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Viscosity correlation development for corn oil biodiesel-diesel fuel blends

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Abstract

In this study, the lowest dynamic viscosity corn oil biodiesel was produced using methanol as alcohol and potassium hydroxide as catalyst by means of transesterification reaction. Dynamic viscosities of produced corn oil biodiesel and its blends with diesel fuel at different temperatures were measured according to international standard. Effects of temperature and biodiesel content in blend on changes of their dynamic viscosities were examined. Changes were described by means of regression models such as two-term exponential model and three-term logarithmic model. Constants and regression coefficients of these models were computed and reported in tables.

Keywords: Canola oil biodiesel, transesterification, viscosity, two-term exponential model, three-term logarithmic model

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1. Introduction

Rapid growth in population coupling with industrial and technological development is leading to towards the depletion of limited fossil fuel resources of the world. Currently, researches are progressively more directed towards exploration of alternative renewable fuels such as bio-ethanol, biodiesel etc. [1]. Biodiesel is becoming popular in the markets of developed countries as well as developing ones [2]. For example, diesel fuel blended with 20% of biodiesel produced by the soybean oil is available in the US market now [3]. While biodiesel faces some technical challenges such as increasing NO_x exhaust emissions and kinematic viscosities, advantages of biodiesel compared to diesel fuel include reduction of most regulated exhaust emissions such as CO, HC and smoke, improved biodegradability, low or no sulfur content, inherent lubricity, higher flash point temperature, domestic origin and renewability [4]. In addition, biodiesel is completely miscible with diesel fuel, allowing the blending of these two fuels in any proportion. However, differences in the chemical nature of biodiesel (mixture of mono-alkyl ester of saturated and unsaturated long chain fatty acids) and diesel fuel (mixture of paraffinic, naphthenic and aromatic hydrocarbons) result in differences in their basic properties such as viscosity, density, cetane number, higher heating value etc., affecting engine performance, combustion characteristics and pollutant emissions. Given the difficulty of obtaining these basic properties of the blends by measurement, the ability to calculate them using regression models is very useful [5], [6]. In literature, many researchers have already suggested lots of regression models as a function of biodiesel content, temperature, chemical structure etc. to estimate fuel properties such as kinematic viscosity, density, cetane number, flash point temperature, distillation curves etc. as following: Qi and Lee [5] determined distillation curves, cold filter plugging points, cloud points, acid values, sulfur contents and oxidation stabilities of soybean biodiesel-diesel blends according to the corresponding standards, and the influences of biodiesel content on these blends' properties were evaluated. Kay's mixing rule was used for predicting the properties. Ebna *et al.* [7] investigated densities, dynamic viscosities and higher heating values of waste cooking palm oil methyl

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ester and its blends with No. 2 diesel fuel under varying temperature. Based on the experimental results, regression correlations such as Kay’s mixing rule and Grunberg-Nissan mixing rule have been proposed for estimating these fuel properties. Gülüm and Bilgin [8] investigated variations of densities, flash point temperatures and higher heating values of corn oil biodiesel-Ultra Force Euro diesel fuel blends. The authors also proposed new one- and two-dimensional models to predict these fuel properties.

In this study, (1) the minimum dynamic viscosity corn oil biodiesel was produced using methanol (CH_3OH) and potassium hydroxide (KOH), (2) the produced biodiesel was blended with commercially available diesel fuel at the volume ratios of 5, 10, 15, 20, 25, 50 and 75%, (3) kinematic viscosities of the biodiesel-diesel fuel blends were measured at different temperatures (10, 20, 30 and 40^{o}C) according to international standard, and (4) regression models were proposed for viscosity-blending ratio and viscosity-temperature relationships.

2. Materials and Methods

2.1. Materials

To produce biodiesel by basic catalyzed transesterification, refined corn oil (purchased from a market), methanol (Merck, 99.8% purity) and potassium hydroxide (Merck, pure grade) were used.

