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ORIGINAL RESEARCH ARTICLE

PREDICTION OF DENSITY AND VISCOSITY OF BIODIESEL FUEL FROM FATTY ACID METHYL ESTER (FAME) COMPOSITION

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ABSTRACT
Viscosity and density are important properties that qualify biodiesel fuel to serve as an alternative fuel because all other properties directly or indirectly depend on them. The processes involved in determining the viscosity and density of biodiesel are relatively simple and costly and there are discrepancies in the results obtained due to the differences in the oil composition of the feed-stocks used as against the reported cause of experimental errors. This work aimed at theoretically determining and developing relationship between the density and viscosity of different feed-stocks and the fatty acid methyl ester composition at different temperatures. In the study, density and viscosity data of biodiesel fuels and the composition of FAME were collected from literatures. A linear regression analysis was carried out for density and viscosity on the average values of viscosity and density data obtained at different temperatures range (10˚C-40˚C) of FAME composition. Equations relating density and viscosity with the percentage composition by weight of FAME of biodiesel fuel were developed. Predicted mean values for kinematic viscosity and density were respectively between 4.31 - 5.64 mm^2/s and 861.67 – 885.66 kg/m^3. The developed equations were able to predict with up to 97.1% accuracy for viscosity and 98.5% accuracy for density. The developed equations could effectively predict the quality of biodiesel (viscosity and density) from various feedstocks based on FAME compositions.

1.0 Introduction

Developing countries are often faced with added impasses about environmental protection owing to their heavy reliance on biomass and fossil fuel. Biomass is gaining more ground and becoming more important because of rampant fuel scarcity, emissions of dangerous pollutants and increase in the prices of fossil fuels (Sensoz et al., 2000). Global warming, the destruction of the ozone layer and acid rain are as a result of economic growth and heavy consumption of natural resources (Thakur, 2006). As a result of the soaring prices of oil coupled with its environmental impact worldwide, there is an increasing use of "green" fuels globally. Most countries these days are taking advantage of crops and even their residues for biofuels production. In the US and Brazil, for example, maize and sugarcane serve as the main feedstocks for the production of ethanol, while kernel seed and rapeseed are respectively used for biodiesel production in Malaysia and Europe (Srinivasa et al., 2010). Biodiesel has also been produced from Nigerian palm kernel, milk bush and sandbox kernel oil (Alamu, et al., 2007a, 2007b, 2007c, 2008, 2009, Jekayinfa, 2018, Oniya et al., 2016 and Ogunkunle et al., 2017).

Rudolf Diesel researched into the use of vegetable oils as fuel for diesel Engines (Lang et al., 2001). It was also established that biodiesel can be obtained from feedstocks like animal fats, and oils from other organisms such as cyanobacteria, micro algae and is produced from triglyceride transesterification which serves as the major constituent of vegetable oils or animal fats in the presence of an alcohol (Jazie etal., 2013). Apart from the fact that biodiesel has lower carbon monoxide emissions and low viscosity, it is also non-toxic, simple to use and essentially free of Sulphur (Alcantara et al., 2000). Biodiesel, though very advantageous, has got some limitations as well especially when using it (Nolte, 2007).

Biodiesel produces relatively high NO2 levels at combustion level due to the high oxygen content in it. This can however be minimized below that of the fossil fuel levels simply by adjusting the timing of the engine. A catalytic converter can as well be used (Manohar et al., 2010). Researchers have attempted to determine the best biodiesel composition that would result into enhancement of combustion process as well as the quantity of various fatty acid that can be employed in predicting both the physical and performance properties of biodiesel (Bamgboye and Hassen, 2008). Viscosity as one of the fuel properties is used as an indicator to ascertain the following; the ease of starting the engine, effectiveness and completeness of the ester conversion process, the quality of spray, the penetration of the injected jet and the quality of the fuel-air mixture combustion is greatly affected by viscosity but reduces considerably with increase in unsaturation (Alptekin and Canakci, 2008).

