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ANTOINE TYPE EQUATION FOR LIQUID VISCOSITY CORRELATIONS

BY

EDWARD GOLETZ, JR.

A THESIS

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ABSTRACT

A modified Andrade[4] equation, similar to the Antoine equation for vapor pressure-temperature correlations, was developed for liquid viscosity-temperature correlations. Included in the investigation were the following compounds: n-alkanes (C_2-C_{20}), n-alkenes (C_2-C_{20}), n-alkyl benzenes (C_6-C_{10}), n-alkyl cyclohexanes (C_6-C_{22}), and fifteen polar compounds. Except for propene, errors of less than 5% were obtained. Normal heptadecane was used to compare correlations developed by Andrade[4], Walther[20], and Doolittle[9], with the modified Andrade equation. The latter was found to give the best correlations in fitting the data from the boiling point to the freezing point. Extrapolated viscosities from four known points were compared using the modified equation and the conventional method of plotting log of the viscosity against 1/T (absolute temperature). Six compounds were used in this comparison with the modified equation giving significantly better results near the freezing and boiling points. For the modified equation, errors of 0.3 to 7.3% were obtained as compared to errors of 0.4 to 16.7% for the conventional method.

INTRODUCTION

The viscosities of fluids are required in most engineering calculations where fluid flow or mixing is an important factor, such as in the design of reactors, heat exchangers, fractionating towers, cooling towers, and distillation units. Viscosity is defined as the measure of the internal fluid friction, which is a constant of proportionality between the rate of shear and the shear stress.

An enormous number of studies of the temperature variation of viscosity have been conducted, and many empirical equations have been proposed to fit the findings. Summaries of many of the methods are presented by Alexander[1], Collins[6], and Reid and Sherwood[16]. Liquid viscosity is a difficult property to correlate, and to date no entirely satisfactory method has been published for describing the viscosity-temperature dependence of compounds in terms of readily available properties of the compound. The two main reasons that correlations are not satisfactory over the entire liquid range of a compound are as follows:

1. Liquid viscosities exhibit extremely strong temperature dependency. At temperatures near the freezing point, viscosities increase by several orders of magnitude over a small temperature range.
2. Viscosities are also structure dependent, and

therefore are sensitive to bond-type, branching, and isomerism.

Of the many empirical equations proposed by investigators to correlate the viscosity-temperature data, only a few of these equations are widely used at the present time. For liquids, the Andrade[4] equation gives good results except when the freezing and boiling points are approached.

The purpose of this study was to determine if a modified Andrade equation (Antoine type) could be made to fit the viscosity-temperature data of various groups of hydrocarbon and polar compounds over their entire liquid temperature range.

BACKGROUND

Liquid viscosities are sensitive to temperature, and at temperatures near the freezing point, viscosities may increase several orders of magnitude over a small temperature range. At temperatures below the boiling point and above the freezing point, the viscosity-temperature data is well represented[16] by the Andrade equation[2,19,22],

$$n = Ae^{B/T} \text{ or } \ln n = \ln A + B/T \qquad (1)$$

where:

n = viscosity of liquid, absolute

T = absolute temperature

The poise, the absolute unit of viscosity, is defined as the viscosity of a material which requires a shearing force of one dyne per square centimeter to maintain a velocity gradient of one centimeter per second between two planes one centimeter apart. The relation is expressed mathematically as:

$$n = r/(dv/dx) \qquad (2)$$

where:

n = viscosity, absolute

r = shearing force in dynes per square centimeter

dv/dx = velocity gradient perpendicular to the planes in centimeters per second

Two other types of equations often quoted in the literature to represent liquid viscosity-temperature data

are as follows:

1. Equations where volume dependency is introduced such as those presented by Doolittle[8], Sounders[17], and Wright[23].

$$nV^x = Ae^{B/V^yT} \qquad (3)$$

where:

V = molar volume

x,y = values that range from 0 to 1

2. Equations where another unknown constant is introduced to improve the fit to the observed data, such as the equation proposed by Girifalco[11],

$$\log n = C/T^2 + B/T + A \qquad (4)$$

where:

C = about zero except for polar or associated liquids

These equations are resonably accurate except at temperatures near the freezing and boiling points of the compound [9,16].

In addition to the equations quoted in the literature, Perry's[15] "Chemical Engineering Handbook" presents an alignment chart for liquid viscosities. Deviations of actual data from the chart are claimed to be less than 10%, except at extremes of the temperature range. Since the lowest temperature on the chart is -30°C (-20°F), viscosities for many of the compounds near their freezing point are not available. This chart is also limited to

a number of commonly encountered liquids.

Although our knowledge about the viscosity of liquids is mainly empirical[12], it is of interest to consider the equation developed by Eyring and co-workers[5], which permits a rough estimate of viscosity from other physical properities. The equation developed by Eyring is as follows:

$$n = \frac{Nh}{V} e^{\Delta G_o/RT} \tag{5}$$

where:

N = Avogadro's number

V = volume of a mole of liquid

h = Plank's constant

R = molar gas constant

ΔG_o = molar free energy of activation in a stationary fluid

T = absolute temperature

Eyring and co-workers[13] later found that the free energy of activation, ΔG_o, determined by fitting experimental viscosity-temperature data in equation (5), correlated with the internal energy of vaporization, ΔU_{vap}, and is nearly constant for a given fluid. The following correlation is given:

$$\Delta G_o = 0.408\, \Delta U_{vap} \tag{6}$$

By using the empirical information and estimating the energy of vaporization from Trouton's rule[21],

equation (5) becomes:

$$n = \frac{Nh}{V} e^{3.8T_b/T} \qquad (7)$$

where:

T = boiling point, ^oK

This equation, which indicates an exponential decrease in viscosity with temperature, is not highly accurate and errors of as much as 30 percent are common[21]. Since N, h, and V, in equation (7), are constants for a given liquid, this equation is similar to the Andrade equation (1).

The Andrade equation for viscosity-temperature relationships is similar to the commonly used equation for vapor pressure-temperature correlations[19]:

$$\log P = A - B/T \qquad (8)$$

where:

P = vapor pressure

A,B = constants

T = absolute temperature

The Antoine equation[2,19,22], which is extensively used for more accurate vapor pressure-temperature calculations, simply substitutes (t + C) for T in equation (8) giving:

$$\log P = A - B/(t + C) \qquad (9)$$

The optimum value of "C" in the Antoine equation, determined by curve fitting over 300 compounds of a

wide variety of classes, is[2,19]:

$$C = 239 + Zt_{B.P.} \qquad (10)$$

where:

$t_{B.P.}$ = normal boiling point, ^{o}C

$Z = -0.19$

From the excellent fit provided by the Antoine equation for vapor pressure-temperature data, it was decided to try the same type of substitution, i.e., (t + C) for T in the Andrade equation for liquid viscosity-temperature correlations using the same equation (10) to predetermine C. Thus, an Antoine type equation for viscosity-temperature data was developed as follows:

$$\log n = A + B/(t + C) \qquad (11)$$

Comparison of Correlation Methods

As a preliminary study, equation (11) was compared with those reported by Doolittle[9]. Doolittle developed two relationships for n-alkanes as follows:

1. For Molecular Weights Less Than 240

$$\ln v_1 = -4.54\, e^{500/T}\left[-Ei\ (-500/T)\right] - 4.66 + C_1 e^{500/T} \qquad (12)$$

where:

v = viscosity

-Ei (-500/T) = logarithmic integral

C_1 = molecular weight dependent constant

2. For Molecular Weights Greater Than 240

$$\ln v_2 = -3.31 - 25Z\,(1 + 30Z + 30 \cdot 29Z^2 + 30 \cdot 29 \cdot 28Z^3 + \ldots + 30!\, Z^{30}) + C_2\,(27.1Z)^{31}\, e^{1/Z} \quad (13)$$

where:

$$Z = (1/27.1)\,(1 + 127/T)$$

C_2 = molecular weight dependent constant

Doolittle uses n-heptadecane to compare equation (12) with two popular equations for correlating viscosity-temperature data, the Walther equation[16] as follows:

$$\log \log (v + 0.8) = -n \log (T/T_1) + \log \log (v_{T1} + 0.8)\ (1$$

where:

v = kinematic viscosity

T = absolute temperature

and the Andrade equation (1). The Walther equation, a double exponential type, is well known as the basis of the ASTM cross section paper for rectifying viscosity-temperature of lubricating oils. The results of this comparison is shown in Table 1, along with the results obtained by using the Antoine type equation (11). As shown, the Doolittle equation is better than the Walther and Andrade equations, but not as good as the modified Andrade equation -- specifically at temperatures near the freezing point of n-heptadecane. Another important point is that although the Doolittle relationships do reproduce the measured values of n-heptadecane satisfactorily,

TABLE 1

COMPARISON OF OBSERVED VISCOSITIES OF N-HEPTADECANE WITH CALCULATED VALUES

Temperature °K	Viscosity Observed Poise x 10^3	Percent Error			
		Andrade *	Walther **	Doolittle ***	Equation (4) ****
293.2	42.09	-6.2	+2.1	-4.3	-2.3
323.2	21.70	+3.4	0.0	-0.2	+1.1
373.2	10.78	+5.2	-2.7	+0.9	+0.9
423.2	5.984	+1.7	-3.8	-0.1	-0.5
473.2	3.938	-1.1	-2.4	-0.6	-0.9
523.2	2.785	-2.4	+0.6	-0.8	-0.7
573.2	2.030	-0.6	+6.4	+0.8	-1.1

* $\ln n = 1785\ (1/T) - 9.320$

** $\log \log\ (v + 0.8) - 3.6000 \log T + 8.7855$

*** $\ln v_1 = Ae^{500/T} - [Ei\ (-500/T)] - 4.66 + C_1e^{500/T}$

**** $\ln n = -2.947 + 929.1/(181.6 + t)$

the equations are complicated to use, and they are restricted to n-alkanes. These preliminary results encouraged further work. The next objective was to determine if the coefficient of $t_{B.P.}$ in equation (10), which was found to be a good value for vapor pressure-temperature calculations[2,19], was also the best value for viscosity-temperature calculations.

RESULTS AND DISCUSSION

Optimum Value of Z

As discussed earlier, Z = -0.19 was adopted from the Antoine equation for vapor pressure calculations. To determine if this was the best constant for correlating the viscosity-temperature data of randomly selected n-alkanes and other hydrocarbons, the value of C was changed by varying the value of Z in equation (10) from -0.57 to 0.00. By comparing the residual sums of squares between the observed viscosities and the predicted viscosities for different values of C obtained by varying Z, the value of -0.19 was found to give a good overall correlation. These results are listed in Table 2, and are also shown graphically in Figure 1. As shown, some of the sums of squares converge at -0.19, others (benzene, cyclohexane, and decene) decrease toward -0.01. Optimum values of octane and cyclohexane appear to be about -0.40, see Figure 1. However, with this value, compounds such as octadecane and hexadecane would have viscosity errors greater than 10%. Overall, on the basis of the hydrocarbons considered in this study, a value of -0.19 for Z, although not optimum, gives very good results yielding an effective two-parameter Antoine type equation.

Three Parameter Antoine Type Equation

Our next consideration was the behavior of a three

TABLE 2

MINIMUM SUMS OF SQUARES* FOR HYDROCARBON CORRELATIONS

Z VARIED IN EQUATION C = 239 + Z $t_{B.P.}$

	Sums of Squares x 10^3			
Values of Z:	-0.57	-0.38	-0.19	0.00
Compound				
Hexane	4.53	1.26	10.99	28.26
Octane	34.27	2.18	6.94	27.94
Decane	80.43	7.12	4.96	29.34
Dodecane	187.02	14.79	9.95	46.73
Tetradecane	430.90	41.84	6.61	68.96
Hexadecane	--	97.01	9.78	122.98
Octadecane	2580.19	188.00	11.04	177.90
Eicosane	--	252.37	11.95	213.56

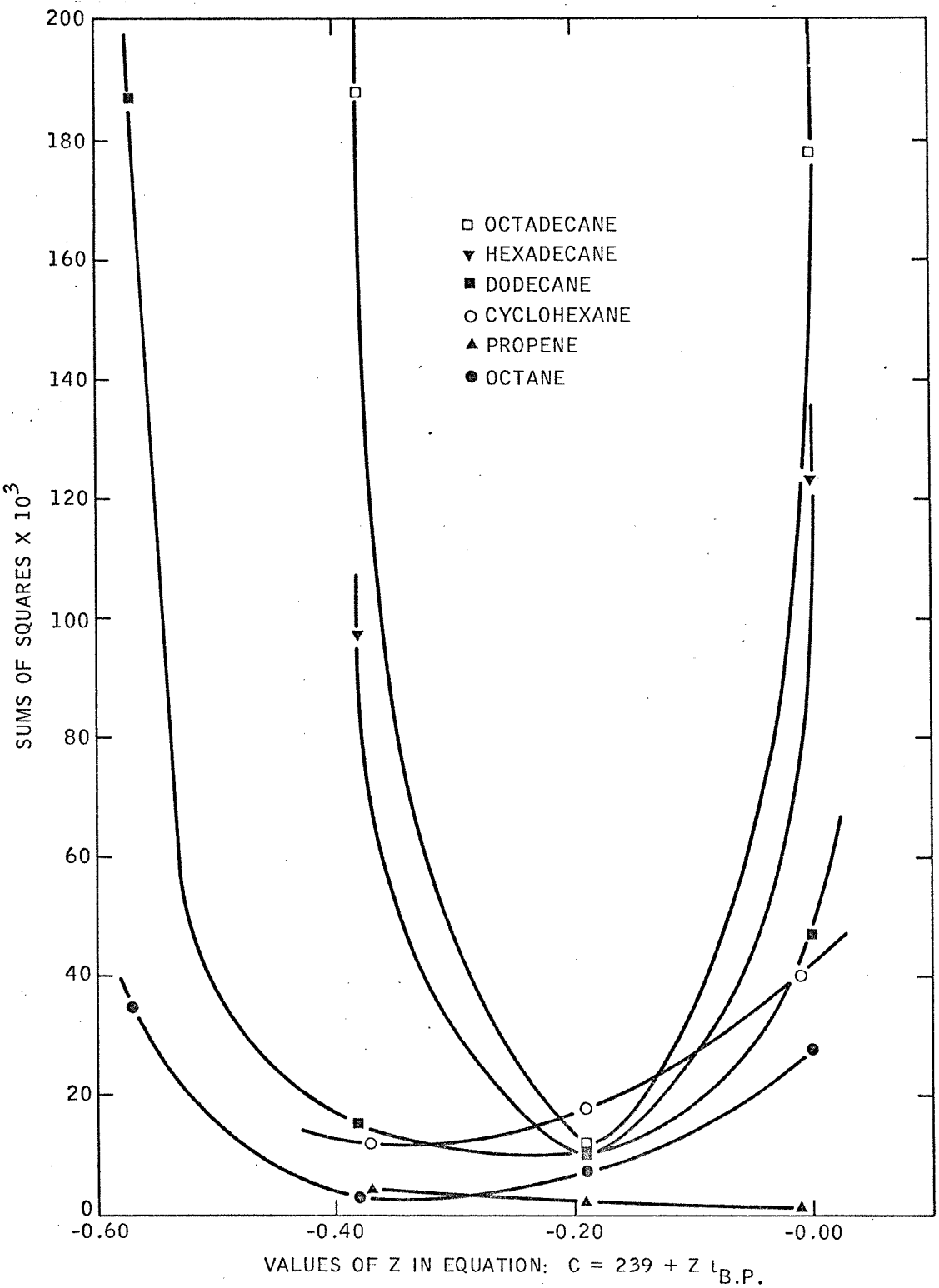
Values of Z:	-0.37	-0.19	-0.01
Benzene	0.04	0.08	0.12
Propene**	4.09	2.26	1.08
Decene	0.93	2.07	3.82
Cyclohexane	11.75	17.75	40.0

* Sums of squares = $\sum_x$(viscosity observed - viscosity calculated)^2, where x is the number of observations.

