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FORMULATION OF RELATIONSHIP BETWEEN VISCOSITY AND TEMPERATURE FOR PALM KERNEL OIL BIODIESEL

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ABSTRACT

Production of Biodiesel from Palm kernel oil (PKO) through transesterification with ethanol using potassium hydroxide (KOH) catalyst was accomplished in a previous study. Characterization of the PKO biodiesel was undertaken. From the results, a possible relationship between viscosity and the temperature of the PKO biodiesel was obtained using the least square regression approach. The resulting Viscosity–Temperature model $\mu_{PKObiodiesel} = 6.4592e^{-0.0075T}$ was developed into a computer program and run with a compiler using lower bound temperature ($0^{O}C$), below the pour point of the PKO biodiesel; upper bound temperature ($325^{O}C$), above the flash point as well as boiling point of the PKO biodiesel and temperature incremental step of $0.2^{O}C$. The computer program generated a database for prediction of viscosity of PKO biodiesel at varying temperatures, with minimal error. Results obtained are in good agreement with experimental measurements.

KEYWORDS: Biodiesel, Palm kernel oil, viscosity, Temperature.

INTRODUCTION

It has been widely reported that the depletion of world petroleum reserves, harmful exhaust emissions from engines, instability in the prices of petroleum products and uncertainties of their supply have created renewed interest among researchers to search for suitable alternative fuels. Greener fuels sources are now attracting wide societal and political interests, especially for its reduced greenhouse emissions, biodegradability and sustainability (Anwar et al., 2010; Baroutian et al., 2011; Agbede et al., 2012; Hayyan et al., 2013; Sakthivel et al., 2014; Elkady et al., 2015). Possible substitutes to fossil fuels are oils extracted from animal or vegetable sources.

Biodiesel, produced mostly through transesterification of vegetable oils and animal fats, offers one of the most promising solutions to the ever-increasing demand of diesel.

Several feedstocks have been considered for production of biodiesel in different parts of the world. There are reports on efforts of researchers on Canola in Canada, China, India, France, Austria and Germany (as reported in Marchetti, 2009); Corn in USA, Mexico, Russia and the United Kingdom (Nisa and Hamzah, 2012; Anastopoulus et al., 2013; Alhassan et al., 2014); Soybean in USA, Argentina, Brazil, India and China (Kim et al., 2010; Gomes et al., 2011; Pisarello et al., 2014); Sunflower in Russia, Argentina, France, Italy and Germany (Sankaranarayanan, 2012; Saba et al., 2016); Coconut in Malaysia, Vietnam, Mozambique, Bangladesh and Ghana (Sulaiman et al., 2010; Hossain et al., 2012); Jatropha curcas in India, Yemen and Nigeria (Baggash and Abdulrahman, 2010; Umaru and Aberuagba, 2012) and Palm oil as well as Palm kernel oil in Malaysia, Indonesia, China, Mexico, Colombia, Cote d'Ivoire, Ghana and Nigeria (Alamu et al., 2007,2009; Suppalakpanya et al., 2010; Baroutian et al., 2012; Shahla et al., 2012; Lee and Ofori-Boateng, 2013; Noipin and Kumar, 2014; Wong et al., 2015).

Alamu et al. (2007, 2009) used Nigerian Palm kernel oil as feedstock and KOH as catalyst for transesterification of PKO with ethanol to obtain PKO biodiesel. Fuels, including biodiesel, are generally characterized through tests for properties such as specific gravity, viscosity, pour point and cloud point amongst others.

