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Engine Performance and Exhaust Emissions from Sandbox (*Hura crepitans*) Seed Methyl Ester

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Authors' contributions

This work was carried out in collaboration between both authors. Author DNO did conceptualization, performed methodology, wrote report, helped in data collection and investigation, collected samples and validation of the manuscript. Author AIB did review the results, correction and edited of report, supervised data visualization of the manuscript. Both authors approved the final version of the manuscript.

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ABSTRACT

The finitude and environmental impact of petroleum fuels have led to the search of alternative fuels and biodiesel has proven to be an alternative fuel to petro-diesel with less environmental impact. Engine performance and exhaust emissions of Sandbox Methyl Ester (SBME) fuel were evaluated. Pure SBME (B100) was blended with diesel at 5, 10, 15, 20, 25 and 50% volume designated B5, B10, B15, B20, B25 and B50 respectively. The diesel was used as a reference fuel. The fuel blends (B100-B5) and diesel was used to power a 4-stroke-single-cylinder diesel engine coupled to a dynamometer and a 7.5 kW alternator with varying loads. The brake specific fuel consumption (bsfc), brake power, thermal efficiency, carbon monoxide (CO), oxides of nitrogen (NO_x) and hydrocarbon emissions were evaluated. The results of no-load to full-load indicated that diesel utilized the lowest bsfc of 0.14-0.62 kg/kW.h to produce the highest brake power of 5.6-3.7 kW. Similarly, the range of B5-B25 utilized bsfc of 0.16-0.86 kg/kW.h to produce the brake power of 5.1-2.9 kW. The brake thermal efficiency was 58-14% for diesel, and 52-10% for B5-B25. CO emission was reduced to 38.24-11.11% for B5 and 64.71-55.56% for B100. HC emission was reduced to 9.09-5.56% for B5 and 45.45-30.56% for B100. NO_x emission increased with SBME concentration. The results obtained for the SBME engine performance and exhaust emissions established it as a potential fuel to power internal combustion engines.

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1. INTRODUCTION

Fossil fuels still supply most of the world's energy, and the demand on these fossil fuels has rapidly increased due to global industrialization and motorization. This development has brought about excessive consumption of these fuels, leading to the reduction in the underground-based carbon resources, thus, causing a global challenge of fossil fuel depletion in addition to environmental degradation caused by its combustion [1]. The depletion of petroleum fuels reserves and damaging consequences to the environment from their combustion brought about the search for alternative and cleaner energy [2,3]. A successful alternative fuel is one that guarantees environmental friendliness from lowered exhaust emissions and also ensures efficiency of operation [4]. Biodiesels are considered to be more suitable than conventional diesel because of their bio-component which makes them biodegradable, nontoxic, clean and renewable. The use of biodiesel reduces environmentally degrading emissions such as CO, sulfur compounds and unburned hydrocarbons when compared to diesel. According to [5], biodiesel refers to diesel fuels from biological materials. It is a range of long chain fatty acid esters produced from various edible and non-edible lipids such as vegetable oils, waste or used cooking oils, automobile oils or animal fat [6]. A product of the transesterification reaction between lipids of organic origin and alcohol of low molecular mass in a hydroxide (mainly sodium or potassium) aided catalyst reaction; biodiesel therefore is a renewable biofuel [7]. The advantages of biodiesel over diesel fuel includes: low emission potential, renewability, non-toxic, and its oil origin, density and viscosity gives it better lubrication ability for engine parts [8].