Density is another property which is greatly influenced by temperature. It also has the capacity to affect fuel performance. Fuel properties such as heating value, cetane number, and viscosity are connected to density (Barabas and Todorut, 2011). The quality of atomization and combustion is affected by density as well (Barabas and Todorut, 2011). Molecular properties had influence on the density and viscosity (kinematic) of biodiesel. As chain length increases, density decreases slightly but larger alkyl esters are all solids at room temperature. It can be affirmed that the level of un-saturation plays a significant role in the determination of density of a given Fatty Acid Methyl Esters sample (Alptekin, and Canakci, 2008).

Also, temperature is one of the key factors that have influence on the density of the liquid as large change in the density at higher temperatures affect the atomization and combustion processes of the engine(Knotheet al., (2005),Tate et al., (2006)and Knothe and Steidley, 2005) carried out investigations on the varying effects of temperature on density of methyl soyate, rapeseed methyl ester and ethyl ester of fish oil and found out that with an increase in temperature, the density decreases linearly and at 300oC the density was as low as 0.5 gcm^{-3}. Geller and Goodrum (2004) opined that the longer the fatty acid chains, the more saturated the molecules and this would automatically result into higher viscosity. However, viscosity is lowered drastically when the saturation is less. There is a vast variation in the values of viscosity and density (Tesfa et al., 2010). Tables 1 and 2 present the value of viscosity and density of the selected feedstocks respectively as obtained from past studies.

Density and viscosity of biodiesel obtained from soybean oil ranged from 882.80 to 900 kgm^{-3} and 3.5-9.31 cSt respectively (Mariceli et al., 2012, Omotola, 2011). For palm-oil derived biodiesel the density and viscosity ranged from 857.80 to 900 kgm^{-3} and 3.70-4.61 cSt respectively (Leung et al.,2010). Also, density and viscosity values obtained for waste cooking oil methyl ester ranged from 879.55 to 889.90 kgm-3 and 5.21 to 6.00 cSt respectively (Tesfa et al., 2010, Leung et al., 2010). The density and viscosity values vary from one feed input to another. This is dependent on the chemical composition of the fuel. It also has effect on the NOx emissions. It has also been observed that there is always a less significant variation in density and viscosity at different temperatures for feedstock of the same type of oil (McCormick et al., 2001).

Density and viscosity fall among properties that can be easily measured though a bit costly. Ballantine et al., (1997) and Josse et al., (2001), noted that these properties can be measured using a Thickness Shear Mode (TSM) resonator or a Guided Shear Horizontal Surface Acoustic Wave (SH-SAW) device. The shortcoming that the TSM systems have are their sensitivity and selectivity to only Newtonian liquids, SH-SAW devices are much more sensitive and selective than their counterparts such as Thickness Shear Mode (TSM), shear Horizontal Acoustic Plate Mode (SH-APM) and Flexural Plate Wave (FPW). Another method of measuring the viscosity is to use a miniaturized thermal conductivity sensor made from molybdenum or another metal and literature reveals that it measures liquids displaying non-Newtonian properties. (Kuntner et al., 2005). In order to theoretically determine the density and the kinematics viscosity of FAME and to establish the findings of researchers that have worked on this subject whether their results conform to the limits set out by the standardization organization, there is a need to develop models that can be used to predict the density and kinematic viscosity of some known parameters. Since the composition of FAME has been established to have great influence on its viscosity and density at varying temperature, models can be developed relating viscosity and density to FAME composition.

