, centistokes
A1, B1 = constants
T = temperature, Kelvin

Table 7 gives the values of A_1 and B_1 for each of the mixtures.

Table 7: Kinematic Viscosity Parameters
CFC-12/ISO 32 Mineral Oil

Mixture	A_1	B_1
100 % Oil	12.68940	-5.01745
90%	11.79032	-4.69974
80%	10.83457	-4.36605
70%	9.88175	-4.03093

Figure 3

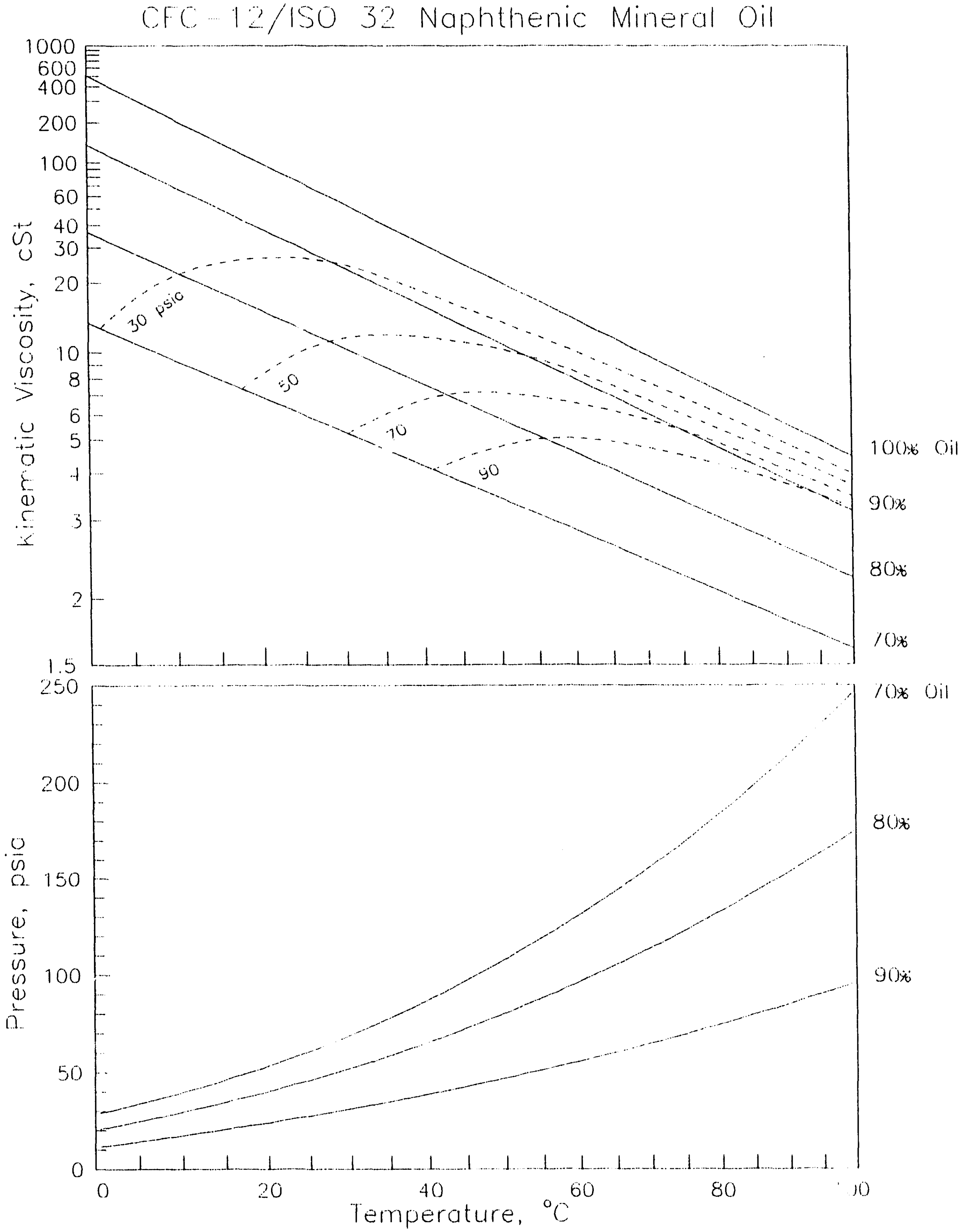
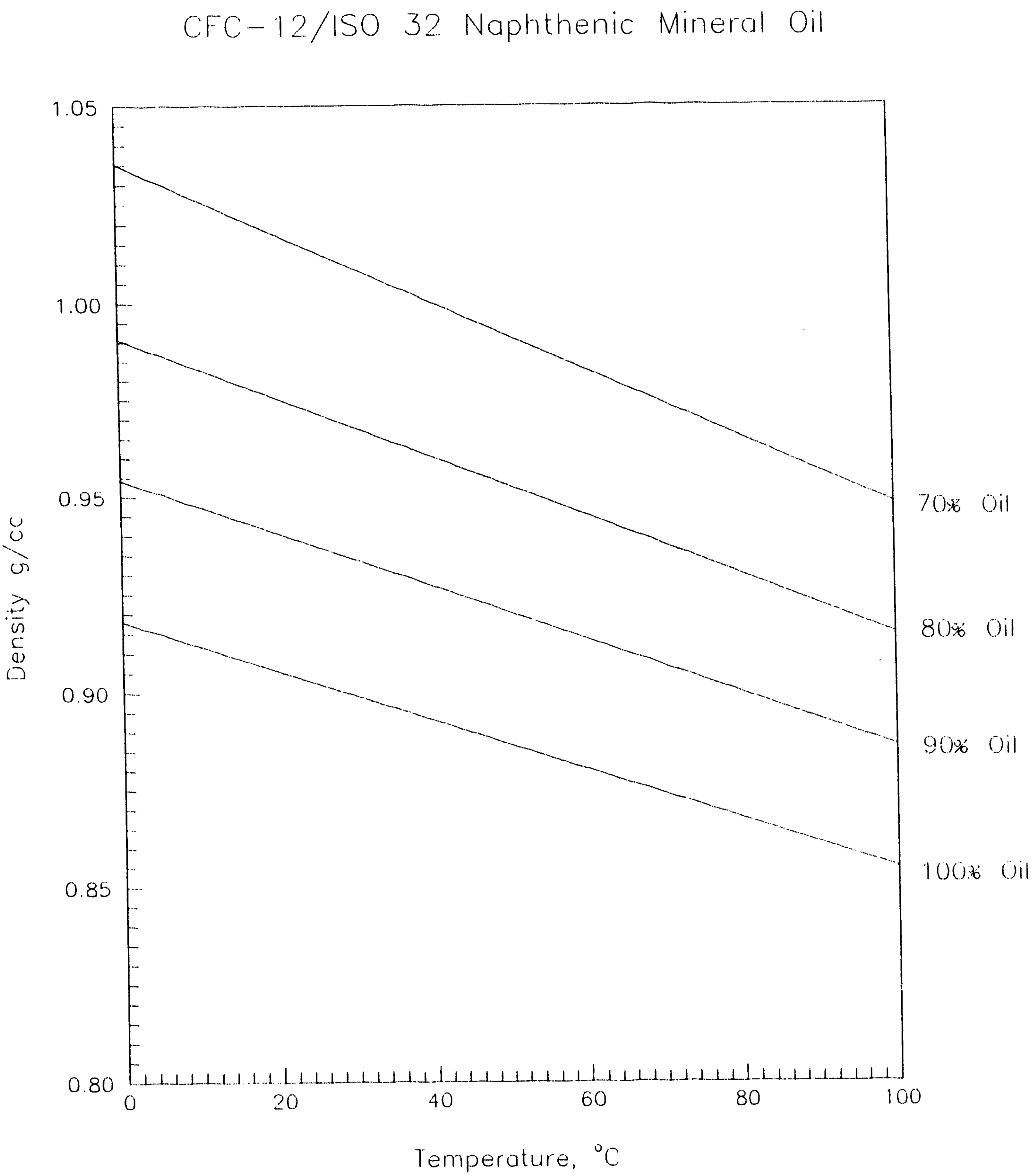

