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The performance characteristics of groundnut (*Arachis hypogea*, L.) biodiesel in a diesel engine

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The performance of groundnut ethyl ester blended with diesel in a compression ignition engine was experimentally determined. Groundnut oil reacted with ethanol to produce ethyl esters in a two-step transesterification process. The ethyl-esters were blended with automotive gas oil at (0 to 20%) mix with 5% increment of groundnut ethyl-esters to produce biodiesel. The performance of a 2.46 kW diesel engine was evaluated using the groundnut biodiesel at five loading conditions (0, 25, 50, 75 and 100% of full load). Automotive gas oil was used as a reference diesel fuel. The engine torque had a peak value of 8.5 Nm at full load, while the peak value of speed was 1300 rev/min at 25% full load when using 15% groundnut ester-AGO blend. The exhaust gas temperature had a peak value of 420°C at full load when using 5% groundnut ester-AGO blend. There were no significant differences ($p > 0.05$) in average values of torque, speed and exhaust gas temperature of the engine for groundnut biodiesel and automotive gas oil. Groundnut biodiesel can be used to fuel a diesel engine.

Key words: Groundnut oil, ethyl esters, biodiesel, diesel engine.

INTRODUCTION

Vegetable oils have attracted attention as potential renewable resources for the production of alternatives for petroleum based diesel fuel also known as automotive gas oil (AGO). Various biofuels derived from vegetable oils have been proposed as alternative fuels for diesel engines, including neat vegetable oils, mixtures of vegetable oil with AGO and alcohol esters of vegetable oil (Ma and Hanna, 1999). Alcohol esters of vegetable oils known more generically as biodiesel appear to be the most promising alternative to petroleum based diesel fuel (Krawczyk, 1996; Conceicaco et al., 2005).

In its most general sense, biodiesel is any biomass de-rived diesel fuel substitute (Sheehan et al., 1998a). Most commonly, it refers to various ester-based oxygenated fuels composed of vegetable oils or animal fats (Hobbs, 2003). Biodiesel can be used in its pure form to fuel any existing diesel engine, and it can be blended with petroleum diesel (Shrestha et al., 2005). The physical and chemical properties of biodiesel fuel are similar to petroleum diesel fuel.

There are four primary ways to make biodiesel. These include direct use and/or blending, micro emulsion, thermal cracking (pyrolysis) and transesterification (Ma and Hanna, 1999; Rakopoulos et al., 2006).

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The use of biodiesel has positive environmental benefits. Biodiesel had been found to reduce emissions of carbon monoxide, carbon-dioxide, hydrocarbons and particulates, thus reducing cancer risks (Watts et al., 1997). However, the fuel qualities and performance of biodiesel are affected by the raw materials used, the method of production, amount of biofuel blended with petroleum diesel, type of esterification process, etc. (Moreno et al., 1999; Ramadhas et al., 2006). Considerable research had been done on vegetable oils as diesel fuel (Ma and Hanna, 1999). That research included palm oil, soybean oil, sunflower oil, coconut oil, rapeseed oil, etc. Elsbett and Biakwoski (2003) noted that animal fats have not been studied as feedstock for transesterification to the same extent as vegetable oils.

The performance characteristics of vegetable oil/-alcohol blends and their derivatives in a diesel engine had been evaluated by various researchers (Dun et al., 1997; Midwest Biofuels, 1994; Shrestha et al., 2005). Their results showed that biodiesel (methyl soyate) posed more significant start-up and operatability problems during cooler seasons in moderate climates. Therefore, cold flow properties of biodiesel need improvement in order to be used in cold weather. The blending of biodiesel with petrodiesel has been found to be an effective means of improving cold flow properties. Also, more than 20% by volume of biodiesel caused blockages of fuel lines and plugged filters. They observed that petroleum diesel left a lot of dirt in the tank and the fuel system, whereas biodiesel was a good solvent; it tended to free the dirt and cleaned it out. Moreover, they reported that biodiesel would rot any natural or butyl rubber parts in the fuel system, whether fuel lines or injector pump seals and they must first be replaced with resistant parts made of viton.

Sterga and Chastain (2008) observed that engine output power was reduced by 11%, and specific fuel consumption was increased by 14% on average when 100% biodiesel was used. Generally, experimental results showed that the basic engine performance parameters such as engine power output and fuel consumption were comparable to diesel when fuelled with vegetable oil and its blends (Wang et al., 2006). Although studies have found that there is a reduction in power output ranging from 1 to 8% for 100% biodiesel (B100), there was no overall marked difference in biodiesel blends between 20% biodiesel (B20) and 50% biodiesel (B50) (Strong et al., 2004). A study on biodiesel produced from canola, rapeseed, soybean and beef tallow showed that the average peak torque for the biodiesel fuels reduced by 5% as compared to AGO (National Biodiesel Board, 1994).

In Nigeria, as there is readily available non-renewable crude petroleum diesel, not enough research has been done on the performance of biodiesel produced from locally grown crops. Groundnut oil is one of the candidate oils for the production of biodiesel. The oil and biodiesel were characterized and it gave a kinematic velocity of 6.6 mm^2/s, flash point of 182°C and cetane number of 51 which are close to the properties of diesel fuel, thus making it an alternate fuel for diesel engines (Bello and Agge, 2012). Biodiesel from groundnut oil is compatible with fossil fuel-based biodiesel and can be mixed in any combination although it is more expensive than petroleum diesel fuel. However, the renewability and clean burning properties of groundnut biodiesel favours its use. The methyl esters obtained from waste groundnut oil had been found to be a promising candidate as an alternate fuel in a diesel engine (Anitha and Dawn, 2010). Although, groundnut oil had been found to be potentially suitable for the production of groundnut biodiesel using methanol as the alcohol for transesterification (Yusuf and Sirajo, 2009), no work was reported in literature on the performance of groundnut biodiesel in any diesel engine. The main objective of this work was to evaluate the performance of a 2.46 kW diesel engine using groundnut biodiesel.

MATERIALS AND METHODS

Preparation of biodiesel samples

Groundnut seeds bought from a market in Ogbomoso were used for this work. The seeds were processed using mechanical extraction method. The extracted oil was transesterified to produce alcohol esters using a closed reactor in a two-step transeterification process as developed by Peterson et al. (1996) and Saifuddin and Chua (2004). The fuel properties of raw groundnut oil and its alcohol esters were determined according to the method prescribed in ASTM (American Society for Testing and Material) standards.

