Technical Sciences
Academy of Romania
www.jesi.astr.ro

Journal of Engineering Sciences and Innovation
Volume 1, Issue 1 / 2016, pp. 110-119

D. Chemical Engineering, Materials Science and Engineering, Natural Resources

Received ***16 March 2016*** *Accepted* ***12 August 2016***
Received in revised from ***27 May 2016***

Viscosity dependence on shear rate and temperature for olive and soybean oils

LIVIU CĂTĂLIN SOLEA, CONSTANTIN GEORGESCU [*]**,**
LORENA DELEANU

"Dunarea de Jos" University of Galati, Faculty of Engineering,
Department of Mechanical Engineering, 47 Domneasca, Galati, 800008, Romania

Abstract. The authors experimentally determined the influence of temperature and shear rate on the dynamic viscosity of two vegetable oils (soybean oil, olive oil). The hydraulic oil ISO VG 46 was used for comparison. The behavior of these two oils was similar to the hydraulic one, for larger shear rates (30 s^{-1}…80 s^{-1}) and for higher temperatures (60ºC…90ºC). For lower shear rate (3 s^{-1}…30 s^{-1}) and lower temperatures (30ºC…50ºC), the dynamic viscosity of the vegetable oils decreases sharper as compared to the hydraulic oil. The authors determined constants in Azian relation and constants in Ostwald de-Waele, Herschel–Bulkley and Carreau models. Based on laboratory data, the authors determined mathematical models for the dependence of dynamic viscosity on temperature and shear rate, for two vegetable oils, as a polynomial relation that could be used with high degree of confidence in predicting the dynamic viscosity in the range of tested parameters. Maps for this relation $\eta = f(\dot{\gamma}, T)$ and maps of the prediction errors were plotted.

Keywords. Soybean oil, olive oil, dynamic viscosity, temperature, shear rate, mathematical model

1. Introduction

Renewable resources gain the markets, the crops of soybean and olive being focused also on industrial applications, especially for environmental friendly fluids. Vegetable oils have become challengers of classical mineral oils because of their supply shortening, but there are industrial applications that are asking for these environmentally friendly fluids due to legislation constraints [1], [2], [3]. Vegetable oils and their products (including lubricant and biodiesel) are preferred alternatives over traditional petroleum-based lubricants [4], [5].

---

[*] Correspondence address: constantin.georgescu@ugal.ro

Abolle et al. [1] proposed an empirical modeling for interpolating viscosity of any kind of diesel oil/Synthetic Vegetable Oil (SVO) blend. This model is fitted on an experimental viscosity database on blends, varying the SVO mass proportion in the blend, the blend temperature between cloud point and 353 K, and including six vegetable oils, varying the composition in fatty acids.

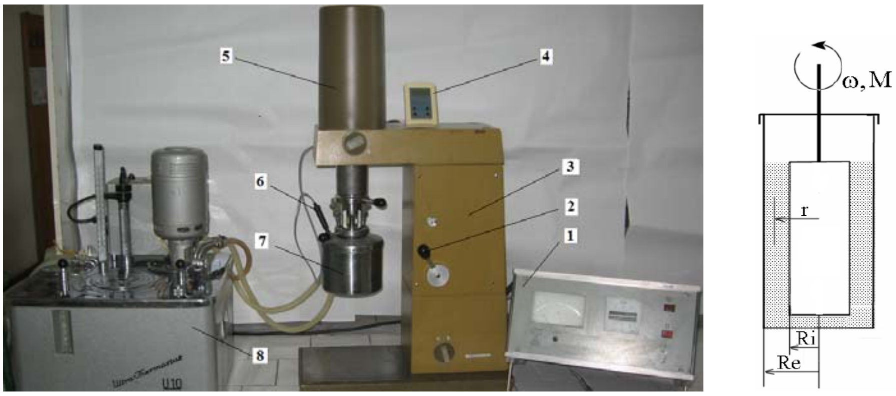
Cheenkachorn [6] presents vegetable oils as a potential replacement for mineral oils when blended with proper additives, tests being done for three different soybean oils (conventional soybean oil, epoxidized soybean oil and high-oleic soybean oil) on a four-ball tester.

