



THE EFFECTS OF TEMPERATURE AND BLENDING ON THE SPECIFIC GRAVITY AND VISCOSITY OF JATROPHA METHYL ESTER

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ABSTRACT

The specific gravity and viscosity of biodiesel fuels are key properties in determining the suitability for use of such fuels in diesel engines. Though generally higher than those of #2 diesel fuel (DF2), they have been mostly reduced by blending with DF2 and preheating to achieve comparable values as DF2. The objectives of this study were to investigate the effects of temperature and blending on specific gravity and viscosity of Jatropha methyl ester, and also investigate the effect of modifying Clements blending equation by substituting volume fraction for mass fraction. Correlation models were developed to predict the variation of specific gravity and viscosity with both temperature and % biodiesel in a blend. Blends of Jatropha methyl ester (JME) and DF2 on volume basis were prepared and investigated in the temperature range 15-60°C together with the pure fuels. Blends B20, B35, B50 and B75 were made. Specific gravity was determined using specific gravity method whereas viscosity was evaluated using the Ostwald viscometer. Specific gravity of JME was found to be generally 4.83% higher than that of DF2. Blending with DF2 lowered the specific gravity significantly, and a correlation model was developed for use to approximate the specific gravity of any JME-DF2 fuel blend. Preheating the fuels lowered the specific gravity as temperature increased. Correlation models were developed to predict the specific gravity of the test fuels as function of both temperature and amount of JME in the blend. Calculating specific gravity using the Specific gravity blending equation proposed by Clements was found to give results within $\pm 0.5\%$ of the measured values with mass fraction replaced by volume fraction. The viscosity of JME was found to be 42.09% higher than that of DF2. Blending with DF2 resulted in significant viscosity reduction, which varied linearly with the amount of DF2 in the blend. Correlation models were proposed to approximate the viscosity of any blend as a function of temperature in the range from 15°C to 60°C, and as a function of % biodiesel. Results showed that blends with up to 50% JME conformed to both specific gravity and viscosity without the need of preheating.

Keywords: Jatropha methyl ester, biodiesel, specific gravity, viscosity, temperature.

INTRODUCTION

Biodiesel is a substitute for, or an additive to diesel fuel that is derived from plant oils and animal fats which are composed of a specific category of organic compounds called triglycerides. It is defined as mono alkyl esters of long chain fatty acids and conforms to ASTM D6751 specifications for use in compression ignition engines. It is produced by reacting a fat or oil with an alcohol in the presence of a catalyst in a process called transesterification. The product of the reaction is a mixture of esters, which is known as biodiesel, and glycerol. Catalysts used for the transesterification of triglycerides are classified as alkali, acid, enzyme or heterogeneous catalysts, among which alkali catalysts like sodium hydroxide, sodium methoxide, potassium hydroxide, potassium methoxide are more effective (Ma and Hanna, 1999). The primary advantages of biodiesel are that it is renewable, non-toxic and biodegradable. Biodiesel is the only alternative fuel that has passed EPA-required Tier I and Tier II Health Effects testing requirements of the Clean Air Act Amendments of 1990. In addition, biodiesel has been shown to be a very promising alternative to crude-oil derived diesel fuels because it is renewable, it significantly reduces particulate matter, hydrogen carbon (HC) and carbon monoxide (CO) emissions (Graboski *et al.*, 1996; McCormick *et al.*, 2001). The physical and chemical properties of biodiesel to a large extent depend

on its chemical constitution (Knothe, 2005). Most vegetable oils are composed of a specific category of organic compounds called triglycerides. A triglyceride (TG) molecule is made up of three fatty acid units attached to a three-carbon backbone. The most common fatty acids occurring in vegetable oils and their physical properties are have been determined by Bagby *et al.*, 1984. The most common derivatives of TG's (or fatty acids) for fuels are fatty acid methyl esters (FAME) formed by transesterification of the TG with methanol in presence of a catalyst.