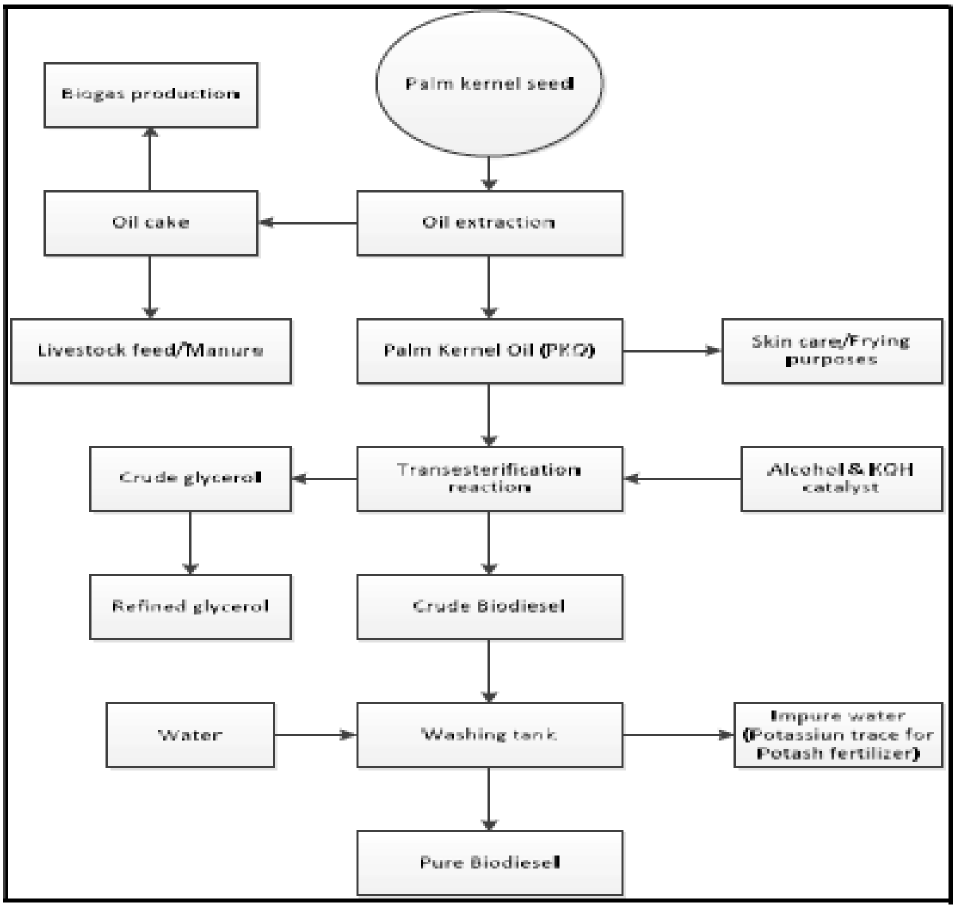

Fig. 1: Process flow chart for biodiesel production from palm-kernel Oil.

Alamu et al. (2007, 2009) analyzed the PKO biodiesel and the commercial grade fossil diesel for basic fuel properties such as specific gravity at reference $60^{O}F$, viscosity at $40^{O}C$, pour point, cloud point and flash point following ASTM standard test procedures. Specific gravity and viscosity measurements were made using the Thermal-Hydrometer apparatus and Viscometer, following ASTM standards D1298 and D445 respectively. Results obtained are re-presented in Table 1.

Viscosity, the measurement of the internal flow resistance of a liquid, constitutes an intrinsic property of vegetable oils. It is of remarkable influence in the mechanism of atomization of the fuel being injected into the engine combustion chamber. Viscosity of liquid fuel has been reported to vary with temperature (Krisnangkura et al., 2005). This work therefore seeks to establish possible empirical relationship between viscosity and temperature for palm kernel oil (PKO) biodiesel, which had previously been produced through transesterification of PKO with ethanol using potassium hydroxide (KOH) catalyst.

MATERIALS AND METHOD

The PKO Biodiesel Fuel

The PKO biodiesel used was produced through transesterification process depicted in Fig.1 using 100g PKO, 20.0% ethanol (wt% PKO), 1.0% KOH catalyst at 60°C reaction temperature and 90 min. reaction time. The transesterification process yielded 95.4% PKO biodiesel. The biodiesel was characterized as alternative diesel fuel through series of ASTM standard fuel tests. The PKO biodiesel had 85.06% reduction of viscosity over its raw vegetable oil at 40°C, while its pour point, flash point and boiling point were 2oC, 167°C and 320°C respectively (Alamu et al., 2007; 2009).

Table 1: Measured PKO biodiesel and fossil diesel fuel properties.

Fuel Characteristics (Properties)	Values (PKO biodiesel)	(Petroleum diesel)
Pour point (oC)	2	-16
Cloud point (oC)	6	-12
Flash Point (oC)	167	74
Boiling Point (oC)	320	191
Gross heat of combustion (MJ/kg)	40.56	45.43
Net heat of combustion (MJ/kg)	37.25	42.91
Specific gravity (at 15.56oC)	0.883	0.853
Viscosity (at 40oC) (mm2/s)	4.839	2.847

Test for Viscosity

Amongst series of tests conducted in characterizing the PKO biodiesel produced as fuel, viscosity measurements were made following ASTM D445 standard test procedure. Viscosity of the Biodiesel produced were measured (in centistokes (cSt)) using viscometer (Canon-Fenske Calibrated, 15cSt max. range), between the temperature intervals of 10°C and 60°C. Similar measurements were made for commercial grade petroleum diesel, for comparison (Alamu et al., 2007; 2009).