Biodiesel performance on internal combustion engines relatively to diesel has been compared by many authors: [9-26]. Effects of biodiesel on engine exhaust emission relatively to diesel have been widely reported: according to [27], the combustion of biodiesel in diesel engines brings about complete combustion with significant decline in unburned hydrocarbons, carbon monoxide, and particulate matter, while nitrogen oxides concentration remain the same with diesel or are increased slightly. Reduction in CO emission by biodiesel comparatively to diesel has been reported by many researchers: for sunflower, safflower, peanut, canola and chicken fat biodiesel [28]. Factors responsible for reduced CO in biodiesels were suggested by [10,29-31]. Higher NO_x emission for biodiesel has been widely reported when compared to diesel fuel [17,18,28,32]. Reasons for higher NO_x were noted by [15]. The use of biodiesel in combustion ignition engine reduces hydrocarbon (HC) emissions in comparison to diesel fuel [16]. Causes of this reduction were reported by [18,32]. Smoke emissions were noted to be higher for diesel and biodiesel blends relatively to pure biodiesel fuel by [15].

The sandbox (*Hura crepitans* Linn.) tree is of the (Euphorbiaceae) family, indigenous to the humid zones of the American continents. Sandbox seeds are flattened, about 2 cm, arranged as carpel of 14-16 seeds in fruit capsules of height 3-5 cm and diameter of 5-8 cm [35,36]. Sandbox seed has been noted to contain a number of important properties that can be useful for the production of feeds, paints, and cosmetics amongst others [37-39]. Sandbox seed was noted amongst seeds with high oil content [39-41]. Sandbox seed properties, proximate composition and its oil's chemical characterization have been studied [36,39,42]. However, sandbox has been classified amongst underutilized species of plants, in most parts of the world the trees have been used as shade due to their large spreading branches [39]. In Nigeria, the trees are grown as cover plants, while the seeds were thrown away as waste [43].

The work on engine performance and exhaust emissions of engine running on sandbox seed biodiesel as reported by [44] focused mainly on the effect of blend ratio on engine performance and exhaust emissions. The current work studied engine performance of sandbox biodiesel in terms of brake power, brake specific fuel consumption and thermal efficiency and emissions of carbon monoxide (CO), oxides of nitrogen (NO_x) and hydrocarbon emissions from blends of sandbox biodiesel relatively to engine load.

2. MATERIALS AND METHODS

About 100 kg of mature sandbox fruits were collected from under the trees in Uyo metropolis, Akwa Ibom State, Nigeria between 2016-2018. The fruits were cracked to remove the seeds and the seeds peeled to get the kernels as shown in Fig. 1.

Fig. 1. Sandbox processing

Fig. 2. SBME extraction

The sandbox seed oil was extracted by solvent method using AOCS 5-04 standard procedure while the mechanical extraction was carried out using oil screw press. The transesterification of the oil into methyl ester was carried out by AOAC standard procedure and all the materials used were of recommended standard grades. Methanol was used as the alcohol in the transesterification reaction, and potassium hydroxide was used as the catalyst for the reaction. The SBME produced was washed thoroughly and blended with diesel at varying proportions of 5, 10, 15, 20, 25 and 50% denoted as B5, B10, B15, B20, B25, B50 and the pure SBME denoted as B100 as shown in Fig. 2.

These blends and diesel were used to power an 8.5 hp, 4-stroke diesel engine connected to a dynamometer and a 7.5 kVA alternator. A circuit board load of 6000 W made up of thirty lamp holders fixed with 200 W bulbs each grouped in six switch controls was used for the engine loading. A flexible hose was used to connect the engine fuel line to a 50 ml burette installed to measure the fuel intake. The engine was operated for about 10 min to stabilize before readings were taken. All the experiment and the readings were carried out per minute interval and replicated thrice. The engine was evaluated using diesel at no-load condition and the load was added by switching on the control switches which adds 1200 W load to the system up to 6000 W. The volume flow rate of the fuel, the engine speed, and the engine torque were recorded per minute intervals at every load level. The experiment was repeated with B5, B10, B15, B20, B25, B50 and B100 fuel respectively. The engine torque, speed, and fuel consumption were recorded and the brake horsepower and brake specific fuel consumption and brake thermal efficiency determined.

