Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

RJEES

Original Research Article

Performance Evaluation of Diesel Engine Fueled with Biodiesels (B100 and B50) Produced from African Breadfruit (*Treculia africana*) Oil

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ARTICLE INFORMATION

Article history:
Received 29 Aug, 2019
Revised 07 Dec, 2019
Accepted 21 Dec, 2019
Available online 30 Dec, 2019

Keywords:
Biodiesel
African breadfruit oil
Engine performance
Renewable energy
Petroleum diesel

ABSTRACT

This work investigates the performance characteristic of single-cylinder diesel engines running on biodiesel produced from African breadfruit oil. The extraction, production, and physicochemical analysis were carried out on B100 (100% biodiesel) and B50 (50% petroleum diesel mixed with 50% biodiesel). The effect of speed on thermal efficiency, air-fuel ratio, engine power, fuel consumption, and exhaust temperature were evaluated for B50, B100 and PD. The results showed that at low speed, the thermal efficiency for B50 (33.8 %), B100 (14.95 %) compared to PD (17.8 %), then at peak 3000 rpm B50 (30.56 %), B100 (27.43 %) compared to PD (30.56 %). The engine power produced for B100 (278 watts), B50 (900 watts) compared to PD (294 watts) at low speed, while at peak B100 (1684 watts), B50 (2184 watts) compared to PD (1730 watts) and the fuel consumption at low speed for B100 (0.069 $kg.kwh^{-1}$), B50 (0.038 $kg.kwh^{-1}$) compared to PD (0.610 $kg.kwh^{-1}$) while at peak for B100 (0.032 $kg.kwh^{-1}$), B50 (0.036 $kg.kwh^{-1}$) compared to PD (0.204 $kg.kwh^{-1}$). The samples have similar performance in terms of thermal efficiency, specific fuel consumption and other tested parameters with slight differences for B100 and B50 compared to petroleum diesel.

2. INTRODUCTION

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, 1995). In Nigeria, African breadfruit is commonly grown in the southern tropical and sub-tropical (Hatchinson, 1973). The seeds contain about 14-17.5 % crude protein, 35-60 % carbohydrate, 2.5 % crude fiber and unsaturated fatty acids which compares well with those of melon-seeds, soybean and groundnut oil (Ejiofor and Okafor,1997).

Nigeria is 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). The use of biofuels is expected to make significant impact by reducing the nation's dependence on imported gasoline, reduce environmental pollution, create a viable industry and produce sustainable domestic jobs. Energy is the source of life and there is abundant supply of energy on earth. Thus, renewable energy must be sourced and developed as an alternative to fossil fuel to further enhance economic activities (Sari, 2006). The desire to move away from fossil fuels has created an interest in alternatives because reliance on imported petroleum and fluctuating prices is creating apprehension among users. Moreover, renewable energy source does not contribute to environmental pollution. The burning of fossil fuels produces emissions which contain carbon dioxide (CO_2) and oxide of Sulphur. This emission causes greenhouse effect, global warming and increased air pollution (Sari, 2006).

There are on-going researches in renewable energy sources such as solar, wind and hydro-power and most importantly biofuel (Meher *et al.,* 2004). Among the biofuel, biodiesel is at the forefront because of its environmental credentials such as renewability, biodegradability and clean combustion behavior (Hanna, 1999). Biodiesel has gained increasing support as an alternative to fossil diesel due to its non-toxicity, closed carbon cycle and lack of sulfur and aromatics. Moreover, its use will shift total dependence on fossil fuels and help save expenditure on petroleum for nations that rely on petroleum for their energy needs (Tickell, 2003). Therefore, the aim of this study is to assess the engineering characteristic of biodiesel produces 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. 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 ^oC. After extraction, the remaining n-hexane was removed from the oil by evaporation at about 105 ^oC (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 (Saiful et al., 2014).

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 heated continuously for two hours for transesterification. There were two methods of heating, namely, direct heating and reflux heating. After two hours, the mixture was left to settle in the separatory funnel for about two hours. Then, two layers were found in which upper layer was for ethanol-water fraction and the bottom layer for the ethyl ester (Demibras, 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). Finally, the biodiesel obtained was heated at a temperature of 130 ^{o}C 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.

