The Effects of Temperature and Blending On the Density and Viscosity of Neem Fatty Acid Methyl Ester

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***Abstract*— The effects of temperature and blending on the density and kinematic viscosity of neem fatty acid methyl ester (NFAME), diesel and their blends was investigated followed by development of empirical models for predicting the density and kinematic viscosity of neem biodiesel, diesel and their blends.The NFAME was blended with diesel in conical flasks with continuous stirring for uniformity of mixing at a percentage volume ratio of biodiesel to diesel of 0, 20, 40, 60, 80, 100% referred to as B0, B20, B40, B60, B80, B100. The density of the blends was determined using pycnometer while the kinematic viscosity was determined using Brookfield viscometer at temperatures of 30, 40, 60, 80, 100oC. The results showed that NFAME has physiochemical properties that is within the ASTM limit and is therefore suitable as compression ignition engine fuel. The density of the NFAME, diesel and their mix decreased linearly with increase in temperature and increased with increase in biodiesel fraction. The kinematic viscosity of the neem biodiesel, diesel and blends decreased exponentially with increase in temperature and increased with increase in biodiesel fraction.Based on the model with highest coefficient of determination, linear model and quadratic model were the best for fitting density and kinematic viscosity respectively as a function of temperature. Second order polynomial proved the best fitting model for density variation with biodiesel fraction and for kinematic variation with biodiesel fraction.**

***Index Terms*— Neem fatty acid methyl ester, biodiesel fraction, density, kinematic viscosity.**

I. INTRODUCTION

The major sources of world energy needs are petroleum, coal and natural gas all of which are fossils derived and non-renewable. Biodiesel, a mono-alkyl ester of long chain fatty acid has properties that approximate that of diesel with added advantages of high lubricity, high cetane number and been highly biodegradable. It is a promising nontoxic alternative fuel used in the transport sector. Biodiesel is produced by the reaction of fat with monohydric alcohol. Various processes have been adopted for biodiesel production from vegetable oil and animal fat, namely; micro emulsion with alcohol, catalytic cracking, pyrolysis and transesterification [1, 2, 3, 4]. Among these methods, transesterification is the key and the most important process for production of a cleaner and environmentally safe biodiesel [5, 6]. The two most important parameters in diesel and biodiesel handling are density and viscosity as they are the key flow properties of fuel for diesel engines [7]. Density is used as a precursor for a number of other fuel properties such as heating value and viscosity [8]. However the density and viscosity of biodiesel are higher than that of the diesel and poses some problems when used in an unmodified engine. Among the biodiesel properties, kinematic viscosity and density are the most important parameters that affect the engine performance and emission characteristics. High viscosity causes poor atomization of the fuel which results to incomplete combustion, high carbon deposit on the engine, clogging of injector tips and consequently reduction in the engine power output. Low viscosity fuel produces very subtle spray which cannot properly get into combustion cylinder,thus forming a fuel rich zone which leads to formation of sooth [9, 10]. The density of the biodiesel is an important parameter as there exist some correlation between the density of the fuel with other important engine performance parameters such as octane number and heating value.Also, density is used to measure the amount of fuel in a fuel compartment by volumetric method. The relatively high density and viscosity of biodiesel compared to diesel can be improved upon by mixing with diesel or by preheating the biodiesel. The objectives of this work are twofold. Firstly,to determine the effect of temperature and blending on the density and kinematic viscosity of neem oil biodiesel, diesel and their blends.Secondly, to develop empirical models for predicting the density and kinematic viscosity of the neem oil biodiesel, diesel and their blends.

II. MATERIALS AND METHODS

A. *Materials*

Neem seeds were sourced locally. The methanol, n-hexane, sodium hydroxide, ethanol, chloroform, iodine, acetic acid, potassium iodine, starch indicator, sodium thiosulphate, HCl, chloroform and sulphuric acid etc were all purchased from De-Cliff Integrated Services Ltd, Enugu and they are of analytical grade.

