

VISCOSITY OF NORMAL PENTANE AS A FUNCTION OF PRESSURE AND TEMPERATURE

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Abstract: The viscosity of normal pentane is measured at temperature 30° C and 50°C at pressures up to 6 kbar by using the rolling-ball viscometer. The estimated error in the viscosity data is ± 1 percent. The experimental data obtained have been compared with values reported by other authors in the literature. The results for pressure variation are represented by an empirical relation. We have also checked up to 4 kbar the validity of some observations made by Kiran and Sen regarding the relationship between viscosity and density of n-paraffin.

Keywords: Viscosity, Rolling-ball Viscometer, Density, Quartz Thermometer, Thermal Equilibrium.

INTRODUCTION

A study of variation of viscosity of normal alkanes with temperature and pressure has considerable scientific importance, as it provides information about intermolecular forces. It is observed mostly for liquids that a pressure change of a few kbar produces several orders of magnitude variation in viscosity. Any theory of viscosity of liquids has to explain this type of observed behavior.

The effect of temperature and pressure on the viscosity of n-paraffins has been investigated earlier also by several authors from time to time using diverse methods. The earliest detailed investigation in this connection is due to Bridgman [1]. He measured the viscosity of numerous liquids including four n-paraffins at pressures up to 10 kbar by the falling weight method (estimated error 2 to 5%). Hogenboom et al [2] investigated the viscosity of some liquids as a function of temperature and pressure including three n-paraffins by the rolling ball method for pressures up to 3.6 k bar (error $\pm 2\%$). Collings and McLaughlin [3] have reported the viscosity of several organic liquids including n-pentane up to 6 k bar (error $\pm 1\%$). Dymond et al [5-7] investigated extensively the viscosity behavior of several pure hydrocarbons including n- hexane, n-octane, n-dodecane and n-hexadecane for pressures up to 5 k bar in the temperature range 25 to 100° C (error $\pm 2\%$). Using a vibrating crystal, Kashiwagi and Makita [8] measured the viscosity of n-hexane, n-heptane, n-octane, n-decane and n-dodecane in the temperature range 25 to 75° C but pressure range limited to 1 kbar. Kiran and Sen [9] have reported their viscosity results for some n-paraffins over a wide temperature range lying between 37 and 177° C but their maximum pressure does not exceed 0.7 k bar. Recently, A. Darysafari and Khalil Shahbazi [10] gave a model to predict the dynamic viscosity of the n-alkanes as a function of pressure, temperature and n-alkane's molecular weight.

EXPERIMENTAL

In this work viscosity measurements have been carried out for n-pentane by using the rolling-ball viscometer. The pressure range in our experiments is up to 6 kbar. The measurements are carried out at temperatures 30°C and 50°C.

MATERIALS

Relevant information about the normal alkanes used in the study is summarized below.

ALKANE	SOURCE	SAMPLE PURITY (%)
n-Pentane	B.D.H Chemicals Ltd. (England)	99.50

PROCEDURE

For each new material the viscometer tube, the ball, and the bellows are washed, dried and then rinsed with liquid to be studied. The viscometer tube is filled with the sample and the ball is carefully inserted into it. The bellows is screwed on the viscometer tube and filled with the sample in such a manner as to avoid any possibility of trapping air bubbles. The other end of the bellows is closed by a nut. The viscometer cell is fixed in the pressure vessel which is immersed in the constant temperature bath. To check for leakage, the pressure vessel is allowed to stand at the highest pressure for more than half an hour. The necessary electrical connections are made between the viscometer cell and the rolling-time measuring instrument. The vertical position of the pressure vessel (and hence the viscometer) is checked with a spirit level.

The temperature of the bath could be controlled to ± 0.02 K and is measured by a quartz thermometer having an accuracy of ± 0.01 K. For measurements at a given temperature about three to four-hour time has to be allowed for attainment of thermal equilibrium because of large thermal capacity of the pressure vessel. The high-pressure fluid is supplied through a flexible metal tube connected to the pressure generator. Following each pressure increment the apparatus is allowed to stand from 10 to 15 minutes so that the heat evolved in the compression may be dissipated.

The pressure vessel can be manually rotated to the required inclination angle. The ball is raised to the top of the viscometer tube by rotating the pressure vessel. It is held at the top for more than a minute with the help of a retaining coil. If this precaution is not taken, the rolling time tends to be erratic. Apparently, this pause allows eddies set up in raising the ball to die away. After the pause, the ball is released and its rolling time between two coils is measured. This procedure is repeated in the reverse direction. At a given temperature, similar observations are made at various pressures. A number of rolling times (5 to 8) of the ball are recorded in each direction (direct and reverse) at a given temperature and pressure. The average of these rolling times is used to determine the viscosity of the sample.

RESULTS AND DISCUSSION

Relative viscosity η_r (the ratio of viscosity at elevated pressure to the viscosity at atmospheric pressure) at each temperature is determined in the pressure range upto 6 kbar at temperatures 30°C and 50°C using

$$\eta = (K \div L) (\rho_b - \rho) t \sin\theta \quad - (1)$$

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 results of our measurements for n-pentane are given in Table 1.