CFC-12/ISO 32 Naphthenic Mineral Oil
Kinematic Viscosity, cSt
1000
600
400
200
100
60
40
30
20
10
8
6
5
4
3
2
1.5
30 psic
50
70
90
100% Oil
90%
80%
70%
Pressure, psic
250
200
150
100
50
0
70% Oil
80%
90%
0
20
40
60
80
Temperature, °C

Figure 4


CFC-12/ISO 32 Naphthenic Mineral Oil
1.05
1.00
0.95
0.90
0.85
0.80
Density g/cc
0
20
40
60
80
100
Temperature, °C
70% Oil
80% Oil
90% Oil
100% Oil

HCFC-22/ISO 32 MINERAL OIL

Measurements and data reduction as described above have been completed for this fluid. Parameters are given in Table 8 and data are plotted in Figures 5 and 6.

Table 8: Solubility, Viscosity and Density Parameters
HCFC-22/ISO 32 Mineral Oil

	70% Oil	80%Oil	90% Oil	100% Oil
Dynamic Viscosity (eq. 1)				
A	9.25145	9.85591	10.69663	11.40495
B	-3.79682	-3.99205	-4.27658	-4.50591
Correlation Coeff.	0.999	0.999	0.999	0.999
Pressure (eq. 2)				
a	56.709	41.773	24.505	----
b	2.243	1.927	1.211	----
c	0.018	0.008	0.002	----
Correlation Coeff.	0.999	0.999	0.944	----
Density (eq. 3)				
a	1.0104	0.9789	0.9487	0.9172
b	-0.00089	-0.00082	-0.00072	-0.00064
Correlation Coeff.	0.998	0.998	0.999	0.999
Kinematic Viscosity (eq. 4)				
A_1	10.03676	10.76249	11.74255	12.70309
B_1	-4.11915	-4.36299	-4.69972	-5.02291

