ORIGINAL PAPER

A NEW VISCOSITY-SHEAR RATE RELATIONSHIP FOR MINERAL OIL

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Abstract. *This article proposes four relationships of dynamic viscosity – shear rate dependence for mineral oil. The purpose of this study was to find a exponential dependence between temperature and dynamic viscosity of mineral oil, using the equations. Equation constants A, B C, D, E and F were determined by fitting exponential.*

Keywords: *viscosity-shear rate, mineral oil, relationship.*

1. INTRODUCTION

Viscosity study has been widely studied by scientist and engineers on various purposes. These include polymer science, heat transfer phenomena, petroleum reservoir development, coatings, scale modeling of magnetic intrusion, oil degradation, lubrication, etc. [1-6]. Viscosity is influenced by different factors, such as, additive, catalyst, temperature, shear rate, time, molecular weight, moisture, pressure, concentration, etc. Among these, temperature and shear rate are the most studied parameters.

In general, viscosity is defined as the ratio of shear stress (force over cross section area) to the rate of deformation (the difference of velocity over a sheared distance), and it is presented by:

$$\eta = \tau / \dot{\gamma} \tag{1}$$

where, η, dynamic viscosity (Pa.s); τ , shear stress (N/m^2); and , $\dot{\gamma}$ rate of deformation or velocity gradient or better known as shear rate (1/s). This relation will gives constant viscosity, if shear stress is proportionally changed with velocity gradient. Fluid that follows this behavior is termed as Newtonian fluid [7].

However, in the measurement of viscosity, an increase in shear stress leads to a greater portion increase in shear rate, and therefore, reducing viscosity value as indicated by viscometer. This phenomenon is known as shear-thinning behavior. For inverse observation, it exhibits shear-thickening. In this study, the authors limit the following literature reviews to shear-thinning, which is the topic of the current study.

Thus, in nature, Equation (1) has failed to provide a good representation of real phenomena for all fluids. It indicates the presence of scientific gap for which new equation is needed. There were numerous researchers responded to propose alternative equation. Among

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those equations are power-law, Cross, Carreau, Bingham, Herschel-Bulkley, Casson, Sisko, etc. These equations are presented in sequence as followings [7-11]:

Bingham:

$$\tau = \tau_o + \eta\dot{\gamma} \tag{2}$$

Casson:

$$\tau^{1/2} = \tau_o^{1/2} + \eta^{1/2}\ \dot{\gamma}^{1/2} \tag{3}$$

Ostwald-de Waele:

$$\tau = k\dot{\gamma}^{n} \tag{4}$$

and Herschel-Bulkley:

$$\tau = \tau_o + k\dot{\gamma}^{n} \tag{5}$$

where τ is the shear stress, τo – yield stress, η - viscosity, $\dot{\gamma}$ - shear rate, n – flow index and k – index of consistency.

This article proposes four new relationships of dependence of dynamic viscosity of mineral oil shear rate. Dynamic viscosity of oils was determined at temperatures and shear rates, the 90 ºC and the 40 ºC, respectively, 3.3 - 120 s^{-1}. The purpose of this study was to find an exponential dependence between shear rate and dynamic viscosity of mineral oil no additive using differed equations. Equation constants A, B C, D, E and F were determined by fitting exponential.

2. MATERIALS AND METHODS

Mineral oil no additives used in this work are provided by a company from Bucharest, Romania.

Mineral oil were investigated using a Haake VT 550 Viscotester developing shear rates ranging between 3 and 120 s^{-1} and measuring viscosities from 104 to 106 mPa.s when the HV1 viscosity sensor is used. The temperature ranging was from 40 to 90 ºC and the measurements were made from 10 to 10 degrees. The accuracy of the temperature was $\pm$ 0.1 ºC.

3. RESULTS AND DISCUSSION

Figs. 1 – 6 show the dynamic viscosity shear rate dependence for studied mineral oil at temperatures absolute. The behavior of oil mineral that the dynamic viscosity decreases with increasing shear rate at temperatures absolute.

This article proposes four equations (6) - (8) shear rate dependence of dynamic viscosity checked only for mineral oil. The software Origin 6.0 was used to determine constants equation for mineral oil. In addition, the parameters A, B, C, D, E, η_0 and F change with temperature. Therefore, by imposing constant temperature, the parameters can be determined. In order to determine the equation constants, the following steps were performed using the Origin 6.0 software: load the non-linear regression package, input experimental data, title x-label, y-label and set the required equation, perform non-linear regression and plot experimental data and best fitted curve, calculate the mean square error and coefficient of determination and show the best fitted equation constant, mean square error and coefficient of determination.

