International Journal of Thermophysics, Vol. 15, No. 3, 1994

Note

Prediction of Saturated Liquid Viscosity for Some Halocarbon Refrigerants Based on the van der Waals Model[1]

A. Kumagai,[2] H. Miura–Mochida,[2,3] and C. Yokoyama[2]

Received December 1, 1993

The viscosity data of saturated liquid halocarbon refrigerants are satisfactorily predicted by a method based on the hard-sphere theory of transport properties. The hard-sphere close-packed volume can be correlated with Bondi's hard-sphere volume. The absolute average deviations between calculated and experimental values for 15 halocarbon refrigerants are 6.3%. It is found that the proposed method can give better results than the previous methods proposed by Gordon et al., Li and Poole, and Srinivasan and Murthy.

KEY WORDS: close-packed volume; halocarbon; saturated liquid; van der Waals model; viscosity.

1. INTRODUCTION

The liquid viscosity of halocarbon refrigerants provides part of the essential basis for evaluating the benign hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) alternatives. In our previous study, we constructed an improved capillary viscometer and reported experimental data for the saturated liquid viscosity of 15 refrigerants. It was found that there are significant differences among saturated liquid viscosity values previously reported for some refrigerants. It should be emphasized that much more effort should be paid to accumulating accurate data for the saturated liquid viscosity of halocarbon refrigerants.

[1] Dedicated to Honorary Professor Hiroji Iwasaki on the occasion of his 77th birthday.

[2] Institute for Chemical Reaction Science, Tohoku University, Sendai 980, Japan.

[3] Present address: Alps Denki Co. Ltd., Sendai 981-31, Japan.

0195-928X/94/0500-0567$07.00/0

In the absence of experimental viscosity data, we should employ predictive methods for viscosity. However, most of the predictive methods reported previously are insufficient for reproducing the saturated liquid viscosity of refrigerants. Therefore, it is imperative for engineering purposes to establish simple predictive methods for the saturated liquid viscosity of refrigerants.

The purpose of this study is to propose a reliable estimation method for saturated liquid viscosities of refrigerants. In this study, based on the van der Waals model proposed by Dymond [1] and viscosity data reported in our previous studies, a new correlation is presented between the volume of close packing for hard spheres and Bondi's hard-core volume [2].

2. THE VAN DER WAALS MODEL

The van der Waals model of a fluid pictures the molecules as having an intermolecular potential made up of a hard core surrounded by a weak and long-range attractive component. At a high density and temperature, the van der Waals model allows approximate expressions for the transport properties to be given by the Enskog theory.

Dymond [1] presented an analytical expression for the viscosity of a hard-sphere system based on the fluid transport theory of Enskog as

$$1/\eta = A/[(MT)^{1/2} V_0^{1/3}](V - 1.384V_0) \quad (1)$$

Table I. Optimized Parameters in the Dymond Equation for Halocarbon Refrigerants

Refrigerant No.	T_c (K)	T_r range	Data points	A	V_0 (cm^3·mol^{-1})	Ref. No.
11	471.2	0.58–0.75	9	154.5	58.18	3
12	385.0	0.71–0.89	8	140.0	48.87	3
22	369.4	0.74–0.88	6	150.0	36.91	3
13B1	340.2	0.80–0.92	5	116.3	40.91	3
152a	386.6	0.71–0.89	8	159.0	39.82	3
113	487.2	0.56–0.72	9	131.7	78.06	3
123	459.5	0.59–0.77	9	149.9	65.64	3
123a	465	0.59–0.76	9	142.6	65.41	3
143a	346.3	0.79–0.93	6	128.5	40.83	3
114	418.8	0.65–0.84	9	143.5	71.33	3
134a	374.4	0.73–0.91	8	143.0	45.58	3
141b	480	0.57–0.73	9	155.8	60.12	4
142b	410.3	0.67–0.86	9	150.2	51.83	4
225ca	477	0.57–0.74	9	135.2	84.58	4
225cb	485	0.56–0.73	9	134.8	84.54	4

where η is the viscosity in mPa · s, M the molecular weight, T the temperature in K, V_0 the hard-sphere close-packed volume in $cm^3 \cdot mol^{-1}$, and V the molar volume in $cm^3 \cdot mol^{-1}$, while $A = 145.20$.

