

# Variation of Viscosity of Castor Oil and Silicone oil with Pressure and Temperature

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**Abstract:** Variation of viscosity data is reported for castor oil and silicone oil with pressure up to 6kbar and temperature from 30 °C to 90°C with accuracy  $\pm 1$  percent, using a rolling-ball viscometer. The results of viscosity of these systems with temperature and atmospheric pressure are also reported with estimated accuracy  $\pm 1$  percent. The experimental data have been represented by empirical relations for pressure and temperature variation. This data has also been used to determine the activation energy of viscous flow as a function of pressure and differential pressure coefficients as a function of pressure and temperature. At the end, Kiran and Sen Observations are also checked with the average modulus of deviation (MD) being less than 1.8 percent.

**Keywords:** Viscosity, Activation Energy, Hoppler's Viscometer, Hydrostatic Pressure, Lubricants

## 1. Introduction

Variation of viscosity with pressure and temperature is an important indicator of lubricating oil and has an important impact on the performance of the lubricating oil. Viscosity increases with increase in pressure and decreases with increase in temperature. So, if the viscosity is too large, it will cause the equipment to start difficult, and also makes the oil cannot be cycled normally among the equipment, resulting in equipment lubrication failure. However, if the viscosity is too small, it is difficult to form a solid oil film, and then cannot achieve the role of reducing friction. Therefore, the choice of the correct viscosity of lubricating oil is of great importance to the normal use of the equipment. At the same time, in the oil monitoring process, viscosity is often the test item. Therefore, this type of information is needed in order to evaluate the suitability and limitation of various lubricating oils for use in commercial engines and also as hydrostatic pressure transmitting media in high pressure technology. Further, it has become important to characterize new synthetic oils for practical use as lubricants.

A number of workers (1-8) have investigated viscosity of lubricating systems using various techniques. Of these the first significant study of pressure dependence of viscosity is that of Hyde [1] who reported viscosity data for several lubricating oils up to 1.5 k bar. A group led by Bradbury and Mark [2] measured the viscosity of 55 well defined lubricants to 12 kbar at 218°C. Brooks and coworkers [3] have reported viscosity of 5 lubricant base stocks (unformulated) at elevated pressure. Abbott and coworkers [4] measured the viscosity of a few lubricants, viz., a synthetic turbine engine oil, a mineral oil, white gasoline and 1: 1 mixture of mineral oil and white gasoline at pressure up to 3 kbar and temperature in the range of 20 to 200°C. Scott Bair [5] measured viscosity for pressure to 1.4GPa and temperatures to 165°C for various lubricants including automotive transmission fluids, aerospace lubricants, turbine oil etc. Longfei Li [6] measured the viscosity of lubricating oil by a viscometer based on the Hele principle. Oyedeko K. F. K. Akinyemi et al [7] gave a prediction of viscosity of automobile lubricants at different temperatures. Recently, Prasad [8] investigated viscosity of mobile oil and paraffin oil to pressure up to 5.2kbar in the

temperature range 30 °C to 90°C. From these references, it may be noted that the lubricants taken by these authors are either mineral oils or organic based lubricating oils. Further, the purity of these lubricating oils, particularly organic based lubricants depending upon the source from which these are obtained. Therefore, it becomes essential to measure the viscosity of such lubricating oils before their application in technology.

## 2. Experimental and Materials

We have used Hoppler's Falling Ball Viscometer for the measurement of viscosity at atmospheric pressure as a function of temperature. The experimental set-up and other procedural details employed is given in [8]. For viscosity measurement at elevated pressure at various temperatures, the experimental set-up and procedure described in [9] is employed. However, the ball used for the present measurements has a lower diameter than in the case of normal pentane because of the higher viscosity of investigated lubricants. Further, the working range of the inclination angle  $\theta$ , in which the calibration coefficient remains constant is determined in each case. Other procedural details have been given in [9]. The average of five to eight rolling-times is used for the calculation of viscosity.

