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ORIGINAL RESEARCH PAPER

RHEOLOGICAL PROPERTIES OF RAPESEED OIL AND HYDRAULIC OIL

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Abstract: This article presents the rheological behavior of refined rapeseed oil and hydraulic oil. Apparent viscosity of both oils was determined at temperatures between 40 and 90°C and shear rates ranging from 3.3 to 120 s^{-1}. The aim of the study was to find a polynomial dependence of oil viscosity on temperature and shear rate. The modified Andrade equation was used. Constants A, B, C and correlation coefficient were determined by correlating a characteristic polynomial equation of each curve.

Keywords: *hydraulic oil, rapeseed oil, rheological behavior*

INTRODUCTION

Interest to researchers and manufacturers on the effect of temperature on oil viscosity increased in recent years [1, 2]. Although the issue seems simple, the contribution is very significant. This is because the viscosity is an important physical property for the design of hydraulic systems.

However, the lack of a precise model which is valid for all liquids is difficult to predict the effect of temperature on viscosity. There are known some commonly used mathematical models developed and expanded, i.e. Vogel-Fulcher, Arrhenius and Andrade [3, 4]. Models are developed using empirical data to predict the dependence of viscosity for a wide range of temperatures.

Vogel-Fulcher's model is one of the first attempts to predict liquid viscosities and has no sound theoretical basis. Later, based on the principles of statistical mechanics theories have done little to improve the accuracy of predictions Fulcher-Vogel viscosity liquid. As all current models are in error by as much as 30 to 150%, predicted viscosities can only orientatively be used. These calculations, however, are still useful, as long as the temperatures involved are below the boiling point and molar volume of liquid. In industrial applications, empirical formulas are generally used for more accurate prediction results.

As mentioned previously, among the famous and old viscosity-temperature law is the Vogel-Fulcher relationship [5-7]:

$$\eta = \eta_0 \exp [K/(T-T_\infty)] \quad (1)$$

Equation (1) requires at least three data points. Published viscosities, for one or more viscosities value at different temperatures, have limited value when viscosities are needed at temperatures other than those published ones. To avoid this from occurring, another equation was required to represent the experimental data. For most liquids at temperatures below the normal boiling point, the plot of ln η versus $1/T$ or ln η versus ln T is approximately linear [8]. Hence, most regressions are presented in the form as mentioned. A simplified form of equation (1) can be written according to Arrhenius type relation [9]:

$$\eta = A \cdot e^{Ea/RT} \quad (2)$$

Using the natural logarithmic format and higher-order polynomial in $1/T$ to give better accuracy, the modified Andrade's equation can be shown as [10, 11]:

$$\ln \eta = A + B/T + C/T^2 + D/T^3 + E/T^4 + \ldots \quad (3)$$

MATERIALS AND METHODS

Vegetable oil used in this work is provided by a company in Bucharest, Romania. In this paper we studied samples containing refined rapeseed oil and hydraulic oil containing no additives.

Vegetable oils have 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 ranged between 40 and 90°C with an increment of 10^0C. The accuracy of the temperature measurement was ± 0.1^0C.

RESULTS AND DISCUSSION

Figure 1 presents the rheogram of refined rapeseed oil. Correlation of shear rate versus dynamic viscosity at different temperatures (313 – 363 K) indicates an exponential decrease of viscosity with shear rate. The refined rapeseed oil has pseudoplastic behavior and correlation coefficient varies between 0.9494 and 0.9999.

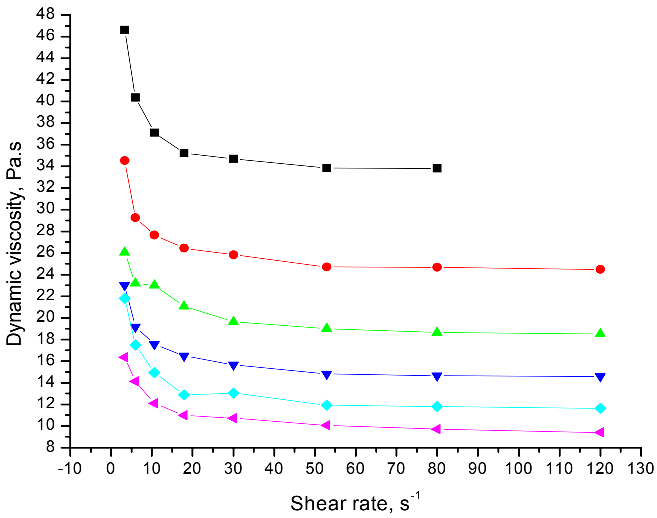

Figure 1. *Rheogram of refined rapeseed oil at: ■ – 313 K, ♦- 323 K, ▲- 333 K, ▼- 343 K, ♦- 353 K, ◀- 363 K*

Figure 2 presents the dependence of dynamic viscosity on shear rate at the same temperature values, for hydraulic oil. Hydraulic oil also acts pseudoplastic, correlation coefficients varying between 0.9849 and 1.0000.