As a result of instability of world fuel prices, limited oil reserves and environmental concerns, there has been a renewed effort in finding replacement of fossil fuels. Biodiesel has been fronted as a suitable replacement for diesel, and has so far been commercialised in parts of Europe and USA. Many feedstocks for biodiesel production have been proposed, with most vegetable oils being suitable candidates. As a result, there is need of property data for as many as possible biodiesel fuels based on different oils to evaluate their suitability for use in diesel engines. Though results of measurements and predictions of some biodiesel properties have been reported, Jatropha oil based biodiesel measurements and predictions are rare or possibly not yet done. With Jatropha being fronted as one of the most viable sources of biodiesel in Africa, and in Kenya in particular, property



data of its biodiesel is needed. The aim of this study was to investigate the variation of specific gravity and viscosity of *Jatropha* based biodiesel with temperature and blending with #2 diesel fuel, and also investigate the effect of modifying Clements blending equation by substituting volume fraction for mass fraction.

The specific gravity of most oils and their methyl esters is higher than that of diesel fuel. This is due to the large molecular mass and chemical structures of vegetable oils (Pramanik, 2002, Graboski and McCormick, 1998). However, this helps in countering their low heating values in terms of brake specific fuel consumption. The specific gravity of a methyl ester depends on its molecular weight, free fatty acid content, water content and temperature (Saeid *et al.*, 2008). Specific gravity data is essential in modelling combustion process in internal combustions engines and also in evaluating the thermal efficiency of the fuel. Specific gravity is also one of the most basic and most important properties because some important performance indicators such as Cetane number and heating value are correlated with it (Tat and Van Gerpen, 2000). It is also an important parameter in connection with fuel storage and transportation. The variation of specific gravity with temperature for biodiesel has been evaluated for some fuels. Liew *et al.*, 1992 in his studies on the densities and viscosities of the methyl esters of hexanoic, heptanoic, octanoic, decanoic and dodecanoic acids found that the densities of the methyl esters vary linearly with temperature for the range of 10 to 80°C. Wenqiao Yuan *et al.*, 2004 also observed similar trend for soybean methyl ester (SMEB) and a yellow grease methyl ester (YGME). Similar trends were also observed by Tate *et al.*, 2006 on his studies on the density of methyl esters of canola and soy and ethyl esters of fish-oil on a temperature range of 20 to 300°C.

The viscosity of typical vegetable oils is 15-20 times higher than that of diesel fuel. The viscosity of biodiesel is slightly greater than that of petrodiesel but approximately an order of magnitude less than that of the parent vegetable oil or fat (Dunn R.O. and Knothe G., 2001). This results in fuel flow problems when vegetable oils are used in diesel engines. Viscosity is directly related to the iodine value of a vegetable oil, in that the higher the iodine value the higher the viscosity. Unsaturated oils therefore have higher viscosities than the saturated oils with lower iodine values. The chain length of the constituent fatty acids or the presence of other constituents also influences viscosity. Kinematic viscosity increases with chain length of either the fatty acid or alcohol moiety in a fatty ester or in an aliphatic hydrocarbon (Knothe G. Kevin R. S., 2005). Though viscosity decreases with unsaturation, it increases markedly with contamination by mono, di- or tri-glycerides.

The viscosity of a fuel exerts a strong influence on the shape of the fuel spray and hence the combustion process. High viscosities increase pumping losses in the injector pump and injectors, reducing the injection pressure. This causes low atomization (large-sized droplets) and high penetration of the spray jet causing

incomplete combustion. Highly viscous fuel in a cold engine may discharge almost as a solid stream into the combustion chamber and starting may be difficult while smoky exhaust will invariably appear. Low viscosities result in increased leakages past the piston in the injection pump.

Estimation techniques for biodiesel properties

As already mentioned, most of biodiesel properties depend on the chemical composition and component mixture. The property data for major pure components for biodiesel namely palmitate, stearate, oleate and linoleate have been determined as reported by Clements (1996).

