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Original Research Article

Investigation of Exhaust Emissions Characteristics of Diesel Engine Fueled with Biodiesel Produced from African Breadfruit Oil and its Blend

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ABSTRACT

Exhaust emissions are the major challenges of diesel engines and are significant environmental pollutants. This study investigates the exhaust emission characteristics of a diesel engine fueled with three types of fuel; biodiesel (B100), biodiesel blend of 50 % pure biodiesel (produced from African Breadfruit oil) and 50 % petroleum diesel (B50) and petroleum diesel (PD). The study compared the exhaust emissions characteristics such has oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2) and nitrogen oxide (NO_x) using Kigas 100 exhaust gas analyzer. The results show that B100 (0.01 ppm) and B50 (0.01 ppm) displayed lower CO emission compared to PD (0.02 ppm). CO_2 emissions for B100 (1.66 ppm) and B50 (1.9 ppm) were lower than that of PD (2.1 ppm). NO_x emission shows that B100 (400 ppm) was higher than B50 (390 ppm) and PD (328 ppm). Based on this study it is concluded that the biodiesel was an environmentally friendly, less harmful and alternative fuel for diesel engine compared to PD. However, the petroleum diesel produced lesser NO_x emission compared B100 and B50 which is one of the major challenges of diesel engine designers.

1. INTRODUCTION

Fossil fuel is one of the major sources of air pollutions that have impacted adversely on human health. Developing countries (like Nigeria) depend heavily on fossil fuel in their day to day activities such as, transportation, industrial processes, manufacturing, energy (electricity) generation (Simonyan and Fasina, 2013). In the last two decades, the need to reduce dependence on petroleum products has suddenly increases around the world, creating opportunities for researches that focused on finding new alternative renewable energy sources and ways of improving existing ones (Patel et al., 2019). The search for alternative fuels for both compression ignition and sparks ignition engines has become inevitable because of increasing environmental concern globally (Azad et al., 2019).

Nigeria is highly endowed with many renewable energy sources and has commenced policies aimed at re-directing the nation's major energy sources from the finite crude oil to renewable sources (FGNPB, 2008). One of the best alternatives to fossil fuels is biodiesel derived from vegetable oils and animal fat.

Biodiesel has comparative advantage over petroleum diesel as it can produce 4.5 units of energy for every unit of fossil energy while it also possesses environmental-friendly properties like non-toxicity and biodegradability (NBB, 2008; Pradhan et al., 2009). Biodiesel is also a clean-burning and stable fuel. Properties of biodiesel such as oxygen content, cetane number, viscosity, density and heat value are greatly dependent on the source of biodiesel (USEPA, 2002).

Biodiesel is used by blending with petroleum diesel. Biodiesel can also be used in its pure form, but the engine configuration must be altered (Kalam and Mohammad, 2018). The engine performance and emissions characteristics depend on the properties of biodiesels. Biodiesel is a highly oxygenated fuel that can improve combustion efficiency and can reduce unburnt hydrocarbons (HCs), carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxide(NO_x) and polycyclic aromatic HC emissions (Lin et al., 2006). The focus of researchers on biodiesel fuels in many countries is driven by the need to reduce the greenhouse gas emissions (Azad et al., 2019). The emission of the engine fueled with biodiesel can be checked or predicted by undertaking tests with a specific engine or creating a simulation model (Patel et al., 2019).

African breadfruit (*Treculia africana*) is one of naturally nutritive species that belongs to the mulberry family Moraceae and the seed contains edible fruit with high nutritional value (Ajiwe et al., 1995). In Nigeria, African breadfruit is commonly grown in the southern tropical and sub-tropical region of the country (Hatchinson, 1973). The seeds have been reported to contain about 14-17.5 % crude protein, 35-60 % carbohydrate, 2.5 % crude fiber, 18.42 % of oil, and unsaturated fatty acids which compares well with those of melon, soybean and groundnut oil (Ejiofor and Okafor, 1997).

The focus of this research was to investigate the emissions characteristic of the biodiesel and biodiesel blend produced from African breadfruit oil.