The following equipment were used in the course of this research work: viscometer, magnetic hot plate, refractometer, separating funnels, conical flasks distillation column, pycnometer, thermostat waterbath etc.

B. *Transesterification reaction.*

Oil reacts with methanol in the presence of sodium hydroxide to produce methyl esters of fatty acids (biodiesel) and glycerol.

A 500ml three-necked round bottomed flask fitted with a

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condenser on the middle arm, a thermometer and sample outlet on the side arms respectively served as the reactor. The heating system consists of an electromagnetic hot plate which heats the reactor and rotates the metal knob in the reactor through an electromagnetic field. Specified quantity of the oil sample was introduced into the flask and the flask content heated to the temperature established for the reaction. Then methanol and the catalyst mixture (sodium methoxide) was added in the amount established for the reaction, and the stirrer switched on at a specified speed, taking this moment as zero time of the reaction. The reaction mixture was vigorously stirred and refluxed for the required reaction time. At the end of methanolysis, the transesterified product was made to stand for a day in a separating funnel where it separates into the upper biodiesel layer and the lower glycerol layer. The lower glycerol layer was tapped off first followed by the upper biodiesel layer. The biodiesel was purified by wet washing and then dried by heating at 1050C on a laboratory hot plate until all the residual moisture has been evaporated.

C. Characterization of the neem oil biodiesel.

The properties of the biodiesel fuel were characterized based on ASTM standards.The properties characterized for include density, viscosity, iodine value, saponification value,cetane number,acid value, free fatty acid, calorific value,andflash point.

D. Blending of the neem oil biodiesel with petrodiesel.

The neem oil biodiesel was blended with #2 diesel oil on a percentage volume ratio of biodiesel to diesel of 0,20, 40, 60, 80 and 100% designated as B0, B20, B40, B60, B80 and B100 respectively. Direct blending of the required volumes of the biodiesel and diesel was carried out in conical flasks with continuous stirring to achieve uniformity of mixing.

E. Effect of temperature and blending on density.

The density of the biodiesel blends B0-B100 were determined at the temperatures of 30, 40, 60, 80 and 1000C using density bottlesheated in a thermostat waterbath. This provided the datafor the plot ofvariation of density with temperature and for plot of variation of density with biodieselfraction as shown in figure1 and figure 2 respectively.

F. Effect of temperature and blending on kinematic viscosity.

The kinematic viscosity of the biodiesel blends, B0-B100 were determined at the temperatures of 30, 40, 60, 80, and 100oC using Brookfield viscometer.This provided the data for plot of variation of kinematic viscosity with temperature and for plot of variation of kinematic viscosity with biodiesel fraction as shown in figures 3 and 4 respectively.

G. Modeling of density and kinematic viscosity as a function of temperature and biodiesel fraction

The form of equations that had been mainly used for modeling density and kinematic viscosity as a function of temperature and biodiesel fraction are linear and quadratic models.In this work, apart from linear and quadratic models, other models,exponential and logarithmic were also employed to correlate density and kinematic viscosity as a function of temperature and biodiesel fraction in order to ascertain the model of best fit. The chosen modeling equations of density and viscosity with temperature are equaions1-4 while the modeling equation of density and viscosity with biodiesel fraction are equations 5-8 as given below.

H. Modeling equations for density and kinematic viscosity as a function of temperature

$\rho=a+bT$ Linear (1)
$\rho=Ce^{\Delta T}$ Exponential(2)
$\rho=f\ln T+g$ Logarithmic(3)
$\rho=hT^2+iT+j$ Polynomial (4)

I. Modeling equations for density and kinematic viscosity as a function ofBiodiesel fraction

$\rho=a+bx$ Linear (5)
$\rho=Ce^{\Delta x}$ Exponential (6)
$\rho=f\ln x+g$ Logarithmic (7)
$\rho=hx^2+ix+j$ Polynomial (8)

where ρ is the density, μ is kinematic viscosity, a,b,c,d,f,g,h,i,j, are constants of the models to be calculated,T is temperature inoC, x is biodiesel fraction. The measured density given in Figures 1 and 2 were correlated as a function of temperature as well as that of biodiesel fraction respectively using Microsoft word excel 2010. Again the measured kinematic viscosity given in Figures3 and 4 were correlated with temperature as well as with biodiesel fraction respectively.

