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Experimental Investigation on Performance and Exhaust Emissions of a Diesel Engine Fueled With Palm Oil/Shea Butter Oil Blends Biodiesels

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ABSTRACT

In this study, experimental investigations on the performance and exhaust emissions of a diesel engine was carried out using Palm oil/Shea butter oil biodiesel as fuel. The two vegetable oils, Shea butter (SB) and Palm oil (PO) were blended in the proportion 25%:75%, 50%:50%, and 75%:25%v/v. The transesterification of the blended oils were carried out using ethanol, with potassium hydroxide as catalyst. The chemo-physical properties of the biodiesels produced were determined experimentally and compared with that of petroleum diesel. Engine performance and emission test were conducted using the engine test bed with the instrumentation unit, emission gas analyzer, and the produced biodiesels as fuel. From the results, it was observed that, the petroleum diesel recorded the highest torque, while biodiesels recorded reduced values of torque at all the loads with the 100%SB and 75%SB: 25%PO biodiesels both recorded the same values of torque at all the loads. The 100%SB biodiesel recorded the highest exhaust temperature, while the petroleum diesel recorded the lowest exhaust temperature at all the loads. Exhaust gas temperature increase as the load increases. Biodiesels showed reduced brake power as compared to petroleum diesel, but the 100%SB and 75%SB: 25%PO both recorded the highest brake power among the biodiesels at all the loads. Biodiesels recorded higher values of BSFC as compared to petroleum diesel, with the 25%SB: 75%PO biodiesel having the highest BSFC at all the loads. The brake thermal efficiency (BTE) of the petroleum diesel was highest as compared to biodiesels at all the loads. The 25%SB: 75%PO and 100%PO biodiesels both recorded the least carbon monoxide (CO) emissions, and CO emissions decreases with increase in loads. The petroleum diesel recorded the highest CO emissions for all the three loads. The carbon dioxide (CO2) emissions increases with increase in loads, with the petroleum diesel recording the least CO2 emissions at all the loads. The petroleum diesel showed increased hydrocarbon (HC) emissions for all the loads, while the 25%SB: 75%PO and 100%PO biodiesels recorded the least HC emission. The 100%SB biodiesel recorded the highest NOx emissions, while the petroleum diesel recorded the least NOx emissions at all the loads. Thus, the 25%SB: 75%PO and 75%SB: 25%PO with improved engine performance and reduced emissions is suitable for use in diesel engine without engine modification.

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KEYWORDS: *Transesterification; biodiesel; engine performance; emissions*

1. INTRODUCTION

The huge investment on foreign exchange through the importation of petroleum products has caused the Nigeria government to consider new sources of energy to substitute for petroleum products. Renewable energy source such as biodiesel is therefore considered to be an immediate solution to their emerging problem. According to Sakthivel *et al,* (2018), biodiesel is the mono alkyl esters of long fatty acids derived from renewable lipid feedstock such as vegetable oils or animal fats, for use in diesel engine. It is produced by the transesterification of vegetable oils in the presence of ethanol or methanol with potassium hydroxide or sodium hydroxide as catalyst, to yield neat biodiesel (BD 100 i.e. 100% biodiesel) with glycerol as by product. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create biodiesel blend.

Among the attractive features of biodiesel fuels are; it is a plant, not petroleum derived, and as such its combustion does not increase current net atmospheric level of CO_2 [2], 'a greenhouse' gas; it can be domestically produced, offering the possibility of reducing petroleum import; it is biodegradable; relative to conventional diesel fuel, its combustion products have reduced levels of particulates, carbon monoxides, and under some conditions, nitrogen oxide (Atadashi *et.al.*, 2012). Biodiesel can be produced from various vegetable oils, waste cooking oils or animal fats. The fuel properties of biodiesel (such as emission characteristics) may be changed when different feed stocks are used. If the fuel properties of biodiesel are compared to petroleum diesel fuel, it can be seen that biodiesel has higher viscosity, density, pour point, flash point and cetane number near zero aromatic compound, and no sulphur link [4]. The main aim of this study is to investigate the performance and exhaust emission of a diesel engine fueled with novel biodiesels produced and characterized from palm oil (PO), shea butter oil (SB), and their blends (SB/PO). The choice of these oils for evaluation came as a result of their abundant availability, and also to determine if their performances would present them as suitable candidate fuels to replace or compliment petroleum-based diesel fuel.