Yuan model (Yuan et al., 2009) with parameters specific for FAMEs was used in the work of Mesquita et al., (2011). Also, Yuan model as revised by Pratas (Pratas et al., 2010) and do Carmo et al., (2012) were used to predict biodiesel viscosity. In correlating pure FAME and biodiesel densities, the Tait Equation of State (EoS) was used (Dymond and Malhotra,1988, Pratas et al., 2011, Schedemann et al., 2013 and Aparicio et al., 2007). Pratas et al., (2011) applied the CPA EoS to correlate pure FAME density, and the calculated pure component parameters were applied to predict the density of methyl biodiesels with deviations ranging from 0.79% to 2.5%. Schedemann et al., (2013) in his own turn made use of the VTPR method to predict density data of methyl linoleate and biodiesel as submitted in the findings of Prieto et al., (2015). In developing the present model, the composition of fatty acid in percentage of ester in pure form together with the mixtures of esters (biodiesel) and their experimental density and viscosity were considered (Bamgboye and Hassen 2008). This study aimed at developing regression equations which can be used to predict the density and viscosity of biodiesel based on the FAME chain compositions and authenticating the applicability of the established equations for predicting the density and viscosity based on the FAME composition of the feedstock oils used for biodiesel production.

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Table 1: Reported values of Viscosity of different biodiesel feedstock (mm^2/s) at varying temperature (10-40°C)

TEMP.°C	SUNME*	COME	SME	CME	POME	RME	CSOME	WCME	OSME
10.00	9.92 [8]**	9.54 [8]	9.31[8]	-	-	-	-	-	-
15.00	-	-	-	-	-	-	-	-	-
20.00	7.44[8]	-	-	7.69[8]	-	-	-	-	-
28.00	-	-	-	-	-	-	-	-	-
30.00	-	5.58[8]	-	-		-	-	-	-
40.00	4.03 [1] 4.63[11] 4.57[8] 4.9[5] 4.51[9] 4.38-4.90[3]	4.18-4.52[1] 4.89 [7] 3.39 [5] 4.32[8] 3.39-4.36[3]	4.44[8] 4.10[6] - 4.08 [5,9] 4.08-4.42[3]	4.34- 4.84[1] 4.68[8]	3.70 [1] 4.42 [5] 4.42-4.76[3] 5.7[4]	4.2[4] 4.83-5.65[1] 4.48[2] 5.48[7] 4.3-5.83[5] - 4.59-5.83[3]	- 4.07 [5] - 4.0-4.96[3]	- 5.78-6.00[1] 5.81[5,9] 5.21[7]	4.70 [1] -

*SUNME: Sunflower methyl Esters; COME: Corn Oil Methyl Ester; SME: Soybean Methyl Ester; CME: Canola Seed Methyl Ester; POME: Palm Oil Methyl Esters; RME: Rapeseed Methyl Ester; CSOME: Cotton Seed Oil Methyl Ester; WCME: Waste Cooking Oil Methyl Ester; OSME: Olive Seed Oil Methyl Ester

**The number in the parenthesis represent the different authors from which the viscosities were sourced from literatures for this study: 1. Barabás & Todoruţ, (2010); 2. Chuepeng & Komintarachat, (2010); 3. Zahan and Kano (2018).; 4. Singh and Singh (2010), 5. Leung et al., (2010), 6. Auwal et al., (2011), 7. Tesfa et al., (2010), 8. Maricelida et al., (2012). 9. Omotola (2011).

Table 2: Reported values of Density of different biodiesel feedstock (kg/m^3) at varying temperature (10-40°C)

TEMP.°C	SUNME	COME	SME	CME	POME	RME	CSOME	WCME	OSME
10.00	887.60[8]	885.86[8]	886.33[8]	886.43[4]	-	-	-	-	-
15.00	882.70[9] 880[10] 882.90[9,10]	880-890[10] 882.20[8] 884[1]	885[9,10] 882.80[8]	888[5]	860-900[10], 867[5] 864.4-870[1]	883.7 [2] 880.2[1] 880-888[10]	875[10] 884.1[3]	874.0[9] 897[6]	881.50[1] -
15.60	-	-	-	-	-	-	-	-	-
20.00	883.41[8]	-	-	-	-		-	-	-
25.00	-	-	-	-	-	-	-	-	-
26.00	-	-	-	-	-	-	-	-	-
30.00	-	-	-	-	-	-	-	-	-
32.00	-	-	-	-	-	-	-	-	-
34.00	-	-	-	-	-	-	-	-	-
36.00	-	-	-	-	-	-	-	-	-
38.00	-	-	-	-	-	-	-	-	-
40.00	874.96[8]	879.65[7]	-	874.51[8]	-	879.35[7]	864.4[3]	879.55[7] 920[1]	-

