Tested Performance Parameters of Diesel Fuel and Transesterified Sheanut Oil Blends in Compression Ignition Engine

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Abstract*-The rapidly depleting conventional crude oil resources and growing environmental concerns has significantly promoted research interest in renewable fuel for internal combustion engines. To this end, this paper presents the results of engine performance characteristics for various blends of diesel fuel and transesterified sheanut oil in a compression ignition engine. In this case, a test rig of 2.43 kW, 165 F single cylinder -four stroke variable speed direct injection engine, and incorporated with a 1.25kVA Honda E 1500 A.C dynamometer manufactured by Ningbo Tri-circle Power Machinery Company, China and Honda Company, Japan, was used to conduct the engine performance tests on samples of fossil diesel fuel (DF), and diesel fuel containing 5%, 10%, 15%, and 20% by volume of sheanut oil methyl ester (i.e. B5, B10, B15, and B20 DF-SHOME blends) respectively. At maximum engine speed the result show that B5 and B15 DF-SHOME fuel blends exhibited slightly higher brake power, brake mean effective pressure, brake thermal efficiency and heat loss in exhaust and lower specific fuel consumption than B10, and B20 fuel blends and diesel fuel benchmark respectively. This study has shown that the use of transesterified sheanut oil as a biodiesel or diesel fuel conserver in compression ignition engines could possibly ameliorate Nigeria's lingering energy crises, and also assist in the conservation of its crude oil reserves.

Keywords: Transesterified sheanut oil; diesel fuel conserver; brake mean effective pressure; brake power; brake thermal efficiency; energy crises; specific fuel consumption.

I. Introduction

Energy has a major impact on every aspect of our socio-economic life. However, the rapidly growing global and domestic demand for petroleum products, and the consequent depletion of the crude oil reserves, adverse environmental concerns and unstable nature of the international oil market the need to explore alternative fuel options from locally available renewable energy resources has become imperative (Peterson, et. al 1990; Al Wydyan and Al Shyouk, 2002; Bernardo et al., 2003; Wirawan et al., 2008). For this reason, a deliberate diversification to achieve a wider energy supply mix will no doubt ensure greater energy security for Nigeria (ECN, 2003). Consequently, the search for an alternative fuel, which promises a harmonious relationship with sustainable development, energy conservation and efficiency, and environmental preservation, is being encouraged (Bhattacharya et. al. 2006).

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Nigeria is no doubt endowed with a variety of edible and non- edible seed crops with even more diverse species found in the nation's forest reserve. The sheanut tree (*Vitellaria paradoxa* formerly called *Butryospernum paradoxum*) is an important oil bearing plant. It is known for its nutritional, industrial and pharmaceutical uses (Alonge and Olaniyan, 2007). The tree is extensively found more in the guinea savanna and less abundantly in the sudan savanna, across 19 countries of the African continent, and these include; Benin, Ghana, Chad, Burkina Faso, Cameron, Central Africa Republic, Ethiopia, Guinea Bissau, Cote d Ivories, Mali, Niger, Senegal, Sierra Leone, Sudan, Togo, Uganda, Zaire (now Democratic Republic of Congo), Guinea and Nigeria (Fobil et al., 2008). Furthermore, the result of a study on the potential use of sheanut oil as an alternative diesel fuel revealed that the oil possess favorable fuel properties but its high viscosity profile, pour point and lower heating value were found to impede optimal engine performance (Yusuf, 2000). In other related studies, seed oils in their unmodified forms exhibited some engine durability problems such as; power loss, carbon build up in combustion chamber, blockage of injector tips due to their comparatively higher viscosities, pour points and lower calorific values that are likely to cause engine failure in the long run (Reid et al. 1982, Tahir et al. 1982, Bacon et al. 1981, Schoedder, 1981, Yarbrough et al. 1981).

However, in the bid to surmount these challenges and also ensure the usability of sheanut oil as a viable alternative to diesel fuel, the oil can be modified into biodiesel through transesterification. The transesterification process presents desirable biodiesel properties such as; low viscosity, low molecular weight, and high volatility to overcome the problem of incomplete combustion, poor atomization, ring sticking, sever engine deposits, and injector coking that are encountered when natural oils and fats are used (Sangha et. al., 2004; Alamu et.al. 2007).