2. Materials and Methods

2.1. Materials/equipment

The Palm oil and Shea butter oil feed stocks used were purchased from Anyigba market in Kogi State, Nigeria. The chemo-physical properties of the oils and biodiesels were determined using ethanol (99/100. M.W.46.07), Diethyl ether (M.W 7412g/mol.), Sodium hydroxide (0.1mol. M.W 40.00. 98.9%), Phenolphthalein solution, Isopropanol (60.10g/mol), thermometer, and Weighing balance of model PM 2500. Absolute ethanol (99/100%), and potassium hydroxide were used as the alcohol and catalyst respectively, during the transesterification process. The equipment used for the biodiesel production were Rotary stirrer/magnet (DF-II Heating stirrer), weighing balance (PM 2500), and separating funnels (500ml). The engine test bed and emission gas analyzer model (SLFA-20) were used for determination of the performance and emission characteristics of the biodiesels.

2.2. Methods

2.2.1. Preparation of the vegetable oil samples

The two vegetable oils were heated to 100^0C for 15 minutes, and filtered to remove moisture and impurities. The oils were blended in different volume proportions as follows: 25% Shea butter: 75% Palm oil (25%SB: 75%PO); 50% Shea butter: 50% Palm oil (50%SB: 50%PO), and 75% Shea butter: 25% Palm oil (75%SB: 25%PO).

2.2.2. Biodiesel production and characterization

The first step of the production process is the weighing of each of the oil samples and alcohol in the ratio 1:6 using a digital weighing balance, (Musa, 2016). For each of the weight ratio, 1% of catalyst (weight of oils) were weighed. The catalyst was dissolved in the alcohol using a magnetic stirrer. The mixture of alcohol and catalyst (ethoxide) was poured into the oil and the first transesterification process was started. With the aid of the magnetic stirrer and magnet, the mixture was stirred for 60 minutes at a temperature of 45^0C. At the end of the reaction time, the mixture was transferred into a separating funnel, where it was allowed to settle, and then separated into two layers (biodiesel and glycerol). The lower denser one was the glycerol, while the upper one was the biodiesel. The glycerol was decanted and the ester (biodiesel) was removed for washing.

The dry purification method was used in the washing of the biodiesel. This involves the use of inorganic matrices (Magnesium silicate) as adsorbents in the biodiesel purification process. The crude biodiesel was heated and stirred slowly until reaching 65^0C. At this point, 2% (m/m) of the adsorbent (Magnesium silicate), related to the mass of biodiesel, was added and maintained at 65^0C and stirring for 25 minutes. The biodiesel was then allowed to settle and was filtered to remove the adsorbent and then stored for further analysis. This methods was in line with the work of (Ouanji *et al.*, 2016), on biodiesel production at small scale for local power generation. The process was repeated for the remaining oil blends. The chemo-physical properties of the biodiesel samples were determined experimentally and was compared with that of the petroleum diesel as shown in Table 2.

2.2.3. Engine performance and emissions

A. Engine Performance evaluation

The performance evaluation of the biodiesels was carried out using engine test bed and the instrumentation units. The specification of the engine test bed and the instrumentation unit is presented in Table 1. The experiment was carried out by running the engine test bed on the biodiesel samples at different loads. For each of the biodiesel tested, the engine was run at different times on three different loads (500kg, 1500kg, and 2500kg), at a constant speed of 2500 revolution per minutes. During each of the test, the torque, exhaust gas temperature, and time were recorded. Other parameters such as; brake power, brake specific fuel consumption, and brake thermal efficiency were calculated using equations (5), (6a), (6b) and (7) respectively. The procedures was repeated for other biodiesels samples produced and petroleum diesel.