2. MATERIALS AND METHODS

2.1. Material collection and Sample Preparation

Fresh African breadfruit nut was purchased from Imeko Afon, a town in Ogun State, southwest, Nigeria. The brown-colored nuts were dehusked and allowed to dry under the sun for three days. The dried seeds were then ground into powder using mechanical grinding machine (Adogbeji et al., 2019). All reagents used in this work were of analytical grade and were obtained from Universal venture Ltd, Ibadan, Oyo State.

2.2. Extraction African Breadfruit Seed Oil

Extraction was done using a Soxhlet extractor in the presence of n-hexane. The crushed nuts (50 g) were placed in the extractor unit and were heated at a temperature 70 °C. After extraction, the remaining n-hexane was removed from the oil by evaporation at about 105 °C (Ajiwe et al., 1995). The percentage yield of oil extracted was determined using Equation (1).

$$\text{Oil yield (\%)} = \frac{\text{Weight of oil extracted}}{\text{Weight of seed}} \times 100 \quad (1)$$

The oil was filtered to remove unwanted particles, then heated to 120 °C to dehydrate the oil. Finally, the pretreated oil was stored in the 500 ml conical flask sealed with aluminum foil (Adogbeji et al., 2019).

2.3. Production of Biodiesel

Acid-catalysed (sulfuric acid) and based-catalyzed (potassium hydroxide) transesterification process were conducted to produce the biodiesel. The preheated oil was poured into 2000 cm^3 round bottom flask containing ethanol and then the mixture was stirred and dissolved by continuous mixing and heating for two hours for transesterification. After two hours, the mixture was left to settle in a separating funnel for about two hours. Two layers were found in which upper layer was for ethanol-water fraction and the bottom layer for the ethyl ester (Demirbas, 2005). The lower layer, which contained impurities and glycerol was drawn off. The upper layer of ethyl esters was washed with waterless magnesium silicate (waterless separation) (Adogbeji et al., 2019). Finally, the biodiesel obtained was heated at a temperature of 130 ºC for the ethanol to evaporate. The biodiesel yield was obtained using the Equation (2).

$$\text{Biodiesel yield (\%)} = \frac{\text{Amount of biodiesel obtained (ml)}}{\text{Amount of oil used (ml)}} \times 100 \quad (2)$$

2.4. Biodiesel Blending

Pure biodiesel was denoted as B100. The blending percentage of B50 was 50 % by volume of petroleum diesel and 50 % by volume of B100. The resulting mixture B50 was stored in a conical flask and sealed with aluminum foil (Adogbeji et al., 2019).

2.5. Diesel Engine Test

Diesel engine test was conducted using stationary single-cylinder diesel engine (Adogbeji et al., 2019). However, the full load condition at 3000 rpm was chosen because at this point, minimum air-fuel ratio is achieved with maximum smoke emission. This condition provides more significant differences when comparing different fuels at similar test condition. All engine specifications are listed in Table 1. Exhaust emissions such as carbon dioxide (CO_2), oxides of nitrogen (NO_X), carbon monoxide (CO) and Oxygen (O_2) were measured in parts per million (ppm) using Kigas 100 exhaust gas analyzer which monitor toxic gases of the exhaust.

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Table 1: Engine specification (Adogbeji et al., 2019)

Specification	Value
Model	R175 A
Bore	75 mm
Stroke/Crank radius	80 mm /41 mm
Absolute maximum power	4.41 kw /3000 /rev/min
Continuous rated power	3.9 kw /3000 /rev/min
Compression ratio	21~23:1
Engine capacity	232 cm^3 (0.232 L)
Piston mean speed	6.93 m/s
Injection timing	22°+/- 2°
Fuel nozzle	Pintle type
Lubrication method	Pressure and splash lubrication
Direction of flywheel	Counterclockwise (view from flywheel end)
Fuel tank capacity	4 L
Cooling water capacity	About 6 L
Lubrication oil capacity	About 2 L
Governor type	Mechanical, all speed and centrifugal
Net weight	60 kg
Co-efficient of discharge for orifice (C_d)	0.185
Engine stroke (cycle)	Single cylinder (4 Stroke)
Fuel type	Diesel
Overall dimensions	589 × 341.5 × 463 mm (L×W×H)

3. RESULTS AND DISCUSSION

The results of the emissions of the biodiesel (B100), biodiesel blend (B50) and petroleum diesel (PD) tested in this study were compared. A total of six experimental trials were conducted, and the mean values were used for the comparison of the exhaust emissions gases.