Viscosity is one of the important properties that strongly affect the lubricant behavior, being dependent on pressure, temperature, time and shear rate. Tests pointing out the simultaneous influence of these factors are rare because of synergic effects that occur. Due to new designed equipment of measuring viscosity data and softwares that could approximate the experimental data, the mapping of this very important characteristic of a fluid could be drawn and interpreted for a better design of lubricated system. Regression of the data showed that the relationship between viscosity and temperature followed the modified Andrade equation [7]. Verduzco [8] studied the effect of molecular weight, number of double bonds and temperature on the dynamic viscosity for different grades of biodiesel. The empirical models correctly reproduced the behaviors of physical properties of methyl ester compounds. The results suggest a relationship between molecular weight, fatty acid methyl ester type (saturated or unsaturated), and temperature, as independent variables; and each one of the density and dynamic viscosity. Mixing rules in conjunction with empirical models were used to successfully predict the density and viscosity of tested biodiesel grades. Based on this study, we can conclude that the mix of components is of great importance when studying the fat acids or the vegetable oils [5].

The aim of this research work is to give mathematical models for the evolution of dynamic viscosity of the tested oils (soybean oil, olive oil and a hydraulic oil ISO VG 46) in order to be used in evaluating the lubrication of mechanical systems that are designed not only to have a certain life span, but also to fulfill regulations for protecting the environment. The model will include two parameters, the shear rate and the temperature.

2. Lubricants and test methodology

The Rheotest 2 (see Fig. 1) was used for determining the dependence of dynamic viscosity on temperature and shear rate, at “Dunarea de Jos” University of Galati, being compose of 1 – module for command and measurement, 2 – shear rate switcher, 3 – body, 4 - thermometer, 5 - engine, 6 – thermometer support, 7 – enclosure with cylinders, 8 – thermostated bath. In the enclosure (7), there are two coaxial cylinders (Fig. 1.b), one being fixed in the enclosure, the other one having the possibility of rotating with a set angular speed. Thus, when the inner cylinder rotates, shear rate is generated inside the fluid in the space between the cylinders. A test begins when the temperature becomes stable (with an acuuracy of ±0.5ºC) and it runs till the recorded viscosity has very small oscilations (less than 5% of the average recorded value).



a) General view b) Working principle

Fig. 1. Rheotest 2 equipment

The tested lubricant tends to drag the other cylinder round, the resistant torque exerted by the fluid is measured and shear stress or viscosity may be calculated. For this rheometer, the following formula is used to calculate the dynamic viscosity:

$$\eta = z \cdot \alpha \cdot f \,, \tag{1}$$

where z is the device constant, in scale divisions in dyn·cm^2·(div.scale)$^{-1}$, α – value read at rheotester and f - a correcting factor.

The tested vegetable oils have the composition given in Table 1 as measured at the laboratory of the supplier of the soybean oil (Expur Slobozia, Romania).