Density

The density of methyl esters of fatty acids as a function of temperature can be simply estimated using an empirical relation (Equation 1) developed by Janarthanan, *et al.* (1996).

$$\rho_i = a_i t + b_i \quad (1)$$

Where t is the temperature in degree Celsius and a and b are component dependent constants. Clements (1996) evaluated and reported the values of the constants for the major pure components for biodiesel for temperatures ranging between 26.7 and 110°C. The density of a mixture of the components (biodiesel) can be estimated using a simple linear mixing rule given in Equation 2, in which x_i is the mole fraction of pure components in the mixture.

$$\rho_{mix} = \sum x_i (a_i t + b_i) \quad (2)$$

Viscosity

Janarthanan *et al.* (1996) tested a number of empirical expressions for representing the temperature dependence of liquid viscosity and suggested that the viscosity for methyl palmitate, stearate and oleate can be approximated by the equation of the modified versions of the Andrade equation in the form of equations 3 and 4 below.

$$\ln v = A + \frac{B}{T} + \frac{C}{T^2} \quad (3)$$

And that of methyl linoleate by the equation of the form;

$$\ln v = A + BT + \frac{C}{T^2} \quad (4)$$

Where A , B and C are constants and T is temperature in degree Celsius. These equations were found by Abramovic *et al.*, (1998) to best predict oil viscosity dependence on temperature for unrefined sunflower oil, refined sunflower oil, refined corn oil, olive oil and unrefined pumpkin oil.

Other expressions have been suggested for viscosity estimation of the form;



$$\ln v_{mix} = \sum x_i f(v) \quad (5)$$

A commonly used form of equation (5) suggested by Clements (1996) is;

$$\ln v_{mix} = \sum x_i (\ln v)^{1/2} \quad (6)$$

The properties and use of Jatropha oil as a diesel engine fuel

The fatty acid composition of Jatropha classifies it as Linoleic or Oleic acid type, which are unsaturated fatty acids as reported by Liang *et al.* (2006), Anamika (2006), and Sangha *et al.* (2004).

MATERIALS AND METHODS

Fuels

Jatropha methyl ester was prepared by alkali-based transesterification process of Jatropha oil. The oil was cold pressed from Jatropha seeds sourced from the western region of Kenya. Diesel fuel #2 was purchased from a Shell petrol Station. The two fuels were blended in volume basis and blends B20, B35, B50 and B75 prepared for investigation.

Experimental procedure

Specific gravity

The specific gravity of the samples was determined using the specific gravity bottle method. Two bottles were used for each test simultaneously and test repeated twice for each temperature and fuel under test. A calibration test using distilled water was done for temperatures ranging from 15 to 60°C at increments of 5°C. The bottles were heated in an electrically heated water bath and temperature controlled by a contact thermometer. The mass of the bottles and fuels were determined using a Mettler 110 Analytical balance. A

calibration test was done using distilled water and the volumes determined using data available in the Hand Book of Chemistry, by Lange (1941).

Viscosity

The viscosity of the fuel samples was determined using the Ostwald viscometer conforming to the British Standards. The viscometer used was a size D BS/U, borosilicate glass. Test involved determining the time of flow of fuel through the viscometer orifice for a predetermined volume as per the viscometer calibration at a given temperature. The procedure was repeated for the temperatures 15 to 60°C at increments of 5°C. This procedure was done for all the test fuels with three runs per sample per temperature. A calibration test using distilled water was done for temperatures ranging from 15 to 60°C at increments of 5°C and viscosity determined using data available in the Hand Book of Chemistry, by Lange (1941). The viscometer was heated in an electrically heated water bath and temperature controlled by a contact thermometer.

RESULTS AND DISCUSSIONS

Specific gravity

The specific gravities of DF2, JME and its blends with DF2 were measured at different temperatures and the results are shown in Figure-1. It was observed that the specific gravities of the blends increased with percentage of JME (biodiesel) in the blend at all temperatures and decreased with increase in temperature for all the tested fuels. The specified range of specific gravity of DF2 by Kenya Bureau of Standards (KEBS) standard KS 1309-1 is 0.820 - 0.870 at 20°C. The specific gravities of B20, B35 and B50 were within the specification at temperatures in the range 15 - 60°C, while the blends B75 and B100 only conformed to the specification when heated to temperatures of above 30°C and 45°C respectively to lower the specific gravity to the specified maximum of 0.87.