(a) Fuel consumption

The fuel consumed by the engine in 60 s was determined using Eq. 1 as adopted [45].

$$\dot{m}_f = C[\rho \times V/t] \quad (kg/s) \ (1)$$

$\dot{m}_f$ = fuel consumption rate (kg/s); C = conversion factor; ρ = fuel density; V = fuel volume; t = time

(b) Fuel power

The input power of the fuel samples were calculated from Eq. 2 [45].

$$P_f = \dot{m}_f \times HV \quad (2)$$

P_f = Fuel equivalent power (kW); HV = Heating Value of fuel samples (J/kg) [Determined using Gallenkemp ballistic bomb calorimeter in the Department of Agricultural Engineering, University of Ilorin, Nigeria]

(c) Brake power

The brake horsepower, bhp was calculated from Eq. 3 as adopted by [16]

$$bhp = 2\pi NT/60000 \ (kW) \quad (3)$$

N = speed (rev/min); T = torque (Nm)

(d) Brake Specific Fuel Consumption (BSFC)

The brake specific fuel consumption was calculated from Eq. 4 [16]

$$bsfc = 3600(\dot{m}_f/Brake\ power) \ (kg/kW.h) \quad (4)$$

(e) Thermal Efficiency

The thermal efficiency was calculated from Eq. 5 [16]

$$Thermal\ Efficiency = (bhp/Power\ Input) \times 100 \quad (\%) \quad (5)$$

The exhaust emissions of carbon monoxide (CO), oxides of nitrogen (NO_x) and hydrocarbon emissions were recorded with digital GX5 exhaust gas analyzer. Engine exhaust gases emissions concentrations are often represented in parts per million (ppm) of percentage volume which represents the mole fraction multiplied by 1,000,000 or by 100 respectively. Many indicators of emission levels are used; the specific emission is one of them, which represents the mass flow rate of the pollutant of unit power output.

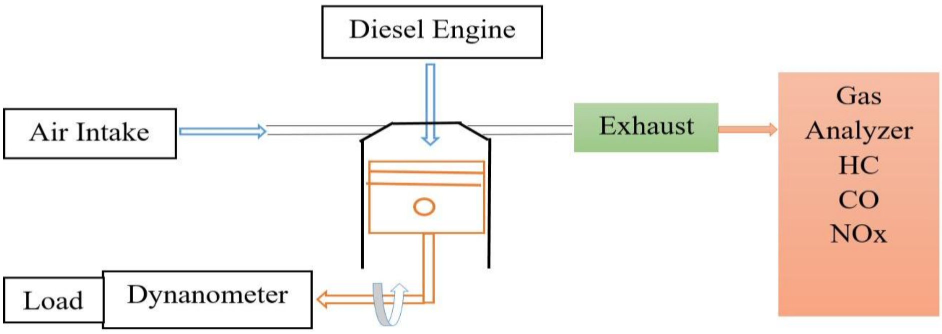

Fig. 3. Engine test setup

3. RESULTS AND DISCUSSION

The fuel properties of sandbox methyl ester are presented in Table 1. The results of the engine performance of the SBME in terms of brake power (bp), brake specific fuel consumption (bsfc) and thermal efficiency against engine load are presented in Figs. 4-6, while the results of the exhaust emissions are presented in Figs. 7-9.

Table 1. Fuel properties of sandbox methyl ester

S/N	Characteristics	Biodiesel blends						
		B5	B10	B15	B20	B25	B50	B100
1	Density, kg m^{-3}	865	878	880	884	890	888	891
2	Specific gravity	0.82	0.83	0.85	0.86	0.86	0.87	0.87
3	Kinetic viscosity, mm^2 s^{-1}	4.0	4.1	4.1	4.2	4.4	5.0	5.8
4	Flash point, °C	90	93	98	102	108	128	160
5	Fire point, °C	140	142	143	145	150	218	230
6	Pour point, °C	-9.2	-8.4	-7.5	-7.3	-7.0	-6.9	-6.8
7	Cloud point, °C	3.4	3.8	3.9	4.0	4.1	4.4	4.6
8	Cetane number							46.71
9	Heating value, MJ kg^{-1}	41.45	41.00	40.98	40.85	40.70	40.55	40.5