Viscosity-Temperature correlation for PKO biodiesel

Several methods of correlating viscosities of different petroleum fractions with temperature have been reported. The Andrade equation, which correlates liquid viscosity and temperature is of the form:

$$\mu = Ae^{\frac{B}{T}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where A and B are constants, T is absolute temperature.

Equation (1) can be used for predicting viscosity up to approximately the normal boiling point of the liquid. Comparing equation (1) to the reaction rate, an equation (Equation (2)) has been proposed by Eyring; as reported in Krisnangura et al. (2005).

$$\mu = \frac{N_A h}{V} e^{\frac{-\Delta G_{vis}}{RT}} \quad \text{..} \quad (2)$$

Where NA, V, h and R are Avogadro's number, molecular volume, Plank's and gas constants, Respectively. ΔG_{vis} is the free energy of activation for flow.

Several modifications of Equation (1) have been made to extend the temperature range. Makhija and Stairs were reported in Krisnangura et al. (2005) to have modified Equation (1), for associated liquids, by adding a third variable parameter as shown in Equation (3).

$$\ln \mu = m + \frac{B}{T - T_o} \quad \text{..} \quad (3)$$

where m, B and T0 are constants.

The effect of temperature on specific gravity of PKO biodiesel had been proposed by Alamu (2012) as shown in Equation (4).

$$SG_{EEPKO} = -0.0007T + 0.8939 \quad \text{..} \quad (4)$$

Where; $\mathbf{SG_{EEPKO}}$ = specific gravity of PKO biodiesel, T = temperature (°C).

In this work, the relationship between viscosity and temperature for both the PKO biodiesel and the petroleum diesel was formulated using the Andrade model.

The constants A and B in equation (1) were determined through linear least square regression method to obtain a model for calculation of viscosity of each fuel at various temperatures, inclusive of ranges not covered by the experimental measurements. This was achieved with the aid of simple computer codes developed in Visual Basic. The software generates viscosity for intended temperature range (within practical limitations) and specific temperature incremental step of interest, as a notepad file on the hard drive of the computer.

Using the developed model (equation 6), the viscosity of the PKO biodiesel was computed at different temperatures. The program was run with a Visual Basic 6.0 professional edition compiler using lower bound temperature (0^{o}C), below the pour point (2^{o}C); and upper bound temperature (325^{o}C), above the flash (167^{o}C) and boiling (320^{o}C) point of the PKO biodiesel. Temperature incremental step of 0.2^{o}C was used (Figure 2).

RESULTS AND DISCUSSION

Viscosity of PKO Biodiesel Fuel

It was noted from previous results that esterification of PKO produced a marked decrease in values of viscosity from the reported range 30-50 mm2/s for vegetable oils at 40^{O}C to 4.839mm2/s for PKO biodiesel at the same temperature. With this value of viscosity, it implies that a reduction of about 85% viscosity has been achieved in the PKO fuel. This reduction in viscosity will enhance the fluidity of the PKO biodiesel in diesel engine.

However, from Table 1, PKO biodiesel has higher viscosity than conventional diesel fuel in agreement with reports from several researchers who conducted similar investigation on the same feedstock after results from Alamu et al. (2007) appeared in print (Kuwornoo and Ahiekpor, 2010; Nisa and Hamzah, 2012; Igbokwe and Obiukwu, 2013; Bejan et al., 2014; Igbokwe and Nwafor, 2016). The PKO biodiesel viscosity of 4.839 mm2/s obtained at 40oC reference temperature is almost twice the viscosity of the fossil diesel as found also in alcohol esters of rapeseed, canola, beef tallow and soybean (Kim et al., 2010; Gomes et al., 2011; Aworanti et al., 2012; Pisarello et al., 2014; Rajaeifa et al., 2014). The value also falls within the specified limits by ASTM D6751, ASTM D975 and BIS (India) standards.

Table 2: Viscosity values obtained for PKO biodiesel and petroleum biodiesel.

	Viscosity of fuel samples in cSt		
Temperature (^{o}C)	**(PKO biodiesel)**	**(Petroleum diesel)**	**PKO biodiesel Petroleum diesel**
10.0	5.979	3.540	1.689
15.0	5.727	3.401	1.684
20.0	5.556	3.270	1.699
25.0	5.330	3.151	1.692
30.0	5.188	3.050	1.701
35.0	5.000	2.920	1.712
40.0	4.839	2.847	1.700
45.0	4.607	2.710	1.700
50.0	4.425	2.612	1.694
55.0	4.265	2.510	1.699