III. RESULTS AND DISCUSSIONS

A. Results of Characterization of neem biodiesel

The results of characteristics of the neem oil biodiesel as well as the ASTM and EN standards are given in table 1. The physiochemical properties of the neem biodiesel produced are within the ASTM and EN standard limit and therefore suitable foruse as a compression ignition engine fuel. In particular the flash point of 160oC and cetane number of 60.58 make the neem biodiesel none flammable and of quick ignition response.

B. Effect of Temperature and Biodiesel fraction on the density of diesel, biodiesel and their blends

The effect of temperature and of biodiesel fraction on the density of diesel, biodiesel and their blends are plotted in figures 1 and 2 respectively. From figure 1, it could be seen that the density of the diesel, biodiesel and the blends decreased linearly with increase in temperature for different biodiesel fractions. Diesel (B0) has the lowest density, biodiesel (B100) has the highest density while the density of the blends increased proportionately with the amount of biodiesel in the mix. This trend could be explained by the fact that density of fuel depends on the chain length of the free fatty acid and fatty acid composition of the fuel [11]. From Figure 2, it could be observed that the density of the diesel, biodiesel and their blends increased with increase in biodiesel fraction at different temperatures. This stems from the fact that the density of the blends increased proportionately with the amount of biodiesel in the mix. While B0 has the lowest density at specific temperature, B100 has the highest. This is attributed to the difference in chain length and composition of the fatty acid content of the fuel.

C. Effect of temperature and biodiesel fraction on the kinematic viscosity of diesel, biodiesel and their blends.

The effect of temperature and of biodiesel fraction on the kinematic viscosity of diesel, biodiesel and their blends are plotted in figures 3 and 4 respectively. From figure 3, it could be observed that kinematic viscosity of the diesel, biodiesel and their blends decreased exponentially with increase in temperature. At a specific temperature, B0 has the lowest kinematic viscosity while B100 has the highest. The kinematic viscosity of the blends decreases proportionately with the amount of biodiesel in the mix at a specific temperature. From figure 4, it could be observed that kinematic viscosity increases with increase in biodiesel fraction at a specific temperature. For a given biodiesel fraction, kinematic viscosity decreases with increase in temperature.

Table 1: Fuel properties of neem biodiesel, with the ASTM and EN standards

Properties	Neem FAME	ASTM 1657	EN 14214
Density (kg/m^3)	870	880	860-900
Moisture content (%)	0.03	0.05max	0.05max
Refractive index	1.4462	1.4580	1.4540
Acid value (mgKOH/g)	0.42	0.50	0.50
Free fatty acid (%)	0.21	0.25	0.25
Iodine value (gI$_2$/100g oil)	30.4	42-46	120max
Saponification value (mgKOH/g)	234.72	170-240	170-240
Kinematics viscosity (cst)	4.97	1.9-6.0	3.5-5.0
Flash point (^{o}C)	160	130	120
Calorific value (kJ/kg)	38	42-46	35
Cetane number	60.58	47	51
Perioxide value (meq/kg)	0.63	0.10	0.10