2.2. Biodiesel production

The parameters of transesterification reaction were determined as 1.1% catalyst (KOH) concentration, 60℃ reaction temperature, 60 minute reaction time and 9:1 alcohol/oil molar ratio to produce the minimum dynamic viscosity corn oil biodiesel in a master thesis done by Gülüm [9]. Details of biodiesel production were given in [8], [9].

2.3. Density measurement

The densities of the biodiesel-diesel fuel blends were determined by means of Eq. (1) and measurements in accordance with ISO 4787 standard:

$$\rho_{biodiesel} = \frac{m_{total} - m_{pycnometer}}{m_{water}} \rho_{water} \tag{1}$$

where ρ and m represent density and mass, respectively. The density measurements were conducted three times for each sample and the results were averaged. Details of the measurements were given in [8,9].

2.4. Dynamic viscosity measurement

The dynamic viscosities were determined in accordance with DIN 53015 standard by using Eq. (2) and making measurements by means of the Haake Falling Ball Viscometer, Haake Water Bath and stopwatch:

$$\mu_{biodiesel} = K_{ball}(\rho_{ball} - \rho_{biodiesel})t \tag{2}$$

where $\mu_{biodiesel}$ is dynamic viscosity, K is coefficient of the viscometer ball, and t is falling time of the ball moving between two horizontal line marked on viscometer tube at limit velocity. K_{ball} and ρ_{ball} are 0.057 mPa.s.cm^3/g/s and 2.2 g/cm^3, respectively. The viscosity measurements were also conducted three times for each sample and the results were averaged.

In this study, densities and viscosities were measured in Internal Combustion Engines Laboratory in the Mechanical Engineering Department at Karadeniz Technical University. The fatty acid methyl ester compositions of the produced biodiesel were determined in Science Research and Application Center at Mustafa Kemal University. Moreover, other fuel properties such as flash point temperature, cold filter plugging point temperature and higher heating value were measured in the Prof. Dr. Saadettin GÜNER Fuel Research and Application Center at Karadeniz Technical University. Table 1 lists these fuel properties with EN 14214 and ASTM D 6751 standard values, and Table 2 shows fatty acid compositions of the produced biodiesel and its calculated average molecular mass and typical formula.

Table 1. Some fuel properties of diesel fuel and produced biodiesel, and corresponding standard values for biodiesel

Properties	Units	B100	D	EN14214	ASTM-D6751
Dynamic viscosity (at 40°C)	mPa.s	3.489	2.233	3.50-5.00	1.90-6.0
Density (at 15°C)	kg/m^3	877.94	833.33	860-900	[4]
Flash point[1]	°C	171	63	101≤	130≤
Cold filter plugging point[2]	°C	-4.0	-6.0	<+5 -15<	[4]
Higher heating value[3]	kJ/kg	39947	45950	[4]	[4]

[1] Measured in EN ISO 3679.
[2] Measured in EN 116.
[3] Measured in DIN 51900-2.
[4] Not specified.

Table 2. Fatty acid methyl ester composition of the produced biodiesel

Fatty acid[1]	Mass, %
Palmitic (C16:0)	20.278
Oleic (C18:1)	47.184
Linoleic (C18:2)	29.575
α-Linolenic acid (C18:3)	1.077
Arachidic (C20:0)	0.972
Gadoleic acid (C20:1)	0.445
Behenic (C22:0)	0.470
Average molecular mass	291.270[2]
Typical formula	$C_{18.66}H_{35.13}O_2$[2]

[1] Determined using gas chromatography device.
[2] Calculated from fatty acid distribution.

3. Result and Discussion

Fig. 1 shows changes of dynamic viscosities of corn oil biodiesel-diesel fuel blends with respect to biodiesel fraction for varying temperature. In this figure, the points correspond to the viscosity values measured by the authors for studied temperatures and biodiesel fractions, while the lines are plots of curve fit equation. It is clear from this figure that all the blends follow the same trend, i.e., viscosities of the blends increase with increasing biodiesel fractions for studied temperatures, as expected. In order to characterize these variations, two-term exponential model was fitted to the experimental data:

$$\mu = \mu(X) = a + b\left(1 - e^{-cX}\right) \tag{3}$$

where μ is dynamic viscosity (mPa. s), a, b and c are regression constants and X is biodiesel fraction.

