ORIGINAL PAPER

RHEOLOGICAL BEHAVIOR OF BIODEGRADABLE LUBRICANT

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Abstract. *This article proposes new rheological models for soybean oil. The purpose of this study was to find an exponential dependence between temperature and the logarithm dynamic viscosity of soybean oil, using one equation. Equation constants ln* η_0, A_1 *and* t_1 *were determined by fitting a suitable correlation. The soybean oil investigated using a Haake VT 550 Viscotester at 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. Soybean oil logarithm of dynamic viscosity decreases with increasing temperature at constant shear rate. Plotting the logarithm of dynamic viscosity as function of temperature shows an exponential decline.*

Keywords: *relationship, viscosity, temperature, soybean oil.*

1. INTRODUCTION

Soybean oil is a vegetable oil extracted from the seeds of the soybean (*Glycine max*). Vegetable oils could be substitutes for petroleum-based oils; they have excellent lubricating properties such as high viscosity index, high lubricity and low volatility but are also eco-friendly, renewable and less toxic [1, 2]. And, even accepting their weaknesses (oxidation stability, low values for viscosity at high temperature, narrower temperature ranges for applications) [3], vegetable oil-based lubricants are being actively demanded for many green industrial activities [4, 5]. In 2006 a study of OECD (OECD 2001–2006) defined vegetable oil "as rapeseed oil (canola), soybean oil, sunflower seed oil and palm oil, except in Japan where it excludes sunflower seed oil" [6]. A study on European agriculture revealed that "in 2007, 18.1 million tones of rapeseed were produced in the EU, a 13% increase on the 2006. The increase in rapeseed production is clearly due to the high demand in recent years for renewable energy sources such as biodiesel". But recently, this crop is used also for producing eco-friendly industrial lubricants [7]. Also, vegetable oils have become a source of eco-friendly and non-toxic additives for lubricants [7-9]. The environmentally friendly base-stocks (vegetable oils) used in this work were soybean oil, delivered by Romania. The soybean oil was commercial grade oil without any further purification. The composition of soybean oil concerning the fatty acids is presented in Table 1.

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Table 1. Fatty acids identified in soybean oils [10].

Fatty acids %	**Soybean oil**
Lauric acid (C12:0)	<0.1
Myristic acid (C14:0)	<0.2
Palmitic acid (C16:0)	9.0-13.5
Palmitoleic acid (C16:1)	<0.2
Stearic acid (C18:0)	2.0-5.4
Oleic acid (C18:1)	17.0-30.0
Linoleic acid (C18:2)	48.0-59.0
Linolenic acid (C18:3)	4.5-11.0
Arachidic acid (C20:0)	0.1-0.6
Acid gadoleic (C20:1)	<0.5
Behenic acid (C22:0)	<0.7
Erucic acid (C22:1)	<0.3
Docosadienoic acid (C22:2)	-

Vegetable oils have been proposed several empirical relationships describing the temperature dependent dynamic viscosity. The more important of these is the Andrade equation (1). Andrade [11] equations are modified versions of equations (2) and (3) [12-20]:

$$\eta = A\cdot 10^{B/T} \tag{1}$$

$$\ln\eta = A + B/T + C/T^2 \tag{2}$$

and

$$\ln\eta = A + B/T + CT \tag{3}$$

where T is the temperature absolute and A, B and C in the equations (1) to (3) are correlation constants.

2. MATERIALS AND METHODS

The types of soybean oil used in this paper are produced from soybean crop produced in Romania. Soybean oil were investigated using a Haake VT 550 Viscotester at 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 and the measurements were made from 10 to 10°C. The accuracy of the temperature was $\pm$ 0.1°C.

3. RESULTS AND DISCUSSION

Fig. 1 shows the dependency of the logarithm of dynamic viscosity with T for studied soybean oil at shear rate $3.3s^{-1}$, $6s^{-1}$, $10.6s^{-1}$, $17.87s^{-1}$, $30s^{-1}$, $52.95s^{-1}$, $80s^{-1}$ and $120s^{-1}$.

This article proposes one correlations (Eq.4) ln dynamic viscosity as function of the absolute temperature for soybean oil. We used the computer program Origin 6.0 to determine the constants $\ln\eta_0$, A_1 and t_1 and the correlation coefficients, R^2. The values of constants $\ln\eta_0$, A_1 and t_1 were determined by fitting exponential curves obtained for soybean oil.

