Viscosity of N-Dodecane at Elevated Pressure and Temperature

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Abstract: *The viscosity of normal dodecane is determined with a rolling-ball viscometer at temperatures 40°C, 50° C, 60°C, 75°C, and 100°C at pressures up to 5.1kbar. The estimated accuracy in the viscosity data is ± 1 percent. The viscosity data is fitted by empirical an relation who facilitates the estimation of viscosity at desired pressure and given temperature. We have also checked the validity of some observations made by Kiran and Sen regarding the relationship between viscosity and density for n-dodecane. Our results have been compared with values reported by other authors in the literature and found to be in good agreement.*

Keywords: Rolling-ball Viscometer, Pressure N-Dodecane, Viscosity, Density, Temperature

1. Introduction

A study of variation of viscosity of liquids with pressure and temperature has considerable importance both for understanding of the fundamental problem of the liquid state and for ever increasing industrial application. The effect of pressure and temperature on the viscosity of liquids is strongly dependent on molecular structure which, in turn, determines properties such as specific volume, phase transition, dielectric relaxation etc. Further, a knowledge of pressure and temperature dependence of viscosity of liquids is needed in order to evaluate their suitability for use in machines. It is observed mostly for liquids that a pressure change of a few kbar produces several orders of magnitude variation in viscosity. This type of observed behavior could be explained by any theory of viscosity of liquids.

The variation of viscosity of n-alkanes with pressure and temperature has been investigated earlier also by several authors from time to time using diverse methods. The detailed pioneer work in this connection is due to Bridgman [1]. He measured the viscosity of various liquids including four n-alkanes at pressures up to 10 kbar by the falling weight method (estimated error 2 to 5%). Hogenboom etal [2] measured the viscosity of some liquids as a function of temperature and pressure including three n-alkanes by the rolling ball method for pressures up to 3.6 k bar (error ± 2%). Using the falling weight method, Dickinson [3] investigated the viscosity of n-hexane, n-octane and their mixtures at 30° C and 50° C and pressure up to 5kbar(error ± 2%). Dymond et al [4-6] investigated the viscosity behaviour of several hydrocarbons including n-dodecane in the temperature range 25 ° C to 100° C and pressures up to 5kbar (error ± 2%). Using a vibrating crystal, Kashiwagi and Makita [7] measured the viscosity of numerous n-paraffins including n-dodecane in the temperature range 25° C to 75° C but pressure range limited to 1 kbar. Kiran and Sen [8] have reported their viscosity results for some n-paraffins over a wide temperature range lying between 37° C and 177° C but their maximum pressure does not exceed 0.7 kbar. A. Darysafar and Khalil Shahbzi [9] gave a model to predict the dynamic viscosity of the n-alkanes as a function of pressure, temperature and n-alkane's molecular weight. Recently, Prasad [10-12] investigated viscosity behaviour of n-pentane n-hexane and n-octane for pressures up to 5.8 kbar in temperature range 30° C to 100° C with estimated accuracy ± 1 percent.

2. Experimental and Materials

In this work viscosity measurements have been carried out for n-dodecane by using the rolling-ball viscometer. The measurements are carried out at temperatures 40℃, 50℃ , 60℃, 75℃ and 100℃ and pressure up to 5.1 kbar. The experimental set up used in this work consists of the three main parts; pressure generator, pressure vessel and the constant temperature bath enclosing it and measuring system. A detailed description of this equipment is given in our previous work [13]. Procedure and other details are the same as in our previous measurement Prasad [10].

The normal dodecane used in this study is obtained from Aldrich Chemicals Ltd.(U.S.A), who claim purity of 99.1 percent.

3. Results and Discussion

Relative viscosity η_r (the ratio of viscosity at elevated pressure to the viscosity at atmospheric pressure) is determined in the pressure range up to 5.1 kbar at temperatures 40℃, 50℃, 60℃, 75℃ and 100℃ using relation

$$\eta = (K/L) (\rho_b - \rho) \, t \, Sin\theta \quad (1)$$

Where η is the coefficient of viscosity, K is the calibration constant, θ is the inclination of the rolling plane with the horizontal, ρ_b and ρ the density of the material of the ball and the liquid respectively and 't' is the rolling time of the ball for covering the distance L in the tube.