60.0	4.078	2.421	1.684

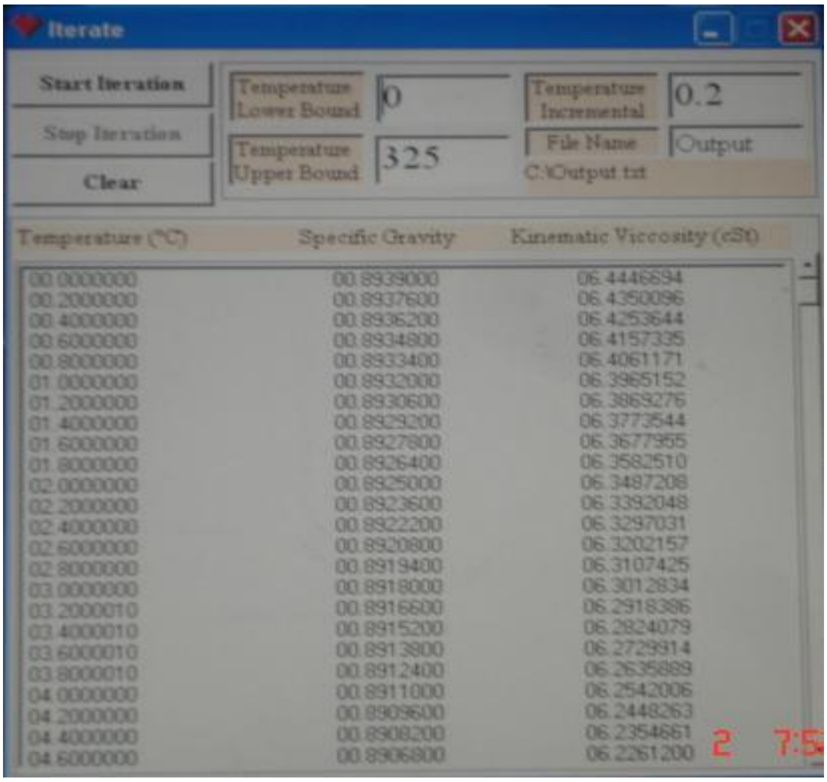

Fig. 2: The software window after compilation.

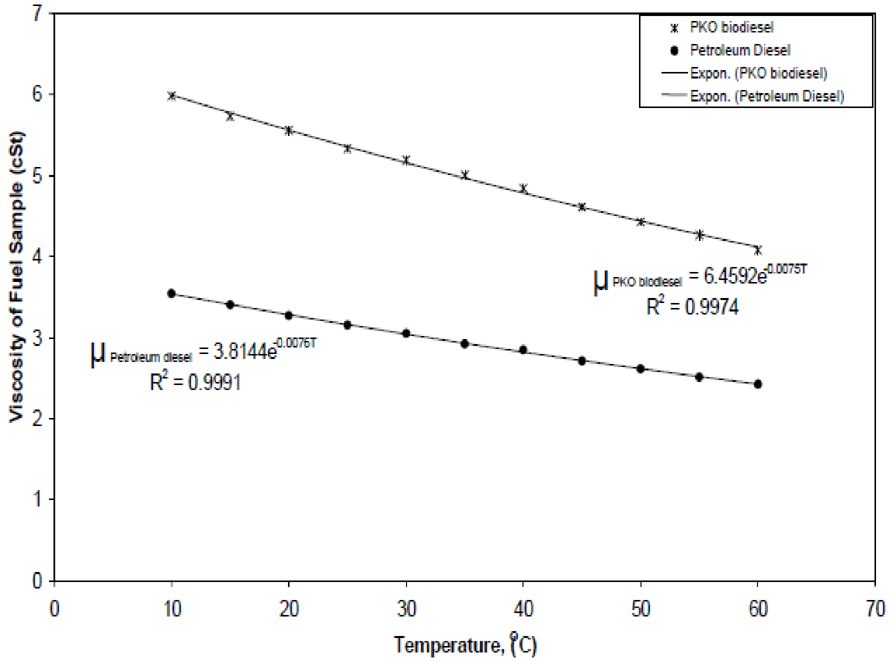

Fig. 3: Variation of Viscosity with Temperature for PKO biodiesel and Petroleum Diesel Viscosity (cSt).