Relevant information about the lubricating oils (available in the local market) used in this investigation is summarized below

Sample	Density (g/cc) at 20°C	Viscosity (cp)
Castor Oil	0.9605	238.00 (at 40°C)
Silicone Oil	0.9613	16.70 (at 20°C)

## 3. Results and Discussion

Viscosity of lubricating oils has been measured at different temperatures between 20°C to 90°C at atmospheric pressure. The results of our measurements for castor oil and silicone oil are given in Table 1. The coefficient of viscosity  $\eta$  (cp) as a function of temperature at atmospheric pressure could be fitted to the polynomial equation

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

For temperature (K) variation. The values of coefficients for each system are given in Table 2

**Table 1:** Coefficient of Viscosity  $\eta$  (cp) at atmospheric pressure

Temp (°C)	Silicone Oil	Castor Oil
20	61.25	-
30	50.94	-
40	42.43	238.13
50	35.7	132.23
60	30.38	79.76
70	26.14	50.64
80	22.59	34.17
90	19.71	24.27

**Table 2:** Values of the coefficients in Eq. (1)

Lubricants	$A_0$	$A_1 \times 10^{-3}$	$A_2 \times 10^{-5}$	$A_3 \times 10^{-8}$
Castor Oil	0.10084	0.083798	-4.0289	2.8298
Silicone Oil	-2.1053	1.9358	-0.32252	-

The relative viscosity  $\eta_r$  (ratio of viscosity at elevated pressure to the viscosity at atmospheric pressure), is measured at various temperatures between 30°C to 90°C and pressure range up to 6kbar. These results for the above-mentioned systems are given in Table 3 and 4. At each temperature our results could be expressed in terms of pressure to the polynomial equation.

Where pressure P is measured in the bar. The values of the coefficients are given in Table 5. Third to fourth order

**Table 5:** Values of coefficients in Eq. (3)

	Temp (0°C)	$a_0 \times 10^3$	$a_1 \times 10^4$	$a_2 \times 10^7$	$a_3 \times 10^{11}$	$a_4 \times 10^{15}$	$a_5 \times 10^{19}$
Castor Oil	30	-0.89713	7.2458	-0.2995	-2.8821	7.3742	-
	50	-0.7707	6.3783	0.078527	-6.9389	25.149	-26.068
	70	-0.13031	6.2215	-1.0718	2.4072	-2.3556	-
	90	-0.10339	5.4177	-0.6822	0.7696	-0.12366	-
Silicone Oil	40	-0.78901	8.1105	-2.6068	7.7668	-8.3622	-
	50	0.41905	7.8077	-2.2649	5.7185	-5.0828	-
	70	-0.772	6.1578	-1.8193	3.947	-3.121	-
	90	-1.0132	6.386	1.259	1.3828	1.6629	-

It is evident from the results given in the tables, it is clear that for both systems the viscosity at any temperature increases with pressure; on the other hand, at a given pressure it decreases with temperature. Such a behavior is to be expected from any rate process and the quantitative variation is most simply represented by the equation

$$\eta = A e^{B/T} \quad (3)$$

polynomials are required to give a representation of our results within our experimental accuracy of  $\pm 1$  percent.

**Table 3:** Relative viscosity ( $\eta_r$ ) of Silicone Oil as a function of pressure and temperature

P (bar)	$\eta_r$ 40°C	P (bar)	$\eta_r$ 50°C	P (bar)	$\eta_r$ 70°C	P (bar)	$\eta_r$ 90°C
1	1.000	1	1.000	1	1.000	1	1.000
385	1.642	394	1.889	396	1.805	379	1.81
645	2.710	649	2.705	652	2.504	634	2.269
1052	4.420	1096	4.425	1096	4.103	1085	3.664
1292	5.717	1608	7.483	1681	7.095	1601	5.795
1614	7.883	2177	12.714	2227	11.217	2126	8.735
2177	19.966	2682	20.207	2701	16.479	2609	12.391
2660	22.606	3168	32.303	3172	24.161	3050	18.199
3258	41.541	3622	49.643	3616	34.774	3629	25.813
		4040	75.213	4152	54.015	4112	36.960
						4607	52.995
						5121	74.470
						5594	94.588
						6062	125.165

**Table 4:** Relative viscosity ( $\eta_r$ ) of Castor Oil as a function of pressure and temperature

	$\eta_r$		$\eta_r$		$\eta_r$		$\eta_r$
P (bar)	30°C	P (bar)	50°C	P (bar)	70°C	P (bar)	90°C
1	1	1	1	1	1	1	1
375	1.842	406	1.801	398	1.706	393	1.595
656	2.84	642	2.492	685	2.432	721	2.297
1078	5.273	1031	4.13	1092	3.765	1070	3.212
1345	7.473	1556	7.144	1615	6.463	1587	5.222
1636	10.667	2072	12.597	2134	10.621	2036	7.665
2018	16.839	2578	18.564	2635	16.669	2565	11.621
2410	26.105	3096	36.287	3085	24.647	3150	18.089
2829	42.547	3600	64.212	3612	38.209	3653	26.41
		4109	113.257	4141	56.886	4109	37.409
		4427	152.584				
		4710	192.685				

where A and B are constants. Here the constant B =  $E_a/R$  defines the activation energy connected with viscous flow.