The experimental results of our measurements of relative viscosity are given in Table 1.The estimated error in the present viscosity data is ± 1 percent, which is equal or less than reported by earlier authors. In Fig.1, we plotted $Log_{10}\eta_r$ (logarithm base 10 of relative viscosity) versus pressure at different temperatures. It may be seen from the figure that the viscosity increases with pressure and decreases with temperature.

Table 1: Relative viscosity (ηr) of n dodecane as a function of pressure and temperature

| P (bar)	(40°C) η_r	P (bar)	(50°C) η_r	P (bar)	(60°C) η_r	P (bar)	(75°C) η_r	P (bar)	(100°C) η_r
1	1.000	1	1.000	1	1.000	1	1.000	1	1.000
270	1.344	439	1.634	299	1.368	616	1.895	616	1.902
432	1.580	818	2.326	439	1.570	998	2.546	998	2.542
638	1.886	1084	2.874	630	1.865	1615	3.911	1616	3.766
836	2.246	1614	4.261	818	2.186	2134	5.338	2134	5.059
983	2.554	2186	6.195	1084	2.698	2706	7.466	2705	6.864
1646	4.300	2705	8.711	1614	3.924	3165	9.480	3164	8.650
2183	6.140	3164	11.909	2186	5.657	3943	14.162	3943	12.385
2662	8.617			2705	7.699	4649	18.995	4649	16.619
				3177	10.087			5153	20.687
				3600	12.803				
				4186	17.512				
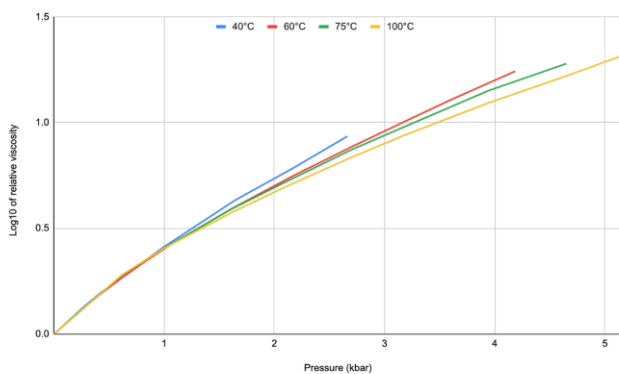
Figure 1: Relative viscosity (ηr) of n-dodecane as a function of pressure and temperature

At each temperature, our results can be fitted to polynomial equation

$$\text{Log } \eta_r = \sum_{i=0}^{n} a_i p^i \quad (2)$$

Where pressure P is measured in bar. The values of the coefficients are given in Table 2. Generally, a fourth order polynomial is found to give a good representation of our results within the estimated accuracy of $\pm$ 1 percent.

Table 2: Values of the coefficients in Eq. 2

Temp (°C)	$a_0 \times 10^3$	$a_1 \times 10^4$	$a_2 \times 10^7$	$a_3 \times 10^{11}$	$a_4 \times 10^{15}$	$a_5 \times 10^{19}$
40	1.787600	4.7940	-0.7846	1.1270	-	-
50	-1.881400	5.5283	-1.5048	3.4850	-2.6694	
60	0.043367	4.8489	-1.0011	1.9732	-1.5592	-
75	0.926420	5.1182	-1.2897	2.8465	-2.5146	-
100	-1.307900	5.7367	-2.3608	8.5124	-15.399	1.0571

We have analyzed our viscosity data using a three-parameter relation given by Kiran and Sen [8] of the form

$$\eta = B_1 \exp (B_2 \times \rho) + B_3 \quad (3)$$

Where B_1, B_2 and B_3 are parameters to be determined from the data. Evidently, according to Kiran and Sen, one set B_1, B_2 and B_3 values would be needed for each n-paraffin data below 0.7 kbar. We have, however, tried Eq. (3) for the representation of viscosity data for pressures up to 4kbar. This, however, makes it necessary to treat B_1, B_2 and B_3 to be temperature dependent. The values of these parameters are given in Table 3. Average modulus of the deviation (M.D) of the values calculated from the Eq. (3) using these parameter values from our smoothed experimental values are also given in Table 3 Our analysis shows that with our parameter values, MD is less than 2 percent.