Table 1 The composition in fat acids of the tested oils

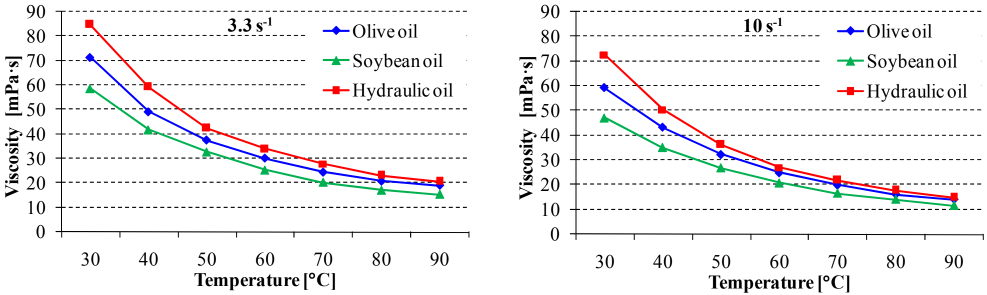
Fat acids		**Composition**		
		Olive oil	**Soybean oil**	**Refined bleached degummed soybean oil** [9]
Myristoleic acid	C14:0	-	0.11	0.08
Palmitic acid	C16:0	12.6	12.7	10.16
Palmitoleic acid	C16:1	1.20	0.13	0.10
Acid heptadecanoic	C17:0	0.10	0.05	0.13
Acid heptadecenoic	C17:1	0.10	0.06	0.07
Stearic acid	C18:0	-	5.40	4.83
Oleic acid	C18:1	79.30	21.60	22.25
Linoleic acid	C18:2	4.70	52.40	53
Linolenic acid	C18:3	0.80	5.70	8.37
Arachidic acid	C20:0	0.40	0.25	0.37
Eicosenoic acid	C20:1	0.25	0.20	-
Behenic acid	C22:0	-	0.50	0.38
Erucic acid	C22:1	-	0.16	-
Lignoceric acid	C24:0	0.16	0.20	0.13
Total saturated (S)		13.65	19.75	16.78
Total unsaturated (U)		86.35	80.25	83.22
Ratio U/S		6.32	4.06	4.95

These are typical compositions [5], [9], [10], [11] for the tested oils (olive oil and soybean oil). Both vegetable oils are non-refined (crude) oils. Schoo [9] give similar information for refined bleached degummed soybean (see the last column in Table 1). The main difference in the composition of these vegetable oils is concerning the fatty acids C18:1 and C18:2. The oleic acid has a higher percentage in the olive oil and the linoleic acid is present in the soybean oil in a percentage almost 10 times higher as compared to that characterizing the olive oil. The fat acid concentration may differ from zone to zone and because of plant particularities (see Table 1).

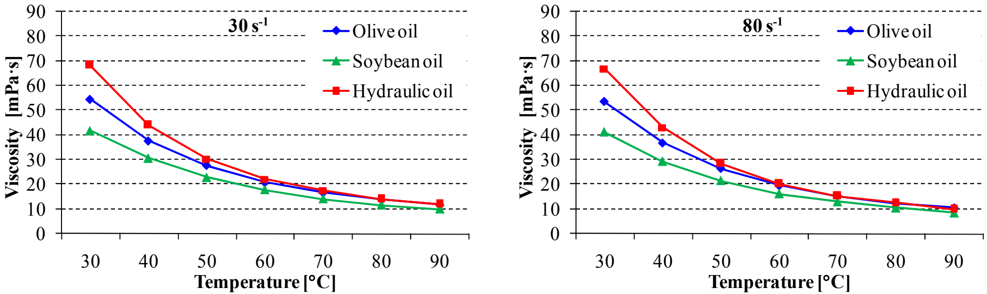
The hydraulic mineral oil OMV ISO VG 46 was tested only for reference and comparison reasons. Oils have been tested in the temperature range of 30ºC and 90ºC, in steps of 10ºC and shear rate between 3.3 s^{-1} and 80 s^{-1}.

3. Results and discussion

The values of dynamic viscosity for each set of parameters (shear rate, oil temperature) is given in Figure 2 by points, the lines suggesting the trend to reduce the dynamic viscosity when the shear rate and temperature increase. The decrease of the dynamic viscosity is more accentuated at small shear rate on the temperature range of 30ºC …60ºC.



a) shear rate 3.3 s^{-1} b) shear rate 10 s^{-1}



c) shear rate 30 s^{-1} d) shear rate 80 s^{-1}

Fig. 2. Dynamic viscosity as a function of temperature, for different shear rates

For higher values of shear rate (30 s^{-1} and 80 s^{-1}), the dynamic viscosity has very small variations for both vegetable oils. This phenomenon of viscosity decrease is characteristic for many lubricants. This could be explained by the fact that the shearing process modifies the molecular arrangement into the fluid, the behavior being reversible [11].For the soybean oil tested at the temperature of 30º C, the dynamic viscosity has a decrease of 29.88% on the shear rate range, and this parameter decreases with 25.1% for the olive oil and with 21.1%. for the hydraulic oil OMV ISO VG 46.For the temperature of 90ºC, on the shear rate range, the ranking of the tested oils is the same: the dynamic viscosity decreases with 44.26% for the soybean oil, with 43.88% for the olive oil and with 47.23% for the hydraulic oil, this being the highest recorded difference.

