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Combustion, Engine performance and Emission Characteristics of Biodiesel from Cyanobacteria (BLUE GREEN ALGAE) Isolated from Alau Dam Maiduguri, Borno State.

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ABSTRACT

Due to the potential exhausting and increasing price of petroleum together with environmental issues caused by the combustion of fossil fuels, the search for alternative fuels has gained much attention. In this study, the combustion, engine performance and emission of characteristics of biodiesel produced from cyanobacteria (blue green algae) will be evaluated. Biodiesel sample used in this research was produced using transesterification processes. 5ml of biodiesel was collected from Department of microbiology department, University of Maiduguri to determine its combustion activities (high heating value, pour and cloud point, flash point and refractive index), engine performance (brake specific fuel consumption, brake thermal energy and brake specific energy consumption) and emission characteristics using biodiesel blend of 95%. All the properties analyzed were within the regulatory limits stipulated for conventional diesel as per ASTM specifications. Biodiesel blended fuels can significantly reduce the emissions of harmful pollutants other than NOx and CO2. Blended biodiesel also improves performance of engine where brake thermal heat (BTE) and brake specific fuel consumption (BSFC) values are reduced significantly.

***Key word:** Cyanobacteria, biodiesel blend and ASTM*

INTRODUCTION

Fuels are essential to human life and account for 70% of the world's overall energy needs. Due to its potential to reduce reliance on fossil fuels, biofuel production is anticipated to eventually replace some natural fuel sources in the energy sector (Gouvcia and Oliveira, 2009). The decrease in fossil fuel and the increasing demand for fuel pose a challenge to society and technology Abas *et al.*, (2015).

Numerous technologies, including water injection (WI), emulsion technology (ET), exhaust gas recirculation (EGR), injection strategy modification, combustion chamber geometry modification, and low temperature combustion strategy, have been employed to improve the combustion and emission characteristics of diesel engines in order to address the issue (Jiaqiang *et al.*, 2017 and Zhang *et al.*, 2022). However, compared with using new technologies to reduce various environmental pollution caused by fossil fuel combustion, using alternative renewable fuels to achieve high efficiency and clean combustion becomes more attractive Verma and Sharma (2015). In this regard, sustainable and alternative fuels such as alcohols, natural gas, biodiesel, and dimethyl ether are considered effective methods to reduce the nitro oxide (NOx), greenhouse gas, and particulate Matter (PM) emissions from diesel engines (Zhang *et al.*, 2022).

Vehicular emissions such as particulate matter (PM), hydrocarbon (HC), carbon dioxide (CO2), carbon monoxide (CO), and nitrogen oxides (NOx) are hugely responsible for air quality deterioration. Two main internal combustion engine (ICE) types, namely, gasoline and diesel engines, contribute to degrading the air quality in the urban environment. Moreover, emissions from the ICEs were classified as a carcinogen by the International community Sipeng *et al.,* (2019).

Biodiesel is an efficient carrier of solar energy and hence has a positive energy balance ratio. In addition, it degrades rapidly in the environment and is non-toxic (Marek, *et al.,* 2008). The rate at which biodiesel degrades is same as that of sugar. Pure biodiesel degrades 85 to 88% in water within 28days Marilena *et al.*, (2014). Its biodegradability can be further accelerated by blending it with diesel Piotr *et al.*, (2014). Many companies have reported the use of biodiesel to breakdown and degrade oil spills. Storing biodiesel is also very safe. Virtually it has same storing and handling requirements as that of diesel storage except the use of copper, brass, lead, tin, and zinc storage containers. The well-organized storage of biodiesel resources can provide energy security to a country (Sharmal. *et al.,* 2008).

2.0 Methodology

2.1 Physico-chemical Properties of the biodiesel

In this study, 5ml of biodiesel produced from transesterification of cyanobacteria lipid were collected from the department of microbiology laboratory, University of Maiduguri and blended with 95% conventional diesel for the research purpose.