$$Pb=2\pi N60\times T \quad (5)$$

Where N= Revolution per minute of the engine

T = Torque (Nm)

$$BSFC=mf10-3Pb\ (gKwh) \quad (6a)$$

Where mf = mass flow rate

P_b = brake power, and

$$mf= Sgf \times 1000\times 8\times 10-6t\ (kgs) \quad (6b)$$

Where Sgf = specific gravity of the fuel

t = time in seconds

$$b= PbmfCv \quad (7)$$

Where C_v = Calorific value of the fuel

Table 1: Specifications of the Diesel Engine Test Bed

S/N	Characteristics	Specifications
1.	Engine type	TD 114
2.	Number of strokes	Four strokes
3.	Number of cylinders	1 cylinder
4.	Engine power range	2.5- 7.5
5.	Maximum torque	15 Nm
6.	Maximum speed	600 rpm
7.	Swept volume	195cc
8.	Dynamometer type	Eddy current, water cooled, with loading unit

B. Emissions determination

The procedures for the determination of the emission characteristics involved running the engine test bed using biodiesel as fuel, as described in section (2.2.1) above. The emission gas analyzer (EGA), was connected to power source, and the sensor was connected to the engine test bed through the exhaust pipe. So, as the engine ran on the different biodiesels at different loads, the amount of gaseous emissions; (carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC), and nitrogen oxide (NO_x)) from the exhaust were read from the EGA, when the reading on the screen became stable. The procedures was repeated for other biodiesels samples produced, and the petroleum diesel.

3. Results and discussion

3.1. Chemo-physical analysis of the biodiesels

The results of the chemo-physical properties of the biodiesels produced from Palm oil, Shea butter and their blends and that of the petroleum diesel is presented in Table 2.

Table 2: Chemo-Physical Analysis of the Biodiesel and Petroleum Diesel

Sample No.	Sample Code	Kinematic Viscosity @ 40 ^{0}C, 60 rpm (mpa.s)	Density (Kg/m^3)	% Free fatty acid (%)	Flash point (^{0}C)	Fire point (^{0}C)	Iodine value (gI$_2$/100g)	Carbon Residue (%vol.)	Moisture content (%vol.)
ASTM D 6751		1.9 - 6.0			>130			0.02 max. (% vol.).	0.05 max (% vol.).
1.	25% SB: 75% PO	5.15	871	0.486	164	188	134	0.031	0.0714
2.	50% SB: 50% PO	5.40	874	0.512	167	190	136	0.034	0.0882
3.	75% SB: 25% PO	5.45	878	0.538	169	193	137	0.038	0.0798
4.	100% SB	5.50	881	0.564	171	195	138	0.041	0.0728
5.	100% PO	5.30	867	0.460	162	185	133	0.027	0.0987
6.	Petro-diesel	3.5	820	-	60	80	8.5	0.060	0.0150

3.2. Engine performance evaluation

The results of the engine performance test on the biodiesels produced, and that of the petroleum diesel are reported and discussed in this section. shown in Figure 1-5 below.

3.2.1. Torque: Figure 1 showed the variation of torque with loads for the Shea butter/Palm oil blends (SB/PO) biodiesel samples.

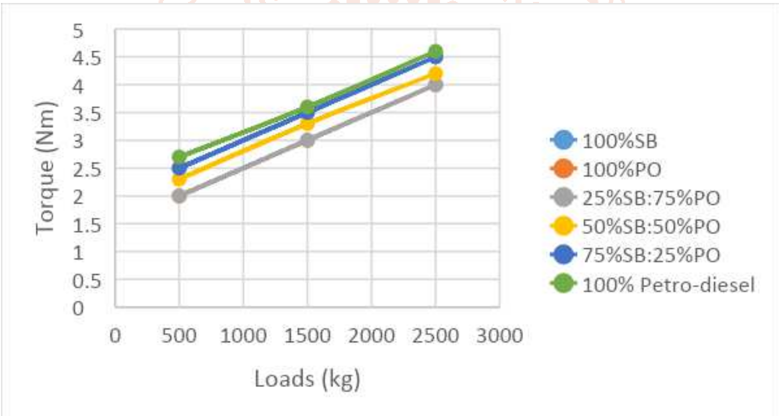

Figure1: Variation of loads with torque for the biodiesels and petroleum diesel.