S/N	Characteristics	Biodiesel blends						
		B5	**B10**	**B15**	**B20**	**B25**	**B50**	**B100**
10	Saponification value, mgKOH g^{-1}	143	150	156	170	182	188	200
11	Acid value, mgKOH g^{-1}	2.2	2.4	2.4	2.5	2.5	2.5	2.7
12	FFA, mg g^{-1}	1.1	1.2	1.2	1.25	1.25	1.25	1.33
13	Iodine value, gI2 $100g^{-1}$	94	98	101	102	104	105	108
14	pH value	5.6	5.8	5.9	6.0	6.4	6.5	6.8
15	Ash content, g $100g^{-1}$	0.16	0.12	0.10	0.06	0.06	0.02	0.01
16	Carbon content, wt%	85.62	85.21	84.56	84.01	83.55	81.99	80.02

The engine brake power decreased with increase in load for all the fuels. At no load to full load as shown in Fig. 4, diesel produced the highest brake power of 5.6 kW which decreased to 3.7 kW. Similar to the diesel fuel, B5-B25 produced 5.1 kW brake power which decreased to 3.2 kW. The B100 produced the lowest brake power of 4.6 kW which decreased to 2.9 kW. Minor reduction in engine torque and power as the degree of methyl ester in biodiesel blends increased was observed by [26]. The lower calorific value of biodiesel, higher viscosity and density when compared to diesel has been suggested as been responsible for the lower engine power [10,12]. However, the higher viscosity, bsfc, oxygen content and combustion rate of biodiesel has been observed to compensate for the engine power loss experienced by engines running on biodiesel blends as against diesel [46]. This trend was corroborated by [13]; that as long as internal combustion engines deliver charge on volumetric basis, biodiesel with a higher density than diesel, supplies more fuel to compensate for the lower heating value.

Gumus and Kasifoglu [47], observed that engine power decreased below that of diesel as the amount of biodiesel in the blend increased beyond B20 and reached a minimum value at B100. Also, [48], observed an initial increase in engine power with increase in biodiesel percentage which later decreased with additional increase in biodiesel content. Comparable outcomes were observed by [49] for (B10, B20, B30, B40, B50) blends of waste cooking biodiesel. In comparison, the trend observed with the SBME is in agreement with these earlier observations.

The bsfc increased with increase in load for all the fuels. At no-load to full-load as shown in Figure 5, diesel had the lowest bsfc of 0.14 kg/kW.h, which increased to 0.62 kg/kW.h. The B5-B25 had bsfc of 0.16 kg/kW.h, which increased to 0.86 kg/kW.h, while B50-B100 had the highest bsfc of 0.22 kg/kW.h, which increased to 1.14 kg/kW.h. According to [20], the lower heating value and higher density of biodiesel requires a larger flow rate to produce the same amount of power a lesser flow rate of diesel would produce at any engine load. Thus, less fuel is consumed by the diesel fuel followed by B5, B10 and B25, with B100 having the highest consumption. The result obtained was similarly to that obtained by [44] for sandbox, who observed that B20 had the lowest bsfc, while B50 had the highest bsfc.