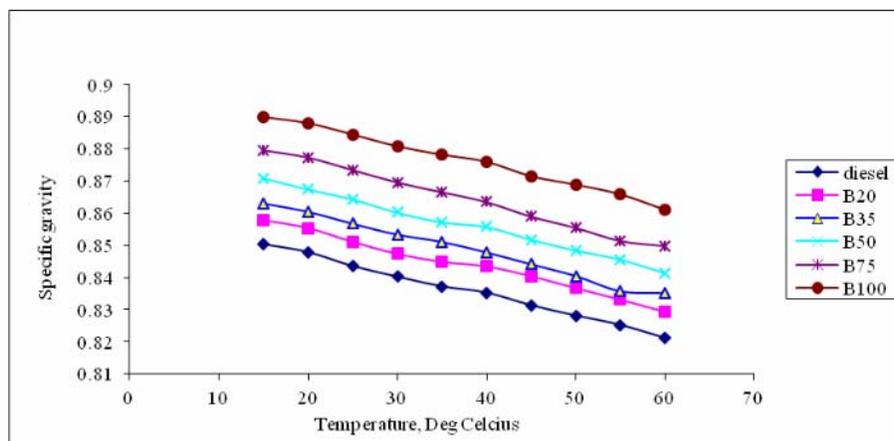


Figure-1. Variation of specific gravity with temperature.



Specific gravity correlation model

The measured specific gravity of the Jatropha oil methyl ester (JME) and its 20, 35, 50 and 75% v/v blends with DF2 were correlated as a function of temperature using the linear regression square method. The following linear regression equation was used:

$$SG = mT + b \quad (7)$$

Where SG denotes the specific gravity, T is the temperature in $^{\circ}C$, and m and b are correlation constants. The linear least square regression lines of DF2, JME (B100) and its blends with DF2 are shown in Figure-2 while the regression constants and coefficient are tabulated in Table-1.

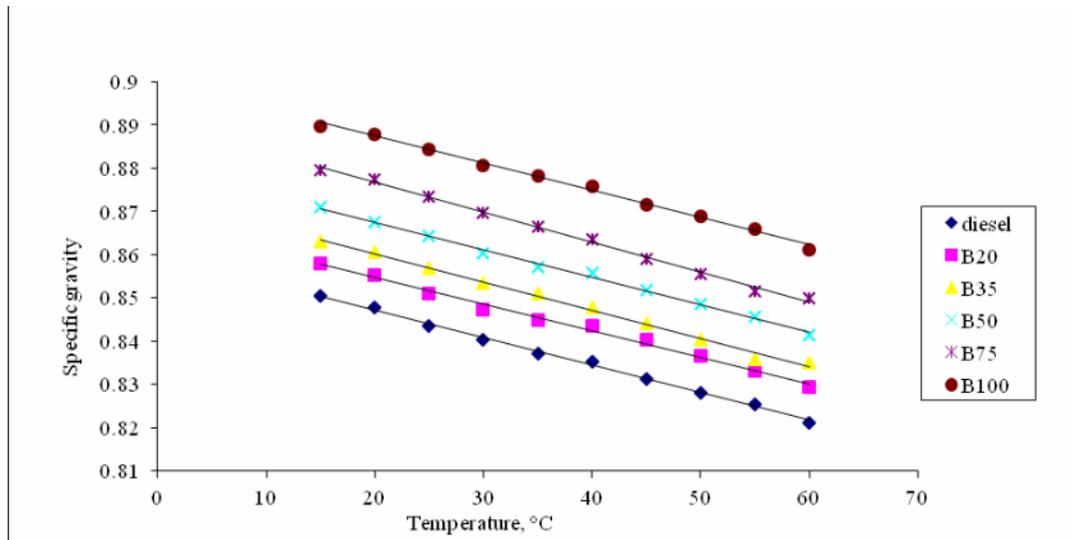


Figure-2. Regression lines of specific gravity for DF2, JME and its blends as a function of temperature.

Table-1. Linear square regression constants and regression coefficients for specific gravity as a function of temperature for the test fuels.