** Sums of squares not multiplied by 10^3.

Figure 1

BEST VALUE OF Z FOR HYDROCARBONS



parameter Antoine type equation, i.e., where C was not predetermined. The performance of this equation was compared with the two parameter Antoine type equation (11). Kinematic viscosities of n-alkanes (C_2 - C_{20}), published by the American Petroleum Institute's[3] Research Project 44, were used.

A nonlinear least-squares program[10] was run in an IBM 1130 computer to determine the constants in the two and three parameter equations. Twenty data points, where available, were selected from the melting point to the freezing point for each of the normal alkanes as listed in Appendix I. A comparison of the deviations between the observed and calculated viscosities for both the two and three parameter equations, is shown in Table 3. The average percent error for the 370 data points was 0.9% for both methods, with maximum percent errors of 4.1 and 4.7% for the three and two adjustable parameter equations, respectively. Both of these methods gave maximum errors of less than 5%, which is considered an acceptable level for industrial applications.

With the excellent fit found for the n-alkanes, the next step was to determine if other hydrocarbons also fit the two parameter equation, which is obviously easier to use than the three parameter equation.

TABLE 3

CORRELATIONS FOR VISCOSITIES OF LIQUID N-ALKANES

MODIFIED ANDRADE EQUATION - 3 PARAMETERS VERSUS 2 PARAMETERS

Number of Carbon Atoms	Temperature Range of Data, °C	No. of Data Points	Average % Error		Range of Errors	
			3 Parameter	2 Parameter	3 Parameter	2 Parameter
2	-175 to -90	17	0.8	0.9	0.0 to 1.3	0.0 to 2.9
3	-185 to -45	20	0.8	1.1	0.1 to 2.4	0.0 to 2.5
4	-90 to -5	13	0.7	1.1	0.1 to 1.8	0.1 to 2.9
5	-125 to 35	20	0.6	1.4	0.0 to 1.3	0.0 to 4.7
6	-95 to 65	20	0.5	1.0	0.0 to 1.5	0.1 to 2.8
7	-90 to 95	20	0.7	1.7	0.0 to 1.7	0.0 to 4.1
8	-55 to 125	20	0.7	0.9	0.0 to 3.3	0.0 to 3.8
9	-50 to 150	20	0.6	1.0	0.0 to 1.3	0.0 to 2.8
10	-25 to 170	20	0.5	0.6	0.0 to 1.1	0.0 to 1.8
11	-25 to 195	20	0.6	0.9	0.0 to 1.2	0.0 to 2.0
12	-5 to 215	20	0.7	0.7	0.0 to 2.0	0.0 to 2.6
13	-5 to 235	20	1.0	1.0	0.0 to 2.9	0.0 to 3.5
14	10 to 250	20	0.8	0.7	0.1 to 2.2	0.0 to 1.6
15	10 to 270	20	0.9	0.8	0.0 to 2.4	0.1 to 2.0
16	20 to 285	20	0.9	0.7	0.0 to 2.2	0.0 to 1.7
17	25 to 300	20	1.0	0.8	0.2 to 2.2	0.0 to 1.7
18	30 to 315	20	1.8	0.8	0.0 to 3.6	0.0 to 2.5
19	35 to 325	20	1.6	0.8	0.0 to 4.1	0.0 to 2.7
20	40 to 340	20	1.8	0.8	0.1 to 4.0	0.0 to 2.7
	Average % Error for 370 Data Points		0.9	0.9		
				Range of Errors	0.0 to 4.1	0.0 to 4.7

An attempt was made to correlate the constants A, B, and C, listed in Tables 4 and 5, with the carbon number of the n-alkanes. Although the constant B increased as the carbon number increased, constants A and C (in the three parameter equation) did not follow a predictable pattern.

Applications of the Two Parameter Equation

Hydrocarbons

Thus far it has been demonstrated that the two parameter equation (11) works well for correlating the viscosity-temperature data of the n-alkanes. Other homologous series that were used to test the equation are as follows:

Homologous Series	Number of Compounds	Results Summarized in Table
Normal Alkyl Cyclohexanes	17	6
Normal Alkyl Benzenes	5	7
Normal Monolefins	19	8

Except for propene, (maximum error 12%, average error 4%), the largest percent error for the forty-one compounds tested (762 data points) was 4.8%, with an average absolute error of 0.6%. This degree of accuracy is better than any other method found in the literature. A comparison of some of these methods was discussed earlier.

TABLE 4

TWO PARAMETER EQUATION - CONSTANTS FOR n-ALKANES

Normal Alkanes

Carbon No.	A	B	C*
2	-2.626	243.6	255.8
3	-2.507	308.4	247.0
4	-2.639	382.1	239.0
5	-2.681	425.6	232.1
6	-2.756	492.6	225.9
7	-2.877	573.4	220.2
8	-2.902	624.7	215.1
9	-2.970	687.6	210.3
10	-2.978	730.3	205.9
11	-3.023	780.1	201.8
12	-2.999	808.7	197.9
13	-3.013	844.0	194.2
14	-2.985	865.2	190.8
15	-2.986	892.7	187.6
16	-2.962	910.1	184.5
17	-2.947	929.1	181.6
18	-2.936	947.1	178.9
19	-2.902	958.1	176.3
20	-2.898	975.8	173.9

* Calculated from $C = 239 - 0.19\ t_{B.P.}$

TABLE 5

THREE PARAMETER EQUATION - CONSTANTS FOR n-ALKANES

Normal Alkanes

Carbon No.	A	B	C
2	-2.469	208.2	247.4
3	-2.437	292.1	244.3
4	-2.373	288.5	215.0
5	-2.495	363.6	220.1
6	-2.568	422.2	212.4
7	-2.599	465.0	201.6
8	-2.753	556.5	202.7
9	-2.763	590.4	193.8
10	-2.846	662.4	194.2
11	-2.871	700.1	188.7
12	-2.893	749.5	188.0
13	-3.015	844.4	194.1
14	-3.068	914.9	198.6
15	-3.053	932.8	193.6
16	-3.061	971.3	193.8
17	-3.056	998.9	192.1
18	-3.267	1167.9	211.3
19	-3.151	1123.0	200.8
20	-3.217	1194.1	205.9

TABLE 6

CORRELATIONS FOR VISCOSITIES OF LIQUID NORMAL ALKYL CYCLOHEXANES

Number of Carbon Atoms	Temperature Range of Data, °C *	Average % Error	Range of Errors	Constants in Equation (4)		
				A	B	C **
6	10 to 80	0.1	0.0 to 0.2	-3.801	981.39	223.66
7	-25 to 100	0.6	0.1 to 1.6	-3.177	748.21	219.66
8	-25 to 110	0.8	0.2 to 1.9	-2.887	691.92	213.96
9	-25 to 110	1.2	0.0 to 3.8	-2.950	732.59	209.22
10	-20 to 110	1.9	0.1 to 4.8	-2.977	780.68	204.62
11	-10 to 110	1.4	0.0 to 3.4	-3.201	872.82	200.30
12	-10 to 110	1.2	0.0 to 3.3	-3.241	918.64	196.30
13	-10 to 110	1.1	0.0 to 3.1	-3.269	957.05	192.47
14	-10 to 110	1.0	0.0 to 3.1	-3.291	990.45	188.91
15	-10 to 110	0.9	0.0 to 3.4	-3.298	1017.28	185.51
16	0 to 110	0.5	0.0 to 1.5	-3.351	1053.22	182.45
17	10 to 110	0.6	0.0 to 1.4	-3.353	1074.52	179.49
18	15 to 110	0.6	0.0 to 1.3	-3.372	1097.94	176.70
19	20 to 110	0.7	0.0 to 2.3	-3.384	1118.00	174.04
20	25 to 110	0.9	0.0 to 2.1	-3.389	1135.51	171.55
21	30 to 110	1.0	0.0 to 2.5	-3.399	1152.41	169.08
22	35 to 110	1.0	0.0 to 2.7	-3.417	1170.51	166.80

* Twenty data points used where available. See Appendix II for detailed data.

** $C = 239 - 0.19\ t_{B.P.}$

TABLE 7

CORRELATIONS FOR VISCOSITIES OF LIQUID NORMAL ALKYL BENZENES

Number of Carbon Atoms	Temperature Range of Data, °C *	Average % Error	Range of Errors	Constants in Equation (4) A	B	C **
6	10 to 80	0.2	0.0 to 0.7	-3.553	791.39	223.8
7	-25 to 110	0.4	0.0 to 1.4	-2.997	583.74	218.0
8	-25 to 135	0.5	0.0 to 1.5	-2.949	617.00	213.1
9	-25 to 150	1.0	0.0 to 2.4	-3.121	727.81	208.7
10	-25 to 150	0.4	0.0 to 1.6	-3.249	821.30	204.2

* Twenty data points used where available. See Appendix III for detailed data.

** $C = 239 - 0.19\ t_{B.P.}$

TABLE 8

CORRELATIONS FOR VISCOSITIES OF LIQUID NORMAL MONOLEFINS

Number of Carbon Atoms	Temperature Range of Data, °C *	Average % Error	Range of Errors	Constants in Equation (4) A	B	C **
2	-165 to -105	0.6	0.0 to 2.0	-2.988	272.58	258.7
3	-180 to -100	4.0	0.0 to 12.8	-3.120	362.29	247.1
4	-115 to -35	0.2	0.0 to 1.3	-2.741	365.10	240.2
5	-90 to 0	0.1	0.0 to 1.1	-2.778	416.66	233.3
6	-55 to 65	0.4	0.0 to 2.7	-2.912	489.36	226.9
7	0 to 90	0.3	0.0 to 2.1	-2.740	495.71	221.2
8	0 to 115	0.6	0.0 to 2.9	-2.810	564.88	215.9
9	0 to 115	0.5	0.0 to 2.5	-2.899	634.28	211.1
10	0 to 115	0.5	0.0 to 2.7	-2.949	689.28	206.6
11	0 to 115	0.5	0.0 to 3.1	-2.978	735.57	202.4
12	0 to 115	0.8	0.0 to 3.5	-2.997	775.66	198.5
13	0 to 115	0.6	0.0 to 2.2	-3.012	811.98	194.8
14	0 to 115	0.9	0.0 to 4.6	-3.018	843.21	191.3
15	0 to 115	0.9	0.0 to 4.7	-3.018	871.38	188.0
16	5 to 115	0.6	0.0 to 2.5	-2.980	887.50	184.9
17	15 to 115	0.5	0.0 to 1.0	-2.934	900.34	181.9
18	20 to 115	0.3	0.0 to 0.7	-2.920	920.09	179.2
19	25 to 115	0.2	0.0 to 0.7	-2.920	941.34	176.5
20	35 to 115	0.2	0.0 to 0.7	-2.892	954.17	173.9

* Twenty data points used where available. See Appendix IV for detailed data.

** $C = 239 - 0.19\ t_{B.P.}$

Polar Compounds

Although there are correlations that give satisfactory results for hydrocarbons over limited liquid temperature ranges, these methods usually are not successful for correlating viscosity-temperature data of polar compounds[9]. The polar compounds investigated in this study are separated into two groups as follows:

1. Polar compounds where hydrogen bonding is not significant.
2. Polar compounds where hydrogen bonding is significant, such as the alcohols, water, and ethylene glycol.

In the first group, liquid viscosity-temperature data of four nitrile compounds[18,21,23], acetone[21], methylethyl ketone[14,18,21], and chloroform[14,18,21] were investigated. Unlike the hydrocarbons, the viscosities of these compounds were reported in the literature in centipoise and therefore absolute viscosity was correlated with temperature. The results of these correlations are shown in Table 9. The viscosity-temperature correlation for all of these compounds was excellent, having a maximum error of 2.5% and an average error of only 0.7% for the 58 data points investigated.

In the second group, polar compounds investigated where hydrogen bonding is present, the value of Z = -0.19 no longer gives satisfactory correlations. A maximum

TABLE 9

CORRELATIONS FOR VISCOSITIES OF POLAR COMPOUNDS

Compound	Temperature Range of Data, °C *	No. of Data Points	Average % Error	Range of Errors	Constants in Equation (4) A	B	C **
Hydrogen Cyanide	-13.3 to 25	10	0.2	0.0 to 1.0	-4.052	610.39	234.1
Acetonitrile	-20 to 40	6	0.8	0.3 to 1.8	-3.289	550.96	223.5
Propionitrile	0 to 80	8	0.7	0.2 to 1.6	-3.638	672.91	220.5
Caprinitrile	20 to 140	9	0.9	0.0 to 2.5	-3.505	743.33	192.7
Acetone	-80 to 41	12	1.0	0.0 to 2.1	-3.347	554.95	228.4
Methylethyl Ketone	0 to 80	4	0.1	0.0 to 0.3	-3.616	675.49	223.8
Chloroform	-13 to 60	9	0.9	0.0 to 2.4	-3.155	638.44	227.3

* See Appendix V for detailed data.

** $C = 239 - 0.19\ t_{B.P.}$

error of 5% was selected as the criterion for acceptable or satisfactory results. However, by varying the constant Z in equation (10), it was found that a satisfactory correlation could be obtained, giving errors of less than 5%.

Viscosity-temperature data of four alcohols[18,21], were correlated, while the constant Z was varied from +0.53 to -0.55. The residual sums of squares between the observed and calculated viscosities for different values of Z are shown in Table 10. The viscosity-temperature data for the methyl and propyl alcohols correlated well over a wide range of constants; while optimum values for ethyl and butyl alcohols appear to be slightly greater than 0.40 and slightly less than 0.40, respectively. These results are shown in Figure II. A value of 0.40 gives the lowest overall residual sums of squares and also gives correlation errors of less than 5% over the temperature ranges investigated, see Table 11.