*SUNME: Sunflower methyl Esters; COME: Corn Oil Methyl Ester; SME: Soybean Methyl Ester; CME: Canola Seed Methyl Ester; POME: Palm Oil Methyl Esters; RME: Rapeseed Methyl Ester; CSOME: Cotton Seed Oil Methyl Ester; WCME: Waste Cooking Oil Methyl Ester; OSME: Olive Seed Oil Methyl Ester

**The number in the parenthesis represent the different authors from which the densities were sourced from literatures for this study:

1. Barabás & Todoruţ, (2010); 2. Chuepeng&Komintarachat, (2010); 3. Prieto et al, 2015; 4. Fan et al., (2009), 5. Nolte (2007) 6. Zahan and Kano (2018)., 7. Tesfaet al., (2010), 8.Maricelida et al., (2012). 9. Omotola (2011), 10. Leung et al., (2010)

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2. Materials and Methods

2.1 Fuel Data Selection

The viscosity and density of the biodiesel (FAME Esters) were gotten from different reports submitted to fuel standards by various testing laboratories (European standard EN 14214, ASTM D 6751) as shown in Tables 3 – 6. Average values of the data collected for the percentage composition of the fatty acids in the diverse feedstocks of pure methyl esters were utilized in this study.

2.2 Regression Analysis

A seven by eight matrix was formed with density $\mathbf{P}$ and Viscosity $\mathbf{B}$ as the dependent variable respectively and pure FAME composition as the independent variables as shown in Tables 3 and 4.

The linear regression equation conceptualized can be presented as follows;

$$\mathbf{P} = \mathrm{M} + ax_1 + bx_2 + cx_3 + dx_4 + ex_5 + fx_6 + gx_7 + hx_8 \quad \text{......... 1}$$

and,

$$\mathbf{B} = \mathrm{M} + ax_1 + bx_2 + cx_3 + dx_4 + ex_5 + fx_6 + gx_7 + hx_8 \quad \text{..........2}$$

where,

$\mathbf{P} = \text{density}$, kg / m^3 and B, is the viscosity in mm^2 / s

M, a, b, c, d, e, f, g, h are constants to be determined in the regression analysis;

x_1......x_8 are % compositions of FAME.

Table 3: Reported average values of Density for pure methyl esters of different fatty acids (kg/m^3) at temperature 40°C

Fatty Acid Methyl Esters	Density ρ kg/m^3	References
Laurate	853.90a,	(Barabás and Todoruţ, 2011)a,
Myristate	852.20a	(Barabás and Todoruţ, 2011)a
Palmitate	850.80a, 852b	(Barabás and Todoruţ, 2011)a, (Lapuertaet al., 2010)b
Palmitoleate	853.80a, 875b	(Barabás and Todoruţ, 2011)a, (Lapuertaet al., 2010)b
Stearate	849.80a, 850b	(Barabás and Todoruţ, 2011)a, (Lapuertaet al., 2010)b
Oleate	859.50a, 874b	(Barabás and Todoruţ, 2011)a, (Lapuertaet al., 2010)b
Linoleate	871.50a, 889b	(Barabás and Todoruţ, 2011)a, (Lapuertaet al., 2010)b
Linolenate	887.00a, 895b	(Barabás and Todoruţ, 2011)a, (Lapuertaet al., 2010)b

Table 4: Reported average values of Density for pure methyl esters of different fatty acids (kg/m^3) at temperature (15˚C)a (15.5ºC)b