From the plots, the 100%PO biodiesel recorded the same torque with the 25%SB: 75%PO. It was observed that, torque increase as loads increases. The torque values obtained for the biodiesels and petroleum diesel agreed with the work of (Stalin and Prabhu, 2007); and [8]. The authors reported that, torque increases as engine loads increases and that, the petroleum diesel recorded higher torque as compared to the biodiesels. The implication of these results is that, the petroleum diesel produced the highest calorific values, as increase in calorific value leads to increase in torque, as reported by Stalin and Prabhu, (2007). Biodiesels with torque values close to that of the petroleum diesel is best suitable for diesel engine, as too low calorific value will produce very low torque.

3.2.2. Exhaust gas temperature: Figure 2 showed the variation of exhaust gas temperature with loads for the Shea butter/Palm oil blends (SB/PO) biodiesel samples.

Figure 2: Variation of loads with exhaust temperature for biodiesels and petroleum diesel.

From the results, it was observed that, the Petroleum diesel recorded the lowest exhaust gas temperature at all the loads. The exhaust gas temperature of the biodiesels did not show much variance, but that of the 100%PO is lower. The results obtained for exhaust gas temperature of the biodiesel samples agreed with the work of [9]; and [10]. The authors concluded that, the exhaust gas temperature increases as the engine load increases, and comparing with Petroleum diesel, biodiesel recorded higher exhaust gas temperature. This is due to higher viscosity and poor volatility of biodiesel, and because of higher oxygen content in biodiesel, it has improved combustion which can also leads to higher temperature as reported by Gnanasekaran, (2016).

3.2.3. **Brake power:** Figure 3 depicts the variation of brake power with loads for the Shea butter/Palm oil blends (SB/PO) biodiesel samples.

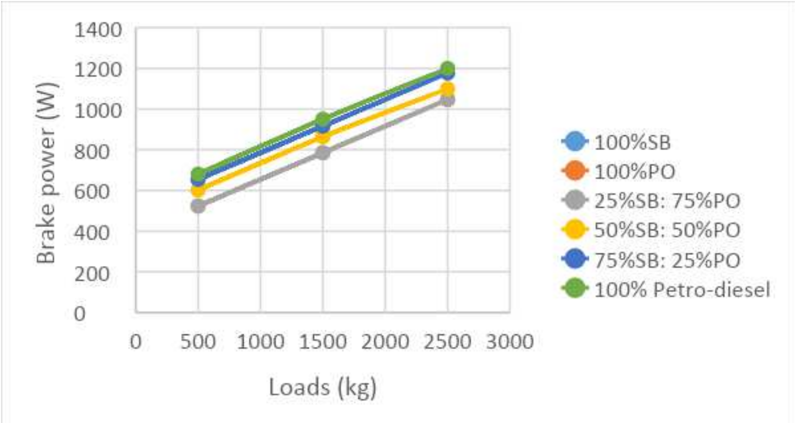

Figure 3: Variation of loads with brake power for biodiesels and petroleum diesel.

From the results, it was observed that, the brake power increase as the load increases. The petroleum diesel recorded the highest brake power at all the loads, while the 100%SB and 75%SB: 25%PO both recorded the highest brake power at all the loads. The 100%PO and the 25%SB: 75%PO also recorded the same brake power at all the three loads. The results obtained for the brake power is in line with the work of Kumar *et al.*, (2015), and (Stalin and Prabhu, 2007). The authors reported that, brake power is a function of calorific values and the torque applied, and that, brake power increases with increase in load. The implication of these results is that, since brake power is a function of calorific value, the petroleum diesel has the highest calorific value. Biodiesels with high brake power can be recommended for use in diesel engine without engine modification.