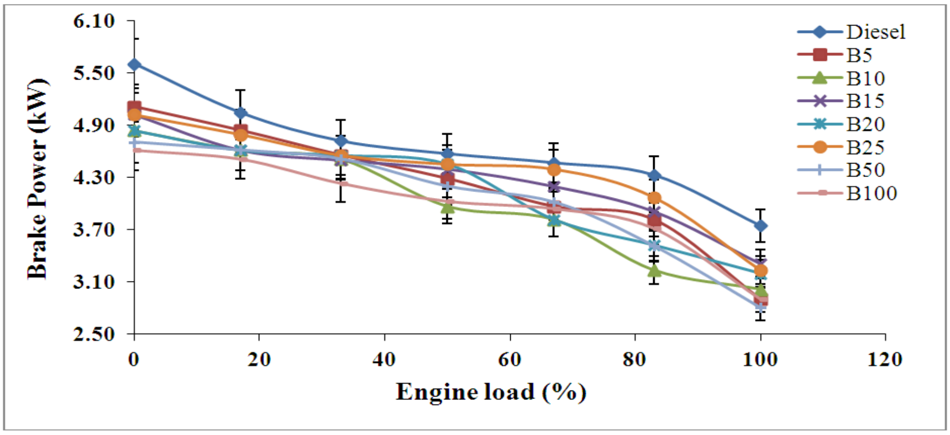

Fig. 4. Brake power against engine load

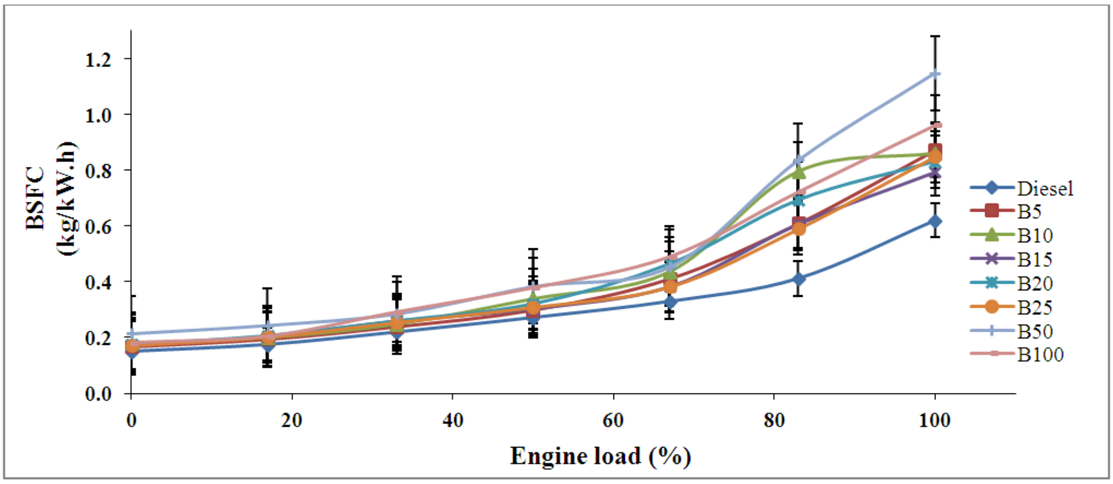

Fig. 5. BSFC against engine load

[22], observed 10% and 15% higher bsfc for B50 and B100 respectively. In comparison to the control (diesel), increase in bsfc with the addition of SBME in the blend at no-load to full-load: the bsfc of B5-B25 increased by 12.5%-29%, B50-B100 increased bsfc by 30%-45%. These trends observed for SBME were in agreement with reports by [33,50] on biodiesel blends.

The brake thermal efficiency decreased with increase in load (Fig. 6). At no-load to full-load, diesel was the most efficient, with 36% thermal efficiency which decreased to 12%. Blends of B5-B25 were next to the diesel with 30% thermal efficiency which decreased to 8%. B100 had an average of 25% thermal efficiency which decreased to about 7%. According to [15], the brake thermal efficiency of neat *Sterculia striata* biodiesel and its blends were lower than that of diesel at all load condition. This lower thermal efficiency of biodiesel was associated to its higher viscosity and density. *Sterculia striata* blend B25 had the thermal efficiency closest to that of the diesel. Similarly, [44], observed that the thermal efficiency decreased as the amount of SBME in the blend increased. [22], observed that the engine brake thermal efficiency was lower in biodiesel blends at low loads when compared to diesel. [33], observed the brake thermal efficiency of B100 and B5 cape chestnut biodiesel to be lower than that of diesel by 20.3% and 7.6% respectively. Brake thermal efficiency as surveyed by [34], suggested that there is no significant difference in the thermal efficiencies of diesel and biodiesel up to B20, above which slight decrease in thermal efficiency occurs till B100. Similarly, B5-B25 blends of SBME produced the thermal efficiency closest to diesel.