AGO also known as petroleum diesel (D2) was used as the reference fuel. It was obtained from a petroleum filling station in Ogbomoso town, Nigeria. Four biodiesel samples were produced by blending groundnut ethyl-ester with AGO at (5 to 20%) mix with 5% increment of groundnut ethyl-esters by volume in the following proportions: B5 = 5% groundnut ethyl-ester and 95% AGO; B10 = 10% groundnut ethyl-ester and 90% AGO; B15 = 15% groundnut ethyl-ester and 85% AGO; B20 = 20% groundnut ethyl-ester and 80% AGO.

Engine performance tests using groundnut biodiesel

A single cylinder, 2.46 kW diesel engine made by Ningbo Tri-Circle Power Engine Company was used for the study. The specifications of the engine are given in Table 1. The engine was coupled to an Al-Tech BK type hydraulic dynamometer and diesel and ethyl ester blends consumption measuring device (Plate 1). Chromal-Aluman (Cr-Al)-Type T-Thermocouples were used to measure the exhaust gas temperatures (Figure 1).

Table 1. The test engine specification.

Engine parameter	Specification
Model	16F
Type	Compression ignition engine
Rated power	2.46 kW (3.3 hp)
Rated speed	2600 rev/min
No. of cylinder	1
Maximum power	2.76 kW (3.7 hp)
Maximum speed	2600 rev/min
Cooling system	Water cooled
Lubrication system	Force feed

The engine was operated with AGO fuel for a baseline study. The engine was started on diesel and run on no load condition for about five minutes. The wide-open throttle of the carburetor was used for all the tests. The engine was operated for 2 min at each data collection interval. The engine was loaded from no-load condition to 100% load at increments of 25% load. The engine was loaded in a similar manner while using groundnut oil ethyl-ester diesel blends having 5, 10, 15 and 20% ethyl esters on volume basis. The blends tested did not exceed 20% of ethyl esters by volume as recommended by Midwest Biofuels (1994), Shrestha et al. (2005) and Ajav and Akingbehin (2002). Torque, speed, fuel consumption rate and exhaust gas temperature were recorded during each test according to Indian Standard Test code (1980) used by Ajav et al. (1999).

Determination of fuel consumption rate of the fuel samples

The time taken for the engine to consume 8 ml of fuel was determined and denoted as 't'. The fuel consumption rate was calculated as given by Srivastava et al. (2005) thus:

$$\mathrm{M_f} = \frac{8\rho \times 10^{-6}}{t}$$

(1)

Where, M_f = fuel consumption rate, kg/s; ρ = density of fuel, kg/m^3; t = time taken, seconds.

Determination of fuel equivalent power of the fuel samples

The fuel equivalent power was calculated as given by Srivastava et al. (2005) thus:

$$P_f = H_g \times M_f$$

(2)

Where, P_f = fuel equivalent power, W; H_g = heating value, J/kg; M_f is as defined above.

Determination of brake power

The engine output was calculated as given by Srivastava et al. (2005) thus:

$$P_B = \frac{2\pi NT}{60}$$

(3)

Where, N = speed, rev/min; T = torque, Nm;

But
$$\omega = \frac{2\pi N}{60}$$

(4)

$$\therefore P_B = T\omega$$

(5)

Where, ω = angular speed, rad/s

Determination of brake specific fuel consumption

The brake specific fuel consumption which measures how efficiently an engine is using the fuel supplied to produce work was computed as given by Srivastava et al. (2005) thus:

$$Bsfc = \frac{M_f}{P_B}$$

(6)

Where, Bsfc = brake specific fuel consumption, kg/kWh; P_B = brake power, kW; M_f is as defined above.

Determination of brake thermal efficiency

The brake thermal efficiency was computed as given by Srivastava et al. (2005) as:

$$\eta_{bth} = \frac{P_B}{M_f \times H_g} \times 100$$

(7)

Where, η_{bth} = brake thermal efficiency, %; P_B, M_f and H_g are as defined above.

Statistical design and analysis

The data sets were analyzed statistically using two-factor analysis of variance. The significance level of the engine performance data recorded or computed was established by conducting an ANOVA using a two-factor experiment in randomized complete block experimental design. The significance level of 0.05 was used as the p-value to determine whether there were significant differences in

Plate 1. Experimental set- up of engine tests.

the mean values of engines parameters when it was running on groundnut biodiesel and AGO.

The statistical design involved fuel types at 9 levels as the main treatment and brake load at 5 levels as the second treatment. Three replicates of each experiment were used in the analysis. The total number of observations used was 135. The class level information is presented in Table 2.

RESULTS AND DISCUSSION

The fuel properties of groundnut ethyl ester that was produced by a two-step transesterification process are presented in Table 3. The performance of a 2.46 kW diesel engine at various loads using AGO and groundnut ethyl ester-AGO blends was evaluated in terms of torque, exhaust gas temperature, speed, brake specific fuel consumption, brake thermal efficiency, fuel equivalent power and brake power. The mean values are presented in Tables 4 to 8.