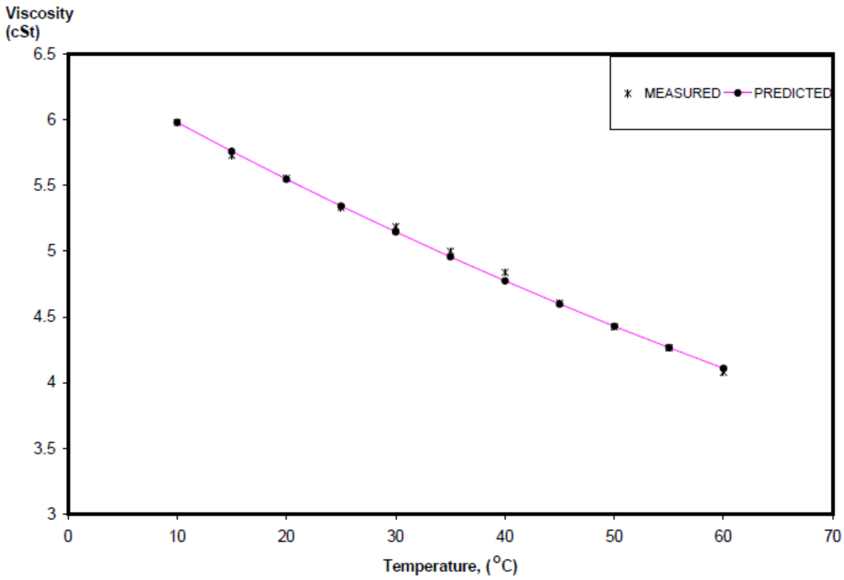

Fig. 4: Comparison between measured and predicted variation of viscosity with temperature for PKO biodiesel.

As presented in Table 2, the ratio of viscosity of PKO biodiesel to that of petroleum diesel at the same temperature ranges between 1.684 and 1.712. This shows that PKO biodiesel is almost twice as viscous as conventional petroleum derived diesel.

Viscosity-Temperature Correlation for PKO Biodiesel

From Table 2, evident from Fig.3, using the linear least square regression method, a linear regression equation is developed as:

$$\mu_{Petroleumdiesel} = 3.81e^{-0.0076T} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (5)$$

For the petroleum diesel used, and;

$$\mu_{PKObiodiesel} = 6.4592e^{-0.0075T} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (6)$$

For the Palm kernel oil biodiesel.

The R^2 value for the linear regression equation for the petroleum diesel (equation 5) and PKO biodiesel (equation 6) are respectively 0.9991 and 0.9974. With these values, the equations could be considered to have described the relationship between the two parameters with a fair degree of accuracy.

It is also observed that the linear regression equation for the petroleum diesel (equation 5) and PKO biodiesel (equation 6) agree very closely in form with Andrade Equation (Equation 1). Therefore, for Biodiesel, comparing equations 1 and 6, the Andrade's constants;

$A = 6.4592$ and

$$\frac{B}{T} = -0.0007T \text{ or } B = -0.0007T^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

With these expressions, viscosities of the PKO biodiesel can be computed at different temperatures.

The viscosity-temperature correlation obtained for PKO biodiesel is also observed to be in good agreement with proposition of Eyring in equation 2. Comparing equation 2 with equation 6, it can be proposed, for PKO biodiesel that:

$$\frac{N_A h}{V} = 6.4592 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

$$\frac{\Delta G_{vis}}{RT} = 0.0007T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Comparison between Predicted and Measured Values

A comparison made between simulated results and actual experimental measurements showed reasonable agreement as there were no appreciable deviation in viscosity. Between the range (10–60^{O}C), the maximum and minimum deviation of computed results from experimental measurements were 6.5% and 0.0%. Similarly, for specific gravity, within the same range of temperature, the maximum and minimum deviation of computed results from experimental measurements were 1.5% and 0.0% (Alamu, 2012).

It should be noted that the comparison made above may not be sufficient to conclude that the correlation agrees perfectly with experimental measurements as available data for experimental measurements in this work was limited to 60^{O}C. However, within the available experimental data range, the predicted results from the least square regression model are in very close agreement with values obtained experimentally. This is further illustrated in Fig.4.

From Fig.4, closer agreement was observed between the computed and measured viscosity values within the temperature range of (10-30) ^{o}C and (45-60) ^{o}C. The relatively higher deviation recorded between the measured and predicted viscosity of the PKO biodiesel occur at 40^{o}C. Similarly, as with specific gravity, the higher deviation reported here is not greater than 6.5%. Thus, with the level of agreement between the measured and computed values of viscosity, results generated from the computer simulation can be used for prediction of specific gravity of PKO biodiesel with minimal error.

CONCLUSION

Viscosity–Temperature model was formulated for PKO biodiesel through least square regression method with R^2 value of 0.9974. The regression equation $\mu_{PKObiodiesel} = 6.4592e^{-0.0075T}$ obtained for PKO biodiesel agree very closely in form with Andrade equation, which correlate liquid viscosity and temperature. With this expression, viscosities of the PKO biodiesel can be computed at different temperatures.

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