Table 3: Values of the coefficients in Eq. 3

Temp (°C)	$B_1 \times 10^{11}$	$B_2 \times 10^2$	B_3 (mPa.S)	MD (%)
40	0.6005	2.4986	0.520	1.5
50	3.5546	2.2749	0.390	2.0
60	19.7300	2.0526	0.285	1.7
75	8.3621	2.1525	0.306	2.0
100	37.7840	1.9433	0.254	1.9

4.Comparison of Results

We show a comparison of our smoothed values at 60°C with the reported result of Hogenboom [2] in Fig. 2. It may be observed that at lower pressures the deviations from our smoothed values are too small to be seen in the figure but at higher pressures small positive deviations can be noted. A detailed numerical comparison of this data is shown in Table 4.

In Fig. 3 our smoothed results are shown at 75°C along with reported results of Kashiwagi and Makita [7] and Dymond etal [4]. It may be seen that the results of Dymond exhibit smaller negative deviations. The limited result of Kashiwagi up to 1kbar, however, shows the lowest deviations from our smoothed values. Once again, the numerical comparison of our results with Dymond's data are shown in Table 5.
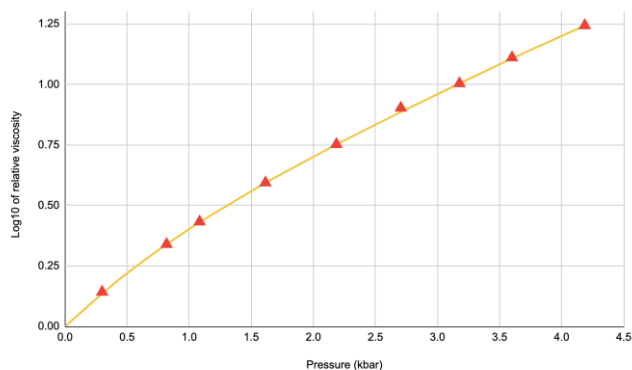

Figure 2: Comparison between our results and Hogenboom's data at 60°C

Table 4: A quantitative comparison between our results and Hogenboom's data at 60°C

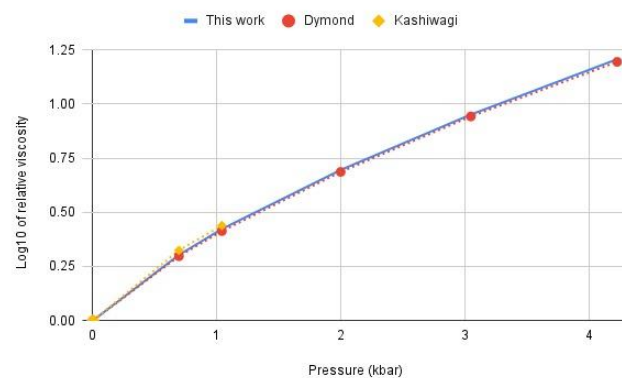| P (bar)	This work	Hogenboom et al
1	1.000	1.000
800	2.144	2.180
1200	2.946	2.978
1600	3.920	3.975
2000	5.092	5.183
2400	6.484	6.591
2800	8.144	8.310
3200	10.151	10.478

Figure 2: Comparison amongst our results, Kashiwagi and Dymond's data at 75°C

Table 5: A quantitative comparison between present results and Dymond's data at 75°C

P (bar)	This work	Dymond et al
1	1	1
694	2.009	1.981
1040	2.647	2.588
1997	4.959	4.856
3046	8.939	8.760
4225	16.094	15.652

5.Conclusion

The present study provides viscosity data for n-dodecane for pressures ranging up to 5.1kbar and temperatures from 40° C to 100° C. It is observed from the study that the viscosity increases multifold with increase in pressure and decreases with increase in temperature. Based on the measured data, an empirical relation is established which is found to give a good representation of our results within the estimated accuracy of $\pm$ 1 percent. Average modulus of the deviation (M.D) of the values calculated from the Eq. (3) using its parameter values from our smoothed experimental values is reported. Our analysis shows that with our parameter values, MD is less than 2 percent. A comparison shows that our data is in good agreement with available literature data. It is hoped that this data could be helpful for scientific and industrial applications.

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