Torque

The torque developed by the engine increased with an increase in the engine load for all the fuel samples (Figure 2). At no loading, the engine developed a torque of 1.47 Nm which was the same when using all groundnut biodiesel samples. The engine developed a torque of 2.87 Nm when using AGO at no loading and was significantly different ($p < 0.05$) from the torque developed when using all the biodiesel samples. The engine developed a torque of 7.07 Nm at 25% loading which was the same when using all the groundnut biodiesel samples, except for 10% groundnut biodiesel
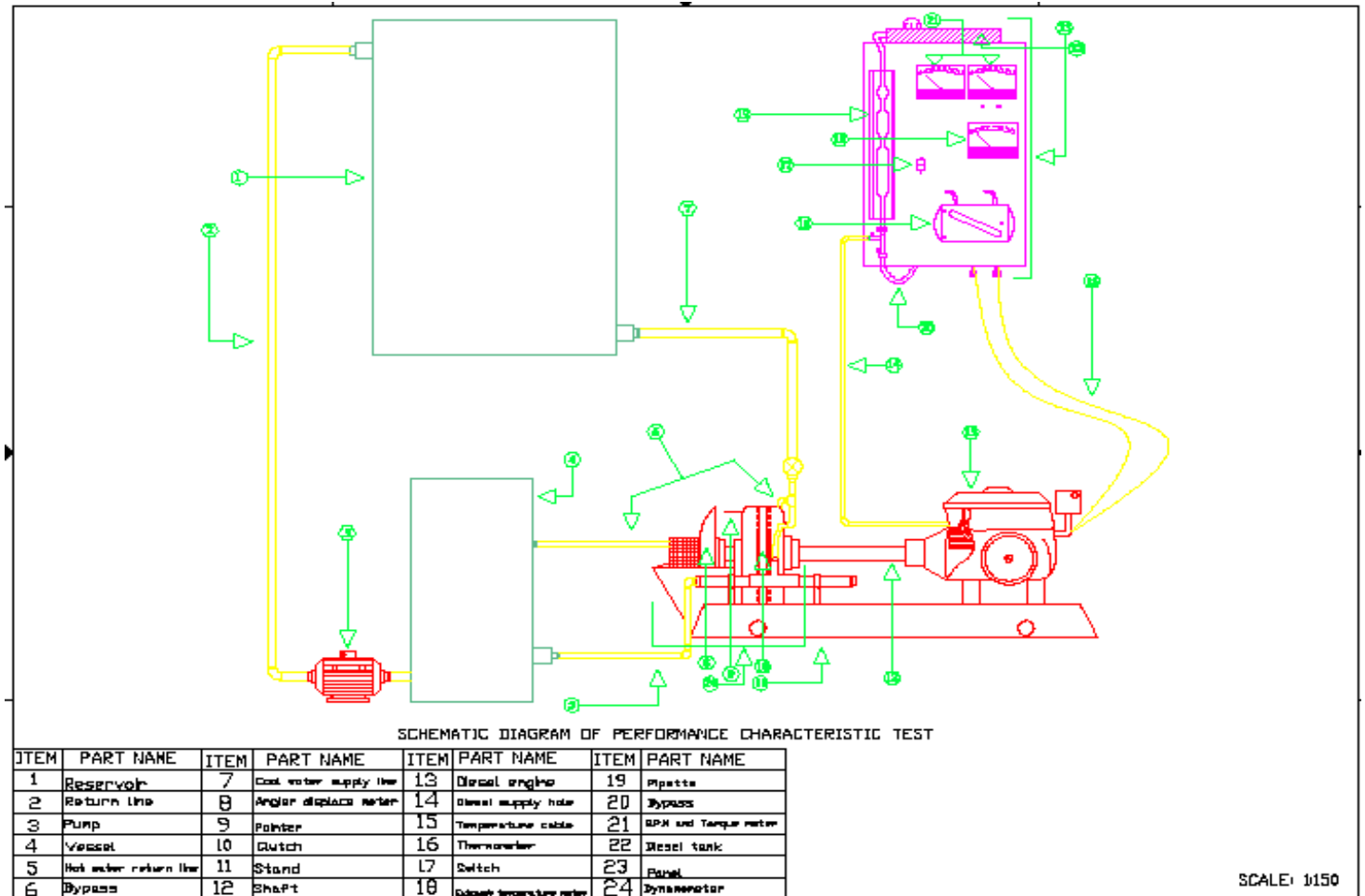
Figure 1. Schematic diagram of the experimental set-up.

Table 2. Class level information.

Class	Levels	Values
Sample	9	1 2 3 4 5 6 7 8 9
Load	5	1 2 3 4 5

Number of observations used = 135.

sample which caused an engine torque of 6.37 Nm, and AGO which caused an engine torque of 9.17 Nm. At 50% loading, the engine developed a torque of 7.77 Nm which was the same when using all the groundnut biodiesel samples at 50% loading, while a torque of 9.86 Nm was developed when using AGO. The engine developed a torque of 8.47 Nm which was the same when using all the groundnut biodiesel samples at 75% loading, while a

torque of 10.56 Nm was developed when using AGO. The engine developed a torque of 8.47 Nm which was the same when using all the groundnut biodiesel samples at 100% loading, while a torque of 10.56 Nm was developed when using AGO.

The same peak value of torque (8.5 Nm) developed by the engine at full load was obtained for groundnut biodiesel using 15% groundnut ethyl ester-AGO blend as compared to 10.6 Nm at full load obtained when using AGO. This implied that the peak value obtained when using groundnut biodiesel decreased by 19.8% as compared to AGO. These results were consistent with earlier studies on biodiesel produced from canola, rapeseed, soybean and beef tallow which showed that the average peak torque for the biodiesel fuels reduced by 5% as compared to AGO (National Biodiesel Board, 1994). Alamu et al. (2009) observed that at all tested

Table 3. Fuel properties of pure diesel, groundnut oil ethyl ester and raw groundnut oil.

Fuel property	Groundnut oil ethyl ester
Viscosity @ 40°C (cst)	7.60
Heating value (mj/l)	30.07
pH	2.90
Specific gravity AT 15°C	0.85
Cloud point (°C)	7
Pour point (°C)	4
Ash content (%)	0.01
Flash point (°C)	200
Sulphur content (%)	9.73
Carbon content (%)	10.40
Iodine value (wijis)	0.34
Peroxide value (meq/koh)	0.13
Saponification value (mgkoh/g)	0.17
Free fatty acid (g/100g)	7

Table 4. Performance of a 2.46 kW diesel engine using 5% groundnut oil biodiesel fuel.

Load	No load	25% load	50% load	75% load	100% load
Torque (Nm)	1.47	7.07	7.77	8.47	8.47
Speed (rev/min)	1450	1200	1000	900	900
Fuel Consumption rate (ml/s)	0.08	0.12	0.15	0.17	0.18
Density (kg/m³)	840	840	840	840	840
Fuel Consumption rate (kg/s*10⁻⁶)	62.80	101.05	124.44	140	152.73
Exhaust gas temperature (°C)	81	223	367	415	420
Fuel Consumption rate (g/h)	226.09	363.79	448	504	549.82
Heating value (MJ/L)	30	30	30	30	30
Heating value (kJ/kg*10³)	35.71	35.71	35.71	35.71	35.71
Fuel equivalent power (W)	2242.99	3609.02	4444.44	5000	5454.55
Angular Speed (rad/s)	151.77	125.6	104.67	94.2	94.2
Brake Power (Kw)	0.22	0.89	0.81	0.80	0.80
Brake Specific fuel consumption (g/kwh)	1011.56	409.84	551.12	632.00	689.45
Brake Thermal efficiency (%)	9.97	24.60	18.29	15.95	14.62

engine speeds, the torque outputs of palm kernel oil (PKO) biodiesel in a diesel engine were generally lower than those for the petroleum diesel.