Fuel sample	$m \times 10^{-4}$	b	R
Diesel	-6.38388	0.85999	-0.99862
B20	-6.15030	0.86701	-0.99641
B35	-6.53079	0.87328	-0.99707
B50	-6.35212	0.88017	-0.99821
B75	-6.96012	0.89070	-0.99830
B100	-6.28630	0.89999	-0.99756

As observed in Figure-2, JME and its blends with No. 2 diesel fuel have a linear specific gravity-temperature relationship as with DF2 fuel. This relationship has been observed on other biodiesel fuels. The specific gravity of each fuel at various temperatures can be easily calculated using the correlation constants in Table-6. The lowest regression coefficient R in Table-1 is 0.99641, and it indicates that the linear least square regression represents accurately the relationship between specific gravity and temperature. The correlation constants for JME were comparable with those of soybean oil methyl ester (SMEA) and yellow grease methyl ester (YGME) as determined by Wenqiao Yuan *et al.* (2004).

The values of specific gravity as measured were also correlated as a function of percentage biodiesel in the blend and a linear relationship was found to exist. This was represented by Equation 8.

$$SG = mB + k \quad (8)$$

Where SG denotes the specific gravity, B is the percentage biodiesel in the blend, and m and k are correlation constants. The regression constants and the correlation coefficients are listed in Table-2 and the linear least square regression lines for different temperatures plotted as shown in Figure-3.

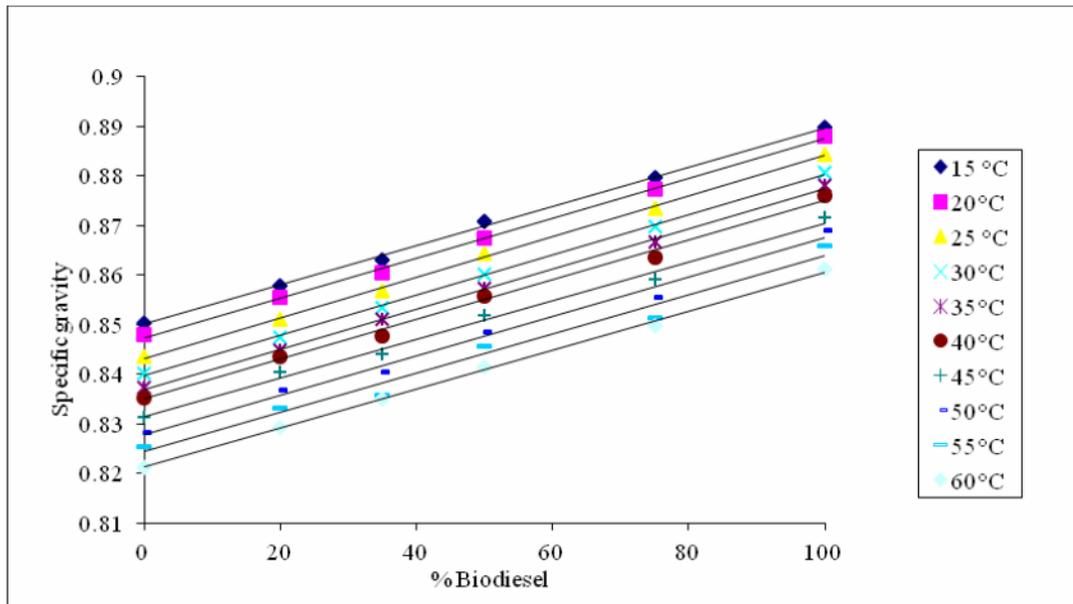


Figure-3. Regression lines of specific gravity as a function of amount of JME (biodiesel) in the blend at various fuel temperatures.

Table-2. Linear square regression constants and regression coefficients for Specific gravity as a function of JME percentage in blend for some temperatures.