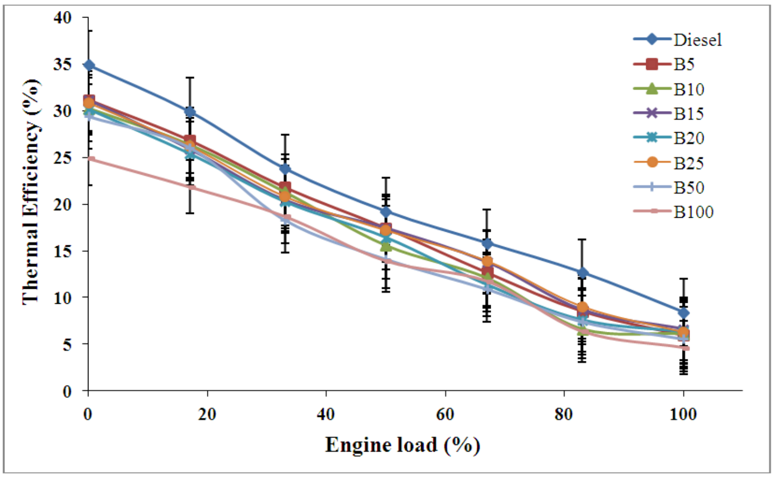

Fig. 6. Thermal efficiency against engine load

Carbon monoxide (CO) increased with increase in engine load. The emission decreased slightly from no-load to about 40% loading and increased sharply as the load exceeded 50% (Fig. 7). The CO emission was highest in diesel and decreased with addition of SBME. At no load, CO emission was reduced by 38.24% for B5 and 64.71% for B100. The gap between CO emission of biodiesel and diesel decreased at full load, as CO emission reduced by 11.11% for B5 and 55.56% for B100 at full load. Similar result was obtained by [44] that diesel produced the highest CO emission which decreased with addition of SBME to about 60% for B100. Similar trend was observed for *Jatropha curcus* biodiesel [51]. Improvement in combustion efficiency relatively to the change in brake thermal efficiency against load was suggested as the cause. Increased CO emissions as engine load increased were observed by [47.48,52,53,22]. This is because there is a decrease in air-fuel ratio as load increases, for all internal combustion engines, resulting to incomplete combustion as load increases. According to [33], the amount of CO at first decreased but increased at maximum load, as a result of biodiesel properties, which ensures improved spraying qualities with uniform charge preparations that gave it better burning conditions at higher temperature. The oxygen content of biodiesel was suggested as ensuring complete oxidation of the fuel, resulting in lower CO emission.

Various percentage reduction in CO by methyl esters have been reported: waste frying oil (17.1%) [12]; five different biodiesel fuels (4-16%) [54]; rapeseed, corn, and waste oil (28%) [22]; rapeseed (50%) [55]; Karanja (4-73%) [56]; waste palm oil and canola oil (86.89% and 72.68 respectively) [57]. The lower CO emissions were credited to the higher oxygen content of biodiesel [29,30,58]. According to [59], lesser carbon concentration of methyl esters relatively to diesel is a main factor for reduced CO emissions.

HC emission increased with increase in engine load. It was highest in diesel and decreased with increase in SBME addition to the blend as shown in Fig. 8. HC emission was reduced by 9.09% for B5, which increased to 45.45% for B100 at no load. HC emission reduced from 5.56% for B5 to 30.56% for B100 at full load.