The error bars for the mean values of torque overlap considerably, indicating that the mean values of torque of the engine at all loading conditions while using 5 to 20% groundnut ethyl ester-AGO blend were unlikely to be different from the values obtained when using the reference AGO. On the average for all engine loading, the torque output of the reference AGO was 8.61 Nm when compared with the corresponding output values of groundnut biodiesel samples ranging from 6.51 to 6.65 Nm. The p-value equals 0.967 which implies $p > 0.05$, the error variances were identical. Therefore, there were no significant differences in the torque mean values developed by the engine at all loading conditions while using groundnut biodiesel samples and AGO. This indicated that there was no significant difference in the performance of groundnut biodiesel samples and pure diesel in a diesel engine at all load conditions based on

Table 5. Performance of a 2.46 kW diesel engine using 10% groundnut oil biodiesel fuel.

Load	No load	25% load	50% load	75% load	100% load
Torque (Nm)	1.47	6.37	7.77	8.47	8.47
Speed (rev/min)	1550	1200	1100	1000	1000
Fuel Consumption rate (ml/s)	0.06	0.11	0.14	0.15	0.17
Density (kg/m³)	843	843	843	843	843
Fuel Consumption rate (kg/s*10^{-6})	51.48	96.34	114.31	127.25	137.63
Exhaust gas temperature (°C)	70	245	300	355	395
Fuel Consumption rate (g/h)	185.33	346.83	411.50	458.08	495.48
Heating value (MJ/L)	30.07	30.07	30.07	30.07	30.07
Heating value (kJ/kg*10³)	35.67	35.67	35.67	35.67	35.67
Fuel equivalent power (W)	1836.34	3436.57	4077.29	4538.88	4909.39
Angular Speed (rad/s)	162.23	125.6	115.13	104.67	104.67
Brake Power (Kw)	0.24	0.80	0.89	0.89	0.89
Brake Specific fuel consumption (g/kwh)	775.69	433.65	460.65	516.98	559.18
Brake Thermal efficiency (%)	13.01	23.27	21.93	19.52	18.05

Table 6. Performance of a 2.46 kW diesel engine using 15% groundnut oil biodiesel fuel.

Load	No load	25% load	50% load	75% load	100% load
Torque (Nm)	1.47	7.07	7.77	8.47	8.47
Speed (rev/min)	1500	1300	1100	1050	1000
Fuel Consumption rate (ml/s)	0.08	0.10	0.15	0.16	0.18
Density (kg/m³)	844	844	844	844	844
Fuel Consumption rate (kg/s*10^{-6})	64.92	87.69	127.40	135.04	150.04
Exhaust gas temperature (°C)	70	185	250	335	355
Fuel Consumption rate (g/h)	233.72	315.68	458.63	486.14	540.16
Heating value (MJ/L)	31	31	31	31	31
Heating value (kJ/kg*10³)	36.73	36.73	36.73	36.73	36.73
Fuel equivalent power (W)	2384.62	3220.78	4679.25	4960	5511.11
Angular Speed (rad/s)	157	136.07	115.13	109.9	104.67
Brake Power (Kw)	0.23	0.96	0.89	0.93	0.89
Brake Specific fuel consumption (g/kwh)	1010.83	328.28	512.90	522.52	609.61
Brake Thermal efficiency (%)	9.70	29.86	19.11	18.76	16.08

mean values of torque, that is fuel type did not have any significant effect on the mean values of torque.

Exhaust gas temperature

As the load increased, the exhaust gas temperature of the engine increased for all the fuel samples (Figure 3). The exhaust gas temperature at any loading condition of the engine decreased with increase in percentage of groundnut ethyl ester in the fuel blends from 5 to 15%

and then increased slightly at 20% (Figure 3). This was comparable to the results obtained by Saravanan et al. (2007) who reported that exhaust gas temperature developed by a diesel engine fuelled by blends of rice bran oil with AGO decreased with increase in percentage of rice bran oil in the blends.

Also, Al-Hasan and Al-Momany (2008) reported that exhaust gas temperature developed by a diesel engine fuelled by blends of iso-butanol with AGO decreased with increase in percentage of iso-butanol in the blends. Prasad et al. (2009) observed that the exhaust gas

Table 7. Performance of a 2.46 kW diesel engine using 20% groundnut oil biodiesel fuel.

Load	No load	25% load	50% load	75% load	100% load
Torque (Nm)	1.47	7.07	7.77	8.47	8.47
Speed (rev/min)	1600	1275	1100	1000	1000
Fuel Consumption rate (ml/s)	0.07	0.12	0.14	0.15	0.15
Density (kg/m³)	847	847	847	847	847
Fuel Consumption rate (kg/s*10^{-6})	56	99.65	116.83	123.2	127.85
Exhaust gas temperature (°C)	65	170	300	345	365
Fuel Consumption rate (g/h)	201.6	358.73	420.58	443.52	460.26
Heating value (MJ/L)	31.5	31.5	31.5	31.5	31.5
Heating value (kJ/kg*10^3)	37.19	37.19	37.19	37.19	37.19
Fuel equivalent power (W)	2082.65	3705.88	4344.83	4581.82	4754.72
Angular Speed (rad/s)	167.47	133.45	115.13	104.67	104.67
Brake Power (Kw)	0.25	0.94	0.89	0.89	0.89
Brake Specific fuel consumption (g/kwh)	817.41	380.37	470.35	500.54	519.43
Brake Thermal efficiency (%)	11.84	25.45	20.58	19.34	18.64

Table 8. Performance of a 2.46 kW diesel engine using AGO.

Load	No load	25% load	50% load	75% load	100% load
Torque (Nm)	2.88	9.17	9.86	10.56	10.56
Speed (rev/min)	1433.3	1000	930	900	900
Fuel Consumption rate (ml/s)	0.07	0.14	0.15	0.2	0.21
Density (kg/m³)	859	859	859	859	859
Fuel Consumption rate (kg/s*10^{-6})	59.76	122.71	127.26	171.8	180.84
Exhaust gas temperature (°C)	70	300	327	390	400
Fuel Consumption rate (g/h)	215.12	441.77	458.13	618.48	651.03
Heating value (MJ/L)	44.68	44.68	44.68	44.68	44.68
Heating value (kJ/kg*10^3)	52.01	52.01	52.01	52.01	52.01
Fuel equivalent power (W)	3108.17	6382.86	6619.26	8936	9406.32
Angular Speed (rad/s)	150.02	104.67	97.34	94.2	94.2
Brake Power (Kw)	0.43	0.96	0.96	1.00	1.00
Brake Specific fuel consumption (g/kwh)	499.41	460.53	477.13	621.53	654.24
Brake Thermal efficiency (%)	13.86	15.03	14.51	11.14	10.58

temperature increased with increase in operating load for all the blends of neat castor oil with AGO.