In the light of the above, this work therefore seeks to evaluate the effect of diesel fuel-transesterified sheanut oil blends on the performance of a compression ignition engine. The result of this study is expected to contribute to the existing database of locally available alternative fuel resource with the potential of ameliorating Nigeria's energy insecurity.

II. MATERIALS AND METHODS.

***Sample collection*:**The tree of Vitteliaria paradoxa was identified within the environs of the Federal Polytechnic, Bauchi by a botanist. The harvested seeds were collected and sun dried for seven days and their oil was extracted mechanically with a manual press. The oil sample was collected in plastic containers and stored at room temperature of 33oC for analysis.

Extraction procedure: Depulped sheanut kernel were dried and baked to prevent the growth of fungi (e.g Aspergillus sp.). The baking process is controlled in a chamber between the temperatures of 85oC-100oC to prevent the charring of the kernel, a condition that reduces the fat content (Fobil et al., 2009). The baked kernel were then crushed and grounded in large wooden mortars. Subsequently, the powdered kernel was mixed with water and boiled. The resulting mixture was stirred continuously into a paste. The paste is allowed with to settle with oil floating on top of the supernatant and eventually scooped-off, decanted, cooled and preserved in an air-tight plastic container.

***Physico-chemical characterization*:**The physical and chemical properties of sheanut oil including the specific gravity, saponification values, peroxide values, iodine values, free fatty acid and PH values respectively were determined according to standard procedure (AOAC, 1980; Pearson, 1981, Pa Qurt, 1979).

***Fatty acid determination*:**The fatty acid of the oil sample was determined by the method described by Atasie et al. (2009). In this case, about 2 grams of the oil sample was weighed, in a small beaker and dissolved in 50ml of chloroform, transferred into a hundred volumetric flasks and diluted to the mark with chloroform. 1 mL of the unknown sample was transferred into a 10 ml screw top culture tube with a Teflon liner. Exactly, 1.00mL of a standard solution of 0.814 mg/mL pentadecanoic acid was then added. The glycerides in the oil sample was esterified as well as the pentadecanoic acid standard, the efficiency for the esterification of the standards is the same as that of the glycerides, the response of the detector to each of the fatty acid methyl ester with the internal standard was the same, with these we were able to determine the amount of each ester in the fat by comparing the integrated areas with the known concentration of the standard. Most of the chloroform was evaporated under a stream of nitrogen until-100µl of the solution remained. 1 ml of inter esterification reagent (25 vol % of a 12% BF3 methanol solution, 20 vol % benzene and 55 vol % methanol) was added. The tube was flushed with nitrogen, sealed and heated in a 100oC water bath for 30 minutes – after which the methyl esters was extracted with hexane and water, the final mixture of the reagent, hexane and water were in the ratio 1:1:1 (adding 1mL each of hexane and water to the reaction mixture). The mixture was shaken thoroughly for 2 minutes. A stable emulsion was formed which was broken by centrifugation. Half of the top hexane phase was transferred into a small text tube for injection.

***Transesterification of sheanut* oil:**1.0g of KOH was weighed on a digital beam balance and dissolved in a beaker containing 100ml of distilled water (H2O) to give 1% of KOH solution.282g of sheanut oil was weighed and preheated to a temperature of 45oC to 50oC. Furthermore 102.2g of methanol was also weighed and poured into the preheated sheanut oil in a plastic container to maintain an alcohol to oil molar ratio of 6:1.1.0g of KOH was weighed on a digital beam balance and dissolved in a beaker containing 100ml of distilled water (H2O) to give 1% of KOH solution.282g of sheanut oil was weighed and preheated to a temperature of 45oC to 50oC. Furthermore 102.2g of methanol was also weighed and poured into the preheated sheanut oil in a plastic container to maintain an alcohol to oil molar ratio of 6:1.