Analyzing the data in Figure 2, the soybean oil tested at the temperature of 30ºC, has a decease in viscosity of 29.88% on the tested range of shear rates, the olive oil is characterized by 25.1%, and the hydraulic oil by the lowest value, 21.1%. Thus, the olive oil has a better behavior as concerning the viscosity as compared to the soybean oil, but at low temperature (a temperature of 30ºC being hard to be maintained in an oil bath, especially in contact when the flash temperature in contact is higher that that in of the bath oil). At 90ºC, the dynamic vscosity decreases with 44.26% for the soybean oil, with 43.88% for the olive oil and with 47.23% for the hydraulic oil. The hydraulic oil has the larger decrease of viscosity at 90ºC.

3.1. Constitutive ecuation for the dependence viscosity - temperature

In recent works, in order to express the dependence viscosity - temperature Andrade equation is used in a linear form [10], [12], [13], [14]. Esteban et al. [13] recommend the use of Azian equation (2), this being more adequate for analysis on large temperature range [15]:

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

where *A*, *B* and *C* are constants for a given oil. The authors applied the Azian equation to the experimental data and obtained the values given in Table 2.

Table 2. Parameters involved in Azian equation (ln $\eta = A + B/T + C/T^2$)

Shear rate [s^{-1}]	Oil	A	B	C	Correlation coefficient
3.3	Soybean oil	38.513	-20915.4	3051743.3	0.9997
	Olive oil	14.628	-9821.67	2024807.6	0.9997
	Hydraulic oil OMV ISO VG46	14.546	-9850.71	2057655.5	0.9998
30	Soybean oil	3.9277	-3301.34	983311.13	0.9999
	Olive oil	9.481	-7012.84	1622156.9	0.99996
	Hydraulic oil OMV ISO VG46	15.19	-11120.71	2363320.7	0.99992
80	Soybean oil	2.338	-2517.52	889912.1	0.9998
	Olive oil	8.883	-6856.33	1628859.13	0.99985
	Hydraulic oil OMV ISO VG46	17.875	-13160.10	2734732.85	0.9997

The correlation coefficients are closer values to the unit, meaning a good agreement between the experimental data and the constitutive model. Azian equation approximates well the experimental data, thus, it could be used for determining the value of dynamic viscosity for the tested oils and for a temperature of interest, within the limits of a range that have already been determined.

3.2. Constitutive ecuation for the dependence viscosity - shear rate

In this study, the flow models for expressing the viscosity dependence on shear rate taking into account by the authors were the relations proposed by Ostwald de-Waele (3), Herschel–Bulkley (4) and Carreau (5), respectively.

$$\eta = K \cdot \dot{\gamma}^{n-1}, \tag{3}$$

$$\eta = K_H \cdot \dot{\gamma}^{n_H - 1} + \eta_{\dot{\gamma},\infty}, \tag{4}$$

$$\eta = \eta_{\dot{\gamma},\infty} + \frac{\eta_{\dot{\gamma},0} - \eta_{\dot{\gamma},\infty}}{\left[1 + \left(\lambda_c \cdot \dot{\gamma}\right)^2\right]^N}, \tag{5}$$

where η – dynamic viscosity [mPa·s], $\dot{\gamma}$ – shear rate [s^{-1}]; K, K_H – consistency index [Pa·s^n], n, n_H – flow index (adimensional), $\eta_{\dot{\gamma},0}$ – the viscosity when the shear rate tends to zero [mPa·s], $\eta_{\dot{\gamma},\infty}$ – the viscosity when the shear rate tends to infinite [mPa·s], λ_c – constant [s], N – shear index (adimensional).