For water[3], ethylene glycol[7], and aniline[14,21], also polar compounds with hydrogen bonding, the best value of Z was found to be -1.10, -0.55, and -0.73, respectively, as shown in Table 10. The correlation errors for all of these compounds are also shown in Table 11, and in each case the maximum percent error is less than 5%. From this limited study of polar compounds

TABLE 10

SUMS OF SQUARES* FOR DIFFERENT VALUES OF C = 239 + Z $t_{B.P.}$

Values of Z	Alcohols				Water, x 10^3	Ethylene Gylcol	Aniline
	Methyl	Ethyl	n-Propyl	n-Butyl			
+0.53	---	1.09	0.019	1.15	37.07	--	--
+0.45	0.046	0.78	0.017	0.50	--	--	--
+0.40	0.040	0.82	0.016	0.23	--	--	4.82
+0.35	0.032	1.39	0.015	0.08	33.30	--	--
+0.25	0.021	3.38	0.013	0.24	--	--	--
+0.17	--	6.24	0.011	0.93	29.25	--	4.21
-0.01	--	16.28	0.009	4.99	25.04	65.78	--
-0.19	0.018	40.78	0.008	14.55	20.57	35.20	2.83
-0.37	--	80.38	0.009	33.78	16.03	8.85	2.00
-0.55	--	148.20	--	--	11.43	2.92	1.08
-0.73	--	--	--	--	7.01	75.26	0.23
-0.91	--	--	--	--	3.16	--	0.99
-1.10	--	--	--	--	0.47	--	--
-1.30	--	--	--	--	0.96	--	--
-1.50	--	--	--	--	8.86	--	--

* Sums of squares = $\sum x$ (viscosity observed - viscosity calculated)^2, where x is the number of observations.

TABLE 11

CORRELATIONS FOR VISCOSITIES OF POLAR COMPOUNDS WITH HYDROGEN BONDING

Compound	Temperature Range of Data, °C *	No. of Data Points	Average % Error	Range of Errors	Constants in Equation (4) A	B	C **
Alcohols							
Methyl	-84.2 to 50	11	1.5	0.7 to 2.6	-4.704	1190.83	264.8
Ethyl	-98.1 to 70	16	2.4	0.2 to 5.0	-5.124	1534.63	270.3
n-Propyl	0 to 100	12	1.4	0.4 to 3.3	-6.812	2269.71	277.8
n-Butyl	-50.9 to 100	12	0.7	0.0 to 1.4	-7.169	2528.01	286.2
Others							
Water ***	2 to 95	20	0.3	0.0 to 0.8	-3.631	542.05	129.0
Aniline	5 to 100	15	1.5	0.0 to 4.6	-2.885	545.45	104.7
Ethylene Glycol	4 to 177	19	0.7	0.0 to 3.5	-3.660	1009.01	130.5

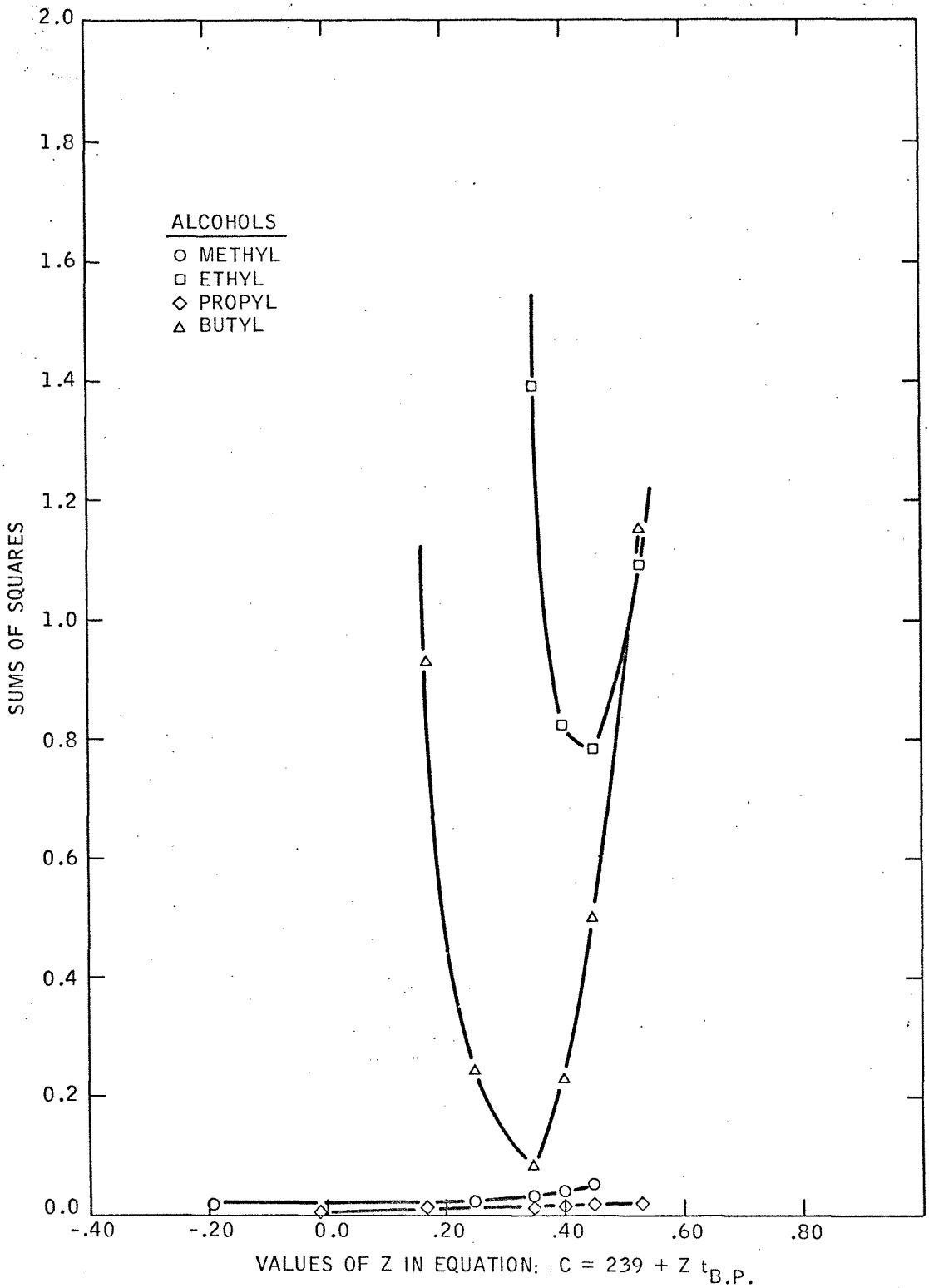
* See Appendix VI for detailed data.

** $C = 239 + Z\ t_{B.P.}$, where Z equals +0.4, -1.1, -0.55, -0.73 for the Alcohols, Water, Ethylene Glycol, and Aniline, respectively.

*** Kinematic viscosity was used for water. Viscosities of all other compounds are in absolute viscosity.

Figure 2

BEST VALUE OF Z FOR ALCOHOLS



with hydrogen bonding, it appears possible to find a constant Z in equation (10) that gives a good correlation over the entire liquid-temperature range of each individual compound. However, there does not appear to be a universal constant for all polar compounds where hydrogen bonding is present.

Although the value of -0.19 for Z did not give correlations with less than 5% maximum error for all polar compounds with hydrogen bonding, it did give better overall results than the conventional method of using C = 273. Table 12 shows that except for ethyl and n-butyl alcohols, the other five compounds had equivalent or lower errors using a value of -0.19 for Z in the Antoine type equation.

TABLE 12

POLAR COMPOUNDS WITH HYDROGEN BONDING

Compound	Andrade Equation		Antoine Type Equation*	
	Sums of Squares**	Maximum Error	Sums of Squares**	Maximum Error
Methyl Alcohol	0.520	3.0	0.018	4.5
Ethyl Alcohol	0.80	5.0	40.78	17.3
n-Propyl Alcohol	0.015	3.3	0.008	2.9
n-Butyl Alcohol	0.16	2.0	14.55	10.4
Water	33.10	6.6	20.57	4.8
Ethylene Glycol	110.0	18.4	35.2	11.0
Aniline	4.90	17.6	2.83	14.6

* $C = 239 - 0.19\ t_{B.P.}$

** Sums of Squares = $\sum x$ (viscosity observed - viscosity calculated)^2, where x is the number of observations.

Extrapolation of Viscosities Using the Antoine Type Equation

Plotting the log viscosity against 1/T (absolute temperature), the data is almost always curved. This means that extrapolation from several points, a method that is frequently used when only several points are available, can produce errors of significant magnitudes. Obviously a more desirable correlation method would be one where a straight line is obtained. To be practical, the value of C must first be easily determined for each compound, as in the two parameter equation (11). A comparison of the percent errors observed using 1/T (absolute temperature) and 1/(t + C) for eight compounds is shown in Table 13. In this part of the study, all of the available viscosity-temperature data, between the melting and boiling points, was used to compare the two methods. The average percent error and range of errors were lower in every case for the value of C calculated from the boiling point of the liquid. The average percent error for the 131 data points was reduced from 2.1% to 0.7% (67% reduction), and the range of errors was reduced from 0.0% - 8.2% to 0.0% - 4.8% (41% reduction in maximum percent error).

In the second part, four viscosity-temperature data points were randomly selected approximately mid-range between the melting point and boiling point. The constants

TABLE 13

COMPARISON OF C = 273 VERSUS C = 239 - 0.19 $t_{B.P.}$

Compound	No. of Data Points	Temp. Range of Data Points, °C	Value of C	Average % Error	Range of Errors
n-Decane	20	-25 to 170	273.0	2.7	0.2 to 6.5
			205.9	0.6	0.0 to 1.8
n-Tetradecane	20	10 to 250	273.0	3.1	0.4 to 7.0
			190.8	0.7	0.2 to 1.6
n-Octadecane	20	30 to 315	273.0	4.0	0.1 to 8.2
			178.9	0.8	0.0 to 2.5
1-Decene	20	0 to 115	273.0	1.3	0.0 to 4.4
			206.6	0.5	0.0 to 2.7
n-Butylcyclohexane	20	-20 to 110	273.0	3.3	0.0 to 7.8
			204.6	1.9	0.1 to 4.8
Benzene	15	10 to 80	273.0	0.6	0.0 to 1.3
			223.8	0.2	0.0 to 0.7
Acetone	12	-80 to 41	273.0	1.6	0.3 to 3.8
			228.4	1.0	0.0 to 2.1
Methylethyl Ketone	4	0 to 80	273.0	0.4	0.2 to 0.6
			223.8	0.1	0.0 to 0.3

A and B were then calculated using:

1. Equation (11), with $C = 239 - 0.19t_{B.P.}$
2. Andrade equation (1), with $C = 273$

Temperatures were then selected near the freezing and boiling points of the compounds, and the corresponding viscosities were determined. Tables 14-19 give the results of the correlation errors using the following compounds: n-decane, n-tetradecane, n-octadecane, n-butylcyclohexane, acetone, and 1-decene, respectively. As shown, using the Andrade equation, errors were obtained that range from 0.4 to 16.7%, with 14 out of 30 cases exceeding 5% error. In contrast, using the Antoine type equation, errors were obtained that range from 0.3% to only 7.3% with only two cases exceeding 5% error. Therefore, the Antoine type equation provides a more accurate method of extrapolating from several known points.

TABLE 14

COMPARISON OF EXTRAPOLATED VISCOSITIES FOR N-DECANE

Temperature, °C	Viscosity Observed, cSt	C = 273 Viscosity Predicted, cSt	C = 273 % Error	C = 205.9 Viscosity Predicted, cSt	C = 205.9 % Error
-25	2.936	2.715	7.5	2.889	1.6
-20	2.612	2.469	5.5	2.590	0.8
-10	2.111	2.064	2.2	2.118	0.3
130	0.4502	0.4276	5.0	0.4450	1.1
170	0.3543	0.3274	7.6	0.3527	0.4

Temperature Range Used to Determine Constants A and B (0 to 90°C).

Constants:	A	B	C
	-3.807	1191.83	273.0
	-2.993	733.40	205.9

TABLE 15

COMPARISON OF EXTRAPOLATED VISCOSITIES FOR N-TETRADECANE

Temperature, °C	Viscosity Observed, cSt	C = 273 Viscosity Predicted, cSt	C = 273 % Error	C = 190.8 Viscosity Predicted, cSt	C = 190.8 % Error
10	3.819	3.181	16.7	3.638	4.7
15	3.414	2.926	14.3	3.276	4.0
40	2.124	2.004	5.6	2.099	1.4
200	0.4662	0.4586	1.6	0.4687	0.5
230	0.3941	0.3861	2.0	0.4017	1.9

Temperature Range Used to Determine Constants A and B (70 to 170°C).

Constants: A	B	C
-3.664	1364.54	273.0
-2.920	845.28	190.8

TABLE 16

COMPARISON OF EXTRAPOLATED VISCOSITIES FOR N-OCTADECANE

Temperature, °C	Viscosity Observed, cSt	C = 273 Viscosity Predicted, cSt	C = 273 % Error	C = 178.9 Viscosity Predicted, cSt	C = 178.9 % Error
35	4.481	3.800	15.2	4.279	4.5
50	3.304	3.003	9.1	3.226	2.3
240	0.517	0.501	3.1	0.520	0.6
300	0.38	0.364	4.2	0.394	3.7
315	0.36	0.339	5.8	0.372	3.3

Temperature Range Used to Determine Constants A and B (90 to 190°C).

Constants: A	B	C
-3.736	1562.12	273.0
-2.853	921.26	178.9

TABLE 17

COMPARISON OF EXTRAPOLATED VISCOSITIES OF N-BUTYLCYCLOHEXANE

Temperature, °C	Viscosity Observed, cSt	C = 273 Viscosity Predicted, cSt	C = 273 % Error	C = 204.6 Viscosity Predicted, cSt	C = 204.6 % Error
-20	3.54	3.26	7.9	3.44	2.8
0	2.33	2.23	4.3	2.27	2.6
80	0.79	0.759	3.9	0.772	2.3
100	0.69	0.622	9.8	0.644	6.6
110	0.64	0.568	11.2	0.593	7.3

Temperature Used to Determine Constants A and B (15 to 55°C).