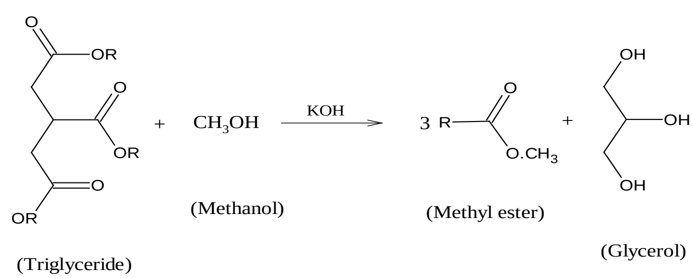

Figure 1.Methanolysis of triglyceride.

***Blending of sheanut oil with diesel fuel*:** 25 ml of SHOME and 475ml of diesel fuel (DF) were measured with a 500ml measuring cylinder and poured into a 500 ml beaker and stirred thoroughly to produce B5 DF-SHOME blended fuel samples. The mixture was allowed to settle for 4-6 hours for miscibility and homogenous consistency. The procedure was repeated for B10, B15 and B20 DF-SHOME blended fuel samples respectively.

Determination of fuel properties: Physical properties of SHOME and DF were conducted in accordance with standardized ASTM test procedures and these include; ASTM D97-93, ASTM D2015-85, ASTM D 2500-91, ASTM D 97-93, ASTM D 93-94, ASTM D D613, ASTM D

445 for density , higher heating value, cloud point, pour point, flash point, cetane number and kinematic viscosity respectively(ASTM, 1993).

Engine Performance Test: A 3.26hp single cylinder four stroke 165F compression ignition engines incorporated with a 1.25kVA Honda E 1500 A.C dynamometer with technical specification presented in Table 3 and 4 respectively was used to conduct the performance test. The engine performance characteristics was monitored within the speed range of 1400rpm and 2600rpm, and varied incrementally by 400 rpm after every interval of two hours. A control test was carried out on Diesel fuel for an experimental period of 8 hours. Similar test procedure was repeated for B5, B10, B15 and B20 DF-SHOME fuel samples. The brake power, specific fuel consumption, and brake thermal efficiency, heat loss in exhaust and generator efficiency were monitored respectively.

Table 1. Technical specifications of engine test rig.

Model	**165 F**
Type	Horizontal single cylinder four stroke, air-cooled
Bore * Stroke	65 mm x 70 mm
Rated output	2.43 kW (3.26 h.p)
Rated speed	2600
S.F.C at rated output	<284.2 g/kW-hr
Method of cooling	Air cooling by blower
Lubrication method	Centrifugal lubrication, combined oil mist and splash
Starting method	Manual cranking
Compression ratio	20.5:1
Manufacturer	Ningbo Tri-circle Power Machinery Co. Ltd. China

Table 2. Dynamometric specifications.

Type	**HONDA Model E 1500**
Maximum operating capacity A.C	220V, 50Hz, Single phase
Maximum operating capacity D.C	12V, 8.3A
Maximum speed	4000rpm
Torque arm radius	130mm
Manufacturer	Honda motor, Tokyo, Japan

III. RESULTS AND DISCUSSION.

Table 3 shows the physico- chemical properties of sheanut oil. The relative density of sheanut oil (0.98). The saponification value of 195 mg/KOH/g explains the oil high tendency to soap formation. According to Halling (1989), the formation of soapy film provides adequate boundary lubrication and reduces engine wear. The peroxide value of 0.28 meq/kg explains that sheanut oil can resist lipolytic hydrolysis and oxidative deterioration. Iodine value of 87 g/100g shows the high degree of oil unsaturation, and is classified as a semi drying oil (90-130g/100g) as expressed by Remington and Wood (1918). Furthermore, the free fatty acid value of sheanut oil of 0.23 mgKOH/g indicates the percentage of fatty acid present in the oil that predisposes the oil to undergo oxidation. It is pertinent to mention, that poor oxidation stability can cause fuel thickening, formation of gums and sediments, which in turn can cause filter clogging and injector fouling. The oil's PH value of 4.22 indicates the degree of the oil acidity. The fatty acid profile of sheanut oil in table 4 show the composition of palmitic acid as 4,00%, stearic acid as 8.0%, oleic acid as 73.11%, linoleic as 13.9%, and linolenic acid as 0.4% respectively. The fairly high percentage of fully saturated fatty acid, and polyunsaturated linoleic and linolenic acids predisposes the oil sample to oxidative instability and shorter shelf life (Asadauskas and Perez, 1997). It could also be seen from table 5 that the specific gravity of SHOME oil sample is slightly heavier than conventional diesel fuel, In addition, the viscosity of the fatty acid methyl ester is also higher in comparison to diesel fuel. It was also noted that beside lubrication of fuel injection system components, fuel viscosity controls the characteristics of the injection from the diesel injector such as; droplet size and spray characteristics (Lele, 2004). Furthermore, the heating value of SHOME is observed to be higher than diesel fuel. The lower heating values of SHOME oil sample suggest a significant effect of oil density on calorific value (Atasie *et* *al.*, 2009; Ams oil, 2005).The flash and pour points of the SHOME oil sample are also higher than diesel fuel. The flash point of biodiesel blend is dependent on the flash point of the base diesel fuel used, and increase with percentage of the biodiesel in the blend. Thus, in storage and usage biodiesel is less flammable and safer than conventional diesel (Lele, 2004). However, the high pour point of SHOME oil sample constrains oil performance at low temperature conditions (Gawrilow, 2003). Furthermore, SHOME oil sample exhibited higher cetane number than conventional diesel fuel and these results in higher combustion efficiency and smoother combustion (Lele, 2004).

