VISCOSITY MEASUREMENT OF GLYCEROL-WATER MIXTURE (GM) AT HIGH PRESSURE AND HIGH TEMPERATURE

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Abstract: Using a rolling-ball viscometer, viscosity of glycerol-water mixture (87 to 13 by weight) has been investigated at 38°C, 50 °C,75°C and 95°C at pressures ranging up to 6.3kbar with accuracy of ±1 percent. A suitable empirical relation is developed to represent our experimental data for pressure variation to facilitate interpolation. Our data has been used to determine differential pressure coefficient of viscosity as a function of pressure and temperature and the activation energy of viscous flow as a function of pressure. The viscosity(cp) of GM with temperature and atmospheric pressure is available in the literature . This data has been fitted by an empirical relation to find viscosity(cp) with temperature at atmospheric pressure.

Keywords: Activation Energy, hydrostatic extrusion, Viscosity, Rolling-ball Viscometer, Glycerol-water mixture(GM)

INTRODUCTION

Measuring viscosity is an effective way to know the state of a liquid . It plays an important role in the quality control and in various research and development stages of a wide range of industries, including Chemical, Petrochemical, Oil and Automotive. For example, the viscosity of a liquid is an important parameter for designing the piping in a plant or transporting crude oil or chemical agent through a pipeline. The last few decades have seen rapid developments in the field of metal working where fluids under high pressure are used in operations such as hydrostatic extrusion. In this connection, the need for reliable viscosity data for various fluid systems as a function of pressure and temperature can hardly be overemphasized. Infect, this fluid property is related not only to the design of hydrostatic equipment but is also vital to the development of process technology. Further, the large increase in viscosity of fluids with pressure in hydrostatic extrusion gives rise to considerable frictional losses resulting in waste of energy. The work done in the compression of fluid from the atmospheric pressure to extrusion pressure constitutes yet another source of energy dissipation which should be minimized. The study of viscosity of glycerol water mixture is taken up to provide some standard materials to compare with, while looking for suitable liquids for hydrostatic extrusion.

Bridgman [1] has measured the viscosity of pure glycerol for pressure up to 12 kbar at 30 °C and 70°C by the falling-weight method. He claimed the error in his results were from 2 to 5 percent. Using a rolling -ball viscometer, Harrison and Grosser [2] have carried out a similar but limited study at 75°C for pressure up to 5 kbar. Shankar and Manoj Kumar [3] have measured the kinematic viscosity of glycerol-water mixtures in the temperature range 10°C to 50 °C. Cheng and Nian-Sheng [4] have proposed an empirical formula for the calculation of viscosity of glycerol-water mixture for mass concentrations in the range of 0-100% and temperature varying from 0°C to 100°C. Abel G. M. Ferreira and coworkers [5] have measured viscosity of glycerol over the temperature range 293 - 394 K at atmospheric pressure with 3% accuracy using the Brookfield thermosel system. Using rolling-ball viscometer, Prasad [6] has investigated the viscosity behaviour of glycerol with pressures up to kbar and temperature from 30°C to 100°C. Thus, it is clear from foregoing references that a more extensive and accurate study of variation of viscosity of glycerol-water mixture is desirable as a function of pressure and temperature.

EXPERIMENTAL AND MATERIALS

Viscosity measurements of glycerol water mixture are carried out by using a rolling-ball viscometer. The experimental setup 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 [7]. Since the viscosity range involved here is generally comparable to that of the lubricants considered in Prasad [8], the same procedure is employed.

The glycerol-water mixture (87 to 13 by weight) investigated here is obtained as such from E. Merc (Germany).

RESULTS

The relative viscosity (the ratio of the viscosity at high pressure to at atmospheric pressure) of glycerol-water mixture has been measured here at temperature 38°C, 50°C, 75 °Cand 95°C in the pressure range starting from atmospheric pressure up to 6.3 kbar using relation

$$\eta = (KL) (\rho_b - \rho) \, t \, Sin\theta \qquad\qquad (1)$$

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 are shown in Tables 1.