Oxygen plays an important role in combustion of biodiesel, the oxygen content of biodiesel ranges between 10 wt % to 12 wt %. Figure 1 shows that the oxygen emission content for B100 is 19.05 ppm, while that of B50 was 18. 53 ppm and that of PD was 18.69 ppm. The results show that the B100 emitted more oxygen than both B50 and PD.

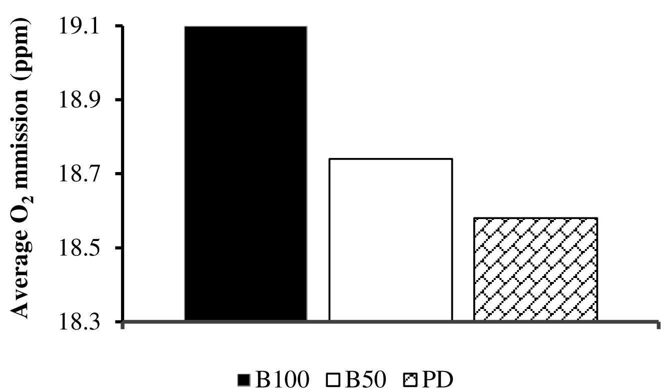

Figure 1: Comparison of oxygen emissions

The value of O_2 for B100 is 36 % and 55 % above that of B50 and PD respectively. This could be attributed to the biodiesel having more oxygen content than the petroleum diesel which can results to more complete combustion process (McCarthy et al., 2011; Azad et al., 2017; Patel et al., 2019). Although some of the literature highlighted the importance of oxygen content in biodiesel fuel but without any direct evidence of results on its effect (Jibanananda and Bhubaneswars, 2017).

It was reported that incomplete combustion of the fuel in the combustion chamber coupled with fuel oxidation can produce carbon monoxide (CO), a colourless and odorless gas which could cause severe health issues if inhaled (IIkilic, 2009). Figure 2 shows the carbon monoxide emissions for B100, B50 and PD. B100 and B50 displayed lower CO emissions when compared to PD. The lower CO emissions for B100 and B50 could be attributed to the fact that biodiesel is more oxygenated than petroleum diesel and have less carbon content both in B100 and B50. This agrees with the report of USEPA, (2002) where it reported 51 % lower CO emissions for biodiesel. This observation could also be attributed to the fact that biodiesels are known to break down oil and water up to four times faster than petroleum diesel (Peterson and Moller 2004). This result in a complete combustion, leading to less CO emission in the exhaust stream. This result is also in consonant with the findings of other researchers (Bhuiya et al., 2014; Ming et al., 2018).

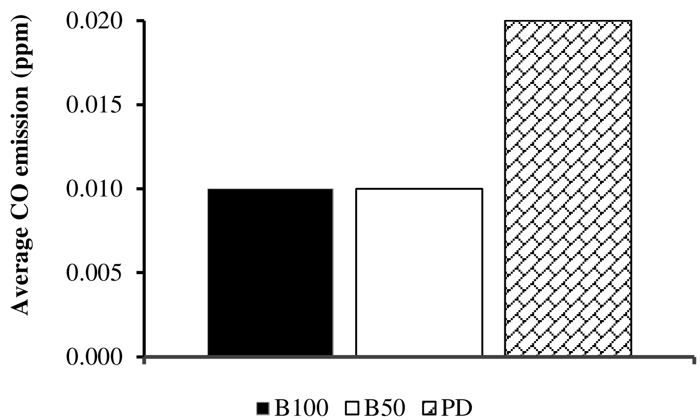

Figure 2: Comparison of carbon monoxide emissions

The level of carbon dioxide emissions in exhausts emission from a diesel engine operating at stoichiometric conditions range from 1.0 % to 10.0 % (v/v) using coffee residue as feedstock for the biodiesel (Patrakhatsev et al., 1994; Coronad et al., 2009). The CO_2 emission is delivered by any consumption of non-renewable energy sources and biofuels. The burning of biofuels likewise delivers CO_2 lower than fossil fuel (Patel et al., 2019). It can be observed from Figure 3 that the biodiesel emits less CO_2 emissions compared to petroleum diesel. The CO_2 emissions for the biodiesel B100 and B50 were significantly lower than that of PD. This could be due to the higher oxygen content of the biodiesel which help during combustion process. However, the PD having highest CO_2 emissions is attributed to the higher temperature at combustion. Carbon bonds are broken down and new bonds with oxygen atoms are formed which releases more CO_2 emissions and water (McCarthy et al., 2011; Wei et al., 2018). Biodiesel blend up to B20 reduces well-to-wheel emissions of CO_2 approximately 16 % compared to petroleum diesel (USEPA, 2002).