Table 1: Relative viscosity (η_r) of n-Pentane as a function of pressure and temperature

P (bar)	η_r 30°C	P (bar)	η_r 50°C
1	1	1	1
390	1.444	404	1.448
746	1.854	745	1.831
983	2.214	981	2.099
1339	2.579	1326	2.511
1682	3.013	1685	2.947
1960	3.393	1962	3.288
2470	4.179	2467	3.978
2948	5.024	2941	4.725
3454	6.084	3495	5.727
3920	7.17	3947	6.81
4469	8.557	4426	8.084
4970	9.925	4906	9.266
5884	13.086		

At each temperature our results could be fitted to polynomial equation

$$\text{Log}_{10} \eta_r = \sum_{i=0}^n a_i P^i \quad - (2)$$

Where pressure P is measured in bar. The values of the coefficients in each case are given in Table 2. Generally, a fourth order polynomial is found to give a good representative of our results within the estimated accuracy of ± 1 percent. The estimated error in the present viscosity data is ± 1 percent. This is less than reported by earlier authors except in the case of Collings whose accuracy matches ours.

Table 2: Values of the coefficients in eq 2

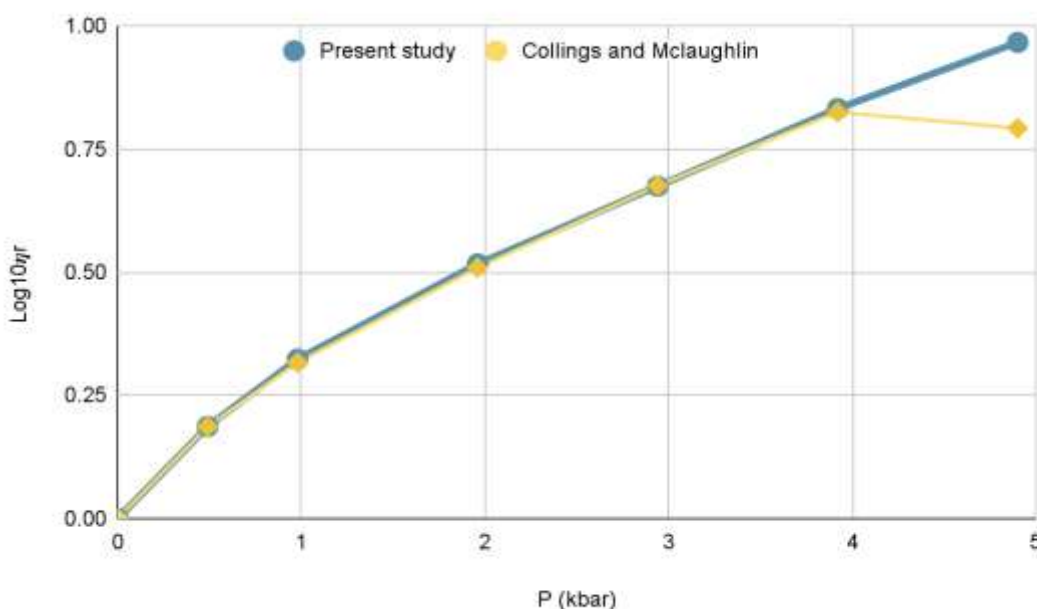
Temp (°C)	$a_0 \times 10^3$	$a_1 \times 10^4$	$a_2 \times 10^7$	$a_3 \times 10^{11}$	$a_4 \times 10^{15}$	$a_5 \times 10^{19}$
30	0.56600	4.64270	-1.74780	5.26210	-7.92820	5.46400
50	0.73228	4.52630	-1.44680	3.23280	-2.65930	

We show some quantitative and illustrative comparison of our results with Collings and Mclaughlin's data at 50°C in Table 3 and Fig. 1. In this figure, our smoothed values from Eq. 1 are shown in a blue line curve (with blue circle symbol) while the results of other authors in the form reported by them are shown by a yellow line curve (with yellow diamond symbol). It is inferred from the figure that the deviations of Collings and Mclaughlin's (3) values are seen only after 3.9 kbar.

Table 3: Quantitative comparison between present results and Colling's data at 50°C

P (kbar)	This work	Collings and Mclaughlin
1	1	1
490	1.537	1.536
980	2.106	2.073
1960	3.286	3.229
2940	4.724	4.7373
3920	6.792	6.682
4900	9.251	6.196

Fig 1: Comparison between present study and Collings and Mclaughlin’s data



Lastly, we also analyzed our viscosity data using a three-parameter relation given by Kiran and Sen (9) of the form:

$$\eta = B_1 \exp(B_2 \times \rho) + B_3 \tag{3}$$

Where B_1, B_2, B_3 are parameters to be determined from the data. Evidently, according to Kiran and Sen one set B_1, B_2, B_3 values would be needed for each n-paraffin data below 0.7 k bar. We have, however, tried Eq. (3) for the representation of viscosity data for pressures up to 4 kbar. This, however, makes it necessary to treat B_1, B_2, B_3 to be temperature dependent. The values of these parameters are given in Table 4. 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 given in Table 4. Our analysis shows that with our parameter values, MD is less than 2.0 percent.

Table 4: Values of the coefficients in eq 3

Temp (°C)	$B_1 \times 10^{10}$	$B_2 \times 10^2$	B_3 (mPa.S)	MD (%)
30	7.9211	1.8789	0.135	1.6
50	159.7400	1.4223	0.102	1.7

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