ORIGINAL PAPER

RHEOLOGICAL MATHEMATICAL MODELS OF DEPENDENCE DYNAMIC VISCOSITY – SHEAR RATE FOR SOYBEAN OIL

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Manuscript received: 07.10.2018; Accepted paper: 03.11.2018;
Published online: 30.12.2018.

Abstract. *The soybean oil was carefully studied in recent years because they may constitute a raw material for biodegradable lubricants getting organic. These oils are an alternative to synthetic mineral oils. This article presents rheological behavior of soybean oil. The dynamic viscosity of soybean oil was determined at temperatures range between 313 – 373 K and shear rates range from 3.3 – 120 s^{-1}. For temperature ranging between 313 – 373 K soybean oil has a Bingham fluid behavior.*
Keywords: *dynamic viscosity, shear rate, soybean, oil.*

1. INTRODUCTION

There are several rheological mathematical models applied on rheograms in order to transform them to information on fluid rheological behaviour. For non-Newtonian fluids the four models presented below are mostly applied [1].
The Herschel Bulkley model is applied on fluids with a non linear behaviour and yield stress. It is considered as a precise model since its equation has three adjustable parameters, providing data [2]. The Herschel Bulkley model is expressed in equation 1 where $_0$ represents the yield stress:

$$\tau = \tau_o + k\dot{\gamma}^n \tag{1}$$

The consistency index parameter (k) gives an idea of the viscosity of the fluid. However, be able to compare K values for different fluids they should have similar flow behaviour index (n). When the flow behaviour index is close to 1 the fluid´s behaviour tends to pass from a shear thinning to a shear thickening fluid. When n is above 1, the fluid acts as a shear thickening fluid. According to Seyssiecq and Ferasse [1] equation 1 gives fluid behaviour information as follows:

$\tau_0 = 0$, n =1 $\Rightarrow$ Newtonian behaviour
$\tau_0 > 0$, n =1 $\Rightarrow$ Bingham plastic behaviour
$\tau_0 = 0$, n < 1 $\Rightarrow$ Pseudoplastic behaviour
$\tau_0 = 0$, n > 1 $\Rightarrow$ Dilatant behaviour

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The Ostwald de Waele model (Eq. 2), also known as the Power Law model, is applied to shear thinning fluids which do not present a yield stress [2]. The n-value in equation 2 gives fluid behaviour information according to:

$$\tau = k\dot{\gamma}^{n} \quad (2)$$

$n < 1 \Rightarrow$ Pseudoplastic behaviour
$n = 1 \Rightarrow$ Newtonian behaviour
$n > 1 \Rightarrow$ Dilatant behaviour

The Bingham model (Eq. 3) describes the flow curve of a material with a yield stress and a constant viscosity at stresses above the yield stress (i.e. a pseudo-Newtonian fluid behaviour [1]).

$$\tau = \tau_o + \eta\dot{\gamma} \quad (3)$$

$\tau_0 = 0 \Rightarrow$ Newtonian behaviour
$\tau_0 > 1 \Rightarrow$ Bingham plastic behaviour

The Casson model (Eq. 4) describes the flow curve of a material with a yield stress and a constant viscosity at stresses above the yield stress:

$$\tau^{1/2} = \tau_o^{1/2} + \eta^{1/2}\,\dot{\gamma}^{1/2} \quad (4)$$

The object of this paper is to determine the rheological behaviour for soybean oils at shear rates ranging between 3 and 120 s^{-1} and temperatures between 40 and 100^{o}C. This study is to find an exponential dependence on dynamic viscosity and oil shear rate for soybean oil [3-10].

2. MATERIALS AND METHODS

The rheological behaviour of soybean oil was determined using a Haake VT 550 Viscotester developing shear rates ranging between 3 and 1312 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 313 to 373K and the measurements were made from 10 to 10 degrees. The accuracy of the temperature measurement was $\pm$ 0.1°C.

3. RESULTS AND DISCUSSION

The dependence of dynamic viscosity on the shear rate for soybean oil at temperature (the black curves from Figs. 1-6) was first order exponential decay as shown in Figs. 1-6. The exponential dependence of dynamic viscosity on the shear rate for soybean oil at 313K is described for equation (5):

$$\eta = 15.57762 + 43.80594\exp\left(-\dot{\gamma}/3.18764\right) \quad (5)$$

The exponential dependence of dynamic viscosity on the shear rate for soybean oil at 323K is described for equation (6):