Table 3 presents the values of the constants involved in each model, based on the experimental data for the extreme tested temperatures 30ºC and 90ºC.

Table 3 Parameter values for models Ostwald de-Waele, Herschel–Bulkley and Carreau

Model	Parameter	Temperature [ºC]	Soybean oil	Olive oil	Hydraulic oil
Ostwald de-Waele	K [Pa·s^n]	30	0.0641	0.0764	0.0893
		90	0.01855	0.02316	0.02593
	n	30	0.8817	0.9071	0.92563
		90	0.8167	0.8061	0.78119
	Correlation coefficient	30	0.9528	0.941	0.94271
		90	0.9942	0.9820	0.985
Herschel - Bulkley	K_H [Pa·s^n]	30	0.0413	0.0548	0.0567
		90	0.01473	0.0204	0.0240
	n_H	30	0.1876	0.102	0.1244
		90	0.6097	0.398	0.410
	$\eta_{\dot{\gamma},\infty}$ [mPa·s]	30	39.11	52.16	65.64
		90	5.94	9.14	8.95
	Correlation coefficient	30	0.9978	0.999	0.9995
		90	0.9981	0.9982	0.9988
Carreau	λ_c [s]	30	0.272	0.328	0.4662
		90	3.65	0.3055	0.3256
	N	30	0.6574	0.6463	0.54
		90	0.196	0.470	0.4445
	$\eta_{\dot{\gamma},0}$ [mPa·s]	30	67.39	83.43	101.9
		90	30.45	22.44	24.91
	$\eta_{\dot{\gamma},\infty}$ [mPa·s]	30	40.46	53.08	66.25
		90	5.96	10.13	10.10
	Correlation coefficient	30	0.9993	9.999	0.9997
		90	0.9981	0.9993	0.9997

Comparing the correlation coefficients, one may notice that Carreau model gave the best values, that is they are the closest to unit.

Analysing the values for the consistency index for the tested oils, for two temperatures (30ºC and 90ºC), the following succesion is obtained:

$$(K_H, K)_{\text{hydraulic}} > (K_H, K)_{\text{olive}} > (K_H, K)_{\text{soybean}}$$

This succession indicates how the values of viscosity could be ordered. When temperature increase from 30ºC to 90ºC, the values of consistency index, shear index and the dynamic viscosity $\eta_{\dot{\gamma},\infty}$ and $\eta_{\dot{\gamma},0}$ decrease for all tested oils, in aggreement with other researches [16], [17].

3.3. Mathematical model for the dependence viscosity - temperature - shear rate

Mathematical models based on regression were reported for other lubricants [11], [18]. The authors determined the equations describing the dependence of dynamic viscosity on shear rate and temperature, for the studied oils, with the help of the software Curve Fitting Tool of Matlab. This program allows for making analyses of data, pre- and post- processings and a comparison among mathematical models. The authors selected the following function for a better approximation of the dependence of dynamic viscosity (η) on temperature (T) and shear rate ($\dot{\gamma}$):

$$\begin{aligned}\eta = a_{00} + a_{10}\cdot\dot{\gamma} + a_{01}\cdot T + a_{20}\cdot\dot{\gamma}^2 + a_{11}\cdot\dot{\gamma}\cdot T + a_{02}\cdot T^2 + \\ + a_{30}\cdot\dot{\gamma}^3 + a_{21}\cdot\dot{\gamma}^2\cdot T + a_{12}\cdot\dot{\gamma}\cdot T^2 - a_{03}\cdot T^3\end{aligned}, \quad (6)$$

where a_{ij} are coefficients, $i = 0 \ldots 3$ and $j = 0 \ldots 3$.

Table 4 presents the equations as determined for each of the two tested vegetable oils and the average of the prediction errors and Table 5 presents the values of the statistical parameters characterizing the ecuation of the dynamic viscosity for the studied oils. In Table 5, the following abbreviations are done: R-Sq – correlation coefficient; R-Sq(Adj) – adjusted correlation coefficient; SSE – sum of squares error; DFE – number of degrees of freedom; RMSE – root mean square errors.