Fatty Acid Methyl Esters	Density ρ kg/m^3	References
Laurate	873.70a	(Barabás and Todoruţ, 2011)a
Myristate	Not determineda,	(Barabás and Todoruţ, 2011)a
Palmitate	Not determineda, 867b	(Barabás and Todoruţ, 2011)a (Janarthananet al.,1996)b
Palmitoleate	872.80a	(Barabás and Todoruţ, 2011)a
Stearate	Not determineda,	(Barabás and Todoruţ, 2011)a,
Oleate	877.70a,	(Barabás and Todoruţ, 2011)a,
Linoleate	889.90a,	(Barabás and Todoruţ, 2011)a,
Linolenate	905.70a	(Barabás and Todoruţ, 2011)a

Table 5: Reported average values of Kinematic Viscosity for pure methyl esters of different fatty acids (mm^2/s) at temperature 40˚C

Fatty Acid Methyl Esters	Viscosity (mm^2/s)	References
Laurate	2.4331a, 2.43c	(Barabás and Todoruţ, 2011)a, (Knothe,2005)c
Myristate	3.3381a, 3.23c,	(Barabás and Todoruţ, 2011)a, (Knothe,2005)c
Palmitate	4.4136a, 4.38c,	(Barabás and Todoruţ, 2011)a, (Knothe,2005)c,
Palmitoleate	3.0642a, 3.67d	(Barabás and Todoruţ, 2011)a, (Moser, 2009)d
Stearate	5.8675a , 5.51c	(Barabás and Todoruţ, 2011)a,(Knothe,2005)c
Oleate	4.5728a, 4.51c	(Barabás and Todoruţ, 2011)a, (Knothe,2005)c
Linoleate	3.7028a, 3.65c	(Barabás and Todoruţ,2011)a, (Knothe,2005)c
Linolenate	3.2980a, 3.14c,	(Barabás and Todoruţ, 2011)a, (Knothe,2005)c

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Table 6: Reported Average % composition of fatty acids in different feedstocks at 40°C

Feedstock	Lauric	Myristic	Palmitic	Stearic	Palmitoleic	Oleic	Linoleic	Linolenic
SME	0a, 0.08e	0.06a, 0b,d, 0.12e	10.64a 13.9d,11.4e, 12b	3.88a, 2.1d, 3b, 4.14e	0.14a, 0.3d, 0b, 0.16e	32.38a, 23.2d, 23b, 23.47e	46.36a, 56.2d, 55b,53.46e	5.53a, 4.3d, 6b, 6.64e
SUNME	0a,	0.01a, 0b,d 0.04e	6.48a, 6.2d,12b, 6.26e	4.25a, 3b, 2.95d, 3.93e	0a, 0.1d, 0b, 0.06e	18.97a,17.35d, 17b, 20.77e	69.07a,73.45d, 74b, 67.75e	0.26a, 0d,b, 0.15e
CSME	0.02a	0.32a, 0d, 0.72e	22.05a, 28.35d, 25.93e	2.17a,0.95d, 1.74e	0.13a, 0.36e	16.13a, 13d, 15.98e	55.72a, 57.7d, 55.12e	0.25a,0d, 0.16e
POME	0a, 0.37e	0a, 1c, 1.13e	11.1a, 42.6d,41c 42.39e	4.22a, 4.4d, 3b,4.20e	0a,0.3d, 0c, 0.17e	47.23a, 40.5d, 45c,40.91e	32.14a,10.1d,9c, 9.97e	0.68a,0.2d,1c, 0.29e
RME	0a	0.02a,0d, 0.04e	4.06a,3.25d,4.07e	1.2a,0.95d, 1.55e	0.04a, 0.23e	63.12a,64.05d, 62.24e	21.28a,22.15d, 20.61e	8.63a,8.1d, 8.72e
WCME	1.98a,0.20e	0a,0.67e	15.65a, 15.69e	3.10a,6.14e	0.31a, 0.73e	29.57a, 42.84e	41.53a, 29.36e	1.04a,2.03e
OSME	0a,	0a	11.60a,	3.10a,	0.9a,	74.98a,	7.80a,	0.60a

Bamboye and Hassen (2008), b. Bagbyet al.,(1987), c. Ziaziet al.,(1996), d. Singh and Singh, (2010), e. Giakoumis, (2013)

3. Results and Discussion

Table 5 presents the reported average values of Kinematic Viscosity for pure methyl esters of different fatty acids (mm2/s) at temperature 40˚C while Table6 presents the reported Average % composition of fatty acids in different feedstocks at 40˚C. Substituting the values of M, a – h in Eq. (1) and (2) respectively for the coefficients obtained during regression analysis for each of the feedstocks whose reported data were used,the new equations are presented in Tables 7 and 8 for viscosity and density respectively.