$$\eta = 13.11614 + 94.48423 \exp(-\dot{\gamma}/1.7176) \qquad (6)$$

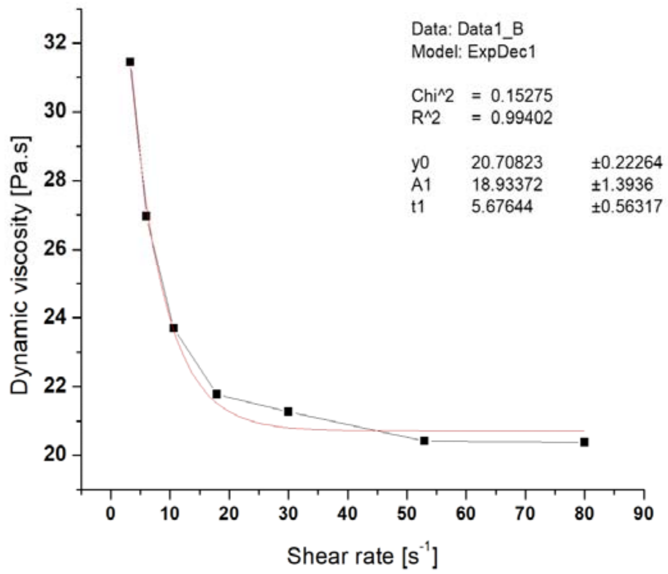

Figure 1. Dependence of dynamic viscosity by shear rate for soybean oil at temperature absolute 313K.

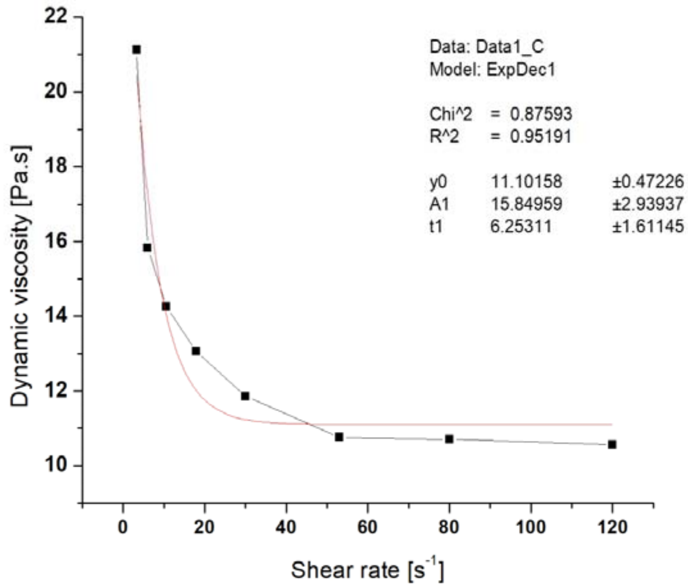

Figure 2. Dependence of dynamic viscosity by shear rate for soybean oil at temperature absolute 323K.

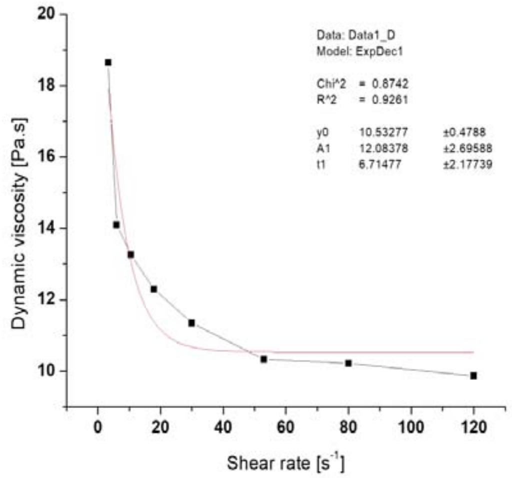

Figure 3. Dependence of dynamic viscosity by shear rate for soybean oil at temperature absolute 333K.

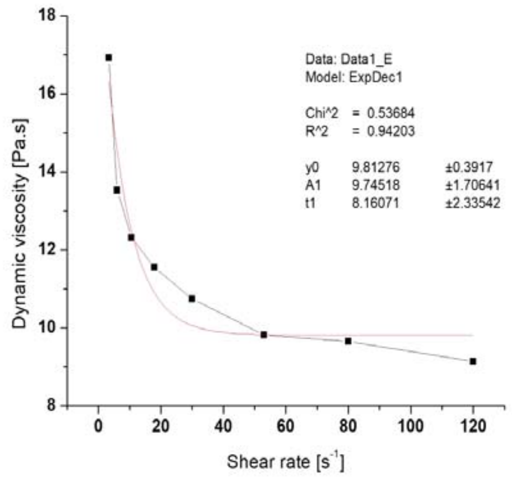

Figure 4. Dependence of dynamic viscosity by shear rate for soybean oil at temperature absolute 343K.