Constants:	A	B	C
	-3.963	1301.55	273.0
	-3.018	785.52	204.6

TABLE 18

COMPARISON OF EXTRAPOLATED VISCOSITIES OF ACETONE

Temperature, °C	Viscosity Observed, cSt	C = 273 Viscosity Predicted, cSt	C = 273 % Error	C = 228.4 Viscosity Predicted, cSt	C = 228.4 % Error
-80.0	1.487	1.386	8.7	1.432	3.7
-59.6	0.932	0.913	2.0	0.926	0.6
0.0	0.399	0.402	0.7	0.405	1.5
25.0	0.316	0.3148	0.4	0.3217	1.8
41.0	0.280	0.2745	1.9	0.2838	1.3

Temperature Range Used to Determine Constants A and B (-42.5 to -13.0°C)

Constants: A	B	C
-3.842	800.76	273.0
-3.244	534.84	228.4

TABLE 19

COMPARISON OF EXTRAPOLATED VISCOSITIES OF 1-DECENE

Temperature, °C	Viscosity Observed, cSt	C = 273 Viscosity Predicted, cSt	C = 273 % Error	C = 206.6 Viscosity Predicted, cSt	C = 206.6 % Error
0	1.490	1.433	3.8	1.458	2.1
5	1.370	1.333	2.7	1.348	1.6
10	1.258	1.242	1.3	1.251	0.5
85	0.560	0.548	2.1	0.556	0.7
105	0.480	0.466	2.9	0.478	0.4

Temperature Range Used to Determine Constants A and B (20 to 60°C).

Constants: A	B	C
-3.685	1104.58	273.0
-2.928	682.90	206.6

CONCLUSIONS AND RECOMMENDATIONS

The modified Andrade equation (11) accurately correlates the viscosity-temperature data over the entire liquid-temperature range of hydrocarbons. This is accomplished by letting $C = 239 - 0.19\ t_{B.P.}$, as suggested by the Antoine equation (9), where $t_{B.P.}$ is the boiling point of the compound in degrees centigrade. Maximum errors of less than 5% were obtained, except for propene (maximum error 12%).

This method works equally well for polar compounds where hydrogen bonding is not a significant factor. When hydrogen bonding is a factor, values other than -0.19, in the above equation, are required to obtain correlations that give less than 5% error. For alcohols, water, ethylene glycol, and aniline, values of 0.40, -1.10, -0.55, and -0.73, respectively, were found to give good correlations. Nevertheless, five of the seven polar compounds investigated with hydrogen bonding gave either equivalent or better correlations using $C = 239 - 0.19\ t_{B.P.}$ than the Andrade equation.

The modified Andrade equation was compared with correlations developed by Andrade (1), Walther (14), and Doolittle (12) for correlating viscosity-temperature data of n-heptadecane. The modified Andrade equation demonstrated the best accuracy near the freezing point of the compound.

An added advantage of equation (11) over most methods for correlating viscosity-temperature data is that it is not complicated to use.

When the log of the viscosity is plotted against $1/(t + C)$ with $C = 239 - 0.19\ t_{B.P.}$, significantly better extrapolated viscosities are obtained than by using the conventional method of plotting log of the viscosity against $1/T$ (absolute temperature). Increased accuracy was noted at both the freezing and boiling points of the compounds investigated. The maximum error obtained was 7.3% as compared to 16.7% for the conventional method.

Attempts to correlate the constants A and B in equation (11) with the carbon number of the n-alkanes were not successful.

Future work could most effectively be used to determine if the modified Andrade equation is effective over a broader range of compounds, including mixtures. Since it was found that setting C equal to $239 - 0.19\ t_{B.P.}$ in equation (11) gives good correlations, but not necessarily optimum correlations for all compounds, perhaps a better constant could be found by changing either one or both of the numerical values of 239 and -0.19. Another possibility is to use another form of the constant C where some physical property of the compound, such as molecular

weight, is incorporated.

APPENDIX I

TABLES OF N-ALKANES

CORRELATION ERRORS USING TWO AND THREE PARAMETER MODIFIED ANDRADE EQUATIONS

ETHANE

Boiling Point, -88.63°C
Melting Point, -183.27°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-175	1.52	1.50	1.47	1.3	2.9
-170	1.25	1.24	1.24	0.8	0.8
-165	1.05	1.06	1.06	0.9	0.9
-160	0.907	0.917	0.919	1.1	1.3
-155	0.796	0.806	0.810	1.2	1.7
-150	0.711	0.718	0.723	1.0	1.7
-145	0.643	0.646	0.651	0.5	1.2
-140	0.588	0.588	0.593	0.0	0.8
-135	0.542	0.539	0.543	0.6	0.2
-130	0.504	0.499	0.501	1.0	0.6
-125	0.469	0.464	0.466	1.1	0.6
-120	0.438	0.434	0.435	0.9	0.7
-110	0.387	0.385	0.384	0.5	0.6
-105	0.365	0.365	0.364	0.0	0.3
-100	0.348	0.347	0.345	0.3	0.7
-95	0.330	0.332	0.329	0.6	0.3
-90	0.314	0.318	0.314	1.3	0.0
			Average % Error	0.8	0.9
			Range	0.0 to 1.3	0.0 to 2.9

PROPANE

Boiling Point, -42.07°C
Melting Point, -187.69°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-185	12.1	12.0	11.8	0.8	2.5
-180	8.24	8.21	8.14	0.3	1.2
-175	5.93	5.92	5.91	0.1	0.3
-165	3.46	3.48	3.50	0.6	1.1
-160	2.78	2.80	2.82	0.7	1.4
-155	2.28	2.30	2.33	0.9	2.2
-150	1.92	1.93	1.96	0.5	2.1
-140	1.435	1.438	1.455	0.2	1.0
-125	1.015	0.011	1.021	0.4	0.6
-110	0.778	0.770	0.774	1.0	0.5
-100	0.671	0.662	0.664	1.3	1.0
-90	0.590	0.581	0.581	1.5	1.5
-80	0.524	0.517	0.517	1.3	1.3
-75	0.496	0.491	0.490	1.0	1.2
-70	0.470	0.467	0.465	0.6	1.0
-65	0.447	0.446	0.443	0.2	0.9
-60	0.425	0.427	0.424	0.5	0.2
-55	0.406	0.409	0.406	0.7	0.0
-50	0.387	0.393	0.390	1.5	0.8
-45	0.370	0.379	0.375	2.4	1.3
			Average % Error	0.8	1.1
			Range	0.1 to 2.4	0.0 to 2.5

n-BUTANE

Boiling Point, -0.50°C
Melting Point, -138.35°C

Temperature, °C	Viscosity, Centistokes				
		Predicted		Predicted Error	
	Observed	3 Parameter	2 Parameter	3 Parameter	2 Parameter
-90	0.910	0.937	0.927	1.8	2.9
-80	0.790	0.789	0.789	0.1	0.1
-70	0.689	0.681	0.684	0.7	1.1
-60	0.609	0.599	0.603	1.0	1.6
-50	0.545	0.535	0.539	1.1	1.8
-40	0.491	0.484	0.487	0.8	1.4
-35	0.468	0.463	0.464	0.8	1.0
-30	0.446	0.443	0.444	0.4	0.7
-25	0.426	0.425	0.425	0.2	0.2
-20	0.407	0.409	0.408	0.2	0.5
-15	0.390	0.394	0.393	0.7	1.0
-10	0.375	0.380	0.378	0.8	1.3
-5	0.362	0.368	0.365	0.8	1.6
			Average % Error	0.7	1.1
			Range	0.1 to 1.8	0.1 to 2.9

n-PENTANE

Boiling Point, 36.07°C
Melting Point, -129.72°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-125	3.82	3.77	3.64	1.3	4.7
-120	3.12	3.11	3.05	0.3	2.2
-115	2.62	2.62	2.59	0.0	1.1
-110	2.23	2.24	2.23	0.4	0.0
-105	1.93	1.94	1.95	0.5	1.0
-100	1.69	1.70	1.71	0.6	1.2
-95	1.49	1.51	1.52	1.3	2.0
-90	1.341	1.348	1.368	0.5	2.0
-85	1.211	1.216	1.236	0.4	2.0
-80	1.103	1.104	1.124	0.1	1.9
-70	0.930	0.929	0.945	0.1	1.6
-60	0.803	0.799	0.812	0.5	1.1
-45	0.663	0.657	0.666	0.9	0.4
-30	0.565	0.558	0.562	1.2	1.2
-10	0.469	0.465	0.465	0.8	0.8
0	0.432	0.427	0.425	1.1	1.6
10	0.401	0.400	0.397	0.2	1.0
20	0.375	0.375	0.370	0.0	1.3
30	0.351	0.353	0.347	0.5	1.1
35	0.339	0.343	0.337	1.2	0.6
			Average % Error	0.6	1.4
			Range	0.0 to 1.3	0.0 to 4.7

n-HEXANE

Boiling Point, 68.74°C
Melting Point, -95.34°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-95	2.82	2.79	2.74	1.0	2.8
-90	2.43	2.41	2.38	0.8	2.0
-85	2.11	2.11	2.10	0.0	0.5
-80	1.85	1.86	1.86	0.5	0.5
-75	1.65	1.65	1.66	0.0	0.6
-70	1.48	1.49	1.50	0.7	1.3
-65	1.335	1.344	1.357	0.7	1.6
-60	1.219	1.224	1.237	0.4	1.5
-50	1.029	1.032	1.045	0.3	1.5
-40	0.888	0.888	0.899	0.0	1.2
-30	0.778	0.776	0.785	0.2	0.9
-20	0.691	0.688	0.695	0.4	0.6
-10	0.621	0.617	0.622	0.6	0.1
0	0.5629	0.5545	0.5569	1.5	1.0
10	0.5144	0.5118	0.5126	0.5	0.3
20	0.4741	0.4716	0.4709	0.5	0.7
40	0.4085	0.4084	0.4050	0.0	0.8
50	0.3817	0.3832	0.3787	0.4	1.8
60	0.3577	0.3612	0.3558	1.0	0.5
65	0.3465	0.3512	0.3454	1.3	0.3
			Average % Error	0.5	1.0
			Range	0.0 to 1.5	0.1 to 2.8

n-HEPTANE

Boiling Point, 98.43°C
Melting Point, -90.61°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-90	4.87	4.79	4.67	1.6	4.1
-85	4.04	4.01	3.91	0.7	3.2
-80	3.41	3.40	3.36	0.3	1.4
-75	2.91	2.93	2.91	0.7	0.0
-70	2.53	2.54	2.56	0.4	1.2
-65	2.221	2.237	2.263	0.7	1.9
-60	1.968	1.983	2.017	0.7	2.5
-55	1.752	1.773	1.810	1.2	3.3
-40	1.315	1.321	1.355	0.4	3.0
-30	1.116	1.117	1.146	0.1	2.7
-20	0.9639	0.9623	0.9866	0.2	2.3
0	0.7511	0.7380	0.7517	1.7	0.1
10	0.6743	0.6693	0.6792	0.7	0.7
20	0.6114	0.6061	0.6123	0.8	0.1
40	0.5137	0.5095	0.5096	0.8	0.8
60	0.4416	0.4398	0.4354	0.4	1.4
70	0.4118	0.4119	0.4058	0.0	1.4
80	0.3857	0.3876	0.3799	0.5	1.5
90	0.3624	0.3663	0.3572	1.1	1.4
95	0.3515	0.3565	0.3469	1.4	1.3
			Average % Error	0.7	1.7
			Range	0.0 to 1.7	0.0 to 4.1

n-OCTANE

Boiling Point, 125.66°C
Melting Point, -56.79°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-55	2.78	2.75	2.72	1.1	2.1
-50	2.45	2.43	2.41	0.8	1.6
-45	2.17	2.17	2.16	0.0	0.4
-40	1.94	1.95	1.94	0.5	0.0
-35	1.75	1.76	1.76	0.6	0.6
-30	1.592	1.598	1.603	0.4	0.7
-25	1.453	1.459	1.467	0.4	0.9
-20	1.334	1.339	1.348	0.4	1.1
-10	1.140	1.143	1.153	0.2	1.1
0	0.9911	0.9786	0.9882	1.2	0.3
10	0.8729	0.8718	0.8803	0.1	0.8
30	0.7005	0.6963	0.7019	0.6	0.2
50	0.5577	0.5762	0.5791	3.3	3.8
60	0.5353	0.5299	0.5316	1.0	0.7
70	0.4950	0.4903	0.4908	0.9	0.8
80	0.4602	0.4562	0.4557	0.9	1.0
100	0.4022	0.4005	0.4984	0.4	0.9
110	0.3779	0.3777	0.3748	0.0	0.8
120	0.3560	0.3574	0.3539	0.4	0.6
125	0.3457	0.3481	0.4444	0.7	0.4
			Average % Error	0.7	0.9
			Range	0.0 to 3.3	0.0 to 3.8

n-NONANE

Boiling Point, 150.79°C
Melting Point, -53.52°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-50	3.87	3.83	3.74	1.3	2.8
-45	3.36	3.34	3.29	0.6	2.1
-40	2.93	2.93	2.91	0.0	0.7
-35	2.59	2.60	2.59	0.4	0.0
-30	2.309	2.321	2.324	0.5	0.6
-25	2.073	2.086	2.097	0.6	1.1
-20	1.872	1.886	1.902	0.7	1.6
-10	1.557	1.567	1.588	0.6	2.0
0	1.321	1.307	1.328	1.0	0.5
10	1.140	1.143	1.163	0.2	2.0
20	0.9978	0.9987	1.015	0.3	0.4
40	0.7921	0.7885	0.8001	0.4	1.0
60	0.6515	0.6462	0.6529	0.8	0.2
80	0.5502	0.5452	0.5480	0.9	0.4
100	0.4743	0.4707	0.4704	0.7	0.8
110	0.4430	0.4406	0.4389	0.5	0.9
120	0.4151	0.4141	0.4113	0.2	0.9
130	0.3900	0.3907	0.3869	0.2	0.8
140	0.3675	0.3700	0.3652	0.7	0.6
150	0.3473	0.3514	0.3459	1.2	0.4
			Average % Error	0.6	1.0
			Range	0.0 to 1.3	0.0 to 2.8

n-DECANE

Boiling Point, 174.12°C
Melting Point, -29.66°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-25	2.936	2.913	2.882	0.8	1.8
-20	2.612	2.604	2.586	0.3	1.0
-15	2.340	2.341	2.333	0.0	0.3
-10	2.111	2.118	2.116	0.3	0.2
-5	1.917	1.926	1.928	0.4	0.6
0	1.749	1.729	1.735	1.1	0.8
10	1.479	1.489	1.498	0.7	1.3
20	1.272	1.279	1.289	0.6	1.3
30	1.110	1.114	1.124	0.4	1.3
40	0.9806	0.9826	0.9916	0.2	0.1
60	0.7886	0.7865	0.7931	0.2	0.6
80	0.6544	0.6503	0.6545	0.6	0.0
90	0.6017	0.5973	0.6003	0.7	0.2
100	0.5561	0.5518	0.5538	0.8	0.4
120	0.4814	0.4781	0.4783	0.7	1.4
130	0.4502	0.4480	0.4475	0.5	0.6
140	0.4227	0.4214	0.4202	0.3	0.6
150	0.3976	0.3978	0.3960	0.0	0.4
160	0.3749	0.3768	0.3744	0.5	0.1
170	0.3543	0.3579	0.3550	1.0	0.2
			Average % Error	0.5	0.6
			Range	0.0 to 1.1	0.0 to 1.8