Table 4 Relations for the viscosity dependence on temperature and shear rate and the average prediction error

Oil	Mathematical model ($\eta = f(\dot{\gamma}, T)$)	Average prediction error [%]
Olive	$\eta = 159.1 - 0.944\cdot\dot{\gamma} - 4.344\cdot T + 0.0175\cdot\dot{\gamma}^2 + 0.0027\cdot\dot{\gamma}\cdot T + 0.04865\cdot T^2 - - 9.962\cdot 10^{-5}\cdot\dot{\gamma}^3 - 3.38\cdot 10^{-5}\cdot\dot{\gamma}^2\cdot T + 6.9\cdot 10^{-6}\cdot\dot{\gamma}\cdot T^2 - 0.00019\cdot T^3$	2.52
Soybean	$\eta = 115.6 - 0.7002\cdot\dot{\gamma} - 2.958\cdot T + 0.0117\cdot\dot{\gamma}^2 + 0.0031\cdot\dot{\gamma}\cdot T + 0.3163\cdot T^2 - - 6.345\cdot 10^{-5}\cdot\dot{\gamma}^3 - 2.75\cdot 10^{-5}\cdot\dot{\gamma}^2\cdot T - 7.811\cdot 10^{-7}\cdot\dot{\gamma}\cdot T^2 - 0.00012\cdot T^3$	2.51

Table 5 Statistical parameters for the mathematical models written in Table 4, for the studied oils

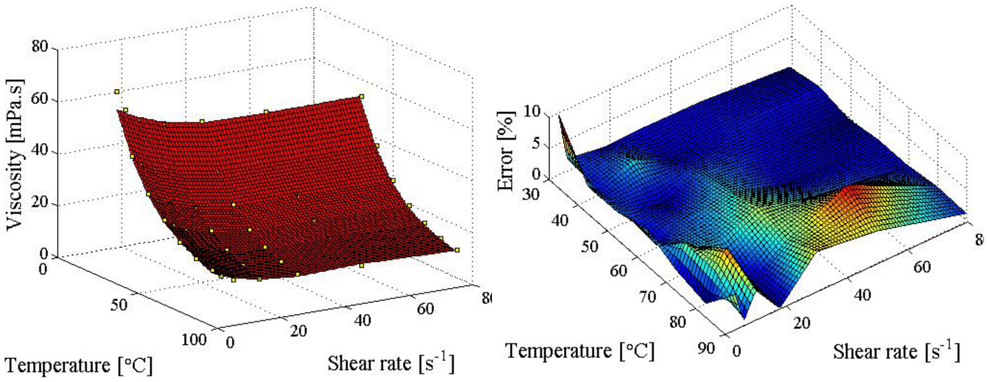
Oil	SSE	R-Sq	DFE	R-Sq(Adj)	RMSE
Olive	44.72	0.996	39	0.995	1.071
Soybean	36.39	0.995	39	0.994	0.966

For the dynamic viscosity equation as a function of shear rate and temperature, the prediction error was calculated using the following relation:

$$Prediction\ error = \frac{\left|\eta_{measured} - \eta_{calculated}\right|}{max\left(\eta_{measured}, \eta_{calculated}\right)} \cdot 100\left[\%\right], \tag{7}$$

As concerning the corn oil, the maximum error was of 9.54% relatively to the experimental data and the minimum error has a value of 0.23%; for the rapeseed oil, the values of the errors were in the range of 8.06% and 0.13%, these values being in an acceptable tolerance range [12], [19]; the average of the prediction error is less than 3% (see Table 4).