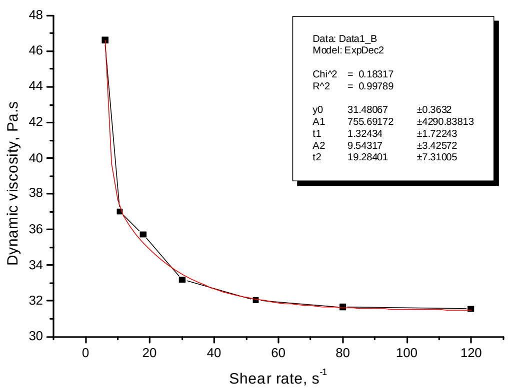

Fig. 1. The viscosity dynamic of investigated oil as a function of shear rate of mineral oil at temperature absolute 313K.

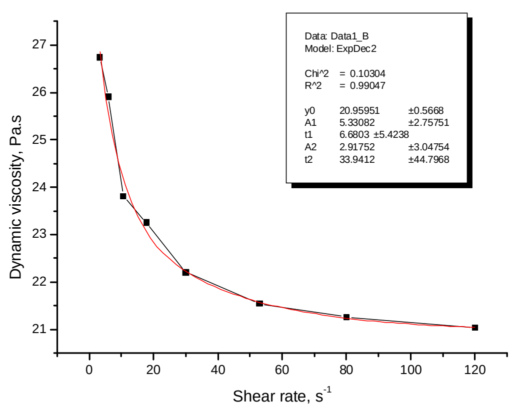

Fig. 2. The viscosity dynamic of investigated oil as a function of shear rate of mineral oil at temperature absolute 323K.

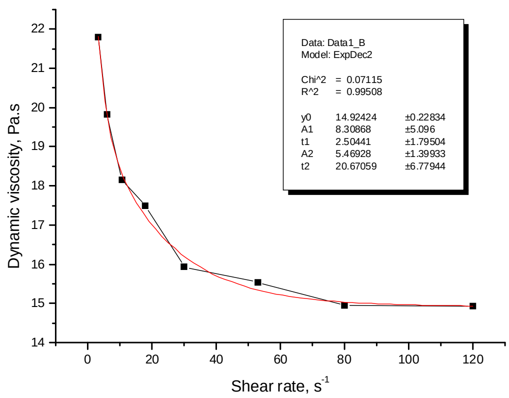

Fig. 3 .The viscosity dynamic of investigated oil as a function of shear rate of mineral oil at temperature absolute 333K.

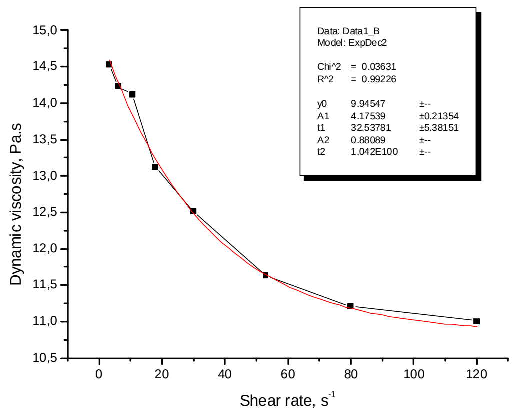

Fig. 4 .The viscosity dynamic of investigated oil as a function of shear rate of mineral oil at temperature absolute 343K

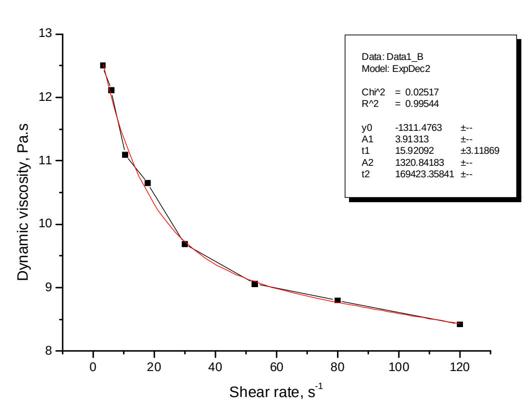

Fig. 5. The viscosity dynamic of investigated oil as a function of shear rate of mineral oil at temperature absolute 353K.