The dependency of ln dynamic viscosity on the absolute temperature for soybean oil at shear rate $3.3s^{-1}$, $6s^{-1}$, $10.6s^{-1}$ $17.87s^{-1}$and $30s^{-1}$ (the black curves from Figs. 2-6) was fitting exponential as shown in Figs. 2-6. The exponential dependence of ln dynamic viscosity on the absolute temperature for soybean oil at $3.3s^{-1}$ is described for equation (5):

$$\eta = 2.73208+1.1982E12exp(-T/ 11.13174) \qquad (5)$$

where $\ln\eta_0$ =2.73208 , t_1 = 11.13174 and A_1 = $1.1982E12$. The correlation coefficient is R^2 = 0.9697.

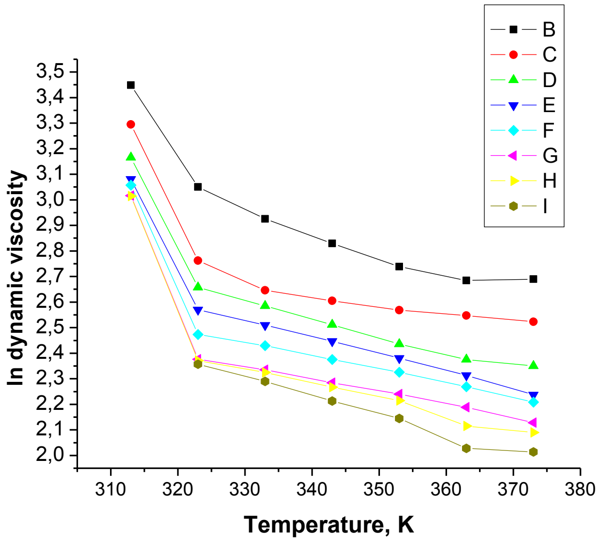

Figure 1. The correlation of logarithm of dynamic viscosity as function of the absolute temperature at: B – $3.3s^{-1}$, C – $6s^{-1}$, D – $10.6s^{-1}$, E – $17.87s^{-1}$, F – $30s^{-1}$, G – $52.95s^{-1}$, H – $80s^{-1}$ and I – $120s^{-1}$.

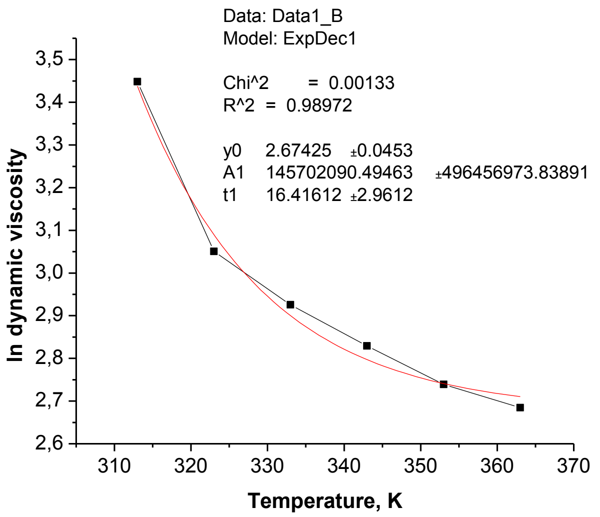

Figure 2. The correlation ln dynamic viscosity on the absolute temperature at $3.3s^{-1}$.

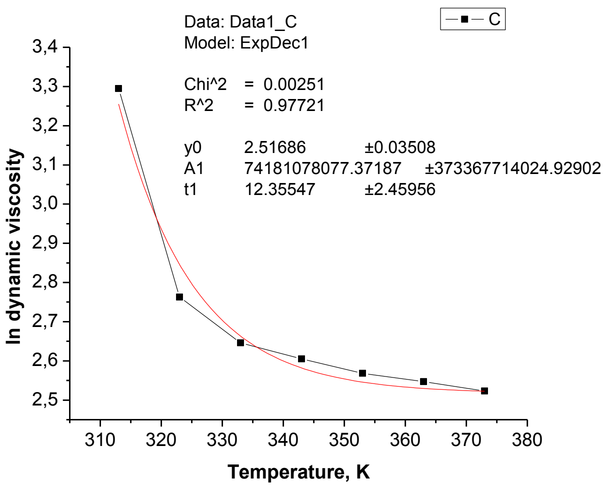

Figure 3. The correlation ln dynamic viscosity on the absolute temperature at $6s^{-1}$.