2.5. Diesel Engine Test

Experiments was conducted with petroleum diesel, B100 and B50 blends with a test engine which is a stationary single-cylinder diesel engine. The engine was coupled with a dynamometer for applying loads while the fuel pump rack position was adjusted to maintain a constant speed. All other engine specifications are listed in Table 1 and the arrangement of the engine set is shown in Figure 1. The engine was tested at 100 % throttle. It was also loaded at six-speed in the range of 2000 – 3000 rpm with 200 rpm period.

Table 1: Engine specifications

Make	Specification
Model	R175A
Bore	75 mm
Stroke/crank radius	80 mm/41 mm
Absolute maximum power	4.41 kW/3000 r/min.
Continuous rated power	3.9 kW/3000 r/min.
Compression ratio	21~23:1
Engine Capacity	232 cm^3 (0.232 L) or 232 cc
Piston mean speed	6.93 m/s
Injection timing	22°+/- 2°
Fuel nozzle	Pintle type
Lubrication method	Pressure and splash lubrication
Direction of flywheel	Counter Clockwise (view from
Fuel tank capacity	4 L
Cooling water capacity	About 6 L
Lubrication oil capacity	About 2 L
Governor type	Mechanical, all speed and
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 ×

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4(2) 2019 pp. 1006-1014

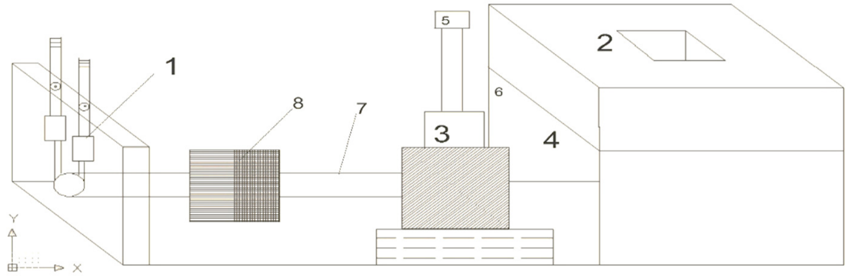

Figure 1: Schematic diagram of the engine test bed

(1) Dynamometer (2) Fuel tank (3) Water cool Engine (4) Thermocouple (5) Exhaust gas analyzer (6) Fuel measuring device (7) Shaft (8) Coupling

2.6. Basic Performance Characteristics

The following sections present the basic performance characteristics evaluated and determined for petroleum diesel (PD), B100 and B50 using the engine test bed shown in Figure 1.

2.6.1. Determination of thermal efficiency

This is the ratio of the heat of combustion from fuel against the useful mechanical power developed by the engine (Eduardo, 2016). Thermal efficiency was obtained using Equation (3).

$$\eta_{th}=\frac{Mechanical\ power}{H_f}\times 100 \tag{3}$$

Where H_f is the heat of combustion and the mechanical power (P) is given as P = 2πNT and N is revolution per second, T is in torque (N/m).

2.6.2. Determination of brake power (kW)

The break power (bp), is the output power measured at the crankshaft. The break power is always less than the indicated power because of frictional losses (Ujjwa, 2014). The break power was calculated from Equation (4).

$$\text{bp}=\frac{(\text{bmep})\text{LAnK}}{60\times1000} \tag{4}$$

Brake power (bp) obtained at the output shaft can also be related as:

$$\text{bp}=\frac{2\pi\text{NT}}{60\times1000} \tag{5}$$

Where bp is the break power (kW), L is length of stroke (M), A is the cross-sectional area of piston (M^2), n is the number of power stroke, k is the number of cylinders, N is the crankshaft speed (revolution per minute) and T is the engine Torque (Nm).

2.6.3. Determination of air-fuel ratio

Air-fuel ratio is the ratio of air to fuel present in a combustion process. The air-fuel ratio was obtained using Equation (6).

$$\text{Air fuel} = \frac{\text{Air mass flow Rate}(kgs^{-1})}{1000 \times \text{Fuel Consumption}(kgs^{-1})} \quad (6)$$

2.6.4. Determination of specific fuel consumption (SFC*)*

The mass flow rate of fuel required to produce a unit of power or thrust, for example, kg per kW-hr is abbreviated as SFC. It is also known as specific propellant consumption.

Mass fuel flow (in kg/s) = fuel density (kg/m³) x fuel volume flow rate (m³/s). (Eduardo, 2016). Specific fuel calculation was calculated from Equation (7).

$$\text{Specific fuel consumption} = \frac{\text{fuel consumption } (kgs^{-1}) \times 1000}{\text{mechanical