We have shown the pressure and temperature variation of viscosity suitably by plotting a number of graphs derived from certain quantitative results of interest shown in Fig 1 to 4.

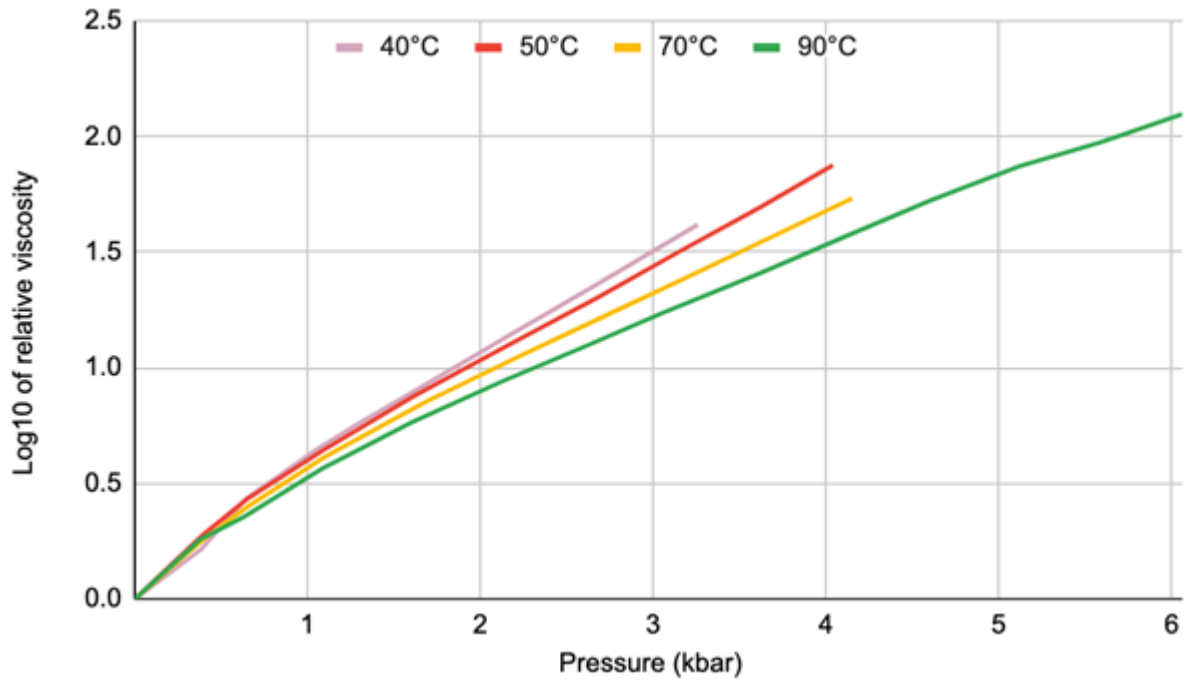


Figure 1:  $\text{Log}_{10}(\eta_r)$  Vs Pressure for Silicone Oil at different temperatures