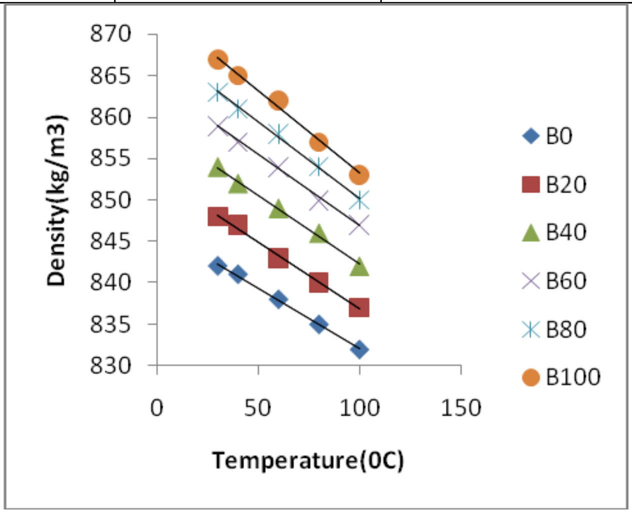

Figure 1: Variation of density with temperature for different biodiesel fractions

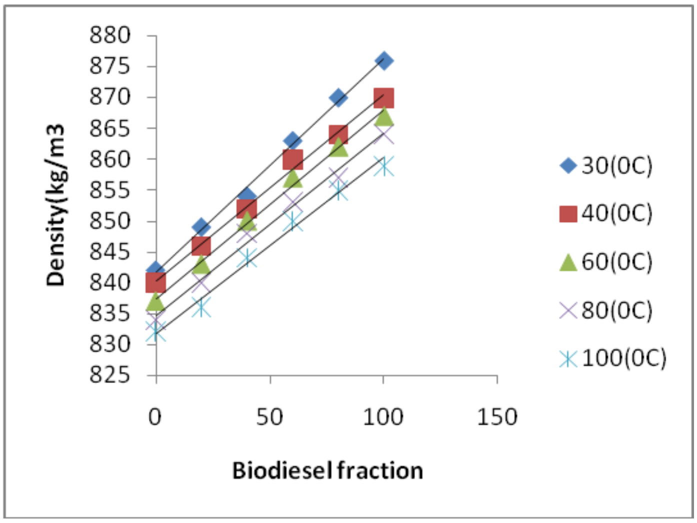

Figure 2: Variation of density with biodiesel fraction at different temperatures

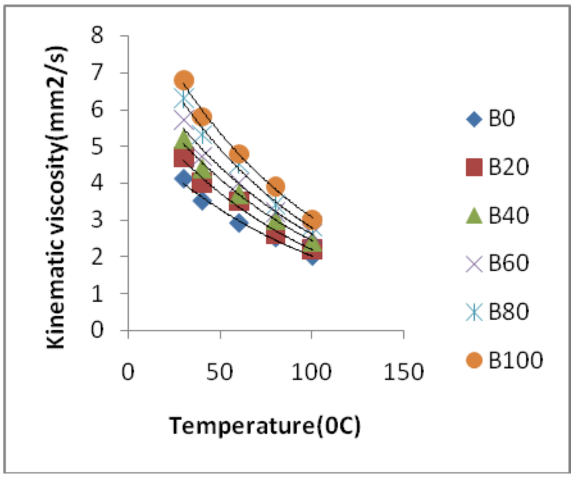

Figure 3: Variation of kinematic viscosity with temperature for different biodiesel fraction

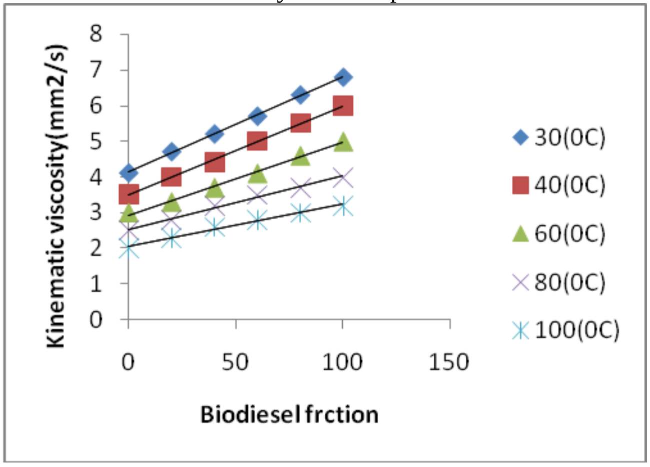

Figure 4: Variation of kinematic viscosity with biodiesel fraction at different temperatures

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D. Modeling of density of diesel, biodiesel and their blend as a function of temperature and of biodiesel fraction.