Temperature, °C	$m \times 10^{-4}$	k	R
15	3.9641	0.85009	0.99910
20	4.0163	0.84734	0.99941
25	4.0986	0.84431	0.99934
30	4.0613	0.83964	0.99939
35	4.0624	0.83690	0.99950
40	4.0000	0.83497	0.99750
45	3.8918	0.83153	0.99650
50	3.9580	0.82789	0.99555
55	3.95887	0.82436	0.99018
60	3.93736	0.82128	0.99932

Specific gravity blending equation

Clements (1996) suggested that the specific gravity of biodiesel blends can be calculated using the blending equation,

$$SG_{blend} = \sum SG_i \times X_i \quad (9)$$

Where SG_{blend} is the specific gravity of blend, SG_i is the specific gravity of the component fuels and X_i denotes the mass fraction of the component i . This equation was used to calculate the specific gravities for the blends tested in this study and were compared with measured values. In this study the mass fraction X_i was replaced with volume fraction, and the calculated specific gravities were found to be within 0.5% of the measured values as shown in Table-3. This showed that the blending equation is applicable to JME biodiesel, and that the mass fractions can be satisfactorily substituted with volume fractions in approximating specific gravities of biodiesel blends with good accuracy.

**Table-3.** Comparison between measured and calculated values of specific gravity for blends.

B20				B35			
Temperature, °C	Measured specific gravity	Calculated specific gravity	Percentage difference	Temperature, °C	Measured specific gravity	Calculated specific gravity	Percentage difference
15	0.85784	0.85823	0.045	15	0.86310	0.86413	0.120
20	0.85540	0.85589	0.058	20	0.86049	0.86189	0.162
25	0.85110	0.85171	0.072	25	0.85677	0.85784	0.125
30	0.84734	0.84836	0.120	30	0.85336	0.85442	0.125
35	0.84488	0.84541	0.063	35	0.85109	0.85155	0.054
40	0.84343	0.84342	-0.001	40	0.84781	0.84952	0.201
45	0.84041	0.83939	-0.121	45	0.84407	0.84541	0.159
50	0.83666	0.83630	-0.044	50	0.84044	0.84241	0.234
55	0.83310	0.83339	0.035	55	0.83566	0.83949	0.458
60	0.82930	0.82916	-0.017	60	0.83508	0.83515	0.009

B50				B75			
Temperature, °C	Measured specific gravity	Calculated specific gravity	Percentage difference	Temperature, °C	Measured specific gravity	Calculated specific gravity	Percentage difference
15	0.87091	0.87004	-0.1	15	0.87961	0.87989	0.0313
20	0.86747	0.86788	0.0473	20	0.87736	0.87787	0.0581
25	0.86437	0.86396	-0.0470	25	0.87349	0.87417	0.0773
30	0.86026	0.86049	0.0267	30	0.86964	0.87060	0.1104
35	0.85724	0.85769	0.0519	35	0.86660	0.86791	0.1515
40	0.85580	0.85562	-0.0220	40	0.86353	0.86578	0.2603
45	0.85183	0.85143	-0.0480	45	0.85900	0.86145	0.2855
50	0.84850	0.84852	0.0018	50	0.85552	0.85870	0.3714
55	0.84565	0.84558	-0.0080	55	0.85144	0.85574	0.5044
60	0.84144	0.84115	-0.0350	60	0.84984	0.85113	0.1521

Viscosity

The viscosities of DF2, JME and its blends with DF2 were measured at ten different temperatures and are as represented in Figure-4. The viscosities increased as the percentage of biodiesel in the blends increased and decreased with increase of temperature. The viscosity of the blend B20 was 7.71% higher than DF2 at all temperatures, and 16.79, 22.48 and 39.13% higher for blends B35, B50 and B75, respectively. JME (B100) had a viscosity 49.20% higher than DF2 at all the temperatures. The viscosity of all the test fuels decreased rapidly with increase in temperature.

The viscosity specifications for DF2 and biodiesel by KEBS KS 1309-1 (Specification for diesel fuels - part 1: Automotive gas oil) and ASTM D 975 (standards for biodiesel) are 1.6 - 5.5 cSt and 1.9-6.0 cSt at 40°C, respectively. It was observed that the viscosities of all blends were within specified limits of both diesel and biodiesel for reference temperatures for viscosity (i.e., 40°C) as shown in Figure-4. Considering these ranges as the most ideal viscosity range of a diesel fuel, it was concluded that for the fuels under study, DF2 and B20 would give normal performance in a diesel engine up to temperatures of around 42°C, B35 and B50 up to 46°C, and B75 and B100 up to 53°C and 55°C, respectively.