The engine performance results illustrated in figures 1-6 shows that the brake power, b.m.e.p, brake thermal efficiency, Air fuel ratio and heat loss in exhaust for tested fuel sample increase with engine speed, while specific fuel combustion and the generator efficiency decrease with engine speed and reach a minimum level at 2600rpm. Table 7 also show that (except for B5 SHOME-Diesel blend that is 4.0% less than diesel fuel) the exhaust temperature for B15 and B20 SHOME-Diesel blend are 8.8% and 16.0% higher than diesel fuel. The increased exhaust gas temperature of the engine in this case may be caused by the rise in peak cylinder pressure resulting in higher peak combustion temperature as reported by Ecklud, (1984). In addition, a relationship could be established between exhaust temperature and brake power because a rise in combustion temperature brings about a commensurate increase in the pressure acting on the piston, to improve mechanical power output (TQ, 2000).

Table 3: Physico-chemical properties of sheanut oil

Appearance	Lightly yellow
Odour	Characteristically flat
Specific gravity	1.5
Saponification value	195
Peroxide value	0.28
Iodine value	87
Free fatty acid	0.23%
PH value	4.22

Table 4: Fatty acid composition (%) of sheanut oil.

Palmitic	4.00
Stearic	8.00
Oleic	73.11
Linoleic	13.9
Linolenic	0.4

Table 5: Fuel properties of SHOME and Diesel Fuel.

Characteristics	SHOME	DF
Specific Gravity at 35°C	0.894	0.835
Viscosity m. Pa at 20°C	4.2	1.6-5.5
Lower heating value Mj/kg	32-37	45.59
Flash Point (°C)	162	65
Pour point	-7	-23
Cetane number	>51	48

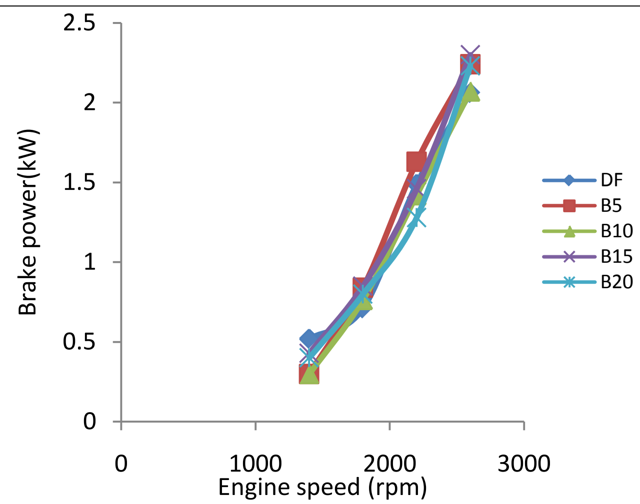

Figure 1: Brake power of DF and DF-SHOME fuel samples.