Table1: Relative viscosity η_r of glycerol-water mixture with pressure and temperature

P (bar)	η_r 38°C	P (bar)	η_r 50°C	P (bar)	η_r 75°C	P (bar)	η_r 95°C
1	1.000	1	1.000	1	1.000	1	1.000
406	1.189	376	1.140	400	1.122	418	1.140
726	1.361	755	1.291	868	1.280	825	1.286
1207	1.652	1265	1.512	1308	1.450	1297	1.470
1719	2.030	1789	1.780	1845	1.686	1746	1.650
2206	2.447	2328	2.109	2339	1.938	2299	1.882
2778	3.040	2898	2.491	2812	2.225	2801	2.130
3334	3.756	3481	2.984	3218	2.502	3276	2.401
3842	4.507	4023	3.564	3800	2.940	3789	2.713
4314	5.346	4545	4.230	4307	3.372	4346	3.089
4812	6.410	5045	4.980	4865	3.935	4856	3.498
5374	7.829	5511	5.805	5392	4.540	5395	3.941
5580	8.462	6282	7.369	5848	5.101	5813	4.276
6199	10.645			6354	5.792	6397	4.677

DISCUSSION OF RESULTS

First, we consider the variation of relative viscosity η_r, with pressure at a given temperature . At each temperature, our results could be fitted to the polynomial equation

$$Log \, \eta = \sum_{i=0}^{n} a_i \, p^i \qquad\qquad (2)$$

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

Table 2: Value of coefficient of Eq.(2)

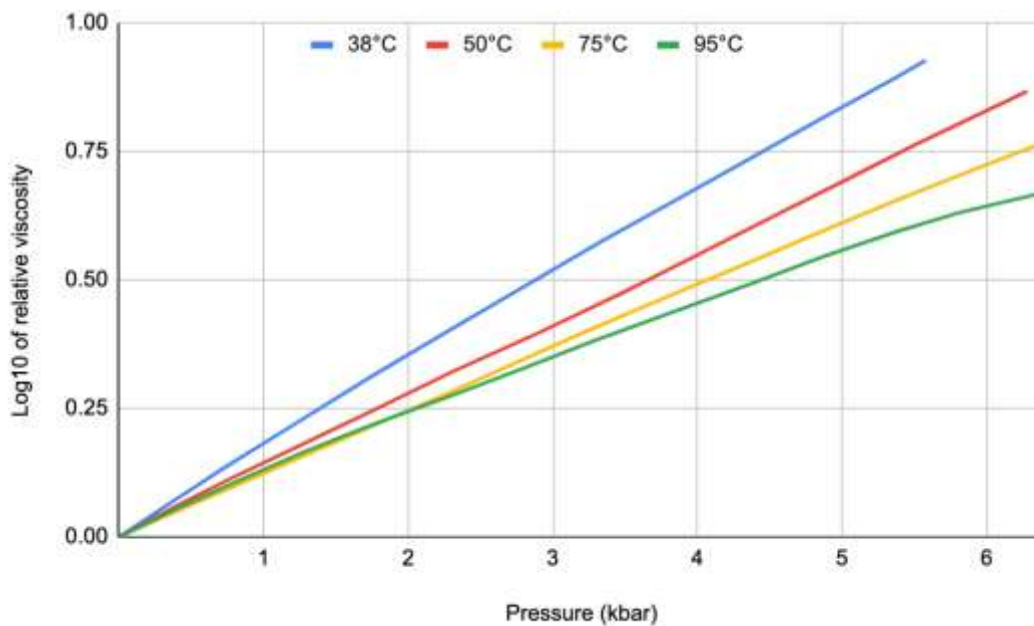| Temp (0°C)	a_0 x 10^4	a_1 x 10^4	a_2 x 10^9	a_3 x 10^{12}	a_4 x 10^{16}
38	-5.9930	1.8944	-6.837900	0.48423	-
50	-3.9743	1.5689	-14.655000	3.46150	-2.55120
75	-1.0119	1.2317	-0.045153	0.12825	-0.31092
90	-1.4154	1,5086	-22.635000	4.89710	-3.88400

Fig1: Relative viscosity η_r of glycerol-water mixture with pressure and temperature

We plotted log of relative viscosity versus pressure at temperatures 38°C, 50°C, 75 °C and 95°C in Fig. 1. It may easily be seen that the viscosity increases with pressure. The pressure coefficient of log of viscosity has been determined as a function of pressure and temperature by using Eq. (2). The values obtained are given in Table 3.