There was no significant difference ($p > 0.05$) in the exhaust gas temperature range 65 to 70°C developed by the engine at no loading when using all the groundnut biodiesel samples except for 5% groundnut ethyl ester-AGO blend whose exhaust gas temperatures was 81°C. The engine developed an exhaust gas temperature of 70°C when using AGO at no loading and was significantly different ($p < 0.05$) from the exhaust gas temperature developed when using all the biodiesel samples. Also, there was no significant difference ($p > 0.05$) in the

exhaust gas temperature of 170 to 185°C developed by the engine at 25% loading when using all the groundnut biodiesel samples except for 5% groundnut biodiesel and 10% groundnut biodiesel when the engine developed exhaust gas temperature values of 223 and 245°C, respectively, and were not significantly different from each other. The engine developed exhaust gas temperature of 300°C when using AGO at 25% loading and was significantly different ($p < 0.05$) from the exhaust gas temperature developed by all the biodiesel samples. There was no significant difference ($p > 0.05$) in the exhaust gas temperature of 235 to 250°C developed by
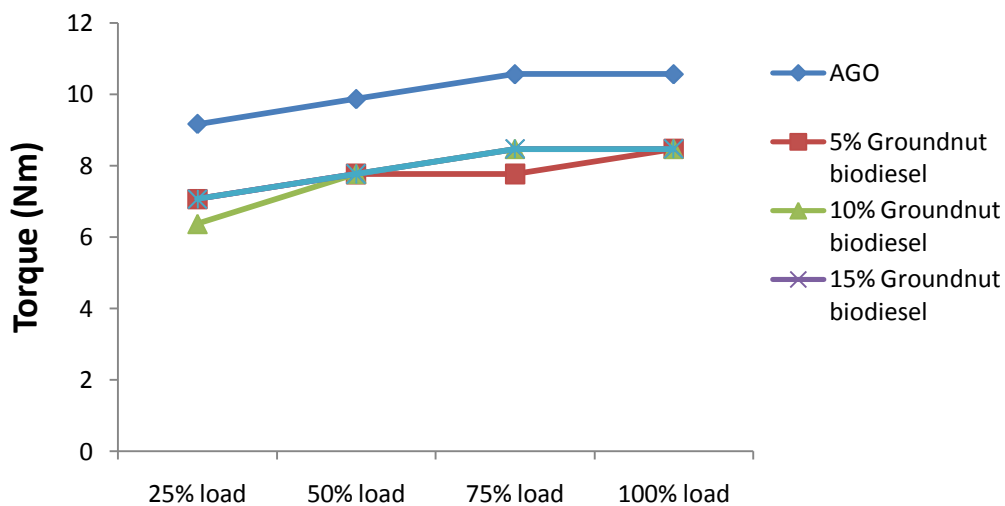
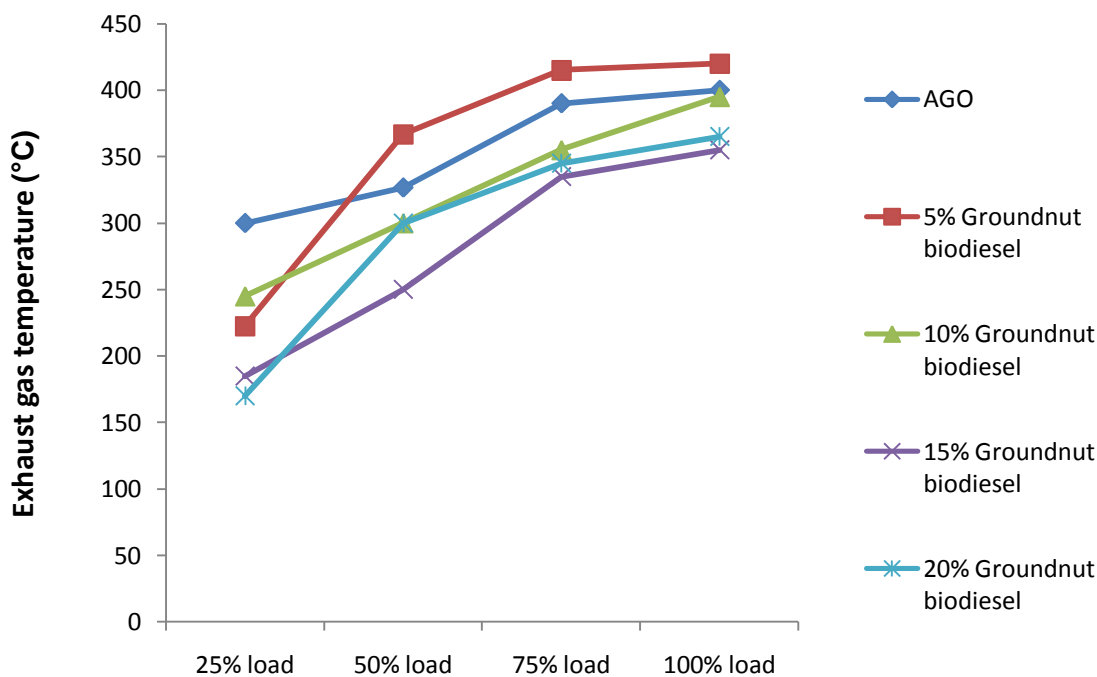**Figure 2.** The torque developed by the engine at different loading conditions.

