

VISCOSITY BEHAVIOR OF GLYCEROL WITH PRESSURE AND TEMPERATURE

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Abstract: Experimental viscosity data is reported for glycerol with pressure up to 6.1kbar in the temperature range of 30°C to 90°C with accuracy of ± 1 percent using a rolling-ball viscometer. The experimental data has been represented by suitable empirical relations for pressure and temperature variation to facilitate interpolation. This data has been used to determine the activation energy of viscous flow as a function of pressure and differential pressure coefficient of viscosity as a function of pressure and temperature. Our results have been compared with available literature and found to be in good agreement. The viscosity(cp) of this system with temperature and at atmospheric pressure is available in the literature. This data has been fitted by an empirical relation to predict viscosity(cp) with temperature at atmospheric pressure.

Keywords: Viscosity, Activation Energy, hydrostatic extrusion, Glycerol, Viscometer

INTRODUCTION

The knowledge of the effect of pressure and temperature on viscosity of glycerol has considerable practical interest. 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. Infact, 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 was 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 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. P. N. Shankar and Manoj Kumar [3] have measured the kinematic viscosity of glycerol-water mixtures in the temperature range 10-50° 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 to 100°C. Recently, 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. Thus, it is clear from foregoing references that a more extensive and accurate study of viscosity behavior of glycerol is desirable as a function of pressure and temperature.

EXPERIMENTAL AND MATERIALS

The experimental set up used in this work consists of three main parts i.e. Pressure Generator, Pressure Vessel & Constant Temperature Bath enclosing it and Measuring System. A detailed description of this equipment is given in our previous work [6]. Since the viscosity range involved here is generally comparable to that of the lubricants considered in Prasad [7], the same procedure is employed to measure the viscosity with pressure and temperature.

The glycerol used in this study is obtained from E. Merc (Germany), who claim purity of 90 percent. Therefore, it is subjected to double distillation. The density measurement of the distillate at 20°C indicated agreement with the standard density of pure glycerol, 0.03 percent.

RESULTS

The relative viscosity η_p/η_o (ratio of the viscosity at elevated pressure to at atmospheric pressure) of glycerol has been determined here in the pressure range starting from atmospheric pressure up to 6.1 kbar at temperatures 30, 50, 75 and 90°C. The results of our measurements are presented in Tables 1. At each temperature these results could be fitted to the polynomial equation

$$\text{Log } \eta_r = \sum_{i=0}^n a_i p^i \quad (1)$$

where pressure P is measured in bar. The values of coefficients of eq. (1) 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 ± 1 percent. The nature and extent of the deviation between the actual data and the values calculated from Eq. (1) is illustrated by giving full details at 30 and 50°C in Table 1.

Table 1 – Relative viscosity η_r of Glycerol as a function of pressure and temperature

P (bar)	η_r at 30°C		P (bar)	η_r at 50°C		P (bar)	η_r at 75°C		P (bar)	η_r at 90°C	
	Exptl	Cal		Exptl	Cal		Exptl	Cal		Exptl	Cal
1	1	1	1	1	1	1	1	1	1	1	1
378	1.420	1.422	365	1.214	1.215	392	1.196	405	1.170		
678	1.497	1.500	584	1.360	1.362	642	1.344	696	1.305		
980	1.792	1.789	1114	1.785	1.783	1117	1.640	1117	1.546		
1215	2.056	2.049	1635	2.301	2.301	1626	2.040	1617	1.870		
1726	2.735	2.733	2170	2.964	2.964	2170	2.532	2134	2.256		
2227	3.588	3.600	2665	3.719	3.716	2655	3.046	2632	2.272		
2885	5.113	5.114	3164	4.649	4.647	3139	3.644	3200	3.395		
3179	5.978	5.962	3650	5.743	5.745	3660	4.375	3743	4.044		
3642	7.559	7.556	4220	7.309	7.322	4163	5.193	4163	4.562		
4112	9.550	9.564	4705	8.969	8.965	4670	5.229	4652	5.503		
4640	12.389	12.388	5265	11.309	11.301	5168	7.186	5121	6.504		
5139	15.742	15.736	5620	13.068	13.072	5642	8.406	5612	7.524		
			6094	15.843	15.849	6184	10.083	6152	8.921		

Table 2: Value of coefficient of Eq.(1)

Temp (0°C)	$a_0 \times 10^4$	$a_1 \times 10^4$	$a_2 \times 10^9$	$a_3 \times 10^{12}$	$a_4 \times 10^{16}$
30	-4.7059	2.6534	-7.34900	0.20500	-
50	-3.9489	2.3544	-9.26470	0.48476	-
75	4.3883	1.9229	-4.31820	-1.16360	1.44190
90	-8.5596	1.7061	-0.69054	-0.57957	0.44607