n-UNDECANE

Boiling Point, 195.89°C
Melting Point, -25.59°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-25	4.124	4.082	4.014	1.0	0.2
-20	3.608	3.596	3.555	0.3	1.4
-15	3.186	3.191	3.169	0.1	0.5
-10	2.836	2.850	2.842	0.5	0.2
-5	2.543	2.562	2.563	0.7	0.8
0	2.294	2.271	2.279	1.0	0.6
10	1.900	1.921	1.936	1.1	1.9
20	1.606	1.622	1.639	1.0	2.0
30	1.381	1.392	1.408	0.8	1.9
50	1.062	1.064	1.078	0.2	1.5
70	0.8519	0.8484	0.8585	0.4	0.8
90	0.7051	0.6986	0.7051	0.9	0.0
110	0.5977	0.5904	0.5940	1.2	0.6
130	0.5160	0.5096	0.5108	1.2	1.0
150	0.4522	0.4476	0.4469	1.0	1.4
160	0.4251	0.4218	0.4203	0.8	1.1
170	0.4006	0.3989	0.3966	0.4	1.0
180	0.3783	0.3783	0.3754	0.0	0.7
185	0.3679	0.3688	0.3546	0.2	0.6
195	0.3483	0.3492	0.3460	0.2	0.6
			Average % Error	0.6	0.9
			Range	0.0 to 1.2	0.0 to 2.0

n-DODECANE

Boiling Point, 216.28°C
Melting Point, -9.58°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-5	3.343	3.328	3.298	0.4	1.3
0	2.983	2.922	2.906	2.0	2.6
5	2.680	2.692	2.682	0.4	0.1
10	2.424	2.440	2.437	0.6	0.5
15	2.204	2.223	2.224	0.8	0.9
20	2.014	2.034	2.038	1.0	0.7
40	1.469	1.483	1.492	0.9	1.5
60	1.132	1.137	1.146	0.4	1.2
80	0.9078	0.9081	0.9148	0.0	0.8
100	0.7512	0.7478	0.7524	0.4	0.1
110	0.6896	0.2652	0.6889	0.6	0.1
120	0.6362	0.6315	0.6343	0.7	0.3
135	0.5687	0.5640	0.5656	0.8	0.5
150	0.5128	0.5088	0.5093	0.8	0.7
160	0.4806	0.4774	0.4773	0.7	0.7
170	0.4516	0.4495	0.4488	0.4	0.6
180	0.4256	0.4247	0.4235	0.2	0.5
190	0.4017	0.4024	0.4007	0.2	0.2
200	0.3800	0.3823	0.3803	0.6	0.1
215	0.3500	0.3558	0.3532	1.6	0.9
			Average % Error	0.7	0.7
			Range	0.0 to 2.0	0.1 to 2.6

n-TRIDECANE

Boiling Point, 235.43°C
Melting Point, -5.39°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
-5	4.336	4.260	4.254	1.7	1.9
0	3.827	3.714	3.709	2.9	3.5
5	3.404	3.404	3.400	0.0	0.1
10	3.049	3.069	3.065	0.6	0.5
15	2.749	2.779	2.777	1.1	1.0
20	2.493	2.529	2.527	1.4	1.3
40	1.771	1.806	1.805	2.0	1.9
60	1.336	1.359	1.359	1.7	1.7
80	1.055	1.067	1.067	1.1	1.1
90	0.9504	0.9574	0.9576	0.7	0.7
100	0.8621	0.8653	0.8656	0.7	0.7
110	0.7873	0.7874	0.7877	0.0	0.0
120	0.7229	0.7208	0.7211	0.3	0.2
140	0.6186	0.6136	0.6140	0.8	0.7
160	0.5381	0.5320	0.5324	1.1	1.0
180	0.4740	0.4683	0.4687	1.2	1.1
200	0.4219	0.4176	0.4181	1.0	0.9
210	0.3987	0.3961	0.3965	0.6	0.5
220	0.3774	0.3766	0.3770	0.2	0.1
235	0.3482	0.3507	0.3511	0.7	0.8
			Average % Error	1.0	1.0
			Range	0.0 to 2.9	0.0 to 3.5

n-TETRADECANE

Boiling Point, 253.51°C
Melting Point, 5.86°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
10	3.819	3.735	3.756	2.2	1.6
15	3.414	3.370	3.383	1.3	0.9
20	3.070	3.056	3.062	0.4	0.2
25	2.779	2.783	2.784	0.1	0.2
30	2.527	2.544	2.542	0.7	1.0
40	2.124	2.151	2.145	1.3	1.0
50	1.813	1.844	1.836	1.7	1.2
70	1.378	1.402	1.394	1.7	1.1
90	1.093	1.107	1.100	1.3	0.6
110	0.8950	0.9017	0.8967	0.7	0.2
130	0.7519	0.7528	0.7495	0.1	0.3
150	0.6443	0.6417	0.6398	0.4	0.7
170	0.5609	0.5565	0.5558	1.0	0.9
190	0.4946	0.4898	0.4900	1.0	0.9
200	0.4662	0.4617	0.4623	1.0	0.8
210	0.4402	0.4364	0.4375	0.8	0.6
220	0.4162	0.4137	0.4151	0.6	0.2
230	0.3941	0.3931	0.3948	0.2	0.2
240	0.3738	0.3745	0.3764	0.2	0.7
250	0.3552	0.3575	0.3596	0.6	1.2
			Average % Error	0.8	0.7
			Range	0.1 to 2.2	0.2 to 1.6

n-PENTADECANE

Boiling Point, 270.61°C
Melting Point, 9.92°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
10	4.724	4.611	4.626	2.4	2.0
15	4.187	4.186	4.138	0.0	1.2
20	3.737	3.736	3.721	0.0	0.4
25	3.357	3.366	3.363	0.2	0.2
30	3.033	3.060	3.054	0.9	0.7
35	2.757	2.793	2.785	1.3	1.0
50	2.128	2.172	2.162	2.0	1.6
70	1.590	1.624	1.615	2.1	1.6
90	1.244	1.265	1.258	1.7	1.1
110	1.009	1.019	1.013	1.0	0.4
130	0.840	0.842	0.839	0.2	0.1
150	0.714	0.712	0.710	0.3	0.5
170	0.618	0.613	0.612	0.8	1.0
190	0.543	0.537	0.536	1.1	1.3
210	0.481	0.476	0.476	1.0	1.0
230	0.430	0.426	0.428	0.9	0.4
240	0.408	0.405	0.407	0.7	0.2
250	0.387	0.386	0.388	0.2	0.2
260	0.369	0.368	0.371	0.3	0.5
270	0.351	0.352	0.355	0.3	1.1
			Average % Error	0.9	0.8
			Range	0.0 to 2.4	0.1 to 2.1

n-HEXADECANE

Boiling Point, 286.79°C
Melting Point, 18.16°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
20	4.505	4.404	4.429	2.2	1.7
25	4.020	3.969	3.982	1.2	0.9
30	3.609	3.594	3.599	0.4	0.3
35	3.262	3.269	3.267	0.2	0.1
40	2.962	2.985	2.979	0.8	0.6
45	2.703	2.736	2.727	1.2	0.9
60	2.109	2.151	2.138	2.0	1.4
80	1.593	1.627	1.613	2.1	1.2
100	1.256	1.277	1.267	1.7	0.9
120	1.024	1.035	1.026	1.1	0.2
140	0.8562	0.8398	0.8541	0.4	0.2
160	0.7309	0.7294	0.7258	0.2	0.7
180	0.6344	0.6297	0.6278	0.7	1.0
200	0.5579	0.5518	0.5514	1.1	1.1
220	0.4955	0.4898	0.4905	1.1	1.0
240	0.4438	0.4395	0.4411	0.9	0.6
250	0.4211	0.4179	0.4199	0.7	0.3
260	0.400	0.398	0.400	0.5	0.0
270	0.380	0.380	0.383	0.0	0.8
285	0.354	0.356	0.359	0.5	1.4
			Average % Error	0.9	0.7
			Range	0.0 to 2.2	0.0 to 1.7

n-HEPTADECANE

Boiling Point, 302.15°C
Melting Point, 21.98°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
25	4.791	4.683	4.712	2.2	1.6
30	4.275	4.223	4.237	1.2	0.9
35	3.839	3.825	3.829	0.3	0.2
40	3.467	3.479	3.475	0.3	0.2
45	3.148	3.177	3.168	0.9	0.6
50	2.873	2.912	2.900	1.3	0.9
70	2.078	2.126	2.108	2.2	1.4
90	1.586	1.622	1.606	2.2	1.2
110	1.261	1.283	1.270	1.7	0.7
130	1.033	1.045	1.035	2.1	0.2
150	0.8682	0.8722	0.8659	0.4	0.4
170	0.7438	0.7423	0.7374	0.2	0.8
190	0.6473	0.6425	0.6397	0.7	1.2
210	0.5705	0.5642	0.5630	1.1	1.3
240	0.4804	0.4748	0.4755	1.1	1.0
260	0.433	0.429	0.430	0.9	0.7
270	0.411	0.408	0.411	0.7	0.0
280	0.392	0.390	0.393	0.5	0.2
290	0.374	0.373	0.376	0.2	0.5
300	0.355	0.358	0.361	0.8	1.7
			Average % Error	1.0	0.8
			Range	0.2 to 2.2	0.0 to 1.7

n-OCTADECANE

Boiling Point, 316.71°C
Melting Point, 28.18°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
30	5.020	4.821	4.941	2.0	1.6
35	4.481	4.370	4.444	2.5	0.8
40	4.025	3.976	4.016	1.2	0.2
45	3.637	3.631	3.646	0.1	0.2
50	3.304	3.328	3.324	0.7	0.6
55	3.015	3.060	3.043	1.5	0.9
70	2.353	2.422	2.384	2.9	1.3
90	1.774	1.838	1.796	3.6	1.2
110	1.396	1.444	1.407	3.4	0.8
130	1.137	1.167	1.138	2.6	0.0
150	0.949	0.966	0.945	1.8	0.4
170	0.808	0.815	0.801	0.8	0.8
190	0.701	0.700	0.692	0.1	1.3
210	0.616	0.609	0.606	1.1	1.6
240	0.517	0.507	0.509	1.9	1.5
260	0.46	0.45	0.46	2.2	0.0
280	0.42	0.41	0.42	2.4	0.0
290	0.39	0.39	0.40	0.0	2.5
300	0.38	0.37	0.38	2.7	0.0
315	0.36	0.35	0.36	2.7	0.0
			Average % Error	1.8	0.8
			Range	0.0 to 3.6	0.0 to 2.5

n-NONADECANE

Boiling Point, 330.6°C
Melting Point, 31.9°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
35	5.202	5.014	5.112	3.6	1.7
40	4.648	4.541	4.603	2.3	0.9
45	4.178	4.130	4.165	1.1	0.3
50	3.777	3.771	3.785	0.1	0.2
55	3.433	3.455	3.454	0.6	0.6
60	3.136	3.176	3.164	1.3	0.9
80	2.272	2.337	2.305	2.8	1.4
100	1.734	1.791	1.759	3.3	1.4
120	1.378	1.419	1.392	3.0	1.0
140	1.130	1.155	1.134	2.2	0.3
160	0.948	0.963	0.947	1.6	0.1
180	0.812	0.817	0.807	0.6	0.6
200	0.707	0.705	0.700	0.7	1.0
220	0.621	0.617	0.615	0.6	0.9
230	0.586	0.580	0.580	1.0	1.0
250	0.524	0.517	0.519	1.3	0.9
270	0.48	0.46	0.47	4.1	2.1
285	0.44	0.43	0.44	2.3	0.0
310	0.39	0.39	0.39	0.0	0.0
325	0.36	0.36	0.37	0.0	2.7
			Average % Error	1.6	0.8
			Range	0.0 to 4.1	0.0 to 2.7

n-EICOSANE

Boiling Point, 343.8°C
Melting Point, 36.44°C

Temperature, °C	Viscosity, Centistokes			Percent Error	
	Observed	Predicted			
		3 Parameter	2 Parameter	3 Parameter	2 Parameter
40	5.360	5.146	5.279	4.0	1.5
45	4.793	4.671	4.756	2.5	0.8
50	4.313	4.257	4.306	1.3	0.1
55	3.903	3.892	3.915	0.3	0.3
60	3.550	3.571	3.574	0.6	0.7
65	3.243	3.287	3.275	1.3	1.0
85	2.354	2.428	2.389	3.1	1.5
105	1.801	1.864	1.823	3.5	1.2
125	1.431	1.478	1.442	3.3	0.6
145	1.174	1.203	1.175	2.5	0.0
165	0.985	1.001	0.981	1.6	0.4
185	0.844	0.849	0.835	0.6	1.0
195	0.786	0.787	0.776	0.1	1.3
215	0.688	0.683	0.677	0.7	1.6
235	0.609	0.601	0.599	1.3	1.6
255	0.54	0.53	0.54	1.8	0.0
270	0.50	0.49	0.50	2.0	0.0
310	0.41	0.41	0.41	0.0	0.0
330	0.38	0.37	0.38	2.6	0.0
340	0.36	0.35	0.37	2.7	2.7
			Average % Error	1.8	0.8
			Range	0.1 to 4.0	0.0 to 2.7

APPENDIX II

TABLES OF N-ALKYL CYCLOHEXANES

CORRELATION ERRORS USING THE TWO PARAMETER MODIFIED ANDRADE EQUATION

CYCLOHEXANE

Boiling Point, 80.74°C
Melting Point, 6.55°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
10	1.494	1.491	0.2
15	1.366	1.365	0.1
20	1.254	1.255	0.1
25	1.157	1.157	0.0
30	1.071	1.070	0.1
35	0.993	0.993	0.0
40	0.923	0.924	0.1
45	0.861	0.862	0.1
50	0.806	0.806	0.0
55	0.756	0.756	0.0
60	0.712	0.711	0.1
65	0.670	0.669	0.1
70	0.632	0.632	0.0
75	0.598	0.597	0.2
80	0.567	0.566	0.2