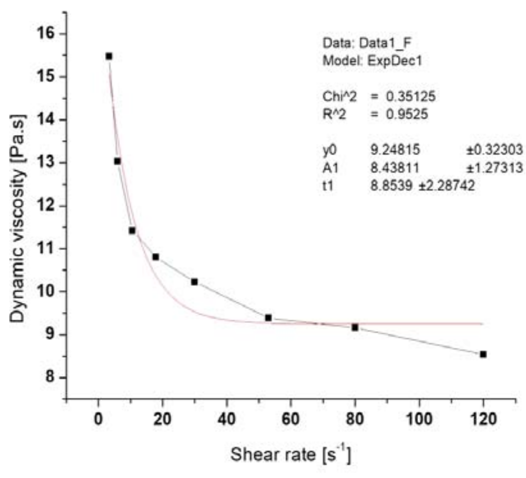

Figure 5. Dependence of dynamic viscosity by shear rate for soybean oil at temperature absolute 353K.

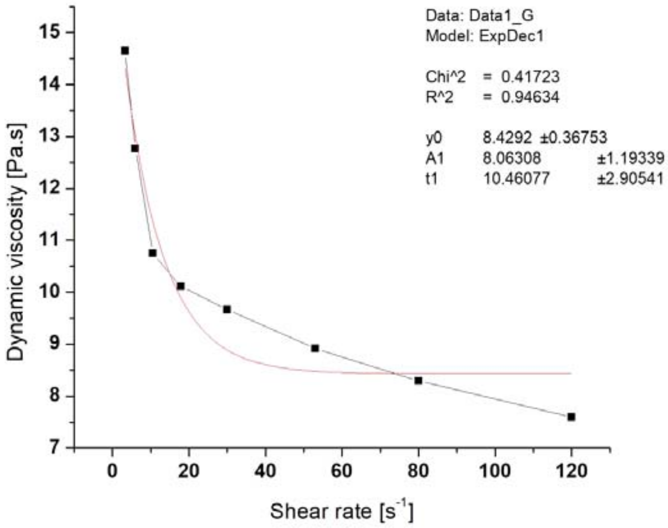

Figure 6. Dependence of dynamic viscosity by shear rate for of soybean oil at temperature absolute 363K

Table 1. The results obtained from mathematical modelling of rheogram data of soybean oil from o: yield stress (Pa); n: flow behaviour index; k: Consistency index; R2: regression coefficient.

T, K	Herschel Bulkley			
	τ_o	n	k	R^2
313	19.8298	1.2624	0.8669	0.9999
323	10.2058	1.1438	0.8186	0.9998
333	9.6248	1.0997	0.8392	0.9997
343	8.9593	1.0742	0.8429	0.9994
353	8.4149	1.0482	0.8476	0.9989
363	7.4829	1.0442	0.8300	0.9975
373	7.3620	1.0371	0.8249	0.9987

Table 2. The results obtained from mathematical modelling of rheogram data of soybean oil from $_o$: yield stress (Pa); n: flow behaviour index; k: Consistency index; R^2: regression coefficient

T, K	Bingham		Ostwald de Waele		
	τ_o	R^2	k	n	R^2
313	19.8298	0.9999	1.2624	0.8669	0.9985
323	10.2058	0.9998	1.1438	0.8186	0.9976
333	9.6248	0.9997	1.0997	0.8392	0.9984
343	8.9593	0.9994	1.0742	0.8429	0.9990
353	8.4149	0.9989	1.0482	0.8476	0.9993
363	7.4829	0.9975	1.0442	0.8300	0.9994
373	7.3620	0.9987	1.0371	0.8249	0.9989

Table 3. The results obtained from mathematical modelling of rheogram data of soybean oil from $_o$: yield stress (Pa); R^2: regression coefficient

T, K	Casson	
	τ_o	R^2
313	0.8669	0.9985
323	0.8186	0.9976
333	0.8392	0.9984
343	0.8429	0.9990
353	0.8476	0.9993
363	0.8300	0.9994
373	0.8249	0.9989

The dynamic viscosity of soybean oil decreases exponential with temperature increasing. The black curves from Figs. 1-6 show that soybean oil is described of equation Bingham (1) with correlation coefficients very close to unity (0.9999) at 313 – 363 K.

4. CONCLUSION

The dynamic viscosity of soybean oil was determined for temperature range between 313 – 373 K and shear rates ranging from 3.3 – 120 s^{-1}. The dynamic viscosity of soybean oil decreases exponential with temperature increasing. Between 313 and 373 K soybean oil has a Bingham fluid behavior.

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