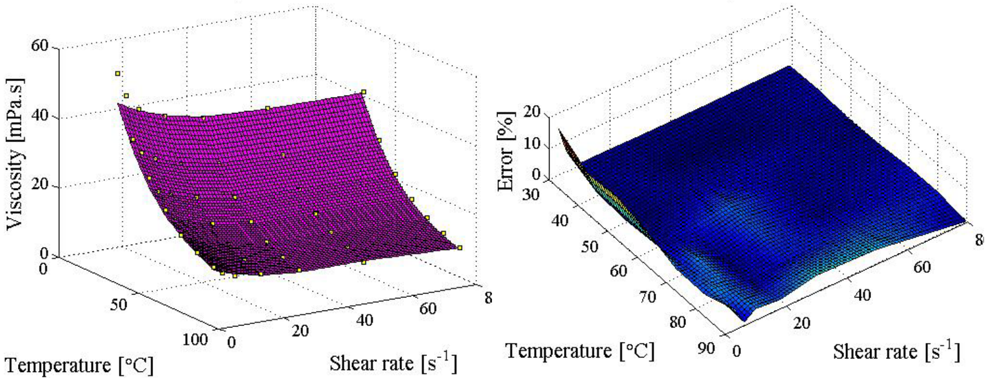
Figures 3 and 4 presents the experimental values (as points) and the surfaces approximating these experimental values and also the prediction error maps by comparing the experimental values to those obtained with the help of the theoretical model.



a) The surface approximating the experimental values (given as light dots)

b) Map of the prediction errors

Fig. 3. Mathematical modeling of the experimental results for the olive oil



a) The surface approximating the experimental values (given as light dots)

b) Map of the prediction errors

Fig. 4. Mathematical modeling of the experimental results for the soybean oil

Analysing the graphs in Figure 2, one may notice that for the soybean oil tested at 30ºC, the viscosity decreases with 29.88% on the entire tested range of shear rates, but for the olive oil this characteristic diminishes with 25.1% and the hydraulic oil reduces it with only 21.1%. When testing at 90ºC, the dynamic viscosity decreases with 44.26% for the soybean oil, with 43.88% for the olive oil and with 47.23% for the hydraulic oil. Thus, at 30ºC, the hydraulic oil had the smallest decrease of the dynamic viscosity, but at 90ºC, this oil had the larger variation of the dynamic viscosity with the shear rate.

4. Conclusions

Based on laboratory tests, the authors determined the influence of the set of parameters (temperature, shear rate) on the dynamic viscosity of two vegetable oils (corn oil and rapeseed oil). The hydraulic oil ISO VG 46 was used as reference and comparison. The behavior of these two oils was similar to the hydraulic one, for larger shear rates (30 s^{-1}…80 s^{-1}) and for higher temperatures (60ºC…90ºC). For lower shear rate (3 s^{-1}…30 s^{-1}) and lower temperature range (30ºC…50ºC), the dynamic viscosity of the vegetable oils decreases sharper as compared to that of the hydraulic oil.

The authors determined the constants in the Azian relation for the dependence of dynamic viscosity on temperature and the constants involved in Ostwald de-Waele, Herschel – Bulkley and Carreau models for the dependence of dynamic viscosity on shear rate.

Based on the experimental data, the authors determined mathematical models for describing the dependence of the dynamic viscosity on temperature and shear rate, for two vegetable oils, the olive oil and the soybean oil, as a polynomial relation that could be used with high degree of confidence in predicting the value of dynamic viscosity in the range of tested parameters (30ºC…90ºC and 3 s^{-1}…80 s^{-1}). Maps for this relation $\eta = f(\dot{\gamma}, T)$ were plotted and also maps for the prediction errors when comparing the experimental values to those given by the mathematical models. The olive oils gave higher values of these errors for all shear rates and temperatures of 70ºC...90ºC, but also had a peak for the combination (low shear rate, low temperature). The soybean oil has higher values for prediction error only for low shear rate.

Taking into account only the dependence of dynamic viscosity on temperature and shear rate, experimental data obtained for the two vegetable oils make them challengers for the hydraulic oil tested for comparison reason, especially for higher temperature (60ºC...90ºC). For low values of shear rate and temperature, the difference in dynamic viscosity between the hydraulic oil and the vegetable oils are greater. The future quest to be solved is the oxidation stability of the oils and they could be used in applications where environment protection is requested.