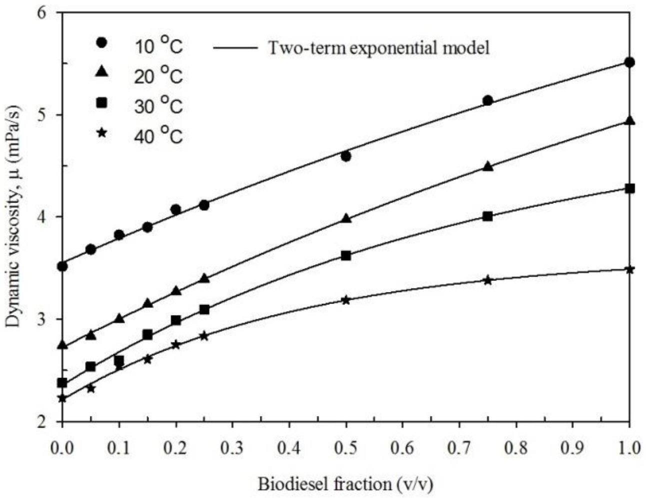

Fig. 1. Variation of dynamic viscosity with respect to biodiesel fraction in blend.

Table 3 lists the measured and calculated dynamic viscosities from Eq. (3), relative errors between them, regression constants and correlation coefficients (R). For the blends, the maximum relative error is 3.1736% with the lowest R value of 0.9986. Therefore, the two-term exponential model is suitable fit for the changes of dynamic viscosities versus biodiesel fractions.

Table 3. For different temperatures, the measured and calculated viscosities from Eq. (3), errors between measured and calculated viscosities, regression constants and correlation coefficients

Tem. (^{o}C)	Measured, μ (mPa. s)									Regression constants			R
	Biodiesel fraction, X (%)												
	0	5	10	15	20	25	50	75	100	a	b	c	
10	3.514	3.681	3.824	3.899	4.072	4.114	4.593	5.137	5.512	3.5520	5.3330	0.4593	0.9987
20	2.743	2.836	2.997	3.148	3.270	3.392	3.976	4.487	4.939	2.7240	5.3910	0.5287	0.9999
30	2.376	2.538	2.598	2.849	2.992	3.092	3.623	4.006	4.281	2.3570	2.6400	1.3070	0.9988
40	2.233	2.326	2.546	2.608	2.753	2.838	3.186	3.381	3.489	2.2150	1.4120	2.3290	0.9986

Table 3. (Continued)

Relative errors								
Biodiesel fraction, X (%)								
0	5	10	15	20	25	50	75	100
1.0814	0.2152	0.8524	0.2064	1.2755	0.4014	1.1598	0.6020	0.0904
0.6927	1.0100	0.1541	0.4123	0.1547	0.0156	0.0076	0.0384	0.0263
0.7997	0.5513	3.1736	0.7723	0.9268	0.0279	0.0170	0.0106	0.0359
0.8061	1.9009	1.4781	0.8947	0.4438	0.0071	0.0108	0.0050	0.0138

The effects of temperature on dynamic viscosities of corn oil biodiesel-diesel fuel blends are illustrated in Fig. 2. It is clear from this figure that viscosities of the all blends follow the same trend: as temperature is increased, viscosities decrease, as expected. The experimental data were correlated with the three-term logarithmic model by applying the least squares method as:

$$\mu = \mu(T) = a + b\mathrm{In}T + c(\mathrm{In}T)^2 \tag{4}$$

where T is temperature (℃), a, b and c are regression constants.