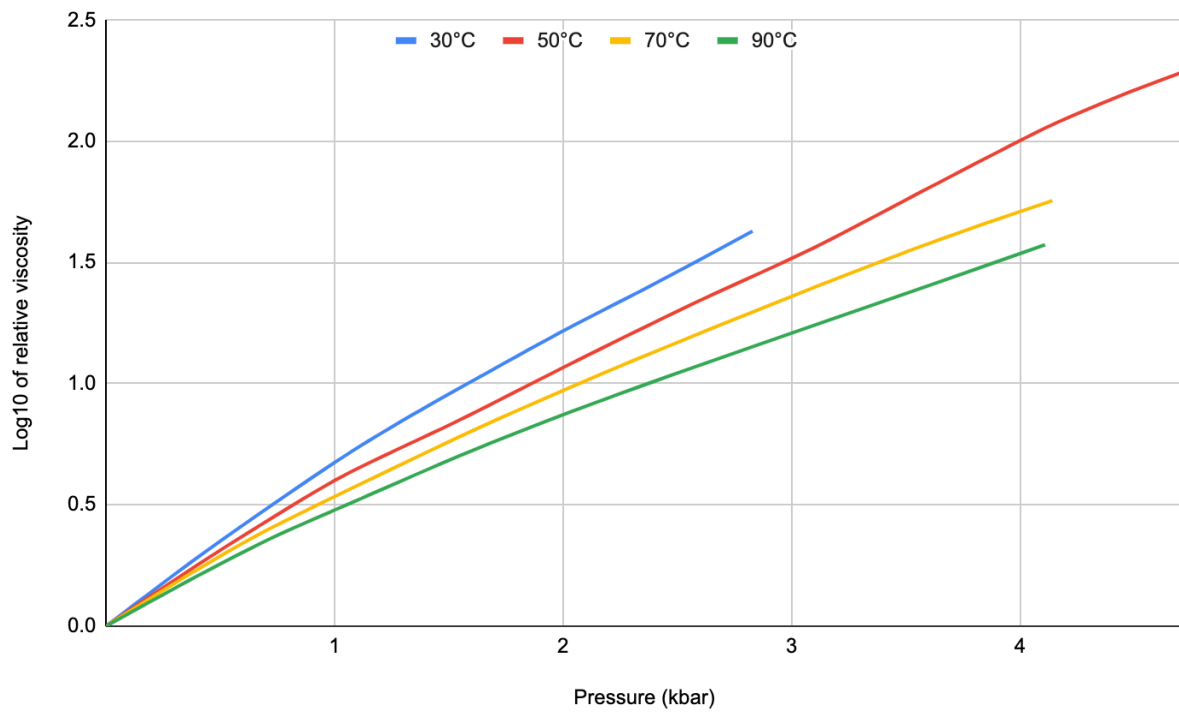


Figure 2:  $\text{Log}_{10}(\eta_r)$  Vs Pressure for Castor Oil at different temperatures

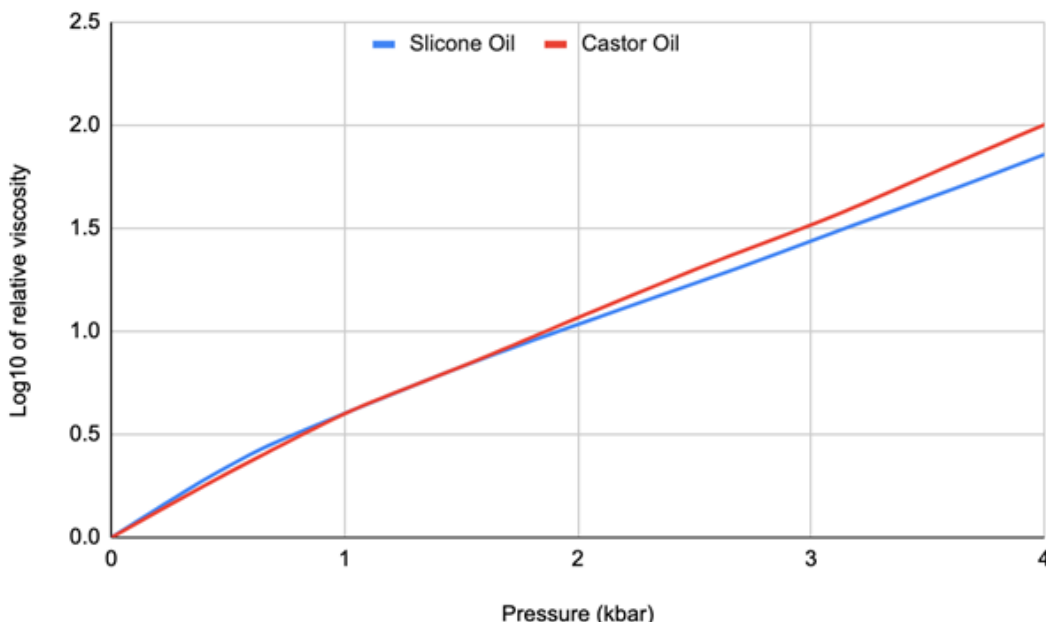


Figure 3: Comparison of  $\text{Log}_{10}(\eta_r)$  Vs Pressure at  $50^\circ\text{C}$