3.2.4. **Brake Specific Fuel Consumption (BSFC):** Figure 4 depicts the variation of BSFC with loads for the Shea butter/Palm oil blends (SB/PO) biodiesel samples.

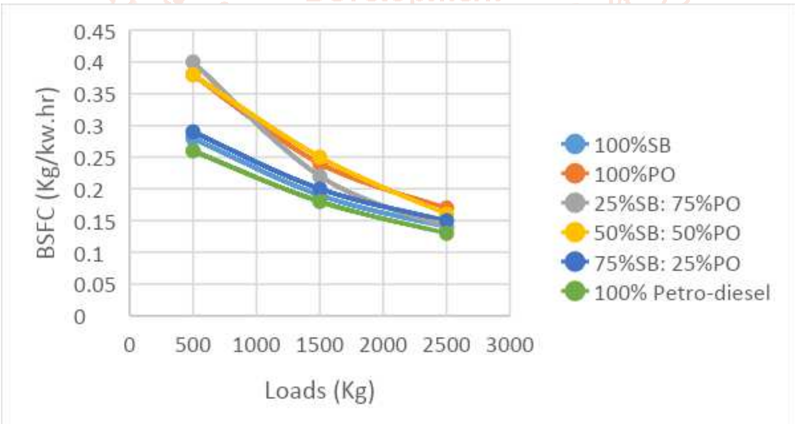

Figure 4: Variation of loads with brake specific fuel consumption for biodiesels and petroleum diesel.

From the experiment, it was found that, the 25%SB: 75%PO biodiesel recorded the highest BSFC of 0.4kg/kw.hr at load 500kg, the 50%SB: 50%PO biodiesel recorded the highest BSFC at load 1500kg, and the 100%PO biodiesel recorded the highest at load 2500kg. The petroleum diesel recorded the lowest BSFC at all the loads. It was observed that, the BSFC decreases as the engine loads increases. The obtained BSFC values for the biodiesel samples and petroleum diesel agreed with the works of [7]; (Kumar *et al.*, 2015); (Gnanasekaran, 2016); and [12]. The authors reported that, the BSFC decreases with increase in load, and that BSFC increases as the biodiesel content of fuel blends increases. The obtained results implied that, biodiesels has the highest BSFC as compared to petroleum diesel, and this could be due to high heating value and low density of the petroleum diesel as reported by [12]

3.2.5. **Brake thermal efficiency (BTE):** The brake thermal efficiency (BTE) is an indication of the efficiency of conversion of the chemical energy of the fuel to work [10]. Figure 5 depicts the variation of BTE with loads for the Shea butter/Palm oil blends (SB/PO) biodiesel samples.

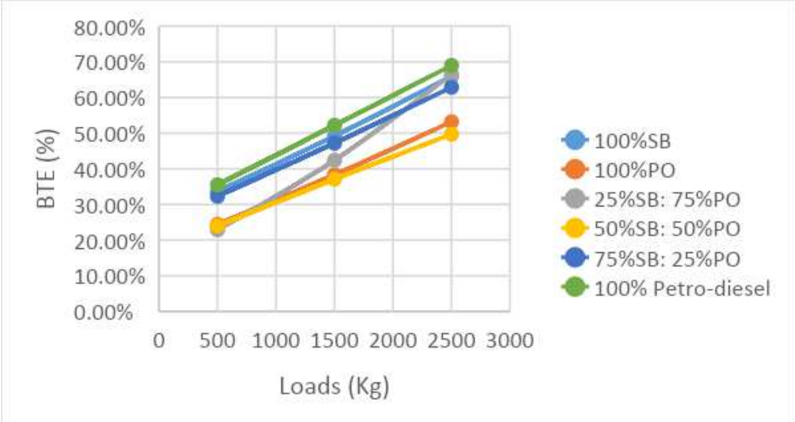

Figure 5: Variation of loads with brake thermal efficiency for biodiesels and petroleum diesel.