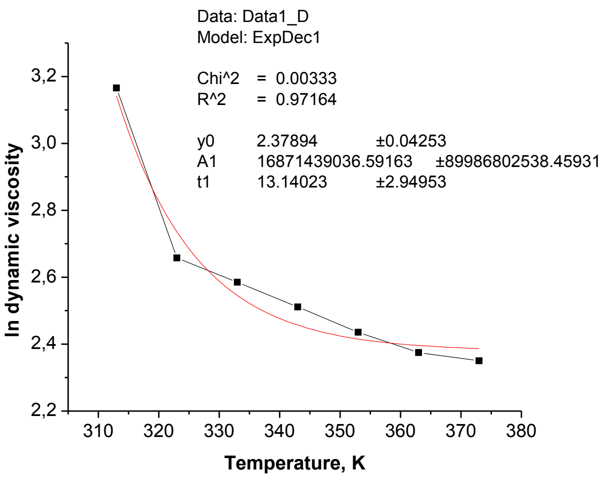

Figure 4. The correlation ln dynamic viscosity on the absolute temperature at $10.6s^{-1}$.

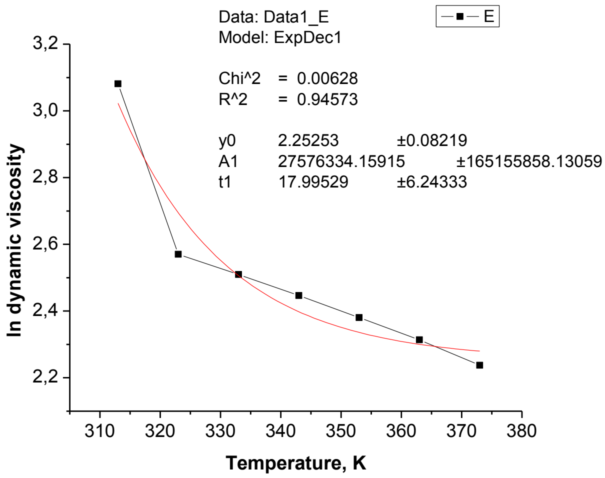

Figure 5. The correlation ln dynamic viscosity on the absolute temperature at 17.87s^{-1}.

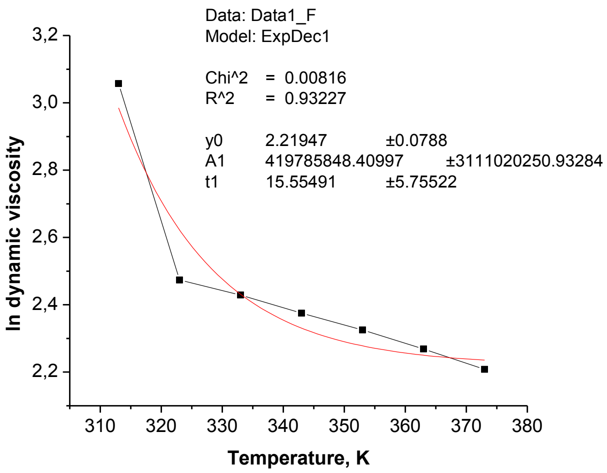

Figure 6. The correlation ln dynamic viscosity on the absolute temperature at 30s^{-1}.

$$\ln\eta = ln\eta_0 + A_1 exp(-T/t_1) \tag{4}$$

Table 2. The shear rate, value of parameters of described by equation (4) and coefficient correlation for soybean oil

Shear rate [s^{-1}]	Value of parameters			Correlation coefficient R^2
	ln η_0	A_1	t_1	
3.3	2.7321	1.1982E12	11.1317	0.9697
6	2.5169	7.4181E10	12.3555	0.9772
10.6	2.3789	1.6871E10	13.1402	0.9716
17.87	2.2525	2.7576E7	17.9953	0.9457
30	2.2195	4.1979E8	15.5549	0.9323
52.95	2.1358	1.2280E9	14.7962	0.9254
80	2.1138	1.1626E10	13.4073	0.9442
120	2.0327	1.1919E7	18.6646	0.8726

The exponential dependence of ln dynamic viscosity on the temperature for soybean oil at $30s^{-1}$ is described for equation (6):

$$\eta=2.2195+4.1979E8\ exp\ (-T/15.5549) \quad (6)$$

The value of the parameter $ln\eta_0$ drops very little by main taining around 2 and the values of the parameters A_1 and t_1 vary within wide limits.

Table 2 shows can be seen that the empirical relations that provide the best results in this study for the temperature dependence of oil logarithm for the dynamic viscosity is described by equation (4), with hight correlation coefficient values are close by 1.00. Equation (4) is not suitable to describe the temperature dependence of oil viscosity, because the values of correlation coefficients are less than 1.

4. CONCLUSION

The equation that best describes the temperature dependence of the logarithm dynamic viscosity of soybean oil studied is Eq. (4) for which the correlation coefficients have values close to one. The soybean oil of logarithm the dynamic viscosity decreases with increasing temperature at constant shear rate. Plotting the ln dynamic viscosity as function of temperature shows an exponential decline.

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