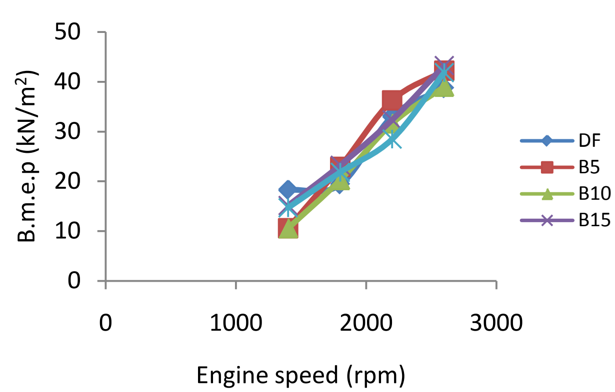

Figure 2: B.m.e.p of DF and DF-SHOME fuel samples

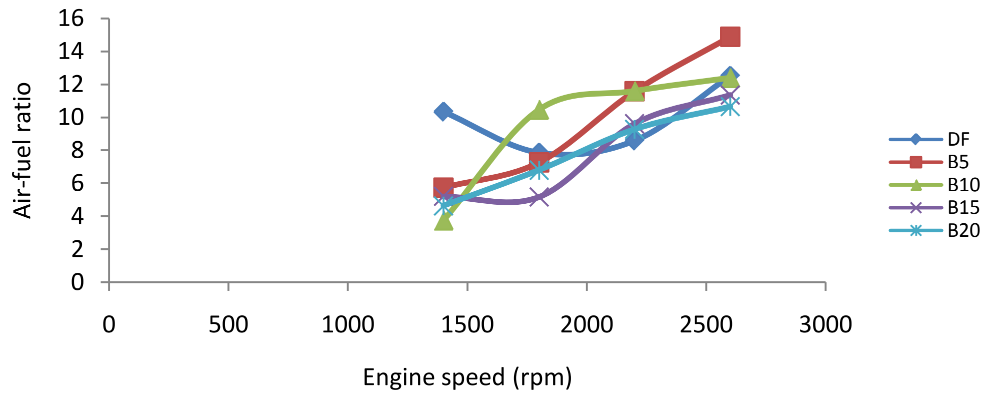

Figure 3: Air-fuel ratio of DF and DF-SHOME fuel samples

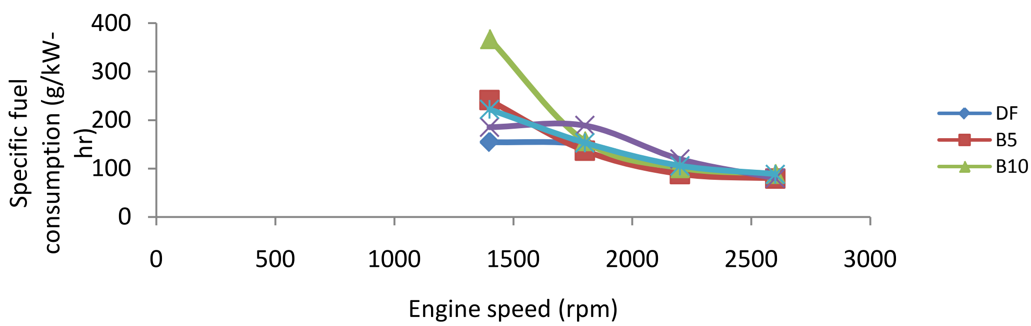

Figure 4: Specific fuel consumption of DF and DF-SHOME fuel samples.