2.1.1 High heating value.

The Bomb Calorimeter (Parr Instrument Co., Moline, Illinois, Model 6100, Bomb Calorimeter) was used to ascertain the samples' high heating value (HHV). Using the procedure outlined by Candice *et al.*, (2020), the Bomb calorimeter was calibrated by burning a known mass, m, of standard benzoic acid, which has a known heat of combustion of 26.45 kJ/g. An oxygen bomb calorimeter was used to determine the gross heat of combustion in accordance with ASTM D2382-88 standards. One milliliter of deionized water and a sample weighing roughly 0.1 grams were added to the calibrated adiabatic bomb calorimeter. The two electrodes in the pressure vessel (bomb) were linked to a Chromel (chromium nickel alloy) wire, which was then brought into contact with the sample to ignite it. The bomb was then put together, sealed, and pressurized twice with pure (99.99%) oxygen to 0.5 MPa before being vented. For the test, it was then pressurized to 2.0 MPa with pure oxygen and placed in a bath with 2 liters of water in an insulated jacket. A motorized stirrer was placed inside the water bath to circulate the water around the bomb creating a uniform temperature. The sample was then ignited by passing an electric current through the Chromel (chromium nickel alloy) wire causing the sample to burn to completion in the high pressure oxygen. The bomb and the bucket were then held in a calorimeter jacket and serves as a thermal shield. The parameters were observed to be in accordance with the standard value (Table 1).

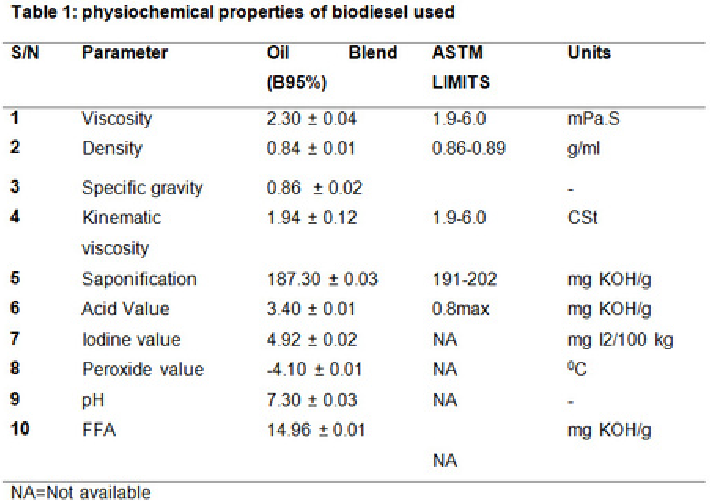

Table 1: physiochemical properties of biodiesel used

S/N	Parameter	Oil Blend (B95%)	ASTM LIMITS	Units
1	Viscosity	2.30 ± 0.04	1.9-6.0	mPa.S
2	Density	0.84 ± 0.01	0.86-0.89	g/ml
3	Specific gravity	0.86 ± 0.02		-
4	Kinematic viscosity	1.94 ± 0.12	1.9-6.0	CSt
5	Saponification	187.30 ± 0.03	191-202	mg KOH/g
6	Acid Value	3.40 ± 0.01	0.8max	mg KOH/g
7	Iodine value	4.92 ± 0.02	NA	mg I2/100 kg
8	Peroxide value	-4.10 ± 0.01	NA	⁰C
9	pH	7.30 ± 0.03	NA	-
10	FFA	14.96 ± 0.01	NA	mg KOH/g

NA=Not available

2.1.2 Determination of refractive index

This determination was made using an Abbe Refractometer (RFT-A2). A drop of the sample was placed on the refractometer glass slide. To maintain a constant temperature on the glass slide, water at 30°C was circulated around it. The dark area visible through the refractometer eyepiece was modified to be parallel to the cross' junction. The scale's indicator pointed to the refractive index with no parallax error. Repeating this, the mean value was noted and used to calculate the refractive index.

2.1.3 Cloud point and pour point

A test tube was filled with the sample to a specific level, and a thermometer was then placed and sealed alongside with the test tube. The sample was then put into the apparatus and examined at regular intervals. The cloud point is the temperature at which a few specks of a cloudy suspension emerge in the test tube and the pour point is the temperature at which the sample starts to flow were documented.

2.1.4 Engine tests and gas emission analysis

A six-cylinder, 206 kW Honda diesel engine with a maximum output of 455.5 kW that was integrated with a Froude hydraulic dynamometer was used for the engine tests. A thermocouple, load cells, a tachometer, a Froude hydraulic dynamometer, and a calibrated tank with an accuracy of 0.5 were all installed as instruments on the engine. Fuel consumption was also measured using this tank. The volumetric measuring approach was used to calculate the fuel consumption as a measure of flow rate (mass per unit time). Different engine torques were measured by the flow of water into the dynamometer and then read off the instrumentation board. To ensure a controlled water flow into the dyno and manage the well-balanced torque required for the engine, preliminary tests were conducted. Following the engine test, the torque was converted into the corresponding speed, fuel consumption (FC), brake power (BP), brake specific energy consumption (BSEC), fuel equivalent power (FEP), and brake thermal efficiency (BTE). Equations, (1), (2), (3), (4), (5), and (6) were used to calculate the fuel consumption rate, equivalent power, braking power, brake specific fuel consumption, and brake thermal efficiency. After an oil blend of B95% (biodiesel 95% and conventional diesel 5%), the engine performance was assessed.