The HC emission was lower than 60% reduction obtained by [44] for sandbox biodiesel. This might be due to atmospheric differences. They are however similar to the values obtained by [60] for fish oil biodiesel and its blends; 9.8%, 19.7%, 21.6%, 23.4% and 26.2%, obtained for 20%, 40%, 60%, 80% and 100% biodiesel blends in diesel respectively. Several authors have reported high reduction in HC emissions when engines are fueled with pure biodiesel instead of diesel [30,46,47,57,61-64]. HC reduction by methyl esters in comparison to diesel fuel: 45-67% for five different methyl ester biodiesels [10,54]; 22.47-33.15% for eight different kinds of biodiesel [46]; 20.73%, 20.64% and 6.75% respectively for *Jatropha*, karanja and polanga [65]. The lower HC emission for methyl esters was attributed to higher viscosity and density [66]. The higher oxygen content and Cetane number of biodiesel blends were suggested as the main causes of reduction in HC emissions when compared to conventional diesel [51]. The oxygen content ensures complete combustion of the fuel when burned and the higher Cetane number reduces ignition delay period, thereby leading to reduced HC emission.

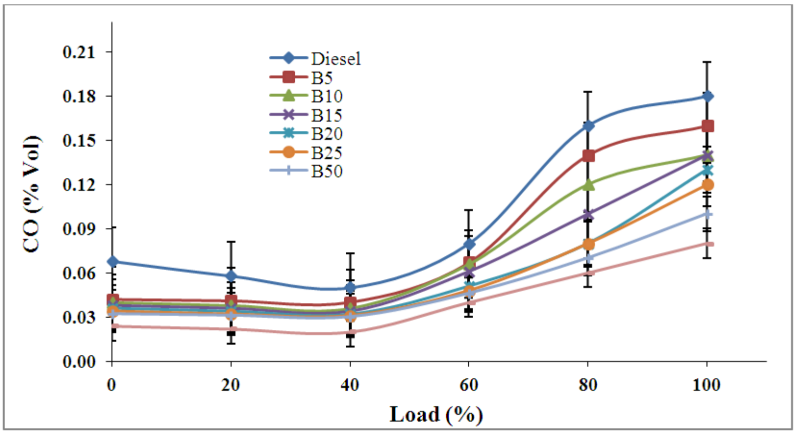

Fig. 7. CO Emission against engine load

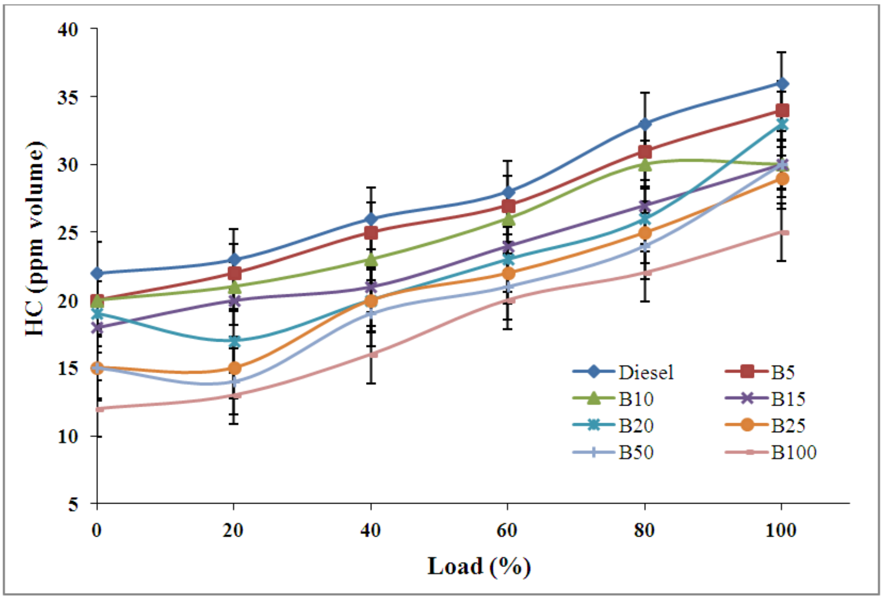

Fig. 8. HC Emission against engine load

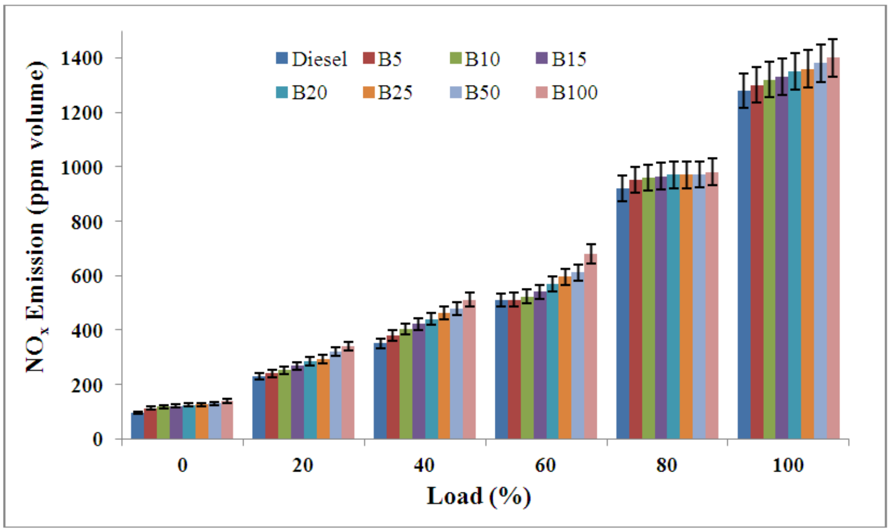

Fig. 9. NO_x Emission against engine load

NO_x emission increased with increase in engine load. It was lowest in diesel and increased marginally as the percentage of SBME in the blend increased (Fig. 9). It increased from 15.93% for B5 to 32.14% for B100. However at full load, NO_x emission from the biodiesel blends tends to even up with that of diesel fuel as the biodiesel concentration in the blend only caused a marginal increase in NO_x concentration of 1.54% for B5 and 8.57% for B100.