Figure 5

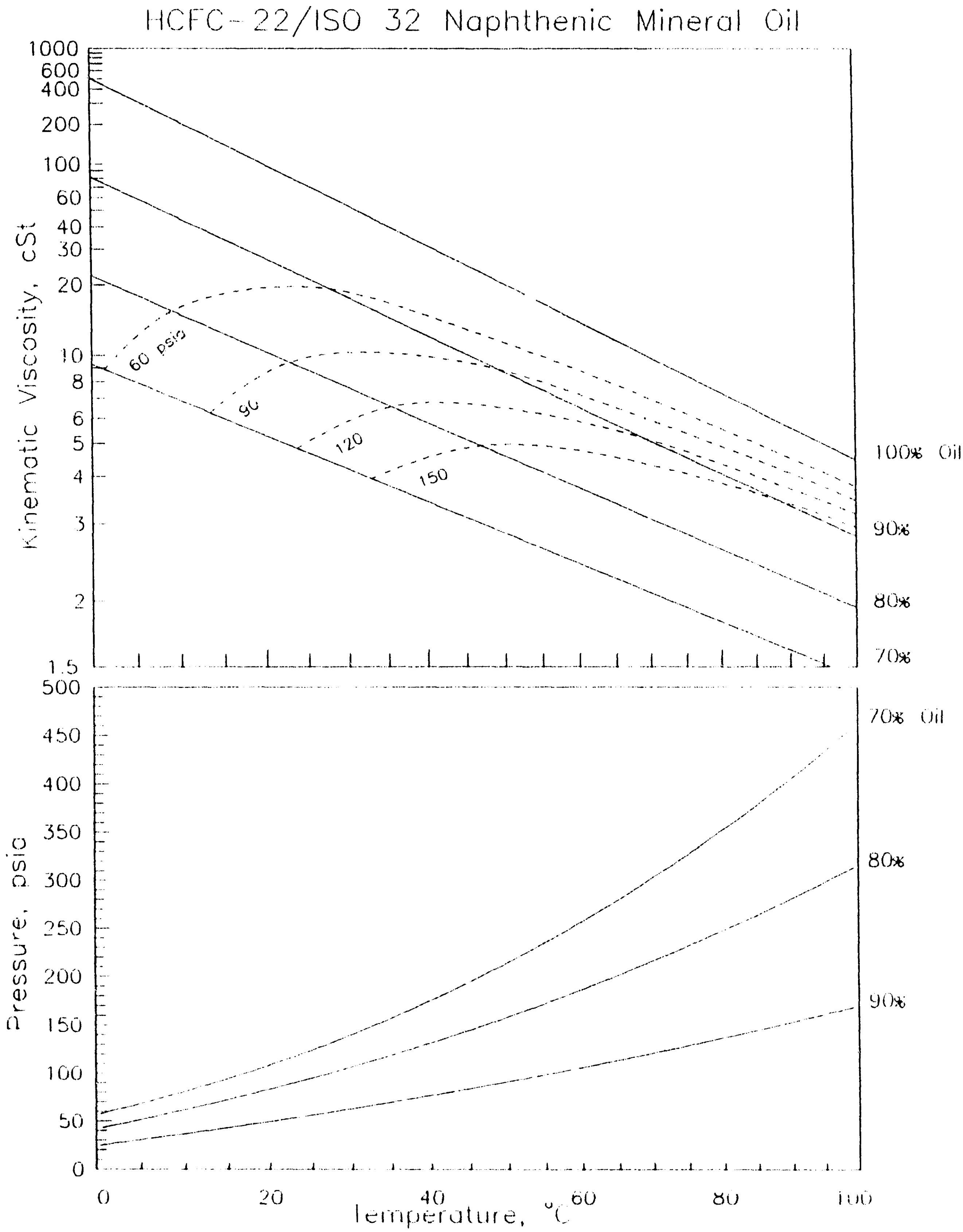
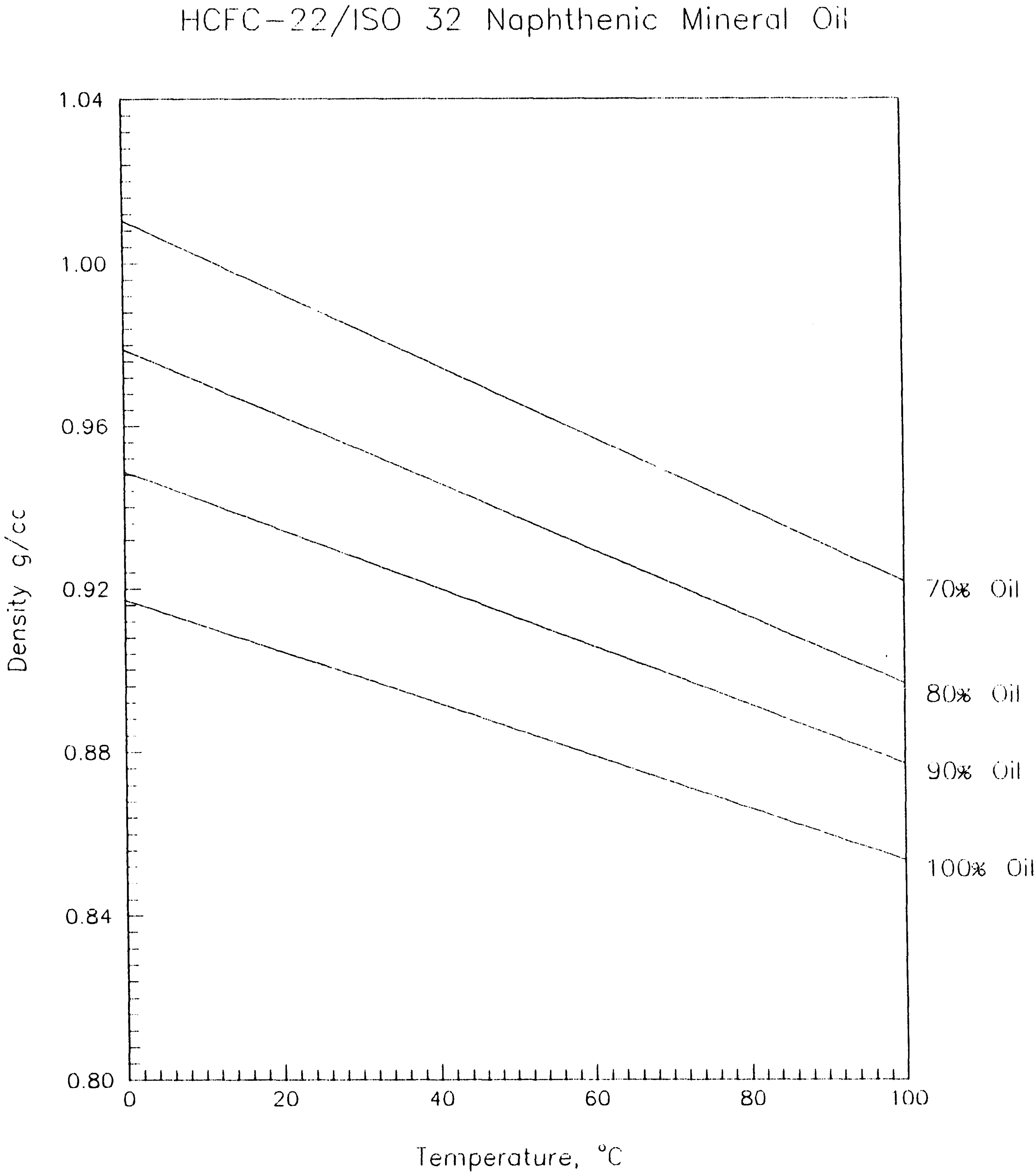