$$\mathrm{Mf} = \frac{(\mathrm{m})}{\mathrm{t}} = \frac{\mathrm{V \, x \, P}}{\mathrm{t}} \qquad (1)$$

$$\mathrm{PF} = \mathrm{Hg \, x \, Mf} \qquad (2)$$

$$\mathrm{BP} = \frac{\mathrm{NT}}{14300} \qquad (3)$$

$$\mathrm{BSFC} = \frac{\mathrm{Mf}}{\mathrm{BP}} \qquad (4)$$

$$\mathrm{BSEC} = \mathrm{BSFC \, x \, Hg} \qquad (5)$$

$$\mathrm{nbth} = \frac{\mathrm{BP}}{\mathrm{Mf \, x \, Hg}} \, \mathrm{x} \, 100 \qquad (6)$$

Where:
Mf = fuel consumption rate (kg/s)
V = volume of fuel used per time (m3)
ρ = density of fuel (kg/m3)
t = time taken (s)
Pf = fuel equivalent power (W)
Hg = heating value (MJ/kg)
BP = brake power (kW)
N = speed (rpm)
T = torque (N m)
BSFC = brake specific fuel consumption (kg/kWh)
BSEC = brake specific energy consumption (kJ/kWh)
ηbth = brake thermal efficiency (%)

3.0 RESULTS

3.1 Energy characteristics

The Table 2 below shows the average values of energy characteristics of oil blend. The flash point value is 119.6°C, cloud point -4.1°C and pour point is -8.3°C and refractive index is 1.562 presented in the Table 2 below.

Table 2 Energy characteristics

S/N	Parameter	Oil	ASTM LIMIT	Units
1	Flash point	119.6	130mim	°C
2	Cloud point	-4.1	-3-(12)	°C
3	Pour point	-8.3	-15-10	°C
4	Refractive index	1.562	NA	-

NA= Not available

3.2 Energy emission properties

The energy emission properties were determine by the number and percentages of gases emitted after the engine load and the result are presented in Table 3. The results showed that O_2 has 0.30%, CO 15%, CO_2 12.8, NO 3.1%, NO_2 13.7%, NOx 16.2, SO_2 20%, CH_4 3%, H_2S 0.7 and pressure is -0.02% are shown in Table 3.

Table 3 Emission properties (chemical composition of gas)

S/N	Gas	Al Co (%)
1	O_2	0.30
2	CO	15
3	EFF	-
4	CO_2	12.8
5	NO	3.1
6	NO_2	13.7
7	NOX	16.2
8	SO_2	20
9	CH_4	3.0
10	H_2S	0.7
11	PRESSURE	-0.02
12	LEL	Bal

3.3 Engine Performance

Different types of parameters were carried out to determine the engine performance and the result obtained after the engine load were identified on the Table 4 below after oil blend (B95%).

Table 4 Engine performance properties of the biodiesel

S/N	Parameters	OIL Blend (B95%)
1	Heating Value (Hg)	30.1457
2	BP	0.004473566
3	BSFC	0.003126524
4	BSEC	0.094251253
5	BTE	10.60993849

BSEC: Brake specific energy consumption
BSFC: Brake specific fuel consumption
BTE: Brake thermal efficiency
BP: Brake power

4.0 Discussion

Pour point represent the lowest temperature at which oil is capable of flowing under gravity. One of the crucial low temperature properties of high boiling fractions is this. It was determined that biodiesel pour point in this study complied with the biodiesel specification set out in ASTM D6751. Similar trend was reported by Singh *et al.* (2019). The cloud point is defined as the temperature at which a cloud or haze of wax crystal appear at the bottom of a test jar when chilled under a prescribe condition. The value of cloud point in this study is lower than the value reported from Bashir *et al.* (2019) (20C). However, similar value was reported by Dawit *et al.* (2019).

Combustion of conventional fuel diesel result to approximately 60% of greenhouse gas emission (CO_2) along with other pollutant such as CO, NOX, HC and smoke (Zhang *et al.*, 2022). The energy emission characteristics as indicated above in Table 3 show that O_2 with the value of 0.30%, CO 12.8%, NO 3.1%, $NO_2$13.7%, NOX 16.2%, $SO_2$20%, $CH_4$3.0%, H_2S 0.7% and pressure -0.02% respectively. The carbon monoxide (CO) value in this research indicate that biodiesel blend have less CO emission compared to fuel. Specifically, if CO_2 emissions increase, then CO emissions will naturally decrease. Since biodiesel has 11–13% oxygen content compared to diesel, CO emissions will be reversed (Zhang *et al.*, 2022).

