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NEW RHEOLOGICAL MODELS FOR MINERAL OIL

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Abstract. *This article proposes new rheological models for mineral oil. The purpose of this study was to find an exponential and linear dependence between temperature and dynamic viscosity of mineral oil, using the equations. Equation constants a, b c and* τ_o *were determined by fitting exponential.*
Keywords: *viscosity-shear rate, mineral oil, relationship.*

1. INTRODUCTION

Viscosity is a measure of the "shear strength" of a thin layer of oil [1, 2] or, in other words, of the property the oil has to develop and maintain a certain amount of shearing stress dependent on flow, and than to offer continued resistance to flow.

The temperature the oil is exposed to in vehicles ranges from cold ambient temperatures in the winter before the vehicle is started up to hot operating temperatures when fully warmed up in summer.

The changes in viscosity with increasing temperature can be reduced using lubricating oil additives, called also viscosity index improvers or modifiers. Such additives are special polymers that, added to low viscosity oils, improve their viscosity/temperature characteristics [3-5].

They effectively thicken the oil at all temperatures, but the increase of viscosity is more pronounced at high temperatures. The lubricating effect is extended across a wider temperature range and the oil becomes thus a multi-grade one. Its viscosity still decreases logarithmically with temperature, but the slope representing the change is lessened. This slope is dependent on the nature and amount of additive to the base oil.

The rheological models for mineral oil that describes the deviations from the Newtonian behaviour [6, 7]:

Bingham:

$$\tau = \tau_o + \eta(d\gamma/dt) \quad (1)$$

Casson:

$$\tau^{1/2} = \tau_o^{1/2} + \eta^{1/2}(d\gamma/dt)^{1/2} \quad (2)$$

Ostwald-de Waele:

$$\tau = k\,(d\gamma/dt)^n \quad (3)$$

and Herschel-Bulkley:

$$\tau = \tau_o + k\eta(d\gamma/dt)^n \quad (4)$$

where τ is the shear stress, τ_o – yield stress, η - viscosity, $(d\gamma/dt)$ - shear rate, n – flow index and k – index of consistency.

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This article proposes four new rheological models for mineral oil. 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 shear stress of mineral oil using differed equations. Equation constants a, b c and τ_o were determined by fitting exponential and linear.

2. MATERIALS AND METHOD

Mineral oil SAE 10W used in this work are provided by a company from Bucharest, Romania.

Mineral oil SAE 10W were investigated using a Haake VT 550 Viscotester developing shear rates ranging between 3 and 120 s^{-1} and measuring viscosities from 10^4 to 10^6 mPa.s when the HV_1 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 ± 0.1 ºC.

3. RESULTS AND DISCUSSION

The rheograms for mineral oil SAE 10W at the specified temperatures and shear rates are shown in Fig. 1.

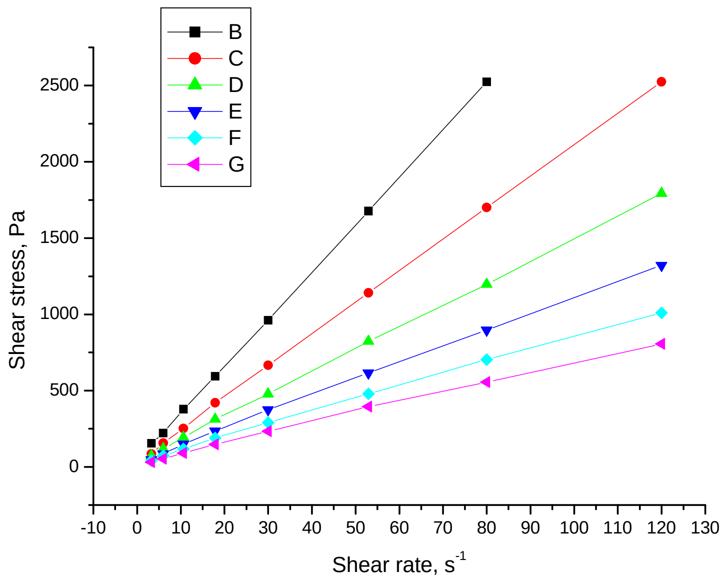

Fig. 1. Rheograms for mineral oil SAE 10W at: ■ - 313; ● – 323; ▲ – 333; ▼ – 343; ♦ - 353 and ◄ – 363K.

This article proposes four equations (5) - (7) shear rate dependence shear stresses 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 and τ_0 change with temperature.

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 0.9486 and 0.9999, respectively.

$$\tau = a + b\dot{\gamma} \quad (5)$$

$$\tau = a + b\dot{\gamma} + c\dot{\gamma}^2 \quad (6)$$

$$\tau = \tau_0 + a\exp(-\dot{\gamma}/b) \quad (7)$$

were a, b, c and τ_0 was constants vegetable oil and variation with temperature.

Table 1. Correlation constants for rheological model (eq.5) at different temperature ranging from 313 K to 363K.

Temperature [K]	Value of parameters of the theoretical model described by equation (5)		R^2
	a	b	
313	42.7174	30.9467	0.9999
323	34.0233	20.8112	0.9999
333	36.5924	14.6359	0.9999
343	31.9990	10.8212	0.9996
353	31.4310	8.2791	0.9994
363	23.3057	6.6329	0.9990

Table 2. Correlation constants for rheological model (eq.6) at different temperature ranging from 313 K to 363K.

Temperature [K]	Value of parameters of the theoretical model described by equation (6)			R2
	a	b	c	
313	50.2509	30.1948	0.0093	0.9999
323	26.6463	21.3598	-0.0047	0.9999
333	32.6288	14.9307	-0.0025	0.9998
343	20.6244	11.6671	-0.0072	0.9996
353	18.4721	9.2428	-0.0082	0.9998
363	10.1763	7.6094	-0.0083	0.9997

Table 3. Correlation constants for rheological model (eq.7) at different temperature ranging from 313 K to 363K.

Temperature [K]	Value of parameters of the theoretical model described by equation (7)			R^2
	τ_0	a	b	
313	3.0800E7	-3.0800E7	995233.4949	0.9999
323	2524.8000	-2677.3853	65.7294	0.9486
333	1792.8000	-1886.9682	66.0119	0.9485
343	1321.2000	-1391.2731	64.5266	0.9538
353	1010.4000	-1059.4790	63.3969	0.9560
363	806.4000	-849.4005	62.8175	0.9591

CONCLUSIONS

This article proposes the rheological models to describe the dependence of the shear stress of mineral oil with no additive, on the shear rate. Experimental data for one type of mineral oil were used to calculate the accuracy the proposed models. Equation constants were determined by exponential or polynomial beast curves obtained at different shear rates using the program Origin 6.0. The correlation coefficients thus obtained varied between 0.9486 and 0.9999.

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