Table 3: Differential pressure coefficient (d η/d P) x 10^4

as a function of temperature and pressure

Temp (°C)	< ------ Pressure in (kbar)------ >				
	1	2	3	4	5
50	3.2	3	3.1	3.1	3.3
75	2.8	2.8	2.8	2.8	2.7
95	2.7	2.5	2.4	2.4	2.2

It may be noted from this table that it is practically independent of pressure except at 95°C, where it shows a slow decrease.

In Fig. 2, we show a representative graph to compare the variation of viscosity for glycerol and glycerol water mixture at 50°C using the glycerol data from Prasad [8] and mixture data from Table 1. It may be observed that for the pure system the variation is much larger as compared to the mixture.
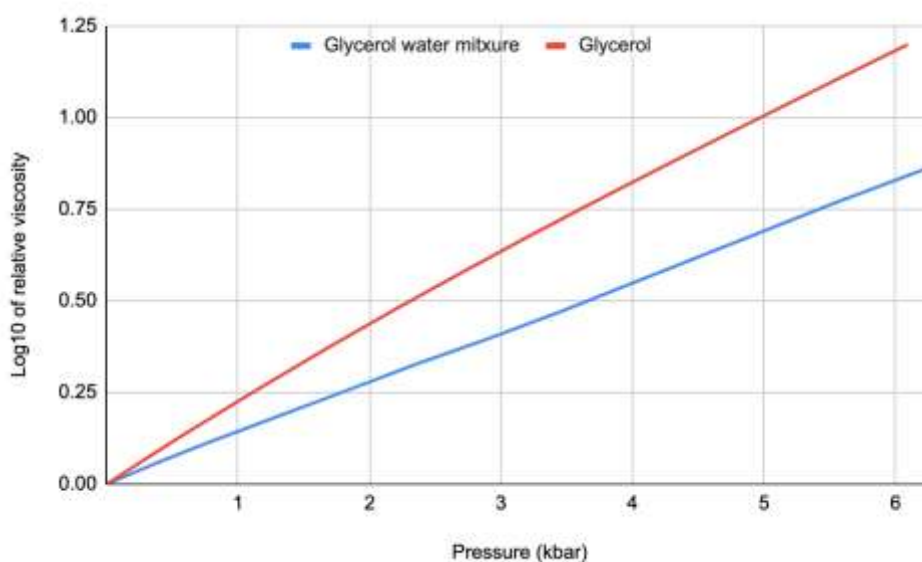

Fig2: Comparison of variation of viscosity for glycerol and glycerol water mixture at 50°C.

Next, we consider the isobaric variation of viscosity with temperature. On the basis of the Eq. (4) in Prasad [7], the activation energy E_a as a function of pressure is determined using the linear part of the Log η versus $1/T$ curves. The values of E_a are given in Table 4.

Table 4: Activation energy E_a (KJ) as a function of pressure

Pressure (Kbar)	1×10^{-3}	1	2	3	4	5	6
Activation Energy (KJ)	30.9	32.4	32.5	33.5	34.4	36.4	38.7