The amount of CO emissions is mostly influenced by the temperature of the engine and is a by-product of carbondioxide combustion. Although the carbon present in any fuel will often be converted to CO_2, the engines limited oxygen intake during combustion results in incomplete combustion. The usage of biodiesel blends results in a decrease in CO emissions, which may be attributable to biodiesel that has been oxygen-enhanced, which encourages the oxidation of CO during the engine exhaust process.

This supports the claims made by Jamshaid *et al.* (2022) and Sathyamurthy *et al.* (2021), who confirmed that utilizing various biodiesel blend ratios reduced CO_2 emissions. However, using a 5% biodiesel blend (B5), the CO emission in this study is reported to be 12.8%. Similar trend (11.38%) was reported by Sayyed *et al* (2022) compared to conventional diesel.

At all load circumstances, biodiesel is found to have higher NOx levels than petroleum diesel. According to Lozhkina and Lozhkina (2016), this is primarily caused by the presence of nitrogen oxide (NO), nitrate (NO_2), carbon monoxide (CO), and sulfur dioxide (SO_2), which are the main components of exhaust gas. The result in this research as indicated above in Table 3 show that NOx has the value of 16.2% which will be affected by different features such as operating points, resident time, combustion chamber, oxygen concentration, combustion temperature as well as fuel system design. Sayyed *et al.* (2022), also reported similar result of 16.56% of NOx which has a higher value compared to conventional diesel as a result of having more oxygen content in biodiesel blend.

In order to meet the requirements and make sure that the alternative energy (biodiesel) won't cause diesel engines to knock, the alternative fuel used in diesel engines often evaluates the engine performance. In order to understand the effect of biodiesel on engine performance, the brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), brake power (BP), and heating value were measure at full load and constant engine speed of 1901 rpm. As indicated in Table 4, the BSFC has the value of 0.003126524Kg/kWh, BTE is 10.60993849%, BP 0.004473566kW, BSEC 0.094251253KJ/Kw-h, and heating value of 30.1457MJ/Kg respectively. Generally, brake thermal efficiency, brake specific energy consumption and exhaust gas temperature determine the working conditions of diesel engine (Zhang *et al.*, 2022).

The quantity of fuel burned per engine power produced is known as brake specific fuel consumption, or BSFC. BSFC is a significant metric because it turns the energy that is supplied into a useful output. For different biodiesel fuels, there is general trend followed by decrease in Brake Specific Fuel Consumption (BSFC) with the increase in engine speed and Brake Power. The efficiency of the engine's conversion to mechanical energy production increases with decreasing value (Yesilyurt and Aydin, 2022). Due to its lower calorific value, biodiesel generally requires more fuel to be pumped into the cylinder in order to produce the same quantity of energy. Therefore, in this research the result (0.003126524Kg/kw-h) shows a significant reduction in BSFC value, this might be as the result of using biodiesel blend of B95% (biodiesel 95% and conventional diesel 5%), lower viscosity and lower density as indicated in Table 4. Viswanathan *et al.* (2021), also observed reduction in BSFC value of biodiesel blend (B50: 50% biodiesel and 50% petroleum diesel) due to low kinematic viscosity and a higher calorific value of the biodiesel blend.

The BTE in this research is said to be 10.60% as indicated in the Table 4 above, this is because of the reduction in heating value, viscosity and density. Similar findings were reported by ztürk *et al.* (2020), who noted a decrease in BTE in a four-stroke single-cylinder diesel engine utilizing a rapeseed biodiesel blend as a result of the biodiesel's lower heating value, viscosity, density, and higher surface tension. However, retardation of injection timing has no effect on BTE. How *et al.* (2014) used a four-stroke, four-cylinder, high-pressure common-rail turbocharged diesel engine at a constant speed of 2000 rpm and five different engine loads to examine the BTE of coconut biodiesel. The results showed that BTE was lower at all loads due to the lower heating value of coconut biodiesel.

4.0 Conclusion

Biodiesel blended fuels can significantly reduce the emissions of harmful pollutants other than NOx and CO2. Blended biodiesel also improves performance of engine where brake thermal heat (BTE) and brake specific fuel consumption (BSFC) values are reduced significantly.

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