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Rheological Behavior of Castor Oil: Shear Stress Dependence Shear Rate

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Abstract

In this paper, new rheological models for castor oil are proposed. The aim of this study was to find a linear, exponential, and polynomial dependence between shear stress and shear rate of castor oil using tree equation. Equation constants τ_0 , A, B, and C were determined by fitting linear, exponential, and polynomial. The castor oil has been evaluated using a Haake VT 550 Viscotester developing shear rates in the range of 3-120 s^{-1} and measuring viscosities from 10^4-10^6 mPa·s when the HV_1 viscosity sensor is used. The castor oil of the dependence shear rate decreases with increasing shear stress at a constant temperature.

Key words: castor oil, rheology, oil

Introduction

Mechanical systems often use lubricants, most of which are petroleum-based, in order to decrease component friction and surface wear. Nowadays, due to the rising of petroleum-based oil prices, the diminishing supplies of natural resources, global climate change, and increased environmental sensitivity, several alternatives for petroleum-based lubricants are now being assessed, including plant-based lubricants and synthetic lubricants (Jaghoubi, 2019). Oils and fats of plant and animal origin were extensively used as lubricants till the middle of the 19th century. Plant oils are generally attractive substitutes for petroleum-based oils as they are readily biodegradable, less toxic, renewable, and environmentally friendly (Khanh et al., 2020).

Plant oils have good potential for various industrial applications and positive production trends. The oilseed production is on the rise worldwide, but now, it is more expensive than petroleum-based oils. When the life cycle advantages of plant-based lubricants are considered, economic losses are justified (Conningham et al., 2004). From both production and life cycle standpoints, the future seems optimistic for plant oils as a viable replacement for petroleum-based lubricants. In general, when compared with mineral oil base stokes, plant oils have the following advantages: higher viscosity index, lower evaporation loss, and enhanced lubricity, which leads to improved energy efficiency. However, plant oils have functional limitations, especially in hydrolytic, oxidative, and thermal stability (Adhvaryu et al., 2004). Plant oils normally contain ~80-95% fatty acids, as major performance improvers in lubricants (Fox et al., 2004). Moreover, mineral oils normally contain saturated aliphatic compounds, namely naphthenic and paraffinic, and a small amount of aromatics. Thereby, the stability of mineral oils is more than plant oils due to their chemical nature; nonetheless, they have lower lubricity (Nariman, 2012). Plant oils are generally very good boundary lubricants but their high-pressure behavior has not been studied accurately. In this research, some high-pressure tribological properties of plant oils were measured and their effect on lubrication was compared (Ohno, 2007). Temperature-pressure-viscosity, as well as temperature-pressure-density relations, are essential to know the lubricating oil performance at high-pressure conditions. Coconut oil, mustard oil, camellia oil, rapeseed oil, olive oil, and castor oil, are considered as testing lubricating oil among plant oils. Plant oils have a high viscosity index, as an important characteristic of lubricant. While low-temperature properties are not sufficiently good as mineral oil, especially coconut oil showed the highest solidification temperature (Alshareef and Ibrahim, 2020). Solidification temperature was measured at atmospheric pressure by a low-temperature test using liquid nitrogen. The pressure-viscosity coefficient α of these oils has been measured by measuring the viscosity at different pressures. Density was measured by a high-pressure densitometer at various temperatures. Comparing all results, plant oils showed better properties at 40-60°C. Due to the considerable pressure-viscosity coefficient, it can be utilized in elastohydrodynamic lubrication. Plant oils would be the alternate of mineral oils.

The fatty acid composition in the weight percentage of castor oil is given in Table 1. Among the fatty acids, stearic acid, palmitic acid, lauric acid, capric acid, caprylic acid, and myristic acid are saturated fatty acids.

Whereas, oleic acid, ricinoleic acid, gadoleic acid, and erucic acid are the monounsaturated fatty acids but linoleic acid and linolenic acid are polyunsaturated fatty acids.