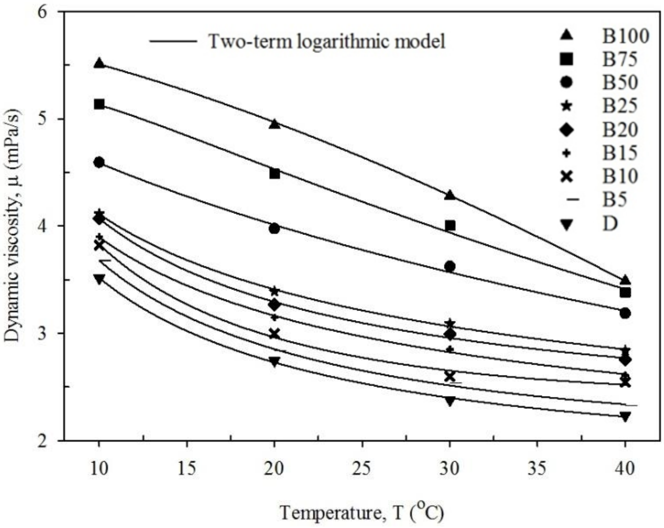

Fig. 2. Variation of dynamic viscosity with respect to temperature.

The measured and calculated dynamic viscosities from Eq. (4), relative errors between them, regression constants and correlation coefficients are given in Table 4. For the blends, the maximum relative error and the lowest R value were computed as 2.0978% and 0.9977. These results and Fig. 2 indicate that the relation between dynamic viscosities with temperature is found to be proper expressed by the three-term logarithmic model.

Table 4. For different biodiesel fractions, the measured and calculated viscosities from Eq. (4), errors between measured and calculated viscosities, regression constants and correlation coefficients

Biodiesel fraction	Measured, μ (mPa. s)				Regression constants			R	Relative errors			
	Temp., T (°C)								Temp., T (°C)			
X (%)	10	20	30	40	a	b	c		10	20	30	40
0	3.514	2.743	2.376	2.233	8.1650	-2.6960	0.2942	0.9996	0.0854	0.5177	0.9554	0.4389
5	3.681	2.836	2.538	2.326	8.6540	-2.9060	0.3236	0.9995	0.0706	0.5818	0.9614	0.4987
10	3.824	2.997	2.598	2.546	9.7930	-3.6160	0.4459	0.9977	0.1831	1.1645	2.0978	0.9544
15	3.899	3.148	2.849	2.608	7.6610	-2.0810	0.1937	0.9994	0.0692	0.5464	0.8810	0.4716
20	4.072	3.270	2.992	2.753	8.4380	-2.4980	0.2606	0.9989	0.1031	0.7156	1.1865	0.5957
25	4.114	3.392	3.092	2.838	7.4590	-1.7940	0.1477	0.9993	0.0656	0.5366	0.8441	0.4581
50	4.593	3.976	3.623	3.186	4.8870	0.4079	-0.2337	0.9978	0.1263	0.8954	1.4380	0.8004
75	5.137	4.487	4.006	3.381	3.3780	2.0090	-0.5420	0.9978	0.1304	1.0096	1.6201	0.9613
100	5.512	4.939	4.281	3.489	0.6314	4.3360	-0.9637	0.9991	0.1089	0.6742	1.1726	0.6735

4. Conclusion

In this study, corn oil biodiesel having minimum viscosity was produced by means of transesterification reaction. The produced biodiesel was blended with diesel fuel at the different volume ratios (5, 10, 15, 20, 25, 50 and 75%). For blends, pure biodiesel and diesel fuel, two-term exponential and three-term logarithmic correlations were developed to represent changes of dynamic viscosities with respect to temperature and biodiesel fraction, respectively. According to results, these exponential and logarithmic models with the max. relative errors and lowest correlation coefficients (3.1755%-0.9986 and 3.1755%-0.9986) are quite suitable to represent these changes.

In the light of this work, researchers could try to develop new or general models to estimate other fuel properties such as heating value, cetane number, acid value etc. of different biodiesel-diesel binary or biodiesel-diesel-alcohol ternary blends for future studies.

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