Equations (1) to (7) show the relationship between Fatty acid composition and viscosity of feedstocks. From equations (1) to (7), it was observed that coefficient of determination (R^2) of viscosity for SME was 0.775, which indicated that the viscosity of SME can be predicted with 77.5% accuracy. The coefficients of determination (R^2) of viscosity of other feedstocks include SUNME (R^2=0.734), POME (R^2=0.609), CME (R^2=0.971), RME (R^2=0.097), WCME (R^2=0.804) and OSME (R^2=0.959). The above results indicated that fatty acid compositions of methyl esters of different feedstocks are a major predictor of viscosity of biodiesel produced from them and the quality of biodiesel produced is positively influenced by saturated and long fatty acids. Also, shorter and more unsaturated chains always increase the viscosity and flow characteristics at low temperatures (desirable characteristics of fuels). Similarly, Table 8shows that the coefficient of determination (R^2) of density for SME was 0.737, which indicated that the viscosity of SME can be predicted with 73.7% accuracy. The coefficients of determination (R^2) of density of other feedstocks include SUNME (R^2=0.524), POME (R^2=0.837), CME (R^2=0.985), RME (R^2=0.0115), WCME (R^2=0.982) and OSME (R^2=0.835). This implies that the density of a methyl ester depends on its molecular weight (saturated and unsaturated), free fatty acid content, water content, and temperature and indicates that fatty acid compositions of methyl esters of different feedstocks are a major predictor of density of biodiesel produced from them. These results agree with the findings of Knothe (2005), who claimed that an appropriate ratio between saturated and unsaturated fatty acids should be maintained in order to obtain a biodiesel with appropriate quality characteristics.

$$B(SME) = 44.61 + 251.15x_1 + 11.1x_2 + 0.67x_3 + 1.55x_4 - 5.24x_5 + 0.45x_6 + 0.448x_7 + 0.34x_8 \quad (R^2 = 0.775) \tag{1}$$

$$B(SUNME) = 638.57 + 0.0x_1 + 0.0x_2 - 10.60x_3 - 6.09x_4 + 0.0x_5 + 10.33x_6 + 8.04x_7 - 49.49x_8 \quad (R^2 = 0.734) \tag{2}$$

$$B(POME) = 124.55 - 0.12x_1 - 0.13x_2 - 1.14x_3 - 1.91x_4 - 0.48x_5 - 1.36x_6 - 0.77x_7 + 0.67x_8 \quad (R^2 = 0.609) \tag{3}$$

$$B(CME) = 125.23 - 1.295x_1 + 3.09x_2 - 0.18x_3 - 0.0x_4 - 0.17x_5 + 0.93x_6 + 2.05x_7 + 4.40x_8 \quad (R^2 = 0.971) \tag{4}$$

$$B(RME) = 0.897 + 0..0x_1 - 0.92x_2 + 0.0x_3 + 0.0x_4 - 0.52x_5 - 0.0x_6 + 0.10x_7 + 0.757x_8 \quad (R^2 = 0.097) \tag{5}$$

$$B(WCME) = 3024.60 + 0..0x_1 + 0.0x_2 - 11.88x_3 - 1.72x_4 + 0.0x_5 - 29.73x_6 - 47.73x_7 + 18.68x_8 \quad (R^2 = 0.804) \tag{6}$$