Table 1: Fatty acid composition of castor oil

Fatty acid	castor oil
C8 Caprylic	-
C10 Capric	-
C12 Lauric	-
C14 Myristic	-
C16 Palmitic	1.1

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C18 Stearic	1.0
C18:1 Oleic	4.1
C18:1+H	88
Ricinoleic	-
C18:2 Linoleic	4.8
C18:3	0.5
Linolenic	-
C20:1 Gadoleic	-
C22:1 Erucic	-
Other	0.7

The object of this study was to determine the rheological behaviour for castor oil at shear rates ranging between 3 and 120 s^{-1} and temperatures between 40 and 100ºC. This study was done to find a linear, exponential, and polynomial dependence on shear stress and shear rate for castor oil. The oil modified Andrade equation was studied. Constants τ_0 , A, B, C and correlation coefficient were determined by correlating a characteristic exponential and equations of each curve for castor oil (Stanciu, 2019; Stanciu, 2018; Stanciu, 2018; Stanciu, 2018).

Material and Methods

The castor oil used in this work was provided from a company in Bucharest, Romania, and was studied with no additives. It was evaluated using a Haake VT 550 Viscotester developing shear rates in a range from 3 to 120s^{-1} and its viscosity was measured from 10^4 to 10^6 mPa.s when the HV_1 viscosity sensor was used. The temperature ranged from 40 to 100°C and was measured 10°C intervals. The accuracy of the temperature was $\pm$ 0.1°C.

Results and Discussion

The dependency of shear stress on the shear rate for castor oil at 40, 50, 60, 70, and 80°C (the black curves in **Fig. 1, 2, 3, 4**, and **5,** respectively) was fitting linear as shown in figures 1, 2, 3, 4 and 5, respectively.