Based on the results (Figure 5), the 25%SB: 75%PO biodiesel recorded the lowest BTE of 22.90% at load 500kg, but the 50%SB:50%PO biodiesel recorded the lowest BTE of 37.10% and 49.70% at loads 1500kg and 2500kg respectively. The petroleum diesel recorded the highest BTE at all the loads. It was observed that, the BTE increases with increase in load. The trends in the BTE values of the biodiesel samples and that of the petroleum diesel were in agreement with the work of [7]; [12], and [9]. The authors reported that, the brake thermal efficiency of petroleum diesel is higher than that of biodiesel fuels. The reasons for this could be due to higher kinematic viscosity, density, low volatility and low heating values of biodiesels as compared to petroleum diesel.

3.3. Emission characteristics of the biodiesels

The SB/PO biodiesel samples and petroleum diesel were run in a four strokes, water cooled, compression ignition engine on three different loads (500kg, 1500kg, and 2500kg), and the emission results are presented in Table 3.

Table 3: Emission characteristics of the biodiesels and petroleum diesel.

Sample No.	Sample Code	Loads (Kg)	CO (%)	CO_2 (%)	HC (ppm)	NOx (ppm)
1.	25% SB: 75%PO	500	0.11	2.08	112	160
		1500	0.09	2.09	110	229
		2500	0.07	2.14	109	279
2.	50%SB: 50%PO	500	0.12	2.09	114	165
		1500	0.10	2.11	112	233
		2500	0.08	2.15	110	283
3.	75%SB: 25%PO	500	0.13	2.11	115	170
		1500	0.11	2.13	112	236
		2500	0.09	2.16	111	287
4.	100%SB	500	0.13	2.12	115	174
		1500	0.10	2.14	113	240
		2500	0.09	2.16	111	290
5.	100%PO	500	0.12	2.06	114	156
		1500	0.09	2.08	110	225
		2500	0.07	2.14	109	275
6.	Petro-diesel	500	1.12	1.02	128	88
		1500	1.10	1.04	125	145
		2500	1.08	1.07	123	198

(i) Carbon monoxide (CO) emissions: The carbon monoxide (CO) emissions decreases with increase in loads, and the petroleum diesel has the highest CO emissions of 1.12%, 1.10% and 1.08% at load 500kg, 1500kg, and 2500kg respectively. Among the biodiesel samples, the 75% Shea butter oil-to-25% Palm oil (75%SB:25%PO), and the pure Shea butter (100%SB) biodiesels both gave the highest emissions of 0.13% at load of 500kg, while the 25%SB:75%PO and 100%PO both recorded the least CO emissions of 0.09% and 0.07% at the loads 1500kg and 2500kg respectively.

The trends in the CO emissions of biodiesel and petroleum diesel is in agreement with the work of [9]; and [10]. The authors concluded that, petroleum diesel has higher CO emissions as compared to biodiesel fuels, and that, CO emissions decreases with increase in the load. The higher CO emissions of petroleum diesel is due to the low oxygen content of the fuel. The (CO) is a toxic gas formed due to the incomplete combustion of any fuel which does not contain oxygen, and factors, such as engine speed, engine loads, air-fuel ratio, injection pressure, injection timing and type of fuel used have an effect on CO emission (Kumar *et al.*, (2016). The results implied that, the 25%SB: 75%PO and 100%PO biodiesels with the lowest CO emissions has the highest oxygen content for complete combustion.