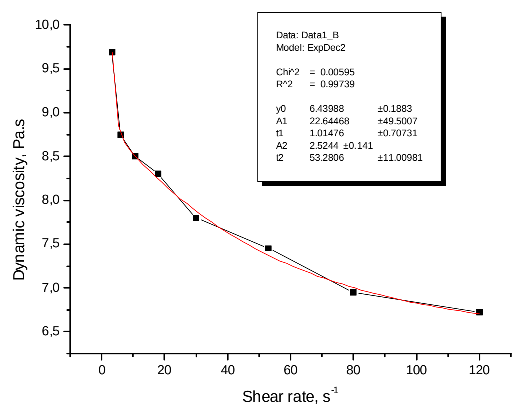

Fig. 6. The viscosity dynamic of investigated oil as a function of shear rate of mineral oil at temperature absolute 363K.

Tables 1 – 3 show the constants mineral oil. As shown in Tables 1 – 3 the software found it exponential equations applied temperature curves of mineral oil. The root mean square error means that experimental data is spread equation. Remains the same shear rate range, where the equation was fitted other experimental data.

From the results of the regression tabulated in tables 1 – 3, the lowest coefficient of determination and the highest mean square error were 0. 9456 and 0.9975, respectively.

$$\eta = \eta_0 + A\exp(-\dot{\gamma}/B) \quad (6)$$

$$\eta = \eta_0 + A\exp(-\dot{\gamma}/B) + C\exp(-\dot{\gamma}_0/D) \quad (7)$$

$$\eta = \eta_0 + A\exp(-\dot{\gamma}/B) + C\exp(-\dot{\gamma}/D) + E\exp(-\dot{\gamma}/F) \quad (8)$$

were A, B, C, η_0, D, E and F was constants mineral oil and variation with temperature.

Table 1. The temperature, value of parameters of the theoretical model described by equation (6), coefficient correlation for mineral oil .

Temperature, K	Value of parameters of the theoretical model described by equation (6)			R^2
	η_0	A	B	
313	32.3024	38.0545	3.2823	0.9575
323	21.1645	6.0613	17.0856	0.9745
333	15.1522	8.2474	12.1258	0.9809
343	10.8806	4.1247	32.0645	0.9926
353	8.5627	4.5268	21.9322	0.9919
363	6.7938	2.7998	28.4838	0.9456

Table 2. The temperature, value of parameters of the theoretical model described by equation (7), coefficient correlation for mineral oil.

Temperature, K	Value of parameters of the theoretical model described by equation (7)					R^2
	η_0	A	B	C	D	
313	31.4896	671.2114	0.7473	9.3350	11.5444	0.9975
323	20.9199	4.6616	12.1131	1.8895	44.4462	0.9761
333	14.9242	8.3087	2.5044	5.4693	20.6706	0.9951
343	10.0329	4.1754	32.5399	0.7933	1.6377E9	0.9923
353	-51.5536	3.9145	15.9279	60.9176	7760.1808	0.9954
363	6.4765	2.7998	28.3800	0.3196	-7.7381E118	0.9456

Table 3. The temperature, value of parameters of the theoretical model described by equation (8), coefficient correlation for mineral oil .

T, K	Value of parameters of the theoretical model described by equation (8)							R^2
	η_0	A	B	C	D	E	F	
313	30.3759	713.0671	0.7369	9.3581	11.5221	1.1143	-3.2861E94	0.9975
323	20.4667	6.4096	15.6645	-30.9707	0.7310	0.7369	-7.1699E95	0.9758
333	14.2151	8.3141	2.4548	5.4529	19.7921	0.8159	-6.5478E148	0.9946
343	9.6359	4.6896	37.9219	0.9006	-246.2583	-0.2644	-9.3638E91	0.9929
353	7.6617	3.6237	14.7862	1.8274	106.6486	0.1857	-7.7408E87	0.9951
363	6.2275	2.1467	13.6703	1.1376	92.8954	0.4069	-8.6508E146	0.9511

4. CONCLUSIONS

This article proposes four new relationships dynamic viscosity dependence of the shear rate mineral oil no additive. Check the only mineral oil. Equation constants were determined by exponential beast curves obtained at different temperatures using the program Origin 6.0. The correlation coefficients thus obtained were 0.9456 and 0.9975 values between.

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