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$$B(OSME) = 17.975 + 4.72x_1 + 9.45x_2 + 0.89x_3 + 1.10x_4 - 11.57x_5 - 0.495x_6 - 2.65x_7 + 69.05x_8$$
$$(R^2 = 0.959) \quad (7)$$

The regression model equations indicating the relationship between Fatty acid composition and density of feedstocks are given in equations (8) to (14)

$$P(SME) = 206060 - 53171.1x_1 - 22972x_2 - 11.14x_3 - 39.05x_4 + 7244x_5 - 10.63x_6 - 11.31x_7 - 9.02x_8$$
$$(R^2 = 0.737) \quad (8)$$

$$P(SUNME) = 386.61 + 0.0x_1 + 0.0x_2 - 5.199x_3 - 0.52x_4 + 0.0x_5 + 6.593x_6 + 5.98x_7 - 26.585x_8$$
$$(R^2 = 0.524) \quad (9)$$

$$P(POME) = 146415 + 21.94x_1 + 21.69x_2 - 6.84x_3 - 33.81x_4 + 97.13x_5 - 2.25x_6 - 7.66x_7 - 71.93x_8$$
$$(R^2 = 0.837) \quad 10)$$

$$P(CME) = 988.49 + 9.31x_1 - 2.58x_2 + 0.36x_3 + 17.53x_4 - 3.02x_5 - 0.12x_6 - 1.94x_7 + 1.25x_8$$
$$(R^2 = 0.985) \quad (11)$$

$$P(RME) = 945.25 + 0.0x_1 - 6.87x_2 + 0..0x_3 + 0.0x_4 + 0.0x_5 - 1.68x_6 - 1.11x_7 + 8.31x_8$$
$$(R^2 = 0.115) \quad (12)$$

$$P(WCME) = 2247.22 + 0.0x_1 + 0.0x_2 + 135.14x_3 - 85.10x_4 + 0.0x_5 - 81.68x_6 + 89.02x_7 + 0.14x_8$$
$$(R^2 = 0.982) \quad (13)$$

$$P(OSME) = 302.23 + 34.79x_1 - 182.97x_2 + 2.26x_3 - 15.97x_4 - 209.60x_5 + 20.20x_6 + 13.64x_7 + 1389.26x_8$$
$$(R^2 = 0.835) \quad (14)$$

Where

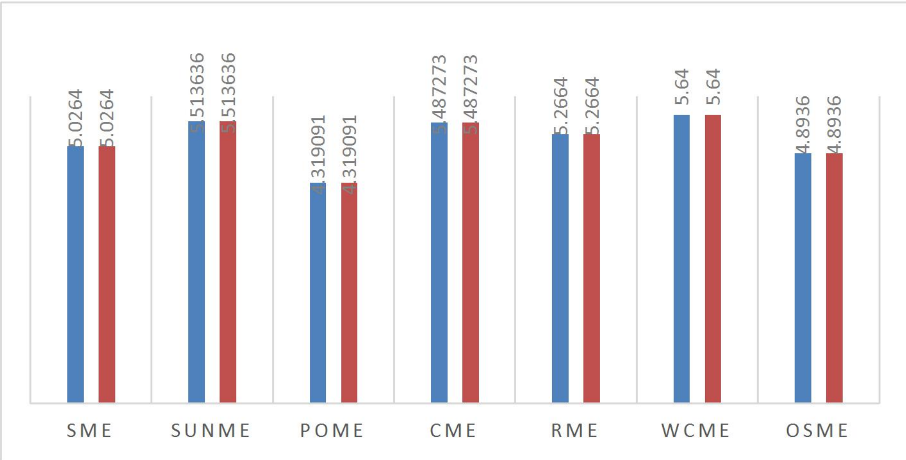
x_1.......x_8 are percentage (%) composition of FAME