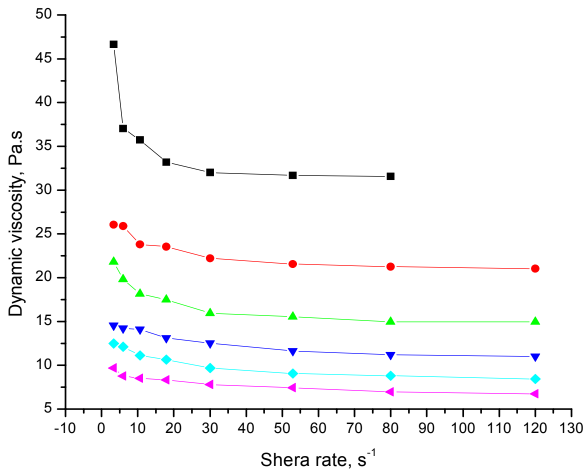

Figure 2. *Rheogram of hydraulic oil at: ■ – 313 K, ♦- 323 K, ▲- 333 K, ▼- 343 K, ♦- 353 K, ◀- 363 K*

The Origin 6.0 software was used in order to determine the Andrade constants for refined rapeseed oil and hydraulic oil. Andrade equation was modified, constant and higher order terms were eliminated, and equation (3) becomes:

$$ln\ \eta = A + B/T + C/T^2 \quad (4)$$

Oil viscosity is a function of temperature. In addition, the parameters *A*, *B* and *C* change with shear rate. Therefore, by imposing constant shear rate, 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.

Tables 1 and 2 show the rheological constants for refined rapeseed oil and hydraulic oil respectively.

From the results of the regression tabulated in Tables 1 and 2, the lowest coefficient of determination and the highest mean square error were 0.9494 and 1.0000, respectively.

Table 1. *Values of A, B, C constants from Andrade's equation, as determined with Origin 6.0 software, for refined rapeseed oil*

Shear rate, s^{-1}	**Constants from Andrade's equation**			**R^2**	**Temp. range (°C)**
	A	**B**	**C**		
3.30	4.0967	-0.3033	0.0165	0.9494	40 - 90
6.00	3.9954	-0.3369	0.0196	0.9916	40 - 90
10.60	3.8805	-0.2853	0.0093	0.9971	40 - 90
17.87	3.8556	-0.3047	0.0099	0.9988	40 - 90
30.00	3.8693	-0.3400	0.0153	0.9995	40 - 90
52.95	3.8596	-0.3552	0.0160	0.9998	40 - 90
80.00	3.8572	-0.3547	0.0152	0.9999	40 - 90
120.00	3.8004	-0.3242	0.0181	0.9999	40 - 90

Table 2. *Values of A, B, C constants from Andrade's equation, as determined with Origin 6.0 software, for hydraulic oil*

Shear rate, s^{-1}	**Constants from Andrade's equation**			**R^2**	**Temp. range (^{0}C)**
	A	**B**	**C**		
3.30	4.2806	-0.5176	0.0312	0.9849	40 - 90
6.00	3.9418	-0.3537	0.0104	0.9953	40 - 90
10.60	3.9147	-0.3797	0.0146	0.9969	40 - 90
17.87	3.8607	-0.3773	0.0147	0.9993	40 - 90
30.00	3.8523	-0.4112	0.0187	0.9993	40 - 90
52.95	3.8775	-0.4463	0.0224	0.9999	40 - 90
80.00	3.8796	-0.4541	0.0220	0.9997	40 - 90
120.00	3.8502	-0.4403	0.0193	1.0000	40 - 90

CONCLUSIONS

All oil samples tested were examined with the modified Andrade equation. There was no need to use a higher order polynomial function of 1/*T*, because most coefficients were determined higher values of 0.9999. Viscosity curve model showed a good fitting for rapeseed oil and hydraulic oil. Representation of temperature dependence of viscosity to determine a mean square error approaches 1 at almost all shear rates. In the present study was possible to obtain the correct value of viscosity at different temperatures by placing the constant changing Andrade equation at different shear rates. Therefore, the model temperature dependence of viscosity can be used to determine oil viscosity at different temperatures for different shear rates with better accuracy for applications such as pipeline system design, hydraulic applications.

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