HCFC-22/ISO 32 Naphthenic Mineral Oil
Kinematic Viscosity, cSt
1000
600
400
200
100
60
40
30
20
10
8
6
5
4
3
2
1.5
60 psia
90
120
150
100% Oil
90%
80%
70%
Pressure, psia
500
450
400
350
300
250
200
150
100
50
0
70% Oil
80%
90%
0
20
40
60
80
100
Temperature, °C

Figure 6



HCFC-22/ISO 32 Naphthenic Mineral Oil
Density g/cc
1.04
1.00
0.96
0.92
0.88
0.84
0.80
0
20
40
60
80
100
Temperature, °C
70% Oil
80% Oil
90% Oil
100% Oil

HFC-134a/ISO 32 PENTAERYTHRITOL ESTER MIXED ACID

Parameters are given in Table 9 and data are plotted in Figures 7 and 8.

Table 9: Solubility, Viscosity and Density Parameters
HCFC-22/ISO 32 Mineral Oil

	70% Oil	80%Oil	90% Oil	100% Oil
Dynamic Viscosity (eq. 1)				
A	8.91339	9.16047	9.30485	9.73910
B	-3.63169	-3.63527	-3.70191	-3.83538
Correlation Coeff.	0.999	0.999	0.999	0.999
Pressure (eq. 2)				
a	29.280	20.944	9.771	----
b	1.072	0.935	0.695	----
c	0.020	0.013	0.005	----
Correlation Coeff.	0.999	0.999	0.999	----
Density (eq. 3)				
a	1.0827	1.0552	1.0321	1.0053
b	-0.00098	-0.00086	-0.00081	-0.00075
Correlation Coeff.	0.997	0.982	0.999	0.999
Kinematic Viscosity (eq. 4)				
A_1	8.93787	9.16148	9.33593	9.86662
B_1	-3.64378	-3.68959	-3.71832	-3.88858