Figure 3. The exhaust gas temperature developed by the engine at different loading conditions.

the engine at 50% loading when using all the groundnut biodiesel samples except for 5% groundnut ethyl ester-AGO blend and 10% groundnut ethyl ester-AGO when the engine developed exhaust gas temperature values of 367 and 300°C, respectively. The exhaust gas temperature when using 5% groundnut ethyl ester-AGO blend at 50% loading is not significantly different ($p > 0.05$) from that of AGO, which was 327°C. The exhaust gas temperature developed by the engine at 75% loading of the engine when using all the other groundnut biodiesel samples ranged from 300 to 415°C and were significantly different ($p < 0.05$) from that of AGO. The exhaust gas
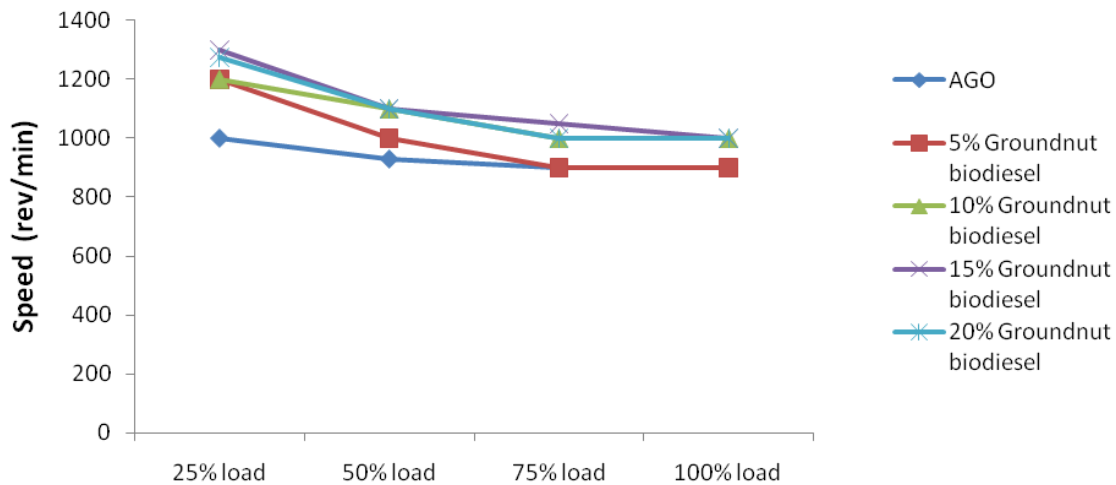
Figure 4. The speed developed by the engine at different loading conditions.

temperature of the engine at 100% loading ranged from 330 to 420°C for all groundnut biodiesel samples. It was only the exhaust gas temperature of 390 and 395°C developed by the engine when using 10% groundnut ethyl ester AGO blend respectively at 100% loading of the engine that was not significantly different (p > 0.05) from that of AGO which was 400°C.

The maximum exhaust gas temperature of 400°C at full load was obtained when the engine was run on AGO, while the corresponding values obtained for 5, 10, 15 and 20% groundnut ethyl ester-AGO blend were 420, 395, 355 and 365°C, respectively. The maximum exhaust gas temperatures for all the biodiesel fuels were lower than that for the AGO fuel, except for 5% groundnut ethyl ester-AGO blend which was higher. Similarly, Ajav et al. (1999) observed that the average maximum exhaust gas temperatures of a diesel engine using 5 to 20% of ethanol-AGO blends were lower than that of AGO. They explained that this reduction could be due to the lower calorific values of the blended fuels as compared to diesel alone.

The error bars for exhaust gas temperature overlap considerably indicating that the mean values of exhaust gas temperature of the engine at all loading conditions while using 5 to 20% groundnut ethyl ester-AGO blend were unlikely to be different from the values obtained when using the reference AGO. On the average for all engine loading, the exhaust gas temperature of the reference AGO was 297°C when compared with the corresponding values of groundnut biodiesel samples ranging from 239 to 301.08°C. The p-value equals 0.957 which implies p>0.05, the error variances were identical. The p-value indicate that there was a non-significant

difference in the mean values of exhaust gas temperature developed by the engine when using groundnut biodiesel samples and AGO at all loading conditions. Therefore, there was no significant difference in the performance of groundnut biodiesel samples and pure diesel in a diesel engine at all load conditions based on mean values of exhaust gas temperature, that is, fuel type did not have any significant effect on the mean values of exhaust gas temperature. This agrees with the result obtained by Ajav et al. (1999) who reported that there were no significant differences in the mean values of the exhaust gas temperature developed by an engine using 5, 10 and 15% ethanol-diesel blends.

Speed

The speed of the engine decreased with increase in engine load up to 75% load for groundnut ethyl ester-AGO blends, as well as for AGO (Figure 4). The speed of the engine remained constant for any increase in engine load after 75% of full load for all the blends and AGO, except for 15% groundnut ester-AGO blend which caused the speed to decrease slightly from 1050 rev/min at 75% of full load to 1000 rev/min at 100% of full load.

The speed of the engine at no loading ranges from 1450 to 1550 rev/min for all groundnut biodiesel samples and there was no significant difference (p > 0.05) between the samples except for 20% groundnut biodiesel which caused a speed of 1600 rev/min. At 25% loading, the engine developed a speed of 1200 rev/min which was the same when using all the groundnut biodiesel samples, except for 15% groundnut ethyl ester AGO

blend and 20% groundnut ethyl ester-AGO blend which caused engine speed of 1300 rev/min and 1275 rev/min, respectively.

The engine developed a speed of 1000 rev/min when using AGO at 25% loading and was significantly different (p < 0.05) from the speed developed by all the biodiesel samples. At 50% loading, the engine developed a speed of 1100 rev/min which was the same when using all the groundnut biodiesel samples, except for 5% groundnut ethyl ester-AGO blend which developed a speed of 1000 rev/min. The engine developed a speed of 926.6 rev/min when using AGO at 50% loading and was significantly different (p < 0.05) from the speed developed by all the biodiesel samples. The engine developed a speed of 1000 rev/min which was the same when using all the groundnut biodiesel samples at 75% loading, except for 15% groundnut ethyl ester-AGO blend which was 1050 rev/min, while a speed of 900 rev/min was developed when using AGO. Also, the engine developed a speed of 1000 rev/min which was the same when using all the groundnut biodiesel samples at 100% loading, while a speed of 900 rev/min was developed when using AGO.
A peak value of speed (1200 rev/min at 25% full load) was developed by the engine when the engine was using 5 and 10% groundnut ester-AGO blends, while peak values of 1300 and 1275 rev/min at 25% full load were obtained when the engine was using 15 and 20% groundnut ethyl ester-AGO blends, respectively. The corresponding value obtained for AGO was 1000 rev/min and lower than the peak values obtained for all the blends.