The modeling equations 1-4 and 5-8 were fitted to the data of Figures 1 and 2 respectively using least square regression method.The correlation constants as well as coefficient of determination of the models for density as a function of temperature and of density as a function of biodiesel fraction are given in Tables 2 and 3 respectively. The correlation constants are used for calculation of density using the modeling equation while the coefficients of determination are used to assess the model of best fit. Comparison between measured and predicted density using linear model is given in Table 4. The model with the highest coefficients of determination is adjudged the best fitting model and that with least percentage error difference between the measured and predicted value gave credence to degree of efficiency of fitting by the model.

From Table 2 it could be observed that liner model is the best fitting model for predicting density as a function of temperature as evidenced by its highest coefficient of determination, though closely followed by and almost of the same fitting degree of accuracy as polynomial model. From Table 3 the model of highest coefficient of determination is the polynomial model and therefore the best fitting model for predicting density as a function of biodiesel fraction. From Table 4, the small percentage difference between the measured and predicted density proved the adequacy of linear model in predicting biodiesel density as a function of temperature.

Table 2: Correlation constants and coefficients of determination of model equations of density as a function of temperature.

Linear model $\rho = a + bT$				Exponential model $\rho + ce^{dT}$				
BF	a	b	R^2	BF	c	d	R^2	
B0	846.60	-0.1451	0.9982	B0	846.64	-0.0002	0.9982	
B20	853.02	-0.1616	0.9958	B20	853.07	-0.0002	0.9959	
B40	858.92	-0.1665	0.9966	B40	858.90	-0.0002	0.9965	
B60	864.06	-0.1720	0.9977	B60	864.40	-0.0002	0.9978	
B80	868.58	-0.1835	0.9972	B80	868.65	-0.0002	0.9970	
B100	873.24	-0.2006	o.9940	B100	873.32	-0.0002	0.9938	
Logarithmic model $\rho = f\ln T + g$				Polynomial model $\rho = hT^2 + iT + j$				
BF	F	G	R^2	BF	h	I	J	R^2
B0	-8.281	871.01	0.9618	B0	-0.0002	-0.1169	845..83	0.9981

B20	-9.289	880.48	0.9738	B20	-0.0002	-0.1839	853.62	0.9961
B40	-9.521	887.01	0.9648	B40	-0.0003	-0.1329	859.01	0.9975
B60	-9.880	893.21	0.9746	B60	-0.0005	-0.1832	860.37	0.9968
B80	-10.420	899.43	0.9588	B80	-0.0004	.0.1330	867.21	0.9984
B100	-11.410	900.85	0.9522	B100	-0.0005	-0.1330	871.41	0.9935

BF-biodiesel fraction Temp.- Temperature(^{0}C]

Table3: Correlation constants and coefficient of determination of model equations of density as a function of biodiesel fraction.

Linear model $\rho = a + bx$				Exponential model $\rho = ce^{dx}$				
Temp.(^{0}C)	a	b	R^2	Temp.(^{0}C)	c	d	R^2	
30	0.3400	841.71	0.9960	30	841.81	0.0004	0.9960	
40	0.3029	840.19	0.9949	40	840.26	0.0004	0.9949	
60	0,3057	837.38	0.9953	60	837.44	0.0004	0.9953	
80	0.2871	834.81	0.9903	80	834.86	0.0003	0.9903	
100	0.2700	833.00	0.9938	100	833.05	0.0003	0.9938	
Logarithmic model $\rho = f\ln x + g$				Polynomial model $\rho = hx^2 + ix + j$				
				Temp.(^{0}C)	h	I	j	R^2
	Trendline computation not feasible			30	0.0001	0.3323	841.89	0.9961
				40	-0.0040	0.3386	839.71	0.9961
				60	-0.0006	0.3637	836.61	0.9985
				80	-0.0007	0.3586	833.86	0.9955
				100	-0.0008	0.3870	832.11	0.9990