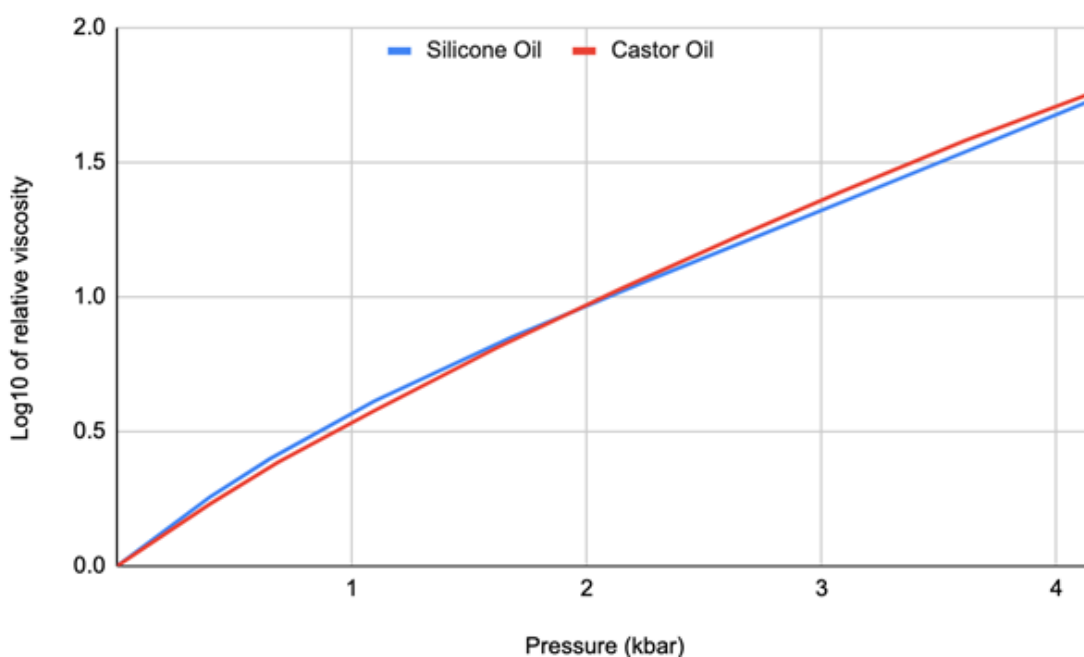


Figure 4: Comparison of  $\text{Log}_{10}(\eta_r)$  Vs Pressure at  $90^\circ\text{C}$

It may be noted from these figures that at a given temperature, viscosity increases with pressure rapidly at first and then more slowly. The differential pressure coefficient of log of viscosity at  $50^\circ\text{C}$  and  $90^\circ\text{C}$  for both cases has been determined at 1 and 3 kbar using Eq. (3). The values obtained are given in Table 6.

Table 6: Differential pressure coefficients of  $(d \ln \eta / d P) \times 10^4$

	Castor Oil		Silicone Oil	
	Pressure in 1 kbar	Pressure in 3 kbar	Pressure in 1 kbar	Pressure in 3 kbar
Temp = $50^\circ\text{C}$	12.3	10.9	11	9.6
Temp = $90^\circ\text{C}$	9.8	6.6	9.9	7.1

It is observed that the differential pressure coefficients of  $\log \eta$  for each system decreases with both pressure and temperature.

The activation energy on the basis of Eq. (3) is determined for each system as a function of pressure using the linear part of the log of viscosity versus the reciprocal of the absolute temperature curves. These values of  $E_a$  for all the systems as a function of pressure are given in Table 7. We have plotted activation energy with pressure as shown in Fig.5. It is clear from the graph that  $E_a$  increases with increase in the pressure.

Table 7: Activation energy  $E_a$  (kJ) as a function of Pressure

System	<----Pressure in (kbar)---->			
	$1 \times 10^{-3}$	1	2	3
Castor Oil	47.4	52.1	58.3	64.3
Silicone Oil	14.5	18.6	22.4	27.3