The error bars for the speed overlap considerably, indicating that the mean values of speed of the engine at all loading conditions while using 5 to 20% groundnut ethyl ester-AGO blend were unlikely to be different from the values obtained when using the reference AGO. On the average for all engine loading, the speed of the reference AGO was 1032 rev/min, when compared with the corresponding values of groundnut biodiesel samples ranging from 1090 to 1195 rev/min. The p-value equals 0.967, which indicates (p>0.05) the error variances were identical. The differences were not significant (p>0.05) for the engine mean speed when using the reference AGO as compared to when using groundnut biodiesel samples. Therefore, there was no significant difference in the performance of groundnut biodiesel samples and pure diesel in a diesel engine at all load conditions based on mean values of speed, that is, fuel type did not have any significant effect on the mean values of speed.

Brake specific fuel consumption

The brake specific fuel consumption trend for AGO and

all groundnut biodiesel samples were similar in nature. Engelman et al. (1978) observed that the brake specific fuel consumption for the fuel blends of 10 to 50% soybean oil fuel blends used in diesel engines at the conclusion of a 50-h test differed slightly from 100% diesel fuel. It was observed that the brake specific fuel consumption of 5, 10, 15 and 20% groundnut ethyl ester-AGO blends and the reference AGO increased from 409.84 - 689.45, 433.65 - 559.18, 328.28 - 609.61, 380.37 - 519.43 and 460.53 - 654.24 g/kWh with increase in engine load from 25 - 100%, respectively (Figure 5). The peak values of brake specific fuel consumption obtained for 5, 10, 15 and 20% groundnut ester-AGO blend were 689.45, 559.18, 609.61 and 519.43 g/kWh respectively, at full load. The differences in the brake specific fuel consumption were due to the differences in the density and heating value of the biodiesel fuels.

Brake thermal efficiency

The brake thermal efficiency decreased as load on the engine increased for all the fuel samples as shown in Figure 6. The maximum brake thermal efficiency obtained when the engine was run at 25% of full load on 5, 10, 15 and 20% groundnut ethyl ester-AGO blend were 24.59, 23.27, 29.86 and 25.45%, respectively. The maximum brake thermal efficiency (15.03%) obtained when the engine was run on AGO at 25% of full load was lower than those obtained for all the blends. Similarly Rao et al. (2008) found that the brake thermal efficiency values for jatropha methyl ester and its blends were slightly higher than that of diesel fuel at tested load conditions while there were no differences between those of esters and its blends with diesel fuels.

Ramadhas et al. (2005) observed that the maximum brake thermal efficiency obtained was about 28% for B10, which was quite higher than that of diesel (25%) when engine is running on biodiesel from rubber seed oil as compared to petroleum diesel while the maximum brake thermal efficiency obtained while using B50, B75 and B100 of rubber seed oil were 25, 25 and 24%, respectively. The results obtained for the maximum brake thermal efficiency of groundnut ester-AGO blends were comparable to the maximum brake thermal efficiency (25.1, 25, 23.9 and 22%) obtained when a diesel engine was run on 5, 10, 15 and 20% ethanol-AGO blends, respectively (Ajav et al., 1999).

Fuel equivalent power

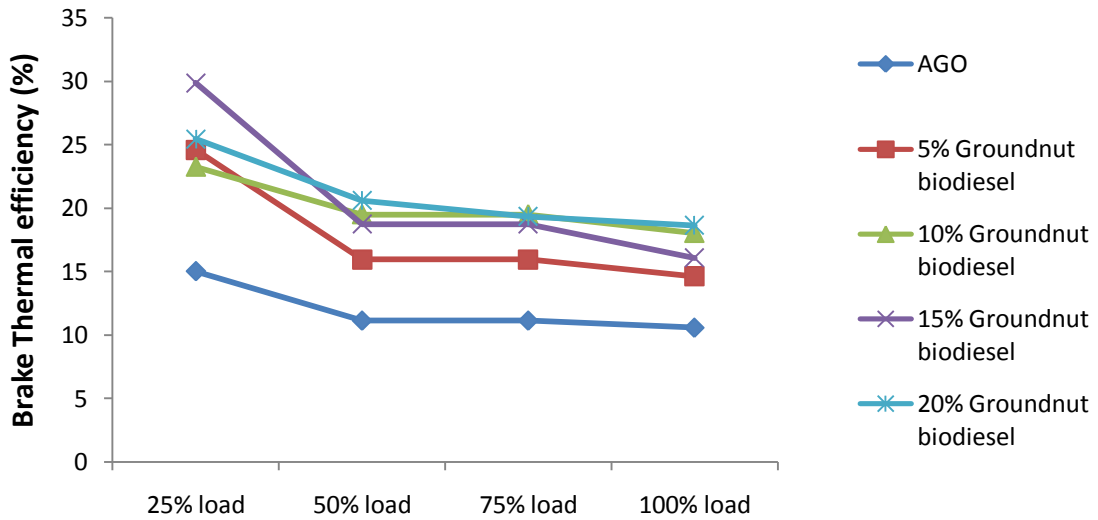The maximum fuel equivalent power of 9.41 kW was

Figure 6. The brake thermal efficiency developed by the engine different loading conditions.
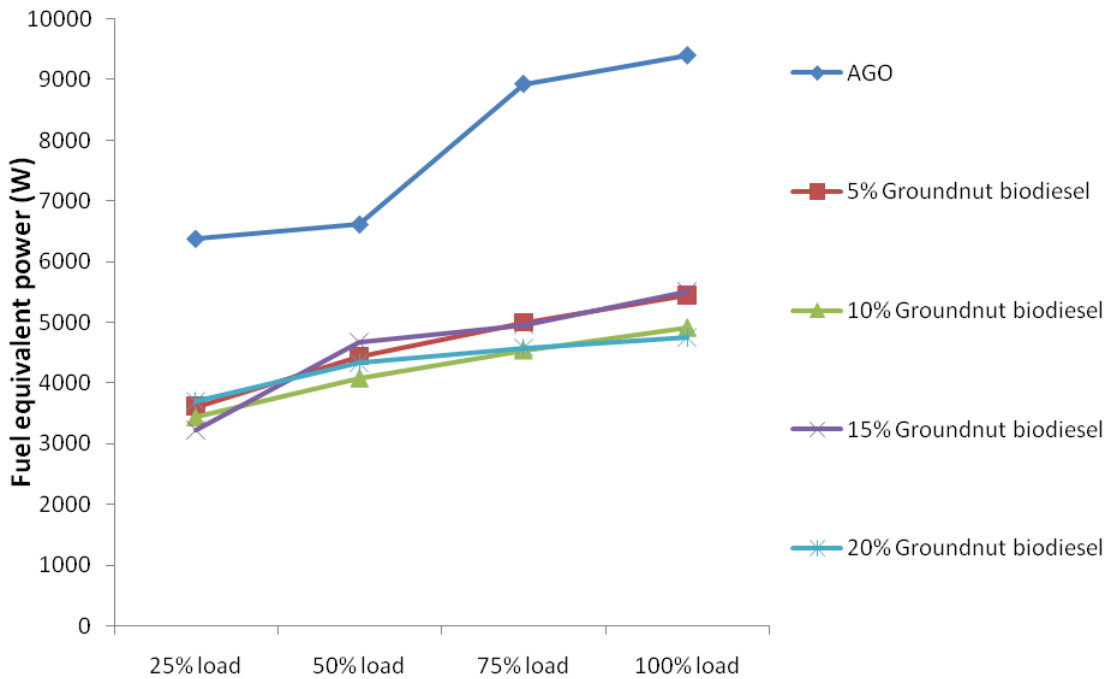