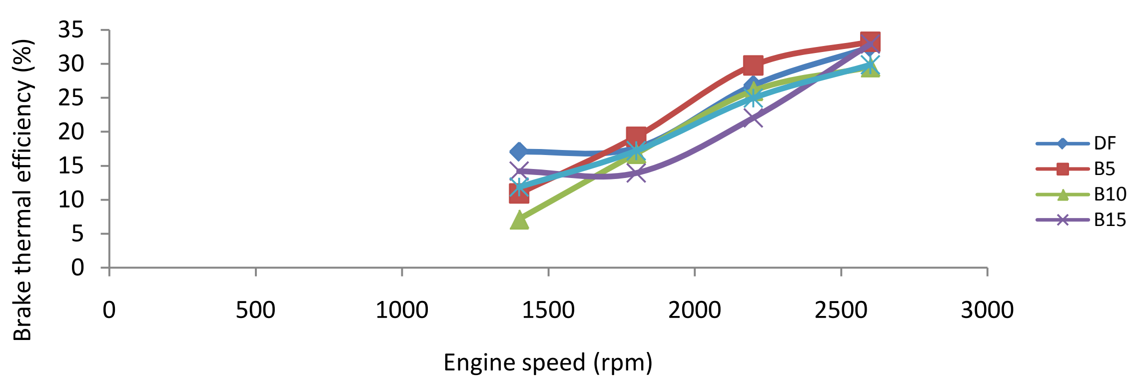

Figure 5: Brake thermal efficiency of DF and DF-SHOME fuel samples.

Table 6: Heating values and specific gravity of fuel samples

Properties	DF	DF-SHOME blends			
		B5	B10	B15	B20
Heating values Mj/kg	45.59	44.96	44.33	43.70	43.07
Specific gravity at 35°C	0.835	0.849	0.864	0.879	0.894

Table 7: Performance characteristics of DF samples and DF-SHOME fuel blends at 2600 rev/min.

Performance Characteristics	Manufacturer's Specification	DF	DF-SHOME blends			
			B5	B10	B15	B20
Exhaust Temperature (°C)	-	125	120	125	136	145
Torque (Nm)	-	8.93	9.01	9.01	9.01	8.87
Brake Power (kW)	2.43	2.06	2.24	2.07	2.30	2.23
Brake Mean Effective Pressure (kN/m2)	-	38.68	42.20	39.03	43.25	41.85
Specific Fuel Consumption (g/kW-h)	< 284.2	81.15	79.22	89.21	79.95	88.15
Brake. Thermal Efficiency (%)	-	32.43	33.22	29.50	32.91	29.85
Air Fuel Ratio.	-	12.51	14.89	12.30	11.35	10.64
Heat Loss in Exhaust (kJ)	-	202.99	228.14	223.43	229.52	211.32
Generator Efficiency ((%)	-	29.15	26.72	28.89	26.01	26.94

At maximum speed, B15, B5, B20 and B10 blends are 10.50%, 8.32%, 7.76% and 6.63% higher than Diesel fuel. However, the comparatively higher brake power generated by DF-SHOME fuel blends could be attributed to their higher calorific (heating) value as it combines with conventional diesel fuel to burn (refer to table 6). The brake mean effective pressure (i.e. the calculated mean pressure that would act upon observed power output, when no mechanical losses occur) behaves in a similar manner as the brake power. Masjuki and Maleque (1996) and Goering (1992) reported that, the average torque, brake power and brake mean effective pressure values of engines running on fatty acid methyl esters (i.e. biodiesel) blended oils are higher in comparison to diesel oil for the reason that biodiesel acts as fuel. In addition, Wirawan et.al. (2008) and Knothe et.al (2004) also reported that the higher engine power rating presented by biodiesel blends is no doubt affected by the lower viscosity profile of the tested pure biodiesel. This is because fuel viscosity also influences fuel injection and combustion. Hence, high fuel viscosity reduces fuel injection efficiency and atomisation, and could adversely affect fuel combustion leading to power losses in engine(s). Furthermore, it was also reported that as the concentration of biodiesel in fuel blends increases, the adsorption layer on metal surface in relative motion to one another (such as, injector system, pistons, rings and sleeves) become better lubricated and initiate a declination of frictional horse power to generate more power and brake mean effective pressure in the engine (Masjuki and Maleque, 1996; and Sabeena et.al., 2004). On the other hand, since fuel combustion could also influence engine power output, the presence of oxygen in biodiesel improves fuel combustion, brake power and b.m.e.p in engines.