COMPARISON OF RESULTS

A comparison of our results with those reported by other authors is shown in Fig.1. It is observed that at 30°C Bridgman’s data practically overlap with our curves. However, at 75°C, Bridgman’s results show noticeable progressively increasing positive deviations from our results. A quantitative comparison of Bridgman’s data with our smoothed values is given in Table 3

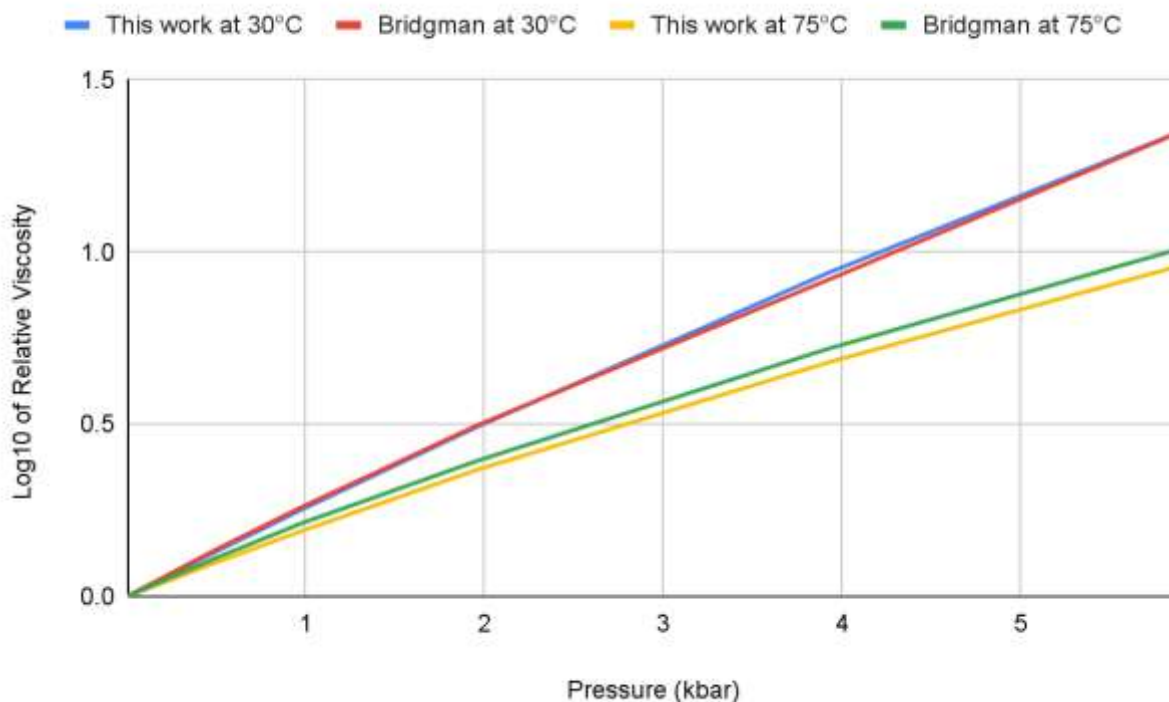


Fig 1: Comparison of present results and Bridgman’s data for glycerol

Table 3: Quantitative comparison of present results and Bridgman’s data

	TEMP (°C)			
	30		75	
P (bar)	This work	Bridgman	This work	Bridgman
1	1.000	1.000	1.000	1.000
490	1.342	1.361	1.250	1.288
980	1.789	1.820	1.551	1.633
1960	3.111	3.141	2.333	2.477
3920	8.691	8.300	4.778	5.236
5880	22.248	22.182	9.094	10.186

It may be noted from this table that at 30°C Bridgman’s results agree with our data within his claimed accuracy while at 75°C, the deviations are larger.

DISCUSSION OF RESULTS

First, we consider the variation of relative viscosity η_r , with pressure at a given temperature. In Fig. 2, we show a representative graph for 50°C using the data in Table 1. It may be observed that the viscosity increases rapidly with increase in pressure. The pressure coefficient of logarithm of viscosity has been determined as a function of pressure and temperature by using Eq. (1). The values obtained are given in Table 4.