Figure 7

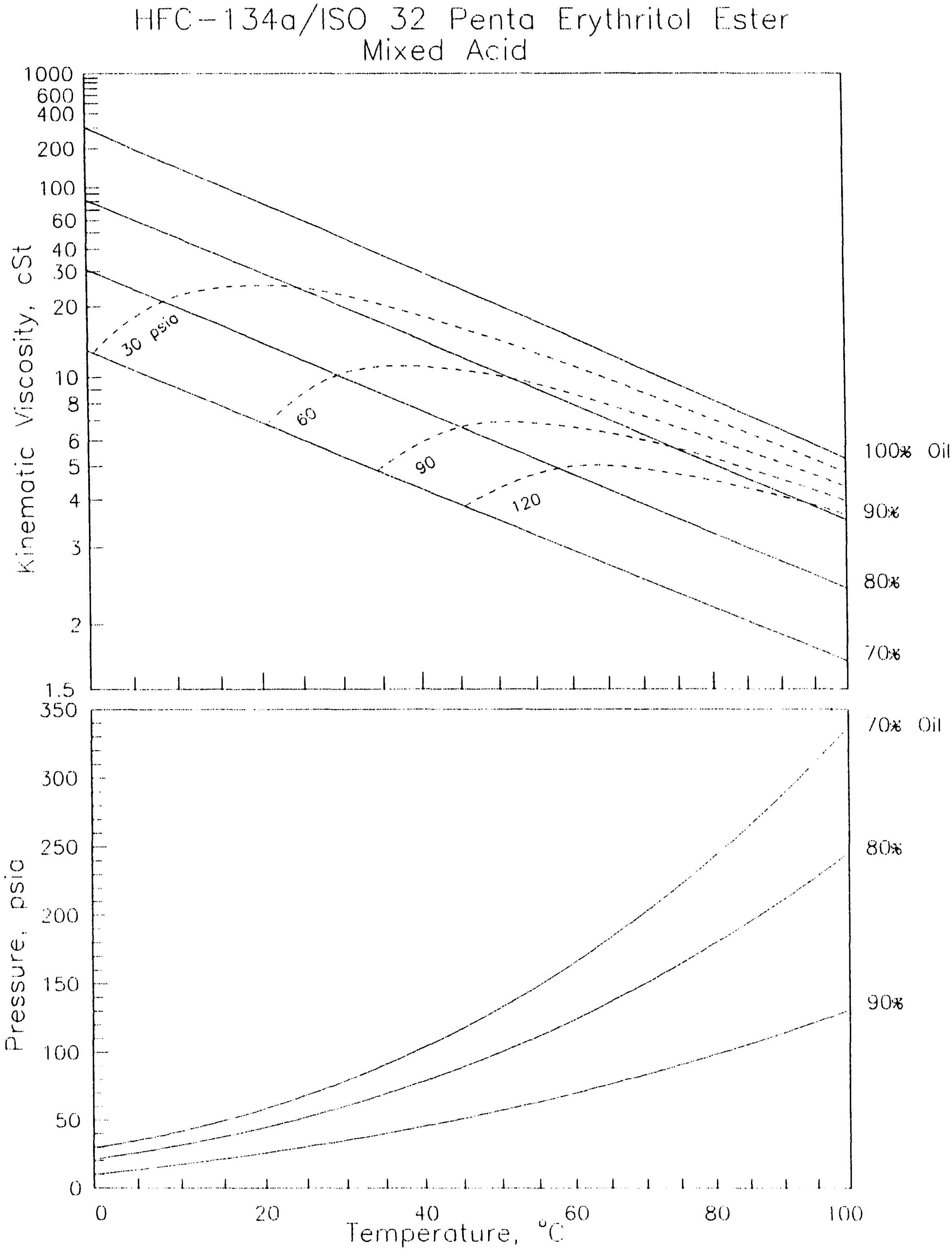
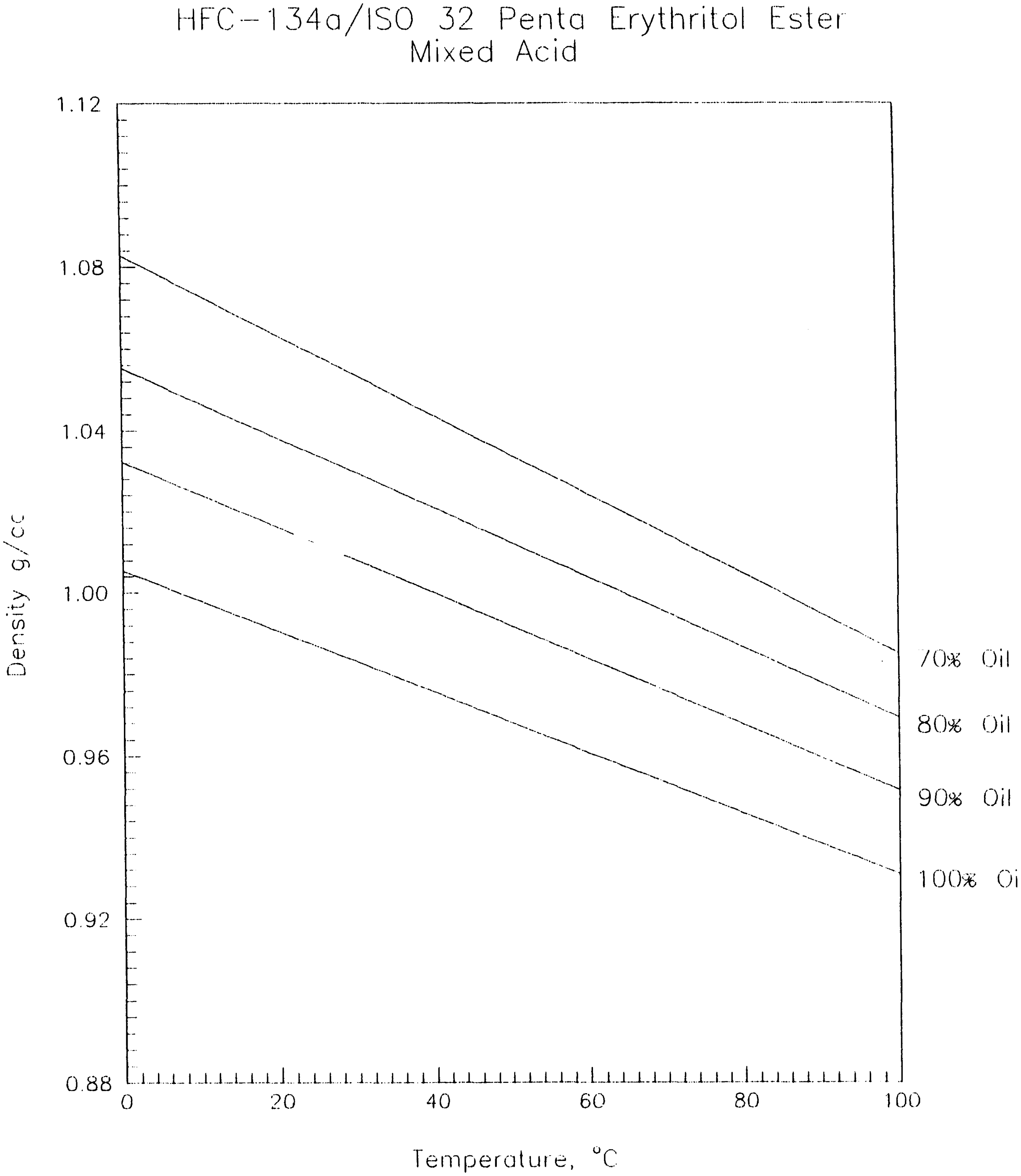