Table 4: Comparison between measured and predicted density of the blends using linear model

B20				B40			
Temperature (^{o}C)	Measured Density	predicted density	percentage difference	Temperature (^{o}C)	measured density	predicted density	Percentage Difference
30	848	848.17	0.0200	30	844	853.93	-0.0082
40	847	846.57	-0.0508	40	852	852.23	0.0270
60	843	843.32	0.0379	60	849	848.93	-0.0083
80	840	840.09	0.0107	80	846	845.60	-0.0473
100	837	836.89	-0.0167	100	842	842.20	0.0321
B60				B80			
Temperature (^{o}C)	Measured Density	predicted density	percentage difference	Temperature (^{o}C)	measured density	predicted density	Percentage Difference
30	859	858 90	-0.0116	30	863	863.08	0.0073
40	857	857.18	0.0210	40	861	861.46	-0.0557
60	854	853.74	-0.0305	60	858	857.57	-0.0501
80	850	850.30	0.0353	80	854	853.90	-0.0117
100	847	846.86	-0.0165	100	850	850.23	0.0271

E. Modeling of kinematic viscosity of diesel, biodiesel and their blends as a function of temperature and of biodiesel fraction.

The modeling equations 1-4 and 5-8 were fitted to the data of Figures 3 and 4 respectively using least square regression method. The correlation constants as well as coefficients of determination of the models for kinematic viscosity as a function of temperature and of kinematic viscosity as a function of biodiesel fraction are given in Tables 5 and 6 respectively.. Comparison between the measured and predicted kinematic viscosity using linear model is given in table 7.

From Table 5 it could be observed that exponential model is the best fitting model for predicting kinematic viscosity as a function of temperature as evidenced by its highest coefficient of determination. From Table 6 the model of highest coefficient of determination is the polynomial model and therefore the best fitting model for predicting kinematic viscosity as a function of biodiesel fraction. Computation of the trend lines of logarithmic model for variation of density and variation of kinematic viscosity with biodiesel fraction are not feasible because of presence of zeros and negative values. Hence the absence of correlation constants and coefficient of determination in Tables 3 and 5.

From Table7, the small percentage difference between the measured and predicted kinematic viscosity as well as the high coefficient of determination proved the adequacy of polynomial model in predictingkinematic viscosity of biodiesel and the blends as a function of biodiesel fraction.The findings on modeling of density and kinematic viscosity as a function of temperature and biodiesel fraction are in agreement with the results obtained by other researchers [12, 7, 13, 14].

Table5: Correlation constants and coefficient of determination of model equations for kinematic viscosity as a function of temperature.

Linear modelμ = a + bT				Exponential model $\mu = ce^{dT}$				
BF	a	b	R^2	BF	c	d	R^2	
B0	-0.0284	4.7579	0.9694	B0	5.3261	0.010	0.9907	
B20	-0.0351	5.5738	0.9739	B20	6.3892	-0.011	0.9867	
B40	-0.0352	6.1140	0.9760	B40	6.9777	-0.011	0.9947	
B60	-0.0419	6.6372	0.9338	B60	7.5780	-0.011	0.9902	
B80	-0.0487	7.4758	0.9741	B80	8.6788	-0.011	0.9924	
B100	-0.0521	8.0848	0.9814	B100	9.3767	-0.011	0.9953	
Logarithmic model μ = flnT + g				Polynomial model $\mu = hT^2 + iT + j$				
BF	f	g	R^2	BF	h	i	J	R^2
B0	-1.669	9.733	0.9940	B0	0.002	-0.0548	5.4777	0.9884
B20	-2.058	11.662	0.9831	B20	0.002	-0.0598	6.2479	0.9848
B40	-2.243	12.789	0.9941	B40	0.002	-0.0698	6.9681	0.9909
B60	-2.468	13.992	0.9900	B60	0.003	-0.0830	7.7556	0.9846
B80	-2.853	15.970	0.9949	B80	0.003	-0.0898	8.5445	0.9898
B100	-3.042	17.134	o.9942	B100	0.003	-0/0651	9.0651	0.9930

Table6: Correlation constants and coefficients of determination of model equations for kinematic viscosity as a function of biodiesel fraction.