Figure 7. The fuel equivalent power developed by the engine at different loading conditions.

obtained when the engine was run on AGO at full load. The maximum fuel equivalent power of 5, 10, 15 and 20% groundnut ethyl ester-AGO blend decreased in the range of 49.45 to 41.41% of that obtained for AGO (Figure 7).

Brake power

The same maximum brake power of 894.18 W at 50% of full load was developed by the engine when the engine was run on 10% groundnut ethyl ester-AGO blend
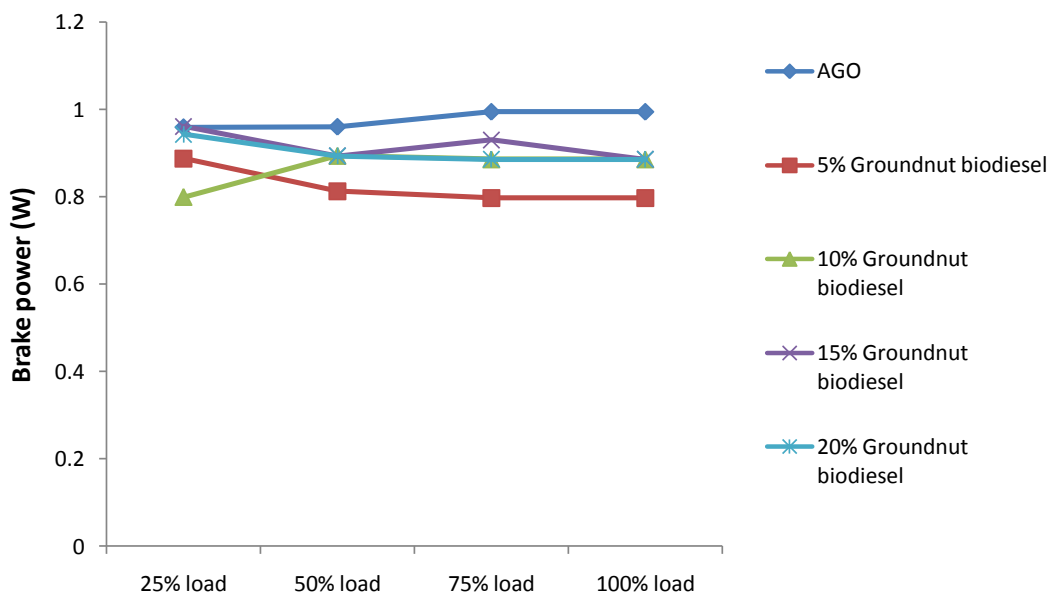
Figure 8. The brake power developed by the engine at different loading conditions.

(Figure 8). This was about 6.88% reduction in the maximum brake power obtained when the engine was run on AGO alone. Similarly, engine power at rated load produced by biodiesel fuels produced from canola, rapeseed, soybean oils and beef tallow was reported to decrease by an average of 4.9% as compared to AGO (National Biodiesel Board, 1994). The percentage decrease in power for palm kernel oil biodiesel relative to the petroleum diesel observed by Alamu et al. (2009) were 5.13, 6.25, 5.46, 7.26, 9.38 and 7.69% at 1300, 1500, 1700, 2000, 2250 rpm, respectively.

There were no significant differences in the speed and torque developed by the engine at all loading conditions while using groundnut biodiesel samples and AGO. Therefore, there was no significant difference in the performance of groundnut biodiesel samples and pure diesel in a diesel engine at all load conditions based on mean values of brake power, that is, fuel type did not have any significant effect on the mean values of brake power. This agrees with the result obtained by Ajav et al. (1999) who reported that there was no significant differences between the brake horsepower developed by an engine fuelled by ethanol-AGO blends and AGO alone.

Engelman et al. (1978) observed that power measurements for the fuel blends of 10 to 50% soybean oil fuel blends used in diesel engines only differed slightly from 100% diesel fuel. Sapaun et al. (1996) reported that power outputs were nearly the same for palm oil, blends of palm oil and diesel fuel, and 100% diesel fuel. Moreno

et al. (1999) reported that the power of the engine are maintained within the same levels when using blends of sunflower methyl ester with diesel in the range of 25 to 50% as when using pure diesel.

Smoke density

There was a noticeable sharp reduction in the smoke density produced by the engine when the engine was running on all the groundnut biodiesel samples as compared to when the engine was running on AGO alone. The smoke produced by the engine was clear when the engine was running on all biodiesel samples as compared to a darkish smoke produced when the engine was running on AGO alone. Similarly, Ziejewski et al. (1984) and Reece and Peterson (1993) had reported reductions in smoke density when fuelling with biodiesel or biodiesel as compared to AGO.

Conclusion

The engine torque had peak value of 8.5 Nm at full load when using 15% groundnut ester-AGO blend as compared to 10.6 Nm (full load) obtained for AGO. Higher peak values of speed (1300 rev/min at 25% full load) and exhaust gas temperature (420°C at full load) were obtained for groundnut biodiesel using 5% groundnut ester-AGO blend. There were no significant differences ($p > 0.05$) in average values of torque, speed and exhaust gas temperature of the engine when it was

using groundnut biodiesel and AGO at all loads.

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