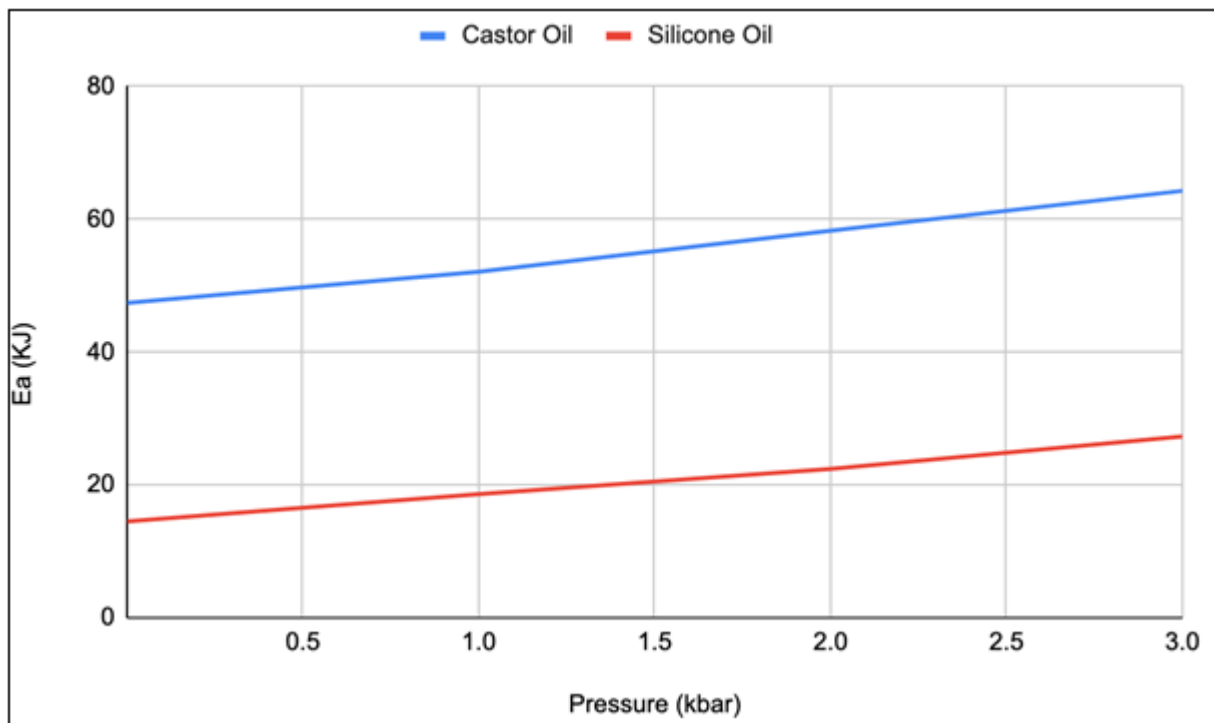


Figure 6: Variation of Activation Energy (E<sub>a</sub>) with pressure

Lastly, we have tried the Equation from Kiran and Sen [10] for the representation of viscosity data of both the systems. The values of parameters B<sub>1</sub>, B<sub>2</sub> and B<sub>3</sub> (along with the pressure limits) for each system are given in Table 9. Average modulus of the deviation (MD) of the values calculated from Equation using these parameters values from our smoothed experimental values are also given in Table 9. Our analysis shows that with our parameter values, MD is less than 2 percent.

Table 9: Values of the parameters in Eq by Kiren and Sen

Temp (0°C)	B <sub>1</sub> x 10 <sup>19</sup>	B <sub>2</sub> x 10 <sup>2</sup>	B <sub>3</sub> (mPa. S)	MD (%)
Castor Oil (pressure limit 1.1kbar)				
50	3.7494	3.5444	21.15	1.8
70	910.73	2.9056	6.17	0.8
90	1147.1	2.8111	5.07	0.7
Silicone Oil (pressure limit 2.2 kbar)				
Temp (0°C)	B <sub>1</sub> x 10 <sup>10</sup>	B <sub>2</sub> x 10 <sup>2</sup>	B <sub>3</sub> (mPa. S)	MD (%)
40	0.1409	2.2588	18.6	1.8
50	1.7062	2.0089	11.26	1.4
70	1.6175	2	10.9	1
90	8.5348	1.8102	8.57	1.2

#### 4. Conclusion

The present study contributed to a reliable experimental database for two lubricants namely castor oil and silicone oil at various temperatures between 30° C to 90° C and pressures ranging up to 6 kbar. It is evident from illustrations that as expected, the viscosity increases 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. The estimated error in the present viscosity data is + 1 percent. 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 reported. Our analysis shows that

with our parameter values, MD is less than 1.8 percent. It is hoped that this data could be useful for industry.

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