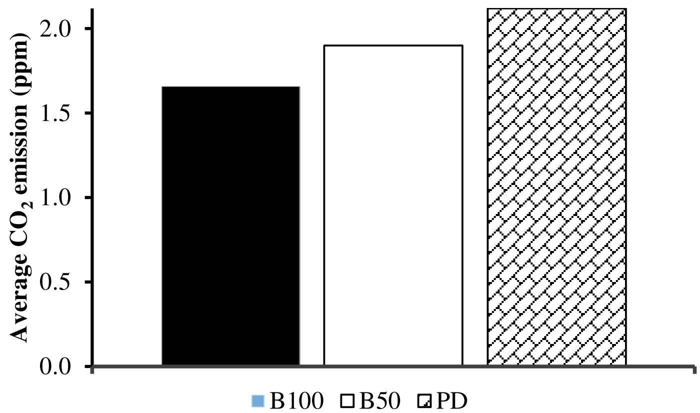

Figure 3: Comparison of carbon dioxide emission

Nitrogen oxides emission (NO_x) is usually formed in large quantities during engine operation and probably the biggest challenge for designers of diesel engines is reducing NO_x emissions (USEPA 2002). NO_x emission in the diesel engine combustion system, excess oxygen, residence time length and the higher temperature (>1300 ºC) can increase or enhance the formation of nitrous oxide (N_2O), as well as nitrogen dioxide (NO_2), which are frequently identified as NO_x in the combustion chemistry (Andric et al., 2019). The high combustion temperatures in diesel engine favor NO_x formation. Figure 4 indicate that B100 emits more NO_x emission due to increased availability of oxygen. The B50 reduces the NO_x emission by reducing the oxygen content in the combustion chamber as well as in the exhaust stream. The PD emitted the least amount of NO_x emission. That of B100 was higher by 10 % compared to B50 and by 70 % compared to PD. The obtained results were compared with previous results of other authors (McCarthy et al., 2011; Azad et al., 2016; Andric et al., 2019; Patel et al., 2019). This comparison showed accepted conformity.

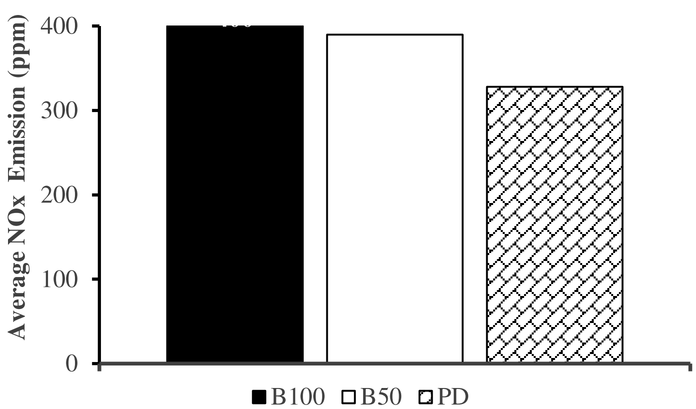

Figure 4: Comparison of nitrogen oxides emissions

4. CONCLUSION

The emission characterization of the biodiesel produced from African breadfruit oil and its blend show that the O_2 content of the emission for B100 and B50 was higher compared to PD. The biodiesel and its blend also produced lower carbon emissions compared to the petroleum diesel. This shows that the biodiesel is an environmentally friendly, less harmful and alternative fuel for diesel engine compared to PD. However, the petroleum diesel produced lesser NO_x emission compared pure biodiesel and biodiesel blend which is one of the major challenges of diesel engine designers. The obtained results were compared with previous results of other authors. This comparison showed accepted conformity. Nevertheless, further research could be done to investigate the percentage of the biodiesel bend and emission characteristic at different operating condition of the engine.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest with this work.

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