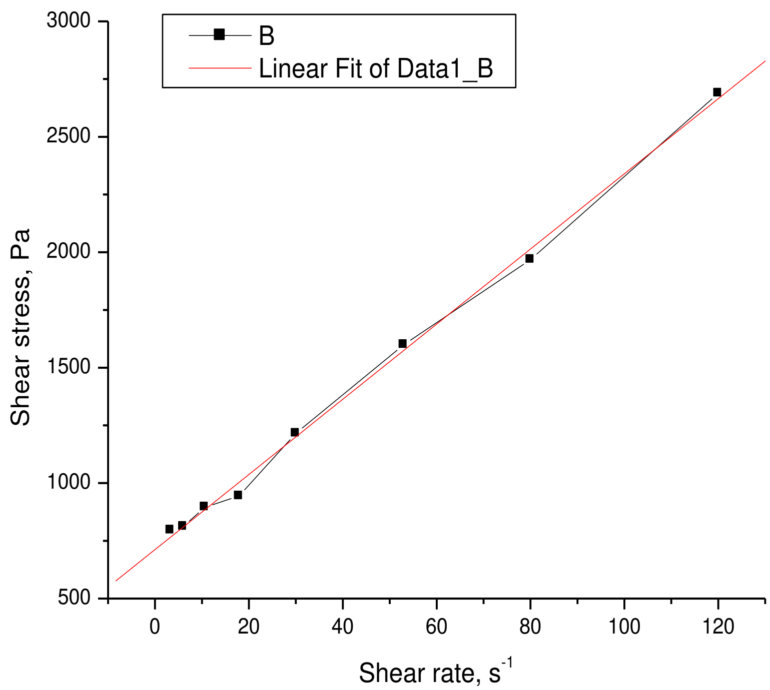

Fig. 1: Rheogram of castor oil at 40°C

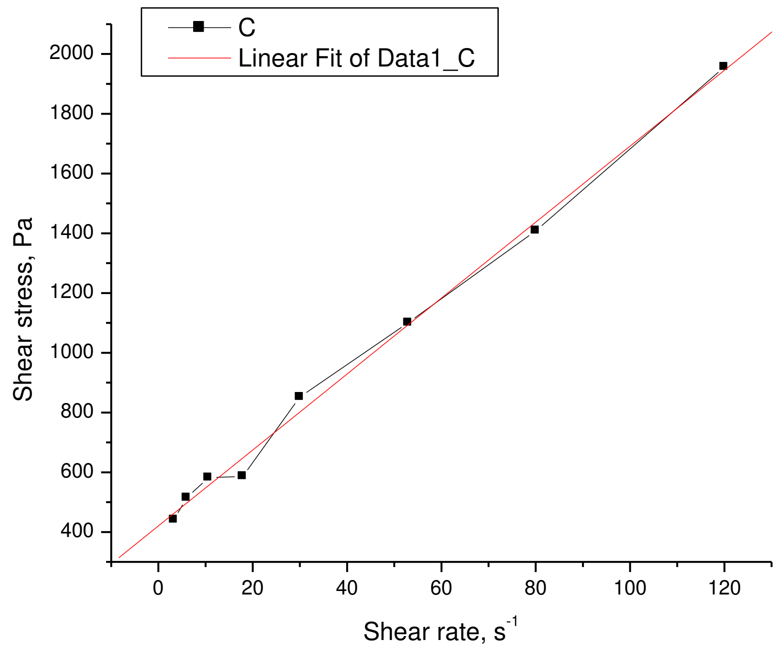

Fig. 2: Rheogram of castor oil at 50°C

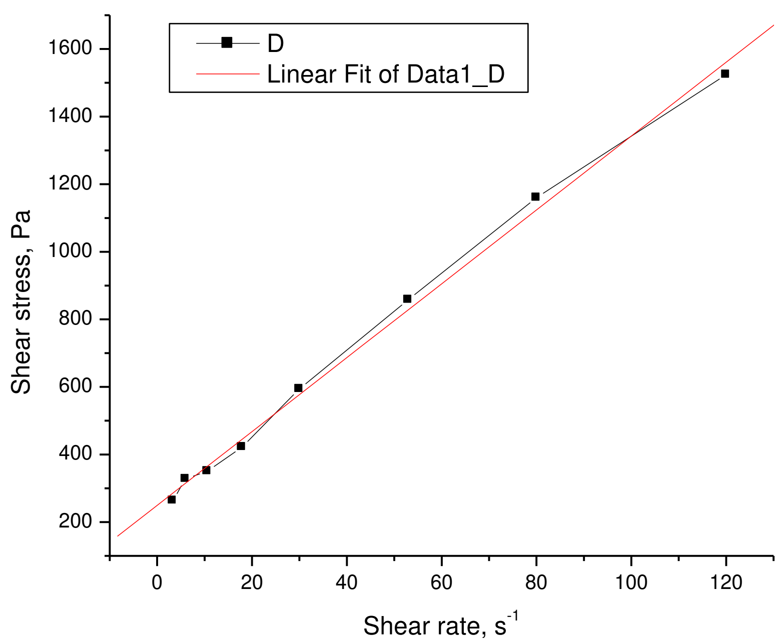

Fig. 3: Rheogram of castor oil at 60°C

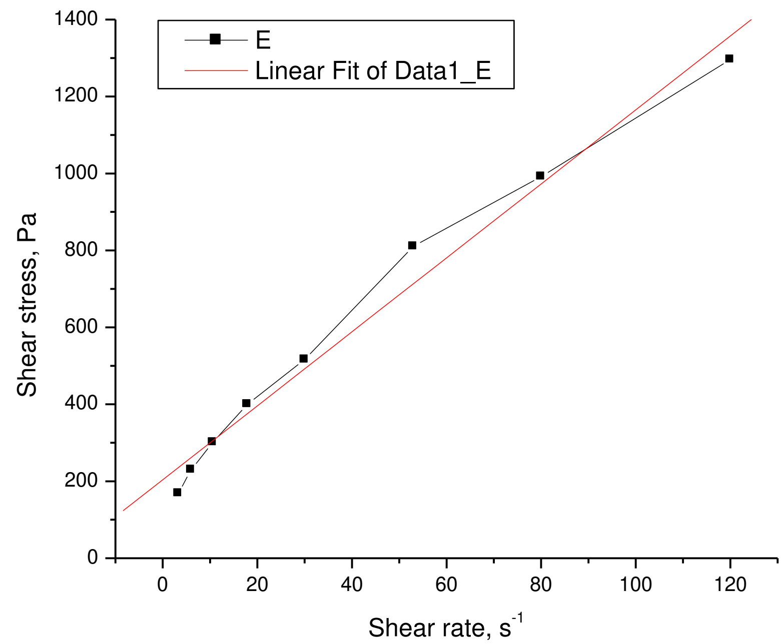

Fig. 4: Rheogram of castor oil at 70°C

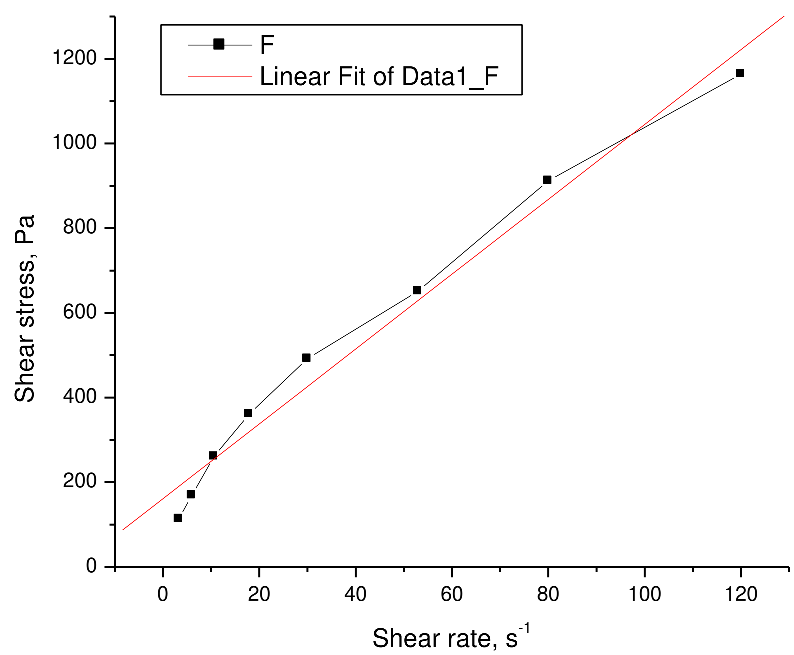

Fig. 5: Rheogram of castor oil at 80°C

In this article, three relations of dependence on the shear rate were proposed depending on the shear voltage. By linear, exponential, and polynomial fits, we found the following relations:

$$\tau = A + B\dot{\gamma} \quad (1)$$

$$\tau = A + B\dot{\gamma} + C\dot{\gamma}^2 \quad (2)$$

$$\tau = \tau_0 + A\exp(-\dot{\gamma}/B) \quad (3)$$

Tables 2, 3, and 4 show the values of parameters described by the equations (1), (2), and (3) castor oil and correlation coefficient, R^2.

Table 2. The temperature, value of the parameters described by equation (1), and coefficient correlation for castor oil

Temperature, °C	Value of parameters		Correlation coefficient, R^2
	A	B	
40	16.2771	711.9302	0.9988
50	12.7109	420.3463	0.9978
60	10.9279	249.4705	0.9982
70	9.6132	203.8444	0.9911
80	8.8389	161.1127	0.9897
90	6.6635	153.2452	0.9715
100	5.9124	103.0524	0.9789

In Table 2, the parameters A and B decrease with increasing oil temperature. Their values are influenced by the chemical structure of oil and the conditions under which they were determined.

Table 3. The temperature, value of parameters described by equation (2), and coefficient correlation for castor oil