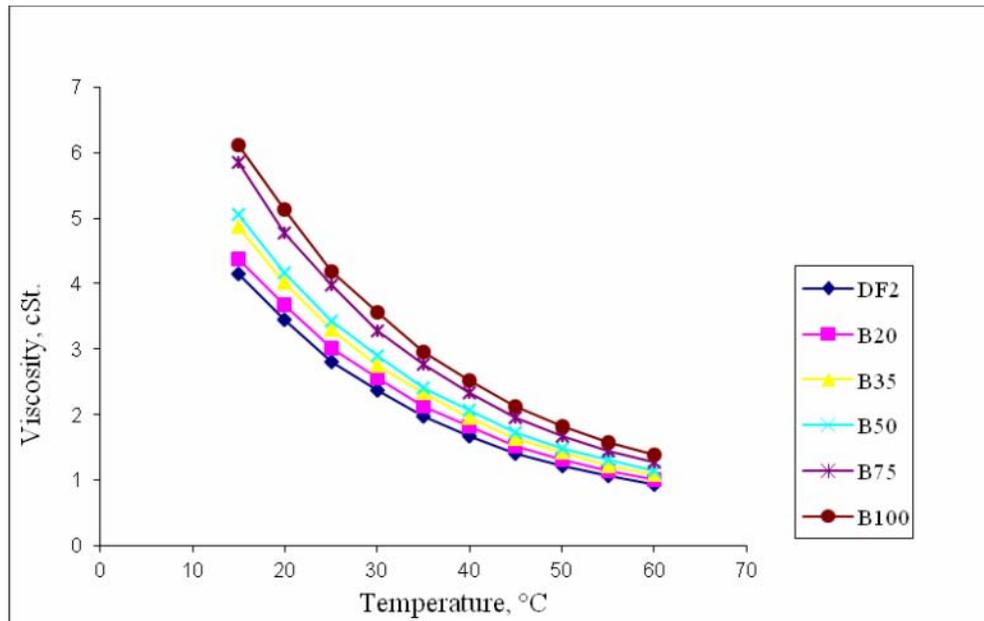


Figure-4. The variation of viscosity with temperature for DF2, JME and its blends with DF2.

Viscosity correlation model

The variation of viscosity with temperature was accurately fitted using a polynomial model of the form of equation 10;

$$v = aT^2 - bT + c \quad (10)$$

Where v is viscosity in centistokes, T is temperature in $^{\circ}\text{C}$ and a , b , c are constants. The values of the constants for the fuel blends are given in Table-4.

Table-4. Viscosity correlation constants and coefficient of determination.

Fuel	a	b	c	R^2
DF2	0.001	0.178	6.436	0.998
B20	0.001	0.182	6.750	0.998
B35	0.001	0.208	7.544	0.998
B50	0.001	0.213	7.784	0.997
B75	0.002	0.251	9.056	0.997
B100	0.002	0.254	9.412	0.998

It can be observed, from the values of the coefficient of determination, R^2 that the polynomial model predicts the relationship of viscosity and the tested fuels quite accurately. Exponential and logarithmic models were also found to give good predictions, but not as the polynomial model. The exponential model was in the form of equation 11;

$$v = a - 0.03T \quad (11)$$

The logarithmic model was in the form of equation 12;

$$v = -b \ln(T) + c \quad (12)$$

Where v is viscosity in centistokes, T is temperature in $^{\circ}\text{C}$ and a , b , c are constants as given in Table-5.

Table-5. Viscosity correlation constants and Coefficient of determination for exponential and logarithmic models.

Fuel	Exponential model		Logarithmic model		
	a	R^2	b	c	R^2
DF2	6.571	0.995	2.36	10.47	0.994
B20	6.979	0.996	2.49	11.09	0.995
B35	7.736	0.995	2.78	12.29	0.994
B50	7.950	0.996	2.86	12.69	0.994
B75	9.324	0.996	3.34	14.77	0.994
B100	9.769	0.997	3.48	15.48	0.995

The variation of viscosity with percentage biodiesel in the blend depicts a linear relationship especially for temperatures above 25°C as shown in Figure-5, and of the form of Equation 13.

$$v = mB + k \quad (13)$$

Where v is kinematic viscosity, m and k are correlation constants. The correlation constants m and k , and the correlation coefficients R are given in Table-6.