The specific fuel consumption values in table 7 also reveal that B10 and B20 biodiesel blend are higher than diesel fuel benchmark by 9.04% and 7.94%, while, B15 ad B5 blends are 1.48% and 2.38% lower than diesel fuel respectively. The appreciably higher s.f.c of B10 and B20 Biodiesel could be explained in terms of higher specific gravity, higher viscosity and heating values of biodiesel and this indicates higher fuel consumption per unit of power produced due to low combustion efficiency (Bhattacharya.et al., 2006; Masjuki and Maleque, 1996; Sethi and Salariya, 2004). However, the fuel economy behaviour of B5 and B15 DF-SHOME fuel blends could be ascribed to their improved miscibility, better fuel atomisation characteristics and combustion. According to Wirawan et al, (2008), higher fuel viscosity reduces the quality of fuel atomisation, and could result in higher gas emission and fuel consumption. Except for B5 DF-SOME fuel blend, which demonstrated a16.01% higher Air fuel ratio (AFR) value than diesel fuel, B10, B15 and B20 DF-SHOME are 8.39%, 9.24% and 14.92% lower than diesel fuel benchmark respectively. The observation made from this finding is that all tested fuel samples reached maximum power output and torque at lower than the stoichiometric AFR values (i.e. 18-25) for compression ignition engines. In this case, maximum power output is achieved at richer mixture, therefore causing the engine to run at lower engine temperature and s.f.c. levels. According to Goering (1992), the stoichiometric AFR values of engines running on biodiesel are usually lower than diesel fuel because more oxygen presence is evident in biodiesel due to the methanolysis of sheanut oil, and it enabled SHOME blended fuel samples to burn much richer than diesel fuel.

The brake thermal efficiency of B5 and B15 DF-SHOME fuel blends are 2.38% and 1.46% higher than diesel fuel, while B10 and B20 blends are 7.95% and 9.04% lower than the diesel fuel benchmark. Plint and Partners (1984) observed that the fall in brake thermal efficiency and power output in some cases reveal that specific fuel consumption relates conversely with thermal efficiency. This however, emphasised the desirability of running engines at near their maximum power output to expect good return for the burnt fuel. The falling off in thermal efficiency are due to increase mechanical losses in engine relative to useful power output, throttling losses and deterioration in combustion efficiency, with increasing concentration of the biodiesel in the DF-SHOME fuel mixture (Pathak, 2004; Singh et. al 2007, and Plint and Partners, 1984). It could also be seen from table 7 that; B20, B15 and B10 DF-SHOME blends show evidence of higher heat losses in engines than diesel fuel by 19.23%, 11.56%, 11.02% and 9.15% respectively. The higher heat losses recorded could be explained in terms of lower calorific (heating) valve, increase in fuel density, the difference between the exhaust and ambient temperatures and the size of the engine. The temperature difference existing between the fuel blends and diesel fuel benchmark in table also presented a proportional increase in the heat carried away by the exhaust. However, for heat unaccounted for by losses is partly a function of the engine size. Hence for smaller engines, considerable conductive and radiative heat losses are usually caused by inefficient combustion (Plint and Partners, 1984).

The generator efficiency (i.e. the ratio of the electrical power output of the machine to the mechanical power input) of B20, B5, B10 and B15 fuel samples are lower in comparison to diesel fuel by 7.59%, 8.33%, 9.05% and 10.78% correspondingly. The decreasing generator efficiency of DF-SHOME fuel blended samples could be attributed to reduced heating value as shown in table 6, lower combustion temperature and flame velocity of blended fuel air mixture (Singh et al. 2007; Asokan, 1990, Bhattacharya et al., 2001 and Uma et al. 2004). However, since the fuel blend exhibit higher brake power and brake mean effective pressure, it implies that the combustion temperature and efficiency of biodiesel blends are significantly higher and therefore their reduced heating value is responsible for the progressive drop in engine generator efficiency with the corresponding increase of biodiesel concentration in the fuel mixture.

IV. CONCLUSION.

The results of the study on the performance characteristics of diesel fuel -transesterified sheanut oil blends in compression ignition engine are presented as follows:

1. Brake power, b.m.e.p., brake thermal efficiency, air fuel ratio and heat loss in exhaust increase with engine speed.
2. Conversely, specific fuel consumption and generator efficiency decrease with engine speed respectively.
3. DF-SHOME fuel blend generated slightly higher brake power, b.m.e.p., and brake thermal efficiency and higher heat losses in exhaust than diesel fuel.
4. The generator efficiencies of DF-SHOME blended fuel samples are lower than diesel fuel samples.
5. iv. B5 and B15 DF-SHOME blended fuel samples exhibited higher brake power, b.m.e.p, fairly higher heat losses in exhaust, and present lower fuel consumption than other tested fuel samples.

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