B= is the viscosity in mm^2 / s

P= is the density in kg/m^3

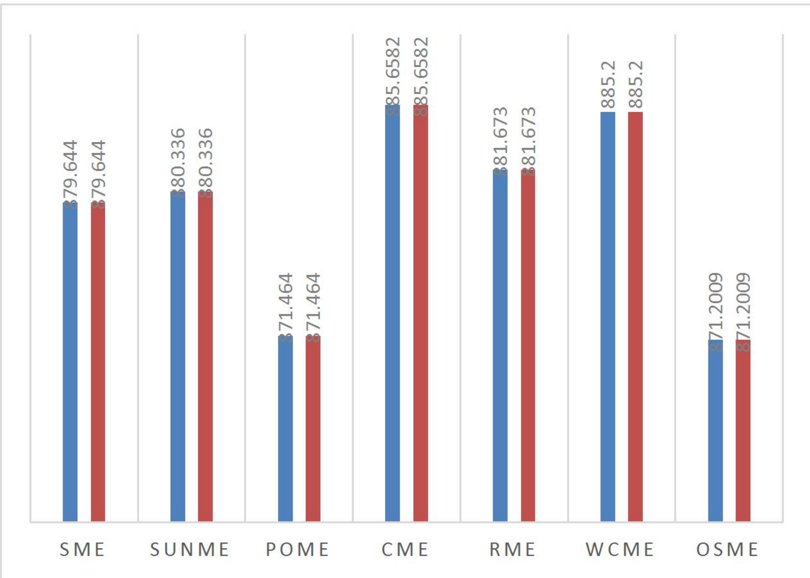
The equations developed (equations 1 to 14) were used to predict the viscosity and density of different biodiesels consisting of different FAME compositions. The predicted values were plotted against the measured values for both the viscosity and density (Figures 1 and 2). The viscosity and density of biodiesel predicted were comparable to the standard values (ASTM D6751). Hence, it could be concluded that the viscosity and density of biodiesel can be predicted based on FAME compositions. The equation developed was applied to other studies previously carried out by different researchers. The results gave an indication of variation of the density and viscosity based on the % composition of FAME. However, the average range of reported values for density and viscosity of different types of biodiesel as shown in Tables 1 and 2 differs considerably. Table 6 projects average FAME compositions of different feedstock for biodiesel fuel as extracted from related past works.

The mean viscosity of SME, SUNME, POME, CME, RME, WCME, and OSME at varying temperatures (10°C to 40°C) were determined and plotted (Figure1). The means of SME, SUNME, POME, CME, RME, WCME and OSME were found to be 5.026, 5.514, 4.319, 5.488, 5.266, and 5.64 and 4.894 respectively. The kinematic viscosity at up to 40°C for the selected biodiesel samples were between 4.319091-5.64cSt which thus satisfies the recommended limits by ASTMD6751 ranges are 1.9—6.0 cSt for a fatty acid methyl ester. In the same vein, the observed mean density ranged from 871.2009 to 885.6582kg/m^3 while the predicted mean density also ranged from 861.673 to 885.6582 kg/m^3 for the selected feedstocks. CME reported highest density (885.6582kg/m^3) while OSME reported lowest mean density (871.2009 kg/m^3) and is within the ranges (860.0—900.0) recommended for fatty acid methyl esters (FAME) EN: 14214, 2008.



Key: Blue bars =Observed value while orange bars=Predicted values

Figure 1: Observed and predicted mean values for the selected feedstocks viscosity



Key: Blue bars =Observed value while orange bars=Predicted values

Figure 2: Observed and predicted mean values for the selected feedstocks density

4.0 Conclusions

The following conclusions were drawn:

The study has established the regression equations relating viscosity and FAME compositions for the selected feedstocks (SME, SUNME, POME, CME, RME, WCME and OSME). Similar equations were also developed for viscosity and FAME compositions. The equations developed to predict based on the FAME composition and were able to predict with up to

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97.1% accuracy for viscosity and 98.5% accuracy for density. The developed equation can effectively predict the quality of biodiesel (viscosity and density) from various feedstocks based on FAME composition. The predicted mean values for kinematic viscosity and density were respectively 4.31 - 5.64 mm^2/s and 861.673– 885.6582Kg/m^3.

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