The results indicated that as load increased, variation in NOx emission between the biodiesel blends and diesel tends to decrease. [44], observed that NO_x emissions concentration of sandbox biodiesel blends were all higher than that of diesel. Lowest NO_x concentration was observed for B20, followed by B10, B50 and B100 which had the highest NO_x concentration. Average increased in NOx emissions from methyl esters are: 10% and 37% respectively for B10 and B100 waste oil, rapeseed oil and corn oil [22]. [33,66,67] reported that NO_x emission concentration was higher in biodiesel and their blends than the diesel at any given load or speed. This trend was related to the oxygen content of biodiesel blends. The oxygen was responsible for the increase in NO_x emission at increased exhaust gas temperature, caused by lower heat transfer, advance in fuel injection timings of biodiesel which has lower compressibility, and shortened ignition delay which is favors NO_x formation [68].

4. CONCLUSION

The performance of the sandbox seed methyl ester (SBME) on diesel engine indicated that the fuel has good quality to power the diesel engine in its pure or blended forms. Carbon monoxide (CO) and hydrocarbon (HC) emissions were reduced by the biodiesel up to 64.71% and 45.45% respectively by B100. The performance of the sandbox seed biodiesel indicates that it can be a reliable source for biodiesel feedstock, and B5-B25 biodiesel blends offered the most efficient quality. The performance of the sandbox seed oil biodiesel in terms of engine power, fuel utilization, and thermal efficiency and exhaust emissions establishes it as a potential fuel to power internal combustion engines with little or no design modifications.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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