Linear μ = a + bx				Exponential $\mu = ce^{dx}$				
Temp.(^{o}C)	a	b	R^2	Temp.(^{o}C)	c	d	R^2	
30	0.0269	4.1236	0.9992	30	4.1961	0.0053	0.9926	
40	0.0204	3.4762	0.9982	40	3.5334	0.0054	0.9954	
60	0.0204	2.9286	0.9953	60	2.9950	0.oo57	0.9985	
80	0.0150	2.5333	0.9916	80	2.5653	0.0047	0.9785	
100	0.0119	2.0571	0.9861	100	2,0790	0.0046	0.9708	
Logarithmic μ = flnx + g				Polynomial $\mu = hx^2 + ix + j$				
				Temp.(^{o}C)	h	i	J	R^2
	Trendline computation not feasible			30	$4x10^{-6}$	0.0273	4.1179	0.9992
				40	$2x10^{-5}$	0.0284	3.5000	0.9986
				60	$4x10^{-5}$	0.0164	2.9821	0.9986
				80	$4x10^{-5}$	0.0186	2.4857	0.9964
				100	$4x10^{-5}$	0.0159	2.0036	0.9985

Table 7: Comparison between measured and predicted kinematic viscosity of the blends using polynomial model.

30^{o}C				40^{o}C			
Biodiesel Fraction	Measured Kinematic viscosity	Predicted kinematic viscosity	Percentage difference	Biodiesel fraction	Measured kinematic viscosity	Predicted kinematic viscosity	Percentage difference
B0	4.1	4,1179	0.4347	B0	3.5	3.500	0.0000
B20	4.7	4.6655	0.8574	B20	4.0	4.060	1.4778
B40	5.2	5.2099	0.1908	B40	4.4	4.468	1.5219
B60	5.7	5.7415	0.7228	B60	5.0	4.976	-0.4823
B80	6.4	6.2763	1.9709	B80	5.5	5.500	0.0000
B100	6.8	6.8074	0.1087	B100	6.0	6.040	0.6623
60^{o}C				80^{o}C			
Biodiesel fraction	Measured kinematic viscosity	Predicted kinematic viscosity	Percentage difference	Biodiesel fraction	Measured kinematic viscosity	Predicted kinematic viscosity	Percentage difference
B0	3.0	2.9820	-0.6000	B0	2.5	2,4857	-0.5753
B20	3.3	3.2941	-0,1791	B20	2.8	2.7937	-0.7938
B40	3.7	3.7021	0.5672	B40	3.2	3.1657	1.0835
B60	4.1	4.1101	0.2457	B60	3.5	3.4577	1.2234

B80	4.6	4.5500	-1.0967	B80	3.9	3.7177	0.4762
B100	5.0	5.0220	0.4381	B100	4.0	3.9457	1.3914

IV. CONCLUSION

From the results of the experiments performed, the following conclusion may be drawn. The physiochemical properties ofthe NFAME are within the ASTM limit and are therefore suitable as compression ignition fuel.The density of the NFAME, diesel and their blends decreases linearly with increase in temperature.The kinematic viscosity of NFAME, diesel and their blends decreases exponentially with increase in temperature and increases as biodiesel fraction increased.The best fitting model for density as a function of temperature is linear model while that for predicting density as a function of biodiesel fraction is a second order polynomial.Exponential model provided the best fit for variation of kinematic viscosity with temperature while polynomial model gave the best fit for kinematic viscosity as a function of biodiesel fraction.

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