We have also plotted the variation of E_a versus pressure in Fig. 3. It may be seen that the variation is slow up to 3 kbar and then tends to be faster at higher pressure. Any theory of viscosity could explain this type of behaviour.
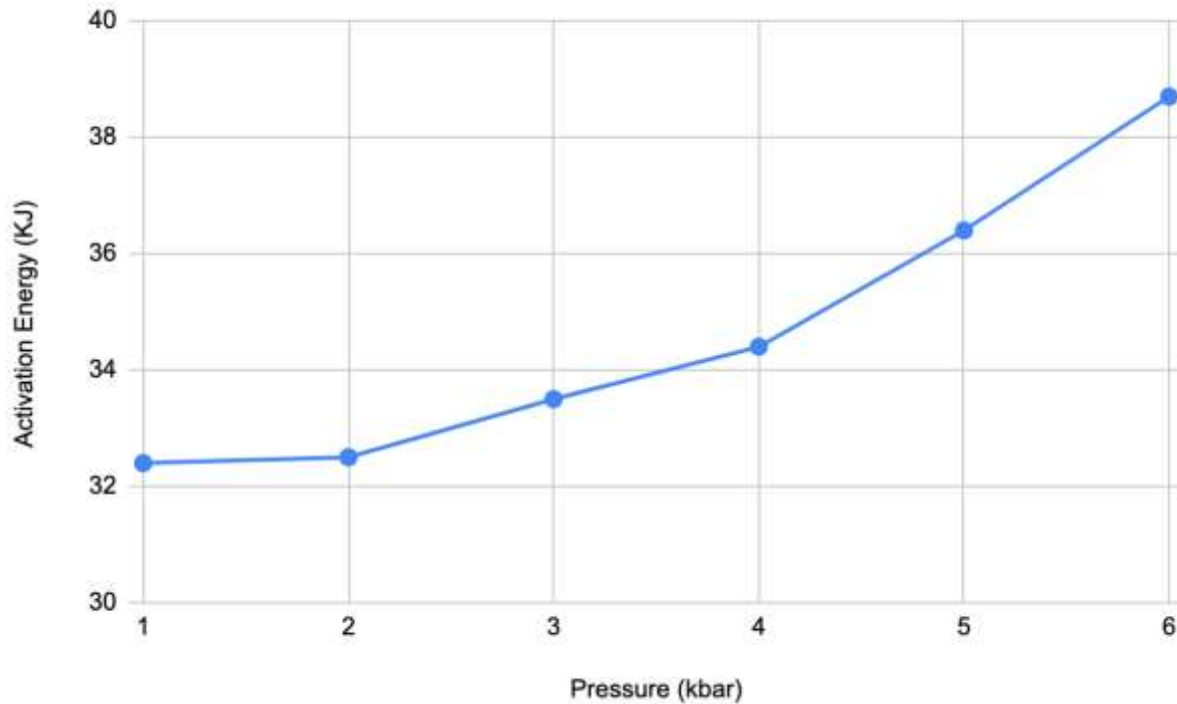

Fig 3: Activation energy E_a (KJ) as a function of pressure

Lastly, at atmospheric pressure, the viscosity data for glycerol-water mixture as a function of temperature is available in the literature [9]. This viscosity (cp) data could be fitted to the polynomial equation

$$\text{In } \eta = \sum_{i=0}^{n} A_i \, (1/T)^i \tag{3}$$

for temperature (K) variation. The values of the coefficient are $A_o = 4.3857$, $A_1 = -3.4601 \times 10^{-3}$, $A_2 = 3.2942 \times 10^{-5}$, $A_3 = 215.4200 \times 10^{-6}$. This equation could be used to determine viscosity(cp) of glycerol water mixture at elevated temperature and atmospheric pressure.

Conclusion

The present study has contributed experimental viscosity data for glycerol-water mixture at temperatures 38° C, 50° C ,75 ° C and 95° C and pressures ranging up to 6.3kbar. It is evident from illustrations that the viscosity increases multifold with pressure and decreases with temperature. Based on the measured data, empirical relation is developed which is found to give a good representation of our results within the estimated accuracy of ± 1 percent. It is observed that the differential pressure coefficient of logarithmic η decreases with both pressure and temperature, while the variation in activation energy is slow up to 3 kbar and then tends to be faster at higher pressure. We hope that this data could be useful to provide some standard materials to compare with, while looking for suitable liquids for hydrostatic extrusion and high-pressure technology.

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