Average % Error 0.1
Range 0.0 to 0.2

METHYLCYCLOHEXANE

Boiling Point, 100.93°C
Melting Point, -126.59°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-25	1.91	1.94	1.6
-20	1.74	1.76	1.1
-15	1.60	1.61	0.6
-10	1.473	1.475	0.1
-5	1.359	1.358	0.1
0	1.258	1.254	0.3
5	1.169	1.163	0.5
10	1.089	1.082	0.6
15	1.016	1.009	0.6
20	0.951	0.944	0.7
25	0.893	0.886	0.8
35	0.792	0.786	0.7
45	0.708	0.704	0.6
50	0.670	0.668	0.3
55	0.637	0.635	0.3
60	0.606	0.605	0.2
70	0.550	0.551	0.2
80	0.50	0.506	1.2
90	0.46	0.467	1.5
100	0.43	0.433	0.7

Average % Error 0.6
Range 0.1 to 1.6

ETHYLCYCLOHEXANE

Boiling Point, 131.78°C
Melting Point, -111.32°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-25	2.18	2.17	0.4
-20	1.98	1.97	0.5
-15	1.81	1.80	0.5
-10	1.665	1.657	0.5
-5	1.533	1.529	0.3
0	1.417	1.394	1.6
5	1.313	1.314	0.1
10	1.222	1.224	0.2
15	1.139	1.145	0.5
25	1.001	1.009	0.8
35	0.889	0.898	1.0
40	0.840	0.850	1.2
45	0.798	0.806	1.0
50	0.758	0.767	1.2
60	0.690	0.697	1.0
70	0.632	0.637	0.8
80	0.59	0.586	0.7
90	0.55	0.543	1.3
100	0.51	0.505	1.0
110	0.48	0.471	1.9

Average % Error 0.8
Range 0.2 to 1.9

n-PROPYLCYCLOHEXANE

Boiling Point, 156.72°C
Melting Point, -94.90°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-25	2.83	2.79	1.4
-20	2.54	2.51	1.2
-15	2.29	2.27	0.9
-10	2.08	2.07	0.5
-5	1.89	1.89	0.0
0	1.736	1.707	1.7
5	1.594	1.599	0.3
10	1.471	1.479	0.5
15	1.360	1.373	0.9
25	1.178	1.194	1.3
35	1.035	1.050	1.4
40	0.973	0.989	1.6
45	0.919	0.934	1.6
50	0.869	0.883	1.6
60	0.785	0.795	1.3
70	0.715	0.721	0.8
80	0.66	0.659	0.1
90	0.61	0.605	0.8
100	0.57	0.559	1.9
110	0.54	0.519	3.8

Average % Error 1.2
Range 0.0 to 3.8

n-BUTYLCYCLOHEXANE

Boiling Point, 180.95°C
Melting Point, -74.73°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-20	3.54	3.49	1.4
-15	3.16	3.12	1.3
-10	2.85	2.81	1.4
-5	2.57	2.54	1.2
0	2.33	2.27	2.6
5	2.12	2.11	0.5
10	1.94	1.93	0.5
15	1.732	1.781	2.8
25	1.514	1.525	0.7
35	1.302	1.323	1.6
40	1.213	1.238	2.0
45	1.136	1.161	2.2
50	1.066	1.092	2.4
55	1.004	1.030	2.6
60	0.951	0.973	2.3
70	0.860	0.874	1.6
80	0.79	0.791	0.1
90	0.73	0.721	1.2
100	0.69	0.661	4.2
110	0.64	0.609	4.8

Average % Error 1.9
Range 0.1 to 4.8

n-PENTYLCYCLOHEXANE

Boiling Point, 203.67°C
Melting Point, -57.5 °C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-10	4.02	4.00	0.5
-5	3.59	3.55	1.1
0	3.22	3.11	3.4
5	2.89	2.86	1.0
10	2.60	2.58	0.8
15	2.35	2.35	0.0
20	2.13	2.14	0.5
25	1.94	1.96	1.0
30	1.774	1.802	1.6
35	1.627	1.662	2.2
40	1.503	1.539	2.4
45	1.399	1.429	2.1
50	1.307	1.331	1.8
55	1.225	1.243	1.5
60	1.155	1.164	0.8
70	1.031	1.028	0.3
80	0.93	0.917	2.5
90	0.84	0.823	0.8
100	0.76	0.745	2.0
110	0.69	0.678	1.7

Average % Error 1.4
Range 0.0 to 3.4

n-HEXYLCYCLOHEXANE

Boiling Point, 224.7°C
Melting Point, -43.0°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-10	5.39	5.42	0.5
-5	4.79	4.76	0.6
0	4.26	4.12	3.3
5	3.80	3.75	1.3
10	3.39	3.36	0.9
15	3.04	3.02	0.6
20	2.73	2.73	0.0
25	2.47	2.48	0.4
30	2.24	2.27	1.3
35	2.03	2.08	2.5
40	1.87	1.91	2.1
45	1.729	1.761	1.8
50	1.606	1.630	1.5
55	1.498	1.514	1.0
60	1.402	1.410	0.6
70	1.236	1.232	0.3
80	1.10	1.087	1.2
90	0.98	0.968	1.2
100	0.88	0.869	1.2
110	0.80	0.785	1.9

Average % Error 1.2
Range 0.0 to 3.3

n-HEPTYLCYCLOHEXANE

Boiling Point, 244.9°C
Melting Point, -30.5°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-10	7.11	7.21	1.5
-5	6.26	6.27	0.1
0	5.53	5.35	3.1
5	4.89	4.84	1.0
10	4.34	4.29	1.1
15	3.87	3.83	1.0
20	3.45	3.44	0.3
25	3.10	3.10	0.0
30	2.78	2.81	1.1
35	2.51	2.55	1.6
40	2.28	2.33	2.2
45	2.10	2.14	1.9
50	1.94	1.97	1.5
55	1.80	1.82	1.1
60	1.678	1.684	0.3
70	1.464	1.457	0.5
80	1.29	1.275	1.1
90	1.14	1.126	1.2
100	1.01	1.003	0.7
110	0.91	0.899	1.2

Average % Error 1.1
Range 0.0 to 3.1

n-OCTYLCYCLOHEXANE

Boiling Point, 263.6°C
Melting Point, -19.7°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-10	9.21	9.43	2.4
-5	8.06	8.12	0.7
0	7.07	6.85	3.1
5	6.19	6.15	0.6
10	5.47	5.41	1.1
15	4.85	4.79	1.2
20	4.29	4.26	0.7
25	3.82	3.81	0.3
30	3.41	3.43	0.6
35	3.06	3.10	1.3
40	2.78	2.81	1.1
45	2.53	2.57	1.6
50	2.33	2.35	0.8
55	2.14	2.16	0.9
60	1.98	1.99	0.5
70	1.71	1.70	0.6
80	1.50	1.48	1.3
90	1.31	1.30	0.8
100	1.15	1.15	0.0
110	1.02	1.02	0.0

Average % Error 1.0
Range 0.0 to 3.1

n-NONYLCYCLOHEXANE

Boiling Point, 281.5°C
Melting Point, -10.2°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-10	11.76	12.15	3.4
-5	10.22	10.35	1.3
0	8.90	8.63	3.0
5	7.77	7.70	0.9
10	6.80	6.72	1.2
15	5.98	5.90	1.3
20	5.26	5.21	0.9
25	4.66	4.64	0.4
30	4.14	4.14	0.0
35	3.69	3.72	0.8
40	3.33	3.36	0.9
45	3.02	3.02	1.0
50	2.75	2.77	0.7
55	2.53	2.54	0.4
60	2.33	2.33	0.0
70	1.99	1.98	0.5
80	1.71	1.70	0.6
90	1.49	1.48	0.7
100	1.30	1.30	0.0
110	1.15	1.15	0.0

Average % Error 0.9
Range 0.0 to 3.4

n-DECYLCYCLOHEXANE

Boiling Point, 297.6°C
Melting Point, -1.7°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	11.08	10.91	1.5
5	9.60	9.66	0.6
10	8.35	8.34	0.1
15	7.30	7.26	0.5
20	6.39	6.37	0.3
25	5.61	5.62	0.2
30	4.97	4.98	0.2
35	4.40	4.45	1.1
40	3.95	3.99	1.0
45	3.56	3.59	0.8
50	3.23	3.25	0.6
55	2.95	2.96	0.3
60	2.71	2.70	0.4
65	2.48	2.47	0.4
70	2.29	2.27	0.9
75	2.11	2.09	0.9
80	1.95	1.94	0.5
90	1.68	1.67	0.6
100	1.46	1.46	0.0
110	1.28	1.28	0.0

Average % Error 0.5
Range 0.0 to 1.5

n-UNDECYLCYCLOHEXANE

Boiling Point, 313.2°C
Melting Point, 5.8°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
10	10.15	10.15	0.0
15	8.82	8.77	0.6
20	7.69	7.64	0.6
25	6.70	6.70	0.0
30	5.88	5.91	0.5
35	5.19	5.24	1.0
40	4.64	4.68	0.9
45	4.17	4.19	0.5
50	3.76	3.78	0.5
55	3.41	3.42	0.3
60	3.12	3.11	0.3
65	2.85	2.83	0.7
70	2.62	2.59	1.1
75	2.40	2.38	0.8
80	2.22	2.20	0.9
85	2.05	2.03	1.0
90	1.89	1.88	0.5
95	1.75	1.75	0.0
100	1.63	1.63	0.0
110	1.41	1.43	1.4

Average % Error 0.6
Range 0.0 to 1.4

n-DODECYLCYCLOHEXANE

Boiling Point, 327.9°C
Melting Point, 12.5°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
15	10.56	10.54	0.1
20	9.12	9.11	0.1
25	7.93	7.93	0.0
30	6.93	6.95	0.3
35	6.08	6.13	0.8
40	5.39	5.44	0.9
45	4.83	4.85	0.4
50	4.34	4.35	0.2
55	3.93	3.92	0.2
60	3.57	3.55	0.6
65	3.26	3.22	1.2
70	2.97	2.94	1.0
75	2.72	2.69	1.1
80	2.49	2.47	0.8
85	2.30	2.28	0.9
90	2.11	2.10	0.5
95	1.95	1.95	0.0
100	1.80	1.81	0.5
105	1.67	1.69	1.2
110	1.56	1.58	1.3

Average % Error 0.6
Range 0.0 to 1.3

n-TRIDECYLCYCLOHEXANE

Boiling Point, 341.9°C
Melting Point, 18.5°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
20	10.78	10.78	0.0
25	9.30	9.32	0.2
30	8.09	8.13	0.5
35	7.06	7.13	1.0
40	6.24	6.29	0.8
45	5.55	5.58	0.5
50	4.98	4.98	0.0
55	4.49	4.47	0.4
60	4.06	4.02	1.0
65	3.68	3.64	1.0
70	3.36	3.31	1.5
75	3.06	3.02	1.3
80	2.79	2.76	1.1
85	2.56	2.54	0.8
90	2.35	2.34	0.4
95	2.16	2.16	0.0
100	1.99	2.00	0.5
105	1.84	1.86	1.1
110	1.70	1.74	2.3

Average % Error 0.7
Range 0.0 to 2.3

n-TETRADECYLCYCLOHEXANE

Boiling Point, 355.0°C
Melting Point, 24.0°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
25	10.85	10.89	0.4
30	9.37	9.43	0.6
35	8.15	8.23	1.0
40	7.17	7.23	0.8
45	6.36	6.38	0.3
50	5.67	5.67	0.0
55	5.08	5.07	0.2
60	4.59	4.55	0.9
65	4.15	4.10	1.2
70	3.77	3.71	1.6
75	3.42	3.37	1.5
80	3.12	3.08	1.3
85	2.85	2.82	1.0
90	2.60	2.59	0.4
95	2.39	2.39	0.0
100	2.19	2.21	0.9
105	2.01	2.05	2.0
110	1.86	1.90	2.1

Average % Error 0.9
Range 0.0 to 2.1

n-PENTADECYLCYCLOHEXANE

Boiling Point, 368.0°C
Melting Point, 29.0°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
30	10.81	10.90	0.8
35	9.35	9.46	1.0
40	8.19	8.27	1.0
45	7.23	7.27	0.5
50	6.42	6.43	0.1
55	5.74	5.72	0.3
60	5.16	5.11	1.0
65	4.65	4.59	1.3
70	4.21	4.14	1.7
75	3.81	3.75	1.6
80	3.46	3.41	1.4
85	3.15	3.11	1.3
90	2.87	2.85	0.7
95	2.62	2.62	0.0
100	2.40	2.42	0.8
105	2.20	2.23	1.4
110	2.02	2.07	2.5

Average % Error 1.0
Range 0.0 to 2.5

n-HEXADECYLCYCLOHEXANE

Boiling Point, 380.0°C
Melting Point, 33.6°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
35	10.67	10.84	1.6
40	9.30	9.42	1.3
45	8.18	8.24	0.7
50	7.24	7.25	0.1
55	6.44	6.42	0.3
60	5.78	5.72	1.0
65	5.17	5.12	1.0
70	4.68	4.60	1.7
75	4.22	4.15	1.6
80	3.82	3.76	1.6
85	3.47	3.43	1.1
90	3.15	3.13	0.6
95	2.87	2.87	0.0
100	2.62	2.64	0.8
105	2.39	2.43	1.7
110	2.19	2.25	2.7

Average % Error 1.0
Range 0.0 to 2.7

APPENDIX III

TABLES OF N-ALKYL BENZENES

CORRELATION ERRORS USING THE TWO PARAMETER MODIFIED ANDRADE EQUATION

BENZENE

Boiling Point, 80.10°C
Melting Point, 5.53°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
10	0.8513	0.8449	0.7
15	0.7895	0.7870	0.3
20	0.7357	0.7353	0.0
25	0.6878	0.6889	0.1
30	0.6453	0.6470	0.3
35	0.6066	0.6092	0.4
40	0.5722	0.5749	0.5
45	0.5415	0.5437	0.4
50	0.5134	0.5152	0.3
55	0.488	0.489	0.2
60	0.466	0.465	0.2
65	0.444	0.443	0.2
70	0.424	0.423	0.2
75	0.406	0.405	0.2
80	0.389	0.387	0.5

Average % Error 0.2
Range 0.0 to 0.7

TOLUENE

Boiling Point, 110.62°C
Melting Point, -94.99°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-25	1.29	1.30	0.7
-20	1.18	1.19	0.8
-15	1.087	1.092	0.4
-10	1.007	1.008	0.1
-5	0.935	0.935	0.0
0	0.870	0.858	1.4
5	0.8132	0.8128	0.0
10	0.7622	0.7616	0.1
15	0.7157	0.7157	0.0
20	0.6747	0.6744	0.0
25	0.6378	0.6372	0.1
30	0.6048	0.6035	0.2
40	0.5465	0.5449	0.3
50	0.4976	0.4960	0.3
60	0.457	0.455	0.4
70	0.421	0.419	0.5
80	0.390	0.389	0.2
90	0.362	0.363	0.3
100	0.338	0.340	0.6
110	0.317	0.320	0.9