References

[1] Abolle, A., Kouakou, L., Planche, H., *The viscosity of diesel oil and mixtures with straight vegetable oils: Palm, cabbage palm, cotton, groundnut, copra and sunflower*, Biomass and Bioenergy, 33 (2009) 1116–1121.

[2] Perez, A. T., *Characterization of the rheological properties of lubricants for EHL film thickness prediction*, TriboUK, Imperial College, London, 2010.

[3] Tudor, A., Vlase, M., Radulescu, A., V., Bojan, E., Stepa, E., Vladut, V., *Experimental researches on biodegradable lubricants with multifunctional properties*, Journal of the Balkan Tribological Association, 18, no 2 (2012) 309-318.

[4] Bisht, R., Kaul, S., Nagendramma, P., Bhatia, V., Gupta, A., *Eco-friendly base fluids for lubricant oil formulations*, Journal of Synthetic Lubrication, 19 (2002) 243–248.

[5] Minami, I., Mori, S., *Concept of molecular design towards additive technology for advanced lubricants*, Lubrication Science, 19 (2007) 127–149.

[6] Cheenkachorn, K., *A Study of Wear Properties of Different Soybean Oils*, Energy Procedia, 42 (2013) 633-639.

[7] Chhetri, A. B., Watts, K. C., *Viscosities of canola, jatropha and soapnut biodiesel at elevated temperatures and pressures*, Fuel, 102 (2012) 789–794.

[8] Verduzco, L. F. R., *Density and viscosity of biodiesel as a function of temperature: Empirical models*, Renewable and Sustainable Energy Reviews, 19 (2013) 652–665.

[9] Rodenbush, C. M., Hsieh, F. H., Viswanath, D. S., *Density and viscosity of vegetable oils*, Journal of the American Oil Chemists' Society, 76 (1999)1415-1419.

[10] Schoo, R., Hoxie, A., *Basic properties of refined, bleached and deodorized soybean oil–butanol blends*, Fuel, 102 (2012) 701–708.

[11] Yilmaz, N., *Temperature-dependent viscosity correlations of vegetable oils and biofuel-diesel mixtures*, Biomass and Bioenergy, 35 (2011) 2936–2938.

[12] Diaconu, N., Palade, V., Buciumeanu, M., Bîrsan, I. G., *Bazele reologiei*, Editura Evrika, Brăila, 2003.

[13] Esteban, B., Riba, J. R., Baquero, G., Rius, A., Puig, R., *Temperature dependence and viscosity of vegetable oils*, Biomass and Bioenergy, 42 (2012)164–171.

[14] Toro-Vazquez, J. F., Infante-Guerrero, R., *Regressional models that describe oil absolute viscosity*, Journal of the American Oil Chemists Society, 70 (1993) 1115-1119.

[15] Azian, M. N., Kamal, A. A. M., Panau, F., Ten, W. K., *Viscosity estimation of triacylglycerols and of some vegetable oils, based on their triacylglycericols composition*, Journal of the American Oil Chemists' Society, 78, no 10 (2001) 1001-1005.

[16] Lomba, R. F. T., de Sá, C. H. M., Brandao, E. M., *A new approach to evaluate temperature effects on rheological behavior of formate-base fluids*, Journal of Energy Resources Technology, 124 (2002) 141-144.

[17] Rao, M. A., Cooley, H. J., Ortloff, C., Chang, K., Wijts, S. C., *Influence of rheological properties of fluid and semi solid foods on the performance of a filler*, Journal of Food Process Engineering, 16 (1993) 289-304.

[18] Krisnangkura, K., Yimsuwan, T., Pairintra, R., *An empirical approach in predicting biodiesel viscosity at various temperatures*, Fuel, 85 (2006) 107–113.

[19] Quinchia, L. A., Delgado, M. A., Valencia, C., Franco, J. M., Gallegos, C., *Viscosity modification of different vegetable oils with EVA copolymer for lubricant applications*, Industrial Crops and Products, 32 (2010) 607–612.