Temperature, °C	Value of parameters			Correlation coefficient, R^2
	A	B	C	
40	724.5639	15.3375	0.0080	0.9978
50	421.6347	12.6151	8.1756E-4	0.9955
60	223.2569	12.8775	-0.0166	0.9988
70	145.6798	13.9389	-0.0369	0.99719
80	108.4131	12.7583	-0.0334	0.9940
90	82.5695	11.9197	-0.0449	0.9880
100	50.3706	9.8304	-0.0334	0.9899

In Table 3, the parameters A, B, and C decrease with increasing oil temperature. Their values are influenced by the chemical structure of oil and the conditions under which they were determined.

Table 4. The temperature, value of parameters described by equation (3), and coefficient correlation for castor oil

Temperature, °C	Value of parameters			Correlation coefficient, R^2
	τ_0	A	B	
40	4.1645E6	-4.1638E6	255778.6399	0.9975
50	756507.8217	-756087.3942	59431.1527	0.9955
60	4553.8205	-4330.9559	333.9558	0.9988
70	1985.2165	-1847.7774	123.2755	0.9977
80	1787.8899	-1688.4209	122.0136	0.9948
90	1005.9358	-947.2226	63.2374	0.9926
100	926.4400	-892.4730	75.4256	0.9937

In Table 4, parameters τ_0 , A, and B decrease with increasing oil temperature. Their values are influenced by the chemical structure of oil and the conditions under which they were determined.

Conclusions

This article presented three relations of the dependence of the shear rate on the shear voltage obtained by the linear, exponential, and polynomial fit of the experimental curves. The correlation coefficients showed values close to the unit for all temperatures at which the oil was studied.

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