HFC-134a/ISO 32 Penta Erythritol Ester
Mixed Acid
Kinematic Viscosity, cSt
1000
600
400
200
100
60
40
30
20
10
8
6
5
4
3
2
1.5
30 psia
60
90
120
100% Oil
90%
80%
70%
Pressure, psia
350
300
250
200
150
100
50
0
70% Oil
80%
90%
0
20
40
60
80
100
Temperature, °C

Figure 8


HFC-134a/ISO 32 Penta Erythritol Ester
Mixed Acid
Density g/cc
Temperature, °C
1.12
1.08
1.04
1.00
0.96
0.92
0.88
0
20
40
60
80
100
70% Oil
80% Oil
90% Oil
100% Oil

COMPLIANCE WITH AGREEMENT

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

PRINCIPAL INVESTIGATOR EFFORT

During this reporting period, Mr. David R. Henderson directed and/or participated in the following activities:

- Establishment of experimental facilities
- Software development
- Data reduction/mathematical modeling
- Conduction of Technical Oversight Subgroup meeting
- Reporting

APPENDIX A - COMMERCIAL IDENTIFICATION

Lubricants tested are commercially available and are:

ISO 32 mineral oil: Witco Suniso 3GS
ISO 32 pentaerythritol ester mixed acid: Mobil Arctic EAL 32

END

DATE
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