(ii) Carbon dioxide (CO_2) emissions: The carbon dioxide (CO_2) emissions, were seen to have increased with increase in load. The petroleum diesel recorded the lowest CO_2 emission values of 1.02%, 1.04%, and 1.07%, at load 500kg, 1500kg, and 2500kg respectively. Among the biodiesels, the 100%SB and 75%SB: 25%PO recorded the highest CO_2 emissions of 2.16% at the load of 2500kg, while the 100%B recorded the lowest CO_2 emissions of 2.06% at the load of 500kg. The trends in the CO_2 emissions of biodiesels and petroleum diesel agreed with the work of (Kumar *et al.*, 2015); and [9]. The authors reported that, CO_2 increases as the loads increases, and that, the CO_2 emissions of biodiesel fuels are always higher than that of the petroleum diesel. The reasons for this was attributed to higher oxygen content of biodiesels. The implication of these results is that, the 100%SB and 75%SB: 25%PO biodiesels burnt completely due to their highest oxygen content as compared to other biodiesels.

(iii) Hydrocarbon (HC) emission: The hydrocarbon (HC) emissions of the biodiesels and petroleum diesel are as presented in Table 3. The HC emissions of the biodiesels varies from (109 - 115) ppm. Among the biodiesel fuels, the 75%SB:25%PO, and 100%PO biodiesels all recorded the highest HC emissions of 115ppm at load 500kg, while the 25%SB:75%PO and the 100%PO biodiesels recorded the least HC emissions of 109ppm at load 2500kg. The petroleum diesel recorded the overall highest HC emissions of 128ppm, 125ppm and 123ppm at loads 500kg, 1500kg, and 2500kg respectively. It was also observed that, the HC emissions decreases as the load increases. The trends in the HC emissions of biodiesels and petroleum diesel were in line with the work of (Kumar *et al.*, 2015); [9]; and [10]. The authors concluded that, petroleum diesel generate more HC emissions at all loading conditions, as compared to biodiesel fuel, and that HC emissions decreases with increase in the loads. The reasons are that, the higher oxygen content of biodiesel resulted in improved combustion, thereby leading to reduced HC emissions. At higher loads, HC emission is reduced due to the fact that, increased loads improved fuel atomization which enhanced complete combustion and reduces the HC emissions. The results obtained implied that, the 25%SB: 75%PO and the 100%PO biodiesels having the least HC emissions will be friendlier to the environment as compared to the petroleum diesel, because of its effects on human respiratory system.

(iv) Nitrogen oxide (NO_x) emissions: The nitrogen oxide (NO_x) emissions of the biodiesels and petroleum diesel are presented in Table 3. The nitrogen oxide emissions (NO_x) of the biodiesels varied from (156 – 290) ppm, with the 100%SB having the highest value of 290ppm at load 2500kg, while the 100%PO biodiesel recorded the lowest NO_x emissions of 156ppm at load 500kg. From the results, it was generally observed that, the biodiesel fuels recorded higher NO_x emissions for all the three loads, as compared to petroleum diesel, and the NO_x emissions increases with increase in the loads. The results obtained for the NO_x emissions for the biodiesels and petroleum diesel were in agreement with the work of Gandhi, (2016). The author reported that, nitrogen oxide emission was higher by 29.37% for biodiesel as compared to petroleum diesel. Since high temperature and availability of oxygen are the two main factors that affects NO_x formation, the results implied that, biodiesels with higher amount of oxygen will produce higher amount of NO_x. And at higher loads, the cylinder temperature is increased causing the fuel to burn completely thereby generating higher amount of NO_x emissions as reported by [12].

4. Conclusions

Biodiesels were produced by transesterification of Palm oil/Shea butter oil blends and alcohol in the presence of potassium hydroxide (KOH) as catalyst. The performance and emission characteristics were investigated for a stationary engine, and the following conclusions were drawn.

1. Engine performance parameters such as, torque, brake power, and brake thermal efficiency were seen to be highest for petroleum diesel as compared to biodiesels, while the exhaust gas temperature, and brake specific fuel consumption were higher for biodiesels as compared to petroleum diesel.
2. All the biodiesels (25%SB: 75%PO, 50%SB: 50%PO, 75%SB: 25%PO, 100%SB and 100%PO) exhibited reduction in exhaust emissions of CO and HC, except for the CO_2 and NO_x.

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