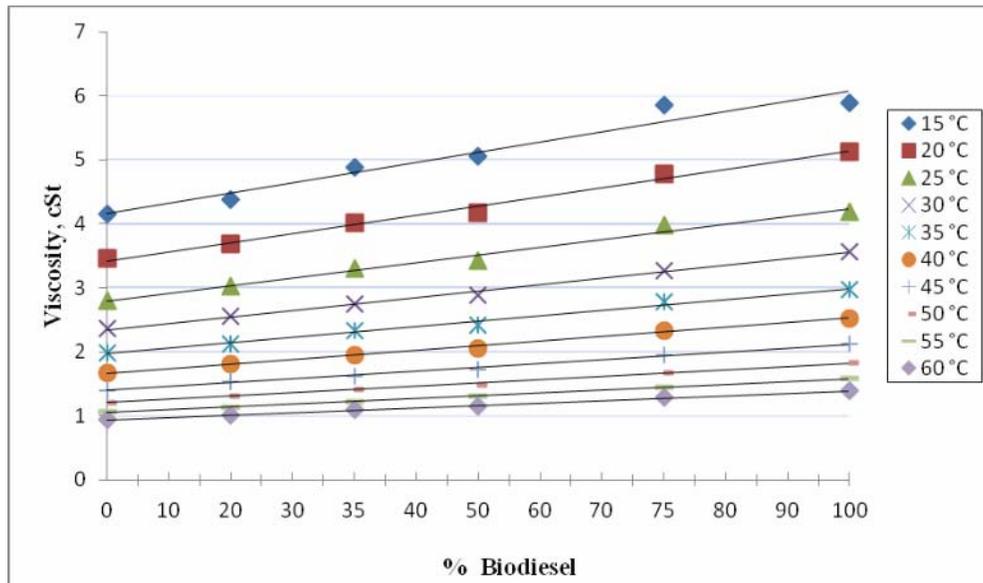


Figure-5. The variation of viscosity with biodiesel percentage in blends for various temperatures.

Table-6. Linear square regression constants and regression coefficients for viscosity as a function of biodiesel percentage in the blend for different temperatures.

Temperature, °C	<i>m</i>	<i>k</i>	<i>R</i>
15	0.0213	4.0506	0.9790
20	0.0183	3.3318	0.9953
25	0.0151	2.7418	0.9885
30	0.0128	2.2917	0.9984
35	0.0106	1.9281	0.9931
40	0.0090	1.6344	0.9983
45	0.0075	1.3693	0.9987
50	0.0064	1.1843	0.9984
55	0.0056	1.0258	0.9996
60	0.0048	0.9172	0.9986

From Figures 4 and 5 it was deduced that the effect of percentage of biodiesel is more prominent at low temperatures. As the temperature increases, the viscosities of the blends tend to converge (Figure-4), and this is also depicted by reducing values of *m* in Table-6 with increase of temperature.

CONCLUSIONS

- The specific gravity of Jatropha methyl ester and its blends with DF2 have a linear specific gravity - temperature relationship as that of DF2.
- The specific gravity of Jatropha methyl blends with DF2 have a linear specific gravity - % biodiesel relationship for the temperature range 15 - 60°C.

- The blending equation for calculating specific gravity of blended fuels is true for JME-DF2 blends with the mass fraction substituted with volume fraction.
- The variation of viscosity with temperature of Jatropha methyl ester and its blends with DF2 depict a polynomial relationship.
- The viscosity of Jatropha methyl blends with DF2 have a linear viscosity - % biodiesel relationship for the temperature range 15 - 60°C.
- Jatropha biodiesel blends of up to B50 can be used conveniently in Kenya, and other countries in the tropics where temperatures rarely go below 15°C, without the need of preheating.

ACKNOWLEDGEMENTS

The authors acknowledge the University of Nairobi for funding and availing facilities for this research. Kenya Industrial Research and Development Institute and Kenya petroleum oil refineries are also acknowledged for their contributions in extraction of oil and determination of some oil properties.

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