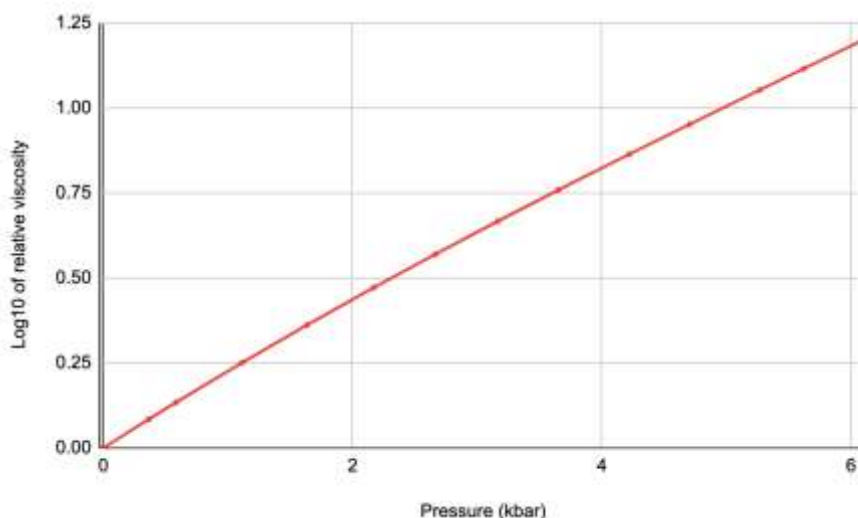


Fig 2: Variation of relative viscosity η_r , with pressure at 50°C

Table 4: Differential pressure coefficient $(d \eta/d P) \times 10^4$ with temperature and pressure

	< ----- Pressure in (kbar)----- >				
Temp (°C)	1	2	3	4	5
50	5.0	4.7	4.4	4.2	4.1
75	4.3	4.0	3.6	3.4	3.2
90	3.9	3.7	3.6	3.4	3.3

It may be seen from this table that the differential pressure coefficient decreases with both pressure and temperature.

Next, we consider the isobaric variation of viscosity with temperature. The activation energy E_a , on the basis of the Eq. (4) in Prasad [7] is determined using the linear part of the $\text{Log } \eta$ versus $1/T$ curves. The values of E_a , are given in Table 5.

Table 5: Activation energy E_a (kJ) as a function of pressure

Pressure in (kbar)	1×10^{-3}	1	2	3	4	5	6
Activation Energy (kJ)	45.1	49.3	50.5	52.5	53.4	54.1	53.8

We have also plotted the variation of E_a versus pressure in Fig. 3. It may be seen that E_a increases up to 3 kbar and then slowly tends to a constant value above 5 kbar. Any theory of viscosity could explain this type of behavior.

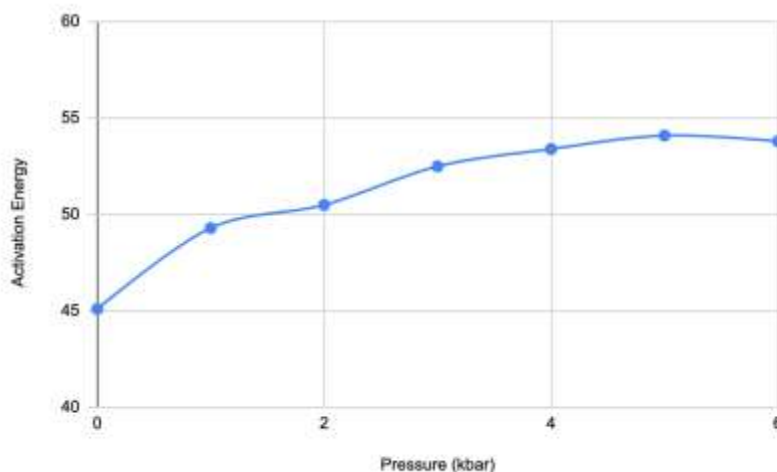


Fig 3: Activation energy E_a (kJ) as a function of pressure

Lastly, at atmospheric pressure, the viscosity of glycerol as a function of temperature are available in the literature [8]. These viscosity (cp) data could be fitted to the polynomial equation

$$\ln \eta = \sum_{i=0}^n A_i (1/T)^i \quad (2)$$

for temperature (K) variation. The values of the coefficient are $A_0=7.1118$, $A_1= -7.8071 \times 10^{-3}$, $A_2 = 23.365 \times 10^{-5}$ and $A_3 = -4.9230 \times 10^{-6}$. This equation could be used to determine viscosity(cp) of this system at elevated temperature and atmospheric pressure.

Conclusion

The present study contributed to a reliable experimental database for glycerol at various temperatures between 30° C to 90° C and pressures ranging up to 6.1 kbar. It is evident from illustrations that the viscosity increases rapidly with pressure and decreases with temperature. Based on the measured data, an empirical relation is developed which is found to give a good representation of our results within the estimated accuracy of ± 1 percent. A comparison of our results with available literature is in good agreement except for 75° C, where deviations are much larger. The differential pressure coefficient of viscosity decreases with both pressure and temperature. It is also observed that the activation energy increases up to 3 kbar and then slowly tends to a constant value above 5 kbar. It is hoped that this data could be useful for the hydrostatic extrusion industry.

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