Average % Error 0.4
Range 0.0 to 1.4

ETHYLBENZENE

Boiling Point, 136.18°C
Melting Point, -94.97°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-25	1.49	1.50	0.7
-20	1.37	1.38	0.7
-15	1.257	1.266	0.7
-10	1.166	1.168	0.2
-5	1.082	1.083	0.1
0	1.008	0.993	1.5
5	0.9413	0.9398	0.1
10	0.8822	0.8798	0.3
20	0.7800	0.7777	0.3
30	0.6975	0.6946	0.4
40	0.6286	0.6260	0.4
50	0.5708	0.5687	0.4
60	0.523	0.520	0.6
70	0.482	0.479	0.6
80	0.446	0.444	0.4
90	0.415	0.413	0.5
105	0.374	0.374	0.0
115	0.351	0.352	0.3
125	0.330	0.333	0.9
135	0.311	0.315	1.3

Average % Error 0.5
Range 0.0 to 1.5

n-PROPYLBENZENE

Boiling Point, 159.22°C
Melting Point, -99.50°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-25	2.12	2.11	0.5
-20	1.91	1.91	0.0
-15	1.740	1.737	0.2
-10	1.592	1.587	0.3
-5	1.459	1.456	0.2
0	1.341	1.320	1.6
10	1.146	1.151	0.4
20	0.9914	1.000	0.9
30	0.8719	0.8798	0.9
40	0.7747	0.7817	0.9
50	0.6958	0.7007	0.7
60	0.631	0.633	0.3
70	0.575	0.576	0.2
80	0.527	0.528	0.2
90	0.487	0.486	0.2
105	0.434	0.434	0.0
120	0.392	0.392	0.0
130	0.367	0.367	0.0
140	0.35	0.35	0.0
150	0.33	0.33	0.0

Average % Error 0.4
Range 0.0 to 1.6

n-BUTYLBENZENE

Boiling Point, 183.27°C
Melting Point, -87.97°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-25	2.78	2.73	1.8
-20	2.49	2.46	1.2
-15	2.23	2.22	0.4
-10	2.01	2.01	0.0
-5	1.851	1.834	0.9
0	1.668	1.650	1.1
10	1.402	1.423	1.5
20	1.199	1.223	2.0
30	1.046	1.064	1.7
40	0.922	0.936	1.5
50	0.816	0.831	1.8
60	0.739	0.744	0.7
70	0.669	0.672	0.4
80	0.609	0.611	0.3
90	0.558	0.558	0.0
105	0.50	0.49	1.4
120	0.44	0.44	0.0
130	0.41	0.41	0.0
140	0.39	0.38	1.5
150	0.37	0.36	2.4

Average % Error 1.0
Range 0.0 to 2.4

APPENDIX IV

TABLES OF N-ALKENES

CORRELATION ERRORS USING THE TWO PARAMETER MODIFIED ANDRADE EQUATION

ETHENE

Boiling Point, -103.71°C
Melting Point, -169.15°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-165	0.91	0.92	1.1
-160	0.79	0.80	1.3
-155	0.70	0.70	0.0
-150	0.62	0.62	0.0
-145	0.56	0.55	1.8
-140	0.51	0.50	2.0
-135	0.46	0.46	0.0
-130	0.42	0.42	0.0
-125	0.39	0.39	0.0
-120	0.36	0.36	0.0
-115	0.34	0.33	1.1
-110	0.31	0.31	0.0
-105	0.29	0.29	0.0

Average % Error 0.6
Range 0.0 to 2.0

PROPENE

Boiling Point, -48.0°C
Melting Point, -185.2°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
-180	11.20	9.76	12.8
-175	6.98	6.71	3.8
-170	4.70	4.85	3.1
-165	3.41	3.64	6.7
-160	2.65	2.82	6.6
-155	2.14	2.25	5.3
-150	1.76	1.84	4.5
-145	1.47	1.53	4.1
-140	1.27	1.30	2.3
-135	1.10	1.12	1.8
-130	0.97	0.97	0.0
-125	0.86	0.86	0.0
-120	0.77	0.76	1.3
-115	0.70	0.68	2.1
-110	0.64	0.62	3.1
-105	0.59	0.56	4.2
-100	0.55	0.52	5.8

Average % Error 4.0
Range 0.0 to 12.8

1-BUTENE

Boiling Point, -6.26°C
Melting Point, -185.35°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-115	1.18	1.19	0.8
-110	1.07	1.06	0.9
-105	0.96	0.96	0.0
-100	0.87	0.87	0.0
-95	0.80	0.80	0.0
-90	0.74	0.73	1.3
-85	0.68	0.68	0.0
-80	0.63	0.63	0.0
-75	0.59	0.59	0.0
-70	0.55	0.55	0.0
-65	0.52	0.52	0.0
-60	0.49	0.49	0.0
-55	0.46	0.46	0.0
-50	0.44	0.44	0.0
-45	0.42	0.42	0.0
-40	0.40	0.40	0.0
-35	0.38	0.38	0.0

Average % Error 0.2
Range 0.0 to 1.3

1-PENTENE

Boiling Point, 29.97°C
Melting Point, -165.22°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-90	1.13	1.14	0.9
-85	1.03	1.03	0.0
-80	0.94	0.94	0.0
-75	0.87	0.86	1.1
-70	0.80	0.80	0.0
-65	0.74	0.74	0.0
-60	0.69	0.69	0.0
-55	0.64	0.64	0.0
-50	0.60	0.60	0.0
-45	0.57	0.57	0.0
-40	0.54	0.54	0.0
-35	0.51	0.51	0.0
-30	0.48	0.48	0.0
-25	0.46	0.46	0.0
-20	0.44	0.44	0.0
-15	0.42	0.42	0.0
-10	0.40	0.40	0.0
-5	0.38	0.38	0.0
0	0.37	0.37	0.0

Average % Error 0.1
Range 0.0 to 1.1

1-HEXENE

Boiling Point, 63.48°C
Melting Point, -139.82°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
-55	0.93	0.94	1.1
-50	0.86	0.86	0.0
-45	0.80	0.80	0.0
-40	0.75	0.74	1.3
-35	0.70	0.70	0.0
-30	0.65	0.65	0.0
-25	0.61	0.61	0.0
-20	0.58	0.58	0.0
-15	0.55	0.55	0.0
-10	0.52	0.52	0.0
-5	0.50	0.49	2.0
0	0.47	0.46	2.1
5	0.45	0.45	0.0
10	0.43	0.43	0.0
15	0.41	0.41	0.0
25	0.37	0.38	2.7
35	0.35	0.35	0.0
45	0.33	0.33	0.0
55	0.31	0.31	0.0
65	0.29	0.29	0.0

Average % Error 0.4
Range 0.0 to 2.7

1-HEPTENE

Boiling Point, 93.64°C
Melting Point, -119.03°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	0.61	0.60	1.6
5	0.58	0.58	0.0
10	0.55	0.55	0.0
15	0.52	0.53	1.9
20	0.50	0.50	0.0
25	0.48	0.48	0.0
30	0.47	0.46	2.1
35	0.45	0.45	0.0
40	0.43	0.43	0.0
45	0.41	0.41	0.0
50	0.40	0.40	0.0
55	0.39	0.39	0.0
60	0.38	0.38	0.0
65	0.36	0.36	0.0
70	0.35	0.35	0.0
85	0.33	0.33	0.0
90	0.32	0.32	0.0

Average % Error 0.3
Range 0.0 to 2.1

1-OCTENE

Boiling Point, 121.28°C
Melting Point, -101.73°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	0.835	0.814	2.5
5	0.783	0.776	0.9
10	0.734	0.734	0.0
15	0.690	0.695	0.7
20	0.654	0.660	0.9
25	0.627	0.628	0.1
30	0.597	0.599	0.3
35	0.571	0.572	0.2
40	0.546	0.547	0.2
45	0.523	0.525	0.4
50	0.501	0.504	0.6
55	0.482	0.484	0.4
60	0.464	0.466	0.4
65	0.447	0.450	0.7
70	0.432	0.434	0.5
75	0.419	0.420	0.2
85	0.394	0.393	0.2
95	0.372	0.370	0.5
105	0.35	0.35	0.0
115	0.34	0.33	2.9

Average % Error 0.6
Range 0.0 to 2.9

1-NONENE

Boiling Point, 146.87°C
Melting Point, -81.37°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	1.124	1.096	2.5
5	1.042	1.037	0.5
10	0.969	0.970	0.1
15	0.901	0.910	1.0
20	0.848	0.857	1.1
25	0.805	0.808	0.4
30	0.764	0.765	0.1
35	0.725	0.725	0.0
40	0.688	0.689	0.1
45	0.654	0.655	0.1
50	0.623	0.625	0.3
55	0.594	0.597	0.5
60	0.568	0.571	0.5
65	0.545	0.548	0.5
70	0.525	0.526	0.2
75	0.505	0.505	0.0
85	0.471	0.469	0.4
95	0.440	0.437	0.7
105	0.41	0.41	0.0
115	0.39	0.38	1.3

Average % Error 0.5
Range 0.0 to 2.5

1-DECENE

Boiling Point, 170.57°C
Melting Point, -66.31°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	1.49	1.45	2.7
5	1.37	1.36	0.7
10	1.258	1.262	0.3
15	1.164	1.175	0.9
20	1.088	1.097	0.8
25	1.022	1.028	0.6
30	0.962	0.965	0.3
35	0.906	0.908	0.2
40	0.855	0.857	0.2
45	0.809	0.811	0.2
50	0.766	0.769	0.4
55	0.727	0.730	0.4
60	0.692	0.695	0.4
65	0.660	0.663	0.4
70	0.632	0.633	0.1
75	0.607	0.606	0.2
85	0.560	0.557	0.5
95	0.519	0.515	0.8
105	0.48	0.48	0.0
115	0.45	0.45	0.0

Average % Error 0.5
Range 0.0 to 2.7

1-UNDECENE

Boiling Point, 192.67°C
Melting Point, -49.18°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	1.95	1.89	3.1
5	1.77	1.76	0.6
10	1.62	1.62	0.0
15	1.49	1.50	0.7
20	1.38	1.39	0.7
25	1.283	1.292	0.7
30	1.200	1.205	0.4
35	1.124	1.127	0.3
40	1.054	1.058	0.4
45	0.990	0.995	0.5
50	0.932	0.938	0.6
55	0.880	0.886	0.7
60	0.835	0.839	0.5
65	0.793	0.796	0.4
70	0.757	0.757	0.0
75	0.723	0.721	0.3
85	0.661	0.658	0.4
95	0.608	0.603	0.8
105	0.56	0.56	0.0
115	0.52	0.52	0.0

Average % Error 0.5
Range 0.0 to 3.1

1-DODECENE

Boiling Point, 213.36°C
Melting Point, -35.23°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	2.53	2.44	3.5
5	2.27	2.26	0.4
10	2.05	2.06	0.5
15	1.86	1.89	1.6
20	1.71	1.74	1.7
25	1.60	1.60	0.0
30	1.49	1.49	0.0
35	1.39	1.38	0.7
40	1.286	1.290	0.3
45	1.200	1.207	0.6
50	1.125	1.132	0.6
55	1.056	1.064	0.7
60	0.995	1.003	0.8
65	0.941	0.948	0.7
70	0.893	0.897	0.4
75	0.850	0.851	0.1
85	0.773	0.770	0.4
95	0.706	0.701	0.7
105	0.65	0.64	1.5
115	0.60	0.59	1.7

Average % Error 0.8
Range 0.0 to 3.5

1-TRIDECENE

Boiling Point, 232.78°C
Melting Point, -23.07°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	3.24	3.11	2.2
5	2.88	2.86	0.7
10	2.58	2.59	0.4
15	2.33	2.36	1.3
20	2.13	2.15	0.9
25	1.96	1.98	1.0
30	1.81	1.82	0.5
35	1.67	1.68	0.6
40	1.56	1.56	0.0
45	1.45	1.45	0.0
50	1.35	1.36	0.7
55	1.261	1.269	0.6
60	1.184	1.190	0.5
65	1.115	1.120	0.4
70	1.052	1.055	0.3
75	0.996	0.997	0.1
85	0.898	0.895	0.3
95	0.817	0.810	0.8
105	0.75	0.74	1.3
115	0.68	0.68	0.0

Average % Error 0.6
Range 0.0 to 2.2

1-TETRADECENE

Boiling Point, 251.10°C
Melting Point, -12.85°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	4.11	3.92	4.6
5	3.64	3.59	1.4
10	3.22	3.22	0.0
15	2.87	2.91	1.4
20	2.60	2.64	1.5
25	2.38	2.41	1.3
30	2.19	2.21	0.9
35	2.01	2.03	1.0
40	1.85	1.87	1.1
45	1.71	1.73	1.2
50	1.60	1.61	0.6
55	1.50	1.50	0.0
60	1.40	1.40	0.0
65	1.31	1.31	0.0
70	1.226	1.232	0.2
75	1.159	1.159	0.0
85	1.039	1.034	0.5
95	0.936	0.929	0.7
105	0.85	0.84	1.2
115	0.78	0.77	1.3

Average % Error 0.9
Range 0.0 to 4.6

1-PENTADECENE

Boiling Point, 268.39°C
Melting Point, -3.73°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
0	5.15	4.91	4.7
5	4.52	4.47	1.1
10	3.98	3.99	0.2
15	3.54	3.58	1.1
20	3.18	3.22	1.2
25	2.89	2.92	1.0
30	2.64	2.66	0.7
35	2.41	2.43	0.8
40	2.21	2.23	0.9
45	2.04	2.06	1.0
50	1.88	1.90	1.1
55	1.75	1.76	0.6
60	1.64	1.64	0.0
65	1.53	1.53	0.0
70	1.43	1.43	0.0
75	1.35	1.34	0.7
85	1.193	1.189	0.3
95	1.070	1.063	0.6
105	0.97	0.96	1.0
115	0.88	0.87	1.1

Average % Error 0.9
Range 0.0 to 4.7

1-HEXADECENE

Boiling Point, 284.87°C
Melting Point, 4.12°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
5	5.58	5.44	2.5
10	4.85	4.82	0.6
15	4.27	4.30	0.7
20	3.82	3.86	1.0
25	3.46	3.48	0.6
30	3.15	3.16	0.3
35	2.87	2.87	0.0
40	2.62	2.63	0.4
45	2.40	2.41	0.4
50	2.21	2.22	0.4
55	2.04	2.05	0.5
60	1.89	1.90	0.5
65	1.76	1.77	0.6
70	1.65	1.65	0.0
75	1.55	1.54	0.6
80	1.46	1.45	0.7
85	1.37	1.36	0.7
95	1.214	1.210	0.3
105	1.09	1.08	0.9
115	0.98	0.98	0.0