We used our previous data for the saturated liquid of 15 halocarbon refrigerants [3, 4]. For each refrigerant, the values of A and V_0 in Eq. (1) fitted by least-squares regression are listed in Table I. It can be seen that the values of A are close to 145.20 for the hard-sphere model. With the values in Table I, the viscosities for the 15 refrigerants can be calculated within an average deviation of 6.3% and a maximum deviation of 23.9%.

When viscosity data are not available, the value of V_0 must be estimated. The van der Waals volume, V_{vdW}, is used very often as a characteristic parameter for a molecular size. Therefore, we correlate V_0 with V_{vdW} and the result is shown in Fig. 1. The value of V_{vdW} was determined from the group-contribution method proposed by Bondi [2]. From the result shown in Fig. 1, the following equation was obtained:

$$V_0 = 1.3139 V_{vdW} - 3.328 \tag{2}$$

Equation (2) can be used to estimate the value of V_0. The proposed generalized Dymond method with Eqs. (1) and (2) and with $A = 145.20$ has been compared with the methods of Gordon et al. [5], Li and Poole [6], and Srinivasan and Murthy [7]. A comparison of these prediction methods is shown in Table II. Evidently the generalized Dymond equation, which has only one parameter, V_0, gives much better results than the other three

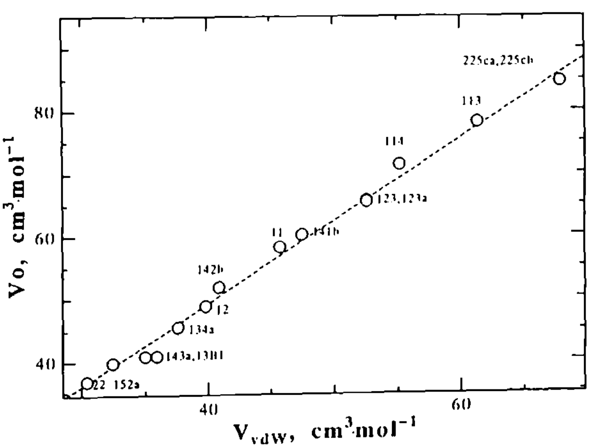

Fig. 1. Relationship between close-packed volume V_0 and van der Waals volume V_{vdW}. (------) Eq. (2).

Table II. Comparison of Predictive Methods for the Saturated Liquid Viscosity of Holocarbon Refrigerants[a]

Refrigerant No.	Average deviation (%)[b]			
	Gordon et al. [5]	Li and Poole [6]	Srinivasan and Murthy [7]	Generalized van der Waals eq.
11	3.7	1.8	6.4	7.0
12	3.5	14.9	5.6	3.0
22	9.1	19.4	12.2	1.2
13B1	11.6	19.0	10.3	8.0
152a	50.3	19.9	32.5	5.2
113	6.9	6.2	17.7	19.6
123	6.6	3.9	3.8	4.6
123a		6.0		1.7
143a	13.0	20.3	31.0	3.0
114	4.4	6.5	2.6	14.3
134a	10.9	9.4	13.1	1.7
141b	12.8	4.1	11.5	1.7
142b	28.2	4.8	24.0	5.8
225ca	23.0	4.5		6.7
225cb	20.8	3.7		7.3
All refrigerants	14.7 (51.4)[c]	9.0 (32.9)	12.8 (38.2)	6.3 (23.9)

[a] T_r range; data points and data source are the same as in Table I.
[b] Calculated from $1/n \sum (|\eta_{exp} - \eta_{pred}|)/\eta_{pred} \times 100$.
[c] Numbers in parentheses are maximum deviations (%), calculated from maximum of $(|\eta_{exp} - \eta_{pred}|)/\eta_{pred} \times 100$.

methods. While the applicability of the proposed generalized Dymond equation is restricted to halocarbon refrigerants, a similar equation for V_0 can be obtained for other types of compounds.

3. CONCLUSION

To estimate the saturated liquid viscosity of halocarbon refrigerants, based on the van der Waals model proposed by Dymond, a new correlation is presented for the volume of close packing for hard spheres. The proposed generalized van der Waals equation can provide much better results than methods proposed previously.

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