Average % Error 0.6
Range 0.0 to 2.5

1-HEPTADECENE

Boiling Point, 300.3°C
Melting Point, 11.2°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
15	5.16	5.14	0.4
20	4.59	4.59	0.0
25	4.14	4.12	0.5
30	3.74	3.72	0.5
35	3.39	3.37	0.6
40	3.08	3.07	0.3
45	2.81	2.81	0.0
50	2.57	2.58	0.4
55	2.36	2.38	0.8
60	2.18	2.20	0.9
65	2.02	2.04	1.0
70	1.88	1.89	0.5
75	1.76	1.77	0.6
80	1.66	1.65	0.6
85	1.56	1.55	0.6
90	1.47	1.46	0.7
95	1.38	1.37	0.7
100	1.30	1.30	0.0
105	1.23	1.22	0.8
115	1.10	1.10	0.0

Average % Error 0.5
Range 0.0 to 1.0

1-OCTADECENE

Boiling Point, 314.8°C
Melting Point, 17.6°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
20	5.45	5.47	0.4
25	4.90	4.88	0.4
30	4.41	4.38	0.7
35	3.98	3.95	0.7
40	3.59	3.59	0.0
45	3.26	3.27	0.3
50	2.98	2.98	0.0
55	2.73	2.74	0.4
60	2.51	2.52	0.4
65	2.32	2.33	0.4
70	2.16	2.16	0.0
75	2.01	2.01	0.0
80	1.87	1.88	0.5
85	1.75	1.75	0.0
90	1.65	1.64	0.6
95	1.55	1.54	0.6
100	1.46	1.45	0.7
105	1.38	1.37	0.7
110	1.30	1.30	0.0
115	1.23	1.23	0.0

Average % Error 0.3
Range 0.0 to 0.7

1-NONADECENE

Boiling Point, 329.1°C
Melting Point, 23.4°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
25	5.77	5.76	0.2
30	5.17	5.14	0.6
35	4.64	4.62	0.4
40	4.17	4.17	0.0
45	3.77	3.78	0.3
50	3.43	3.44	0.3
55	3.13	3.14	0.3
60	2.87	2.88	0.3
65	2.64	2.66	0.7
70	2.45	2.45	0.0
75	2.28	2.27	0.4
80	2.12	2.11	0.5
85	1.97	1.97	0.0
90	1.85	1.84	0.5
95	1.73	1.73	0.0
100	1.63	1.62	0.6
105	1.53	1.53	0.0
110	1.44	1.44	0.0
115	1.36	1.36	0.0

Average % Error 0.2
Range 0.0 to 0.7

1-EICOSENE

Boiling Point, 342.4°C
Melting Point, 28.6°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
35	5.36	5.34	0.4
40	4.81	4.80	0.2
45	4.33	4.33	0.0
50	3.91	3.93	0.5
55	3.58	3.58	0.0
60	3.27	3.28	0.3
65	3.00	3.01	0.3
70	2.77	2.77	0.0
75	2.57	2.56	0.4
80	2.38	2.38	0.0
85	2.21	2.21	0.0
90	2.06	2.06	0.0
95	1.93	1.93	0.0
100	1.81	1.81	0.0
105	1.70	1.70	0.0
110	1.60	1.60	0.0
115	1.50	1.51	0.7

Average % Error 0.2
Range 0.0 to 0.7

APPENDIX V

TABLES OF POLAR COMPOUNDS

CORRELATION ERRORS USING THE TWO PARAMETER MODIFIED ANDRADE EQUATION

HYDROGEN CYANIDE

Boiling Point, 25.7°C
Melting Point, -13.3°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
-13.3	0.2756	0.2759	0.1
-10	0.2644	0.2649	0.2
-5	0.2492	0.2496	0.2
0	0.2355	0.2332	1.0
5	0.2228	0.2233	0.2
10	0.2114	0.2119	0.2
15	0.2014	0.2015	0.0
18	0.1955	0.1957	0.1
22	0.1885	0.1885	0.0
25	0.1834	0.1833	0.0

Average % Error 0.2
Range 0.0 to 1.0

ACETONITRILE

Boiling Point, 81.8°C
Melting Point, -45.7°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
-20	0.554	0.559	0.9
0	0.442	0.434	1.8
15	0.375	0.376	0.3
25	0.345	0.343	0.6
30	0.325	0.328	0.9
40	0.301	0.302	0.3

Average % Error 0.8
Range 0.3 to 1.8

PROPIONITRILE

Boiling Point, 97.3°C
Melting Point, -91.9°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
0	0.547	0.548	0.2
15	0.454	0.458	0.9
20	0.431	0.431	0.0
30	0.388	0.386	0.5
40	0.351	0.348	0.8
50	0.318	0.316	0.6
60	0.292	0.289	1.0
80	0.243	0.247	1.6

Average % Error 0.7
Range 0.0 to 1.6

CAPRINITRILE

Boiling Point, 243.7°C
Melting Point, -17.9°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
20	0.975	0.990	1.5
30	0.842	0.846	0.5
40	0.733	0.733	0.0
50	0.648	0.643	0.8
60	0.576	0.569	0.5
80	0.465	0.459	1.5
100	0.385	0.381	1.0
120	0.324	0.324	0.0
140	0.274	0.281	2.5

Average % Error 0.9
Range 0.0 to 2.5

ACETONE

Boiling Point, 56°C
Melting Point, -94°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
-80.0	1.487	1.480	0.4
-59.6	0.932	0.942	1.1
-42.5	0.695	0.696	0.1
-30.0	0.575	0.577	0.3
-20.9	0.510	0.510	0.0
-13.0	0.470	0.462	1.7
-10.0	0.450	0.446	0.9
0.0	0.399	0.395	1.0
15.0	0.337	0.344	2.1
25.0	0.316	0.314	0.6
30.0	0.295	0.301	2.1
41.0	0.280	0.276	1.4

Average % Error 1.0
Range 0.0 to 2.1

METHYLETHYL KETONE

Boiling Point, 80°C
Melting Point, -86°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
0.0	0.5429	0.5427	0.0
20.0	0.4284	0.4294	0.2
40.0	0.3490	0.3480	0.3
80.0	0.2482	0.2484	0.1

Average % Error 0.1
Range 0.0 to 0.3

CHLOROFORM

Boiling Point, 61.3°C
Melting Point, -63.5°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
-13.0	0.850	0.839	1.3
-10.0	0.786	0.805	2.4
8.1	0.643	0.642	0.1
15.0	0.596	0.594	0.2
20.0	0.563	0.563	0.0
25.0	0.542	0.535	1.2
30.0	0.514	0.510	0.8
40.0	0.464	0.464	0.0
60.0	0.389	0.393	1.1

Average % Error 0.2
Range 0.0 to 2.4

METHYL ALCOHOL

Boiling Point, 64.5°C
Melting Point, -97.0°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
-84.23	6.8	6.62	2.6
-72.55	4.36	4.43	1.7
-44.53	1.98	2.02	1.9
-22.29	1.22	1.23	0.7
0	0.82	0.80	2.5
15	0.623	0.638	2.5
20	0.597	0.593	0.7
25	0.547	0.551	0.8
30	0.510	0.514	0.8
40	0.456	0.450	1.2
50	0.403	0.398	1.2

Average % Error 1.5
Range 0.7 to 2.6

ETHYL ALCOHOL

Boiling Point, 78.3°C
Melting Point, -115.0°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
-98.11	44.0	44.1	0.3
-89.8	28.4	29.3	3.1
-71.5	13.2	13.4	1.4
-59.42	8.41	8.60	2.3
-52.58	6.87	6.85	0.3
-32.01	3.84	3.72	2.9
-17.59	2.68	2.58	3.7
-0.30	1.80	1.75	2.8
0	1.773	1.70	4.0
10	1.466	1.419	3.1
20	1.200	1.175	2.0
30	1.003	0.986	1.7
40	0.834	0.836	0.2
50	0.702	0.716	2.0
60	0.592	0.619	4.5
70	0.514	0.540	5.0

Average % Error 2.4
Range 0.2 to 5.0

PROPYL ALCOHOL

Boiling Point, 97°C
Melting Point, -126°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
0	3.883	3.777	2.7
10	2.897	2.928	1.1
15	2.520	2.560	1.5
20	2.256	2.247	0.4
30	1.720	1.754	2.0
40	1.405	1.390	1.0
50	1.130	1.118	1.0
60	0.882	0.911	3.3
70	0.760	0.751	1.1
80	0.6315	0.6259	0.9
90	0.5355	0.5267	1.6
100	0.443	0.447	1.0

Average % Error 1.4
Range 0.4 to 3.3

BUTYL ALCOHOL

Boiling Point, 118°C
Melting Point, -90°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
-50.9	36.100	35.700	1.1
-30.1	14.700	14.900	1.4
-22.4	11.100	11.200	0.7
-14.1	8.380	8.340	0.4
0	5.186	5.120	1.3
15	3.379	3.400	0.6
20	2.948	2.965	0.6
30	2.300	2.283	0.7
40	1.782	1.787	0.3
50	1.411	1.419	0.5
70	0.930	0.930	0.0
100	0.540	0.536	0.7

Average % Error 0.7
Range 0.0 to 1.4

WATER

Boiling Point, 100°C
Melting Point, 0°C

Temperature, °C	Viscosity, centistokes Observed	Predicted	% Error
2	1.673	1.659	0.8
3	1.619	1.608	0.7
5	1.517	1.512	0.3
10	1.302	1.307	0.4
15	1.137	1.142	0.4
20	1.002	1.006	0.4
25	0.8899	0.8943	0.5
30	0.7963	0.8006	0.5
34	0.7331	0.7363	0.4
40	0.6526	0.6543	0.2
45	0.5961	0.5967	0.1
55	0.5046	0.5038	0.1
60	0.4671	0.4660	0.2
65	0.4338	0.4328	0.2
70	0.4045	0.4035	0.2
75	0.3782	0.3774	0.2
80	0.3548	0.3542	0.2
85	0.3337	0.3333	0.1
90	0.3147	0.3146	0.0
95	0.2976	0.2977	0.0

Average % Error 0.3
Range 0.0 to 0.8

ANILINE

Boiling Point, 184°C
Melting Point -6°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
0	10.20	9.73	4.6
5	8.06	8.06	0.0
10	6.50	6.49	0.1
15	5.31	5.32	0.1
20	4.40	4.43	0.7
25	3.71	3.74	0.9
30	3.16	3.20	1.3
35	2.71	2.77	2.2
40	2.37	2.42	2.1
50	1.85	1.90	2.5
60	1.51	1.53	1.4
70	1.27	1.27	0.0
80	1.09	1.07	1.8
90	0.935	0.919	1.6
100	0.825	0.802	2.8

Average % Error 1.5
Range 0.0 to 4.6

ETHYLENE GLYCOL

Boiling Point, 197.3°C
Melting Point, -13.0°C

Temperature, °C	Viscosity, centipoise Observed	Predicted	% Error
4	45.0	46.6	3.5
10	33.6	33.8	0.6
16	25.66	25.21	1.7
21.1	19.97	19.99	0.1
27	15.82	15.58	1.5
38	10.38	10.26	1.1
49	7.17	7.11	0.8
60	5.17	5.14	0.6
71	3.86	3.85	0.2
82	2.97	2.97	0.0
93	2.34	2.35	0.4
104	1.89	1.90	0.5
116	1.56	1.54	1.3
127	1.30	1.29	0.7
138	1.10	1.10	0.0
149	0.95	0.95	0.0
160	0.83	0.83	0.0
171	0.72	0.73	1.4
177	0.68	0.68	0.0

Average % Error 0.7
Range 0.0 to 3.5

REFERENCES

1. Alexander, J., "Colloid Chemistry", Volume VII, Reinhold Publishing Corporation, New York, (1950)
2. American Chemical Society, "Physical Properties of Chemical Compounds - II", p. 4, (1959)
3. American Petroleum Institute, "Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds", Project 44, Carnegie Press, Pittsburgh, Pennsylvania, (1953)
4. Andrade, E. N. da C., Nature, 125, 309, (1930)
5. Bird, R. B., Stewart, W. E., and Lightfoot, E. N., "Transport Phenomena", Chapter 1, John Wiley and Sons, Inc., New York, (1960)
6. Collins, F. C., J. Chem. Phys., 56, 398, (1957)
7. Curme, G. O., "Glycols", Reinhold Publishing Corporation, (1953)
8. Doolittle, A. K., J. Appl. Phys., 22, 1473, (1951)
9. Doolittle, A. K., J. Appl. Phys., 22, 1032, (1951)
10. Esso Research and Engineering Company, Computer Program written for the IBM 1130 Computer
11. Girifalco, L. A., J. Chem. Phys., 23, 2446, (1955)
12. Glasstone, S., Lardler, K. J. and Eyring, H., "Theory of Rate Processes", Chapter 9, McGraw-Hill, New York, (1941)

13. Kincaid, J. F., Eyring H., and Stearn, A. E., Chem. Rev., 28, 301, (1941)

14. Lange, N. A ., "Handbook of Chemistry", Revised 10th Edition, McGraw-Hill book Co., New York, (1967)

15. Perry, J. H., "Chemical Engineers' Handbook", 3rd Edition, 373, McGraw-Hill, New York, (1950)

16. Reid, R. C., and Sherwood, T. K., "The Properties of Gases and Liquids", 2nd Edition, Chapter 9, McGraw-Hill, New York, (1966)

17. Sounders, M., J. Am. Chem. Soc., 59, 1252, (1937)

18. Timmermans, J., "Physico - Chemical Constants of Pure Organic Compounds", Volume I, Elsevier Publishing Co., New York, (1950)

19. Thomas, G. W., Chem. Rev., 38, 1 (1946)

20. Walther, C., Proc. World Petroleum Congr., London, 2, 419, (1933)

21. Weast, R. C., "Handbook of Chemistry and Physics", 51st Edition, The Chemical Rubber Co., Cleveland, Ohio, (1970 - 1971)

22. Weissberger, A., "Physical Methods of Organic Chemistry", 3rd Edition, Volume I, Interscience Publishers, Inc., New York, (1959)

23. Wright, F. J., J. Chem. Eng. Data, 6, 454, (1961)

NOMENCLATURE

A = constant in equation (11) for calculating viscosity

B = constant in equation (11) for calculating viscosity

C = constant in equation (11) for calculating viscosity, calculated from equation (10)

n = viscosity, kinematic or absolute depending on data used to calculate A and B in equation (11)

$t_{B.P.}$ = normal boiling point, ^{o}C

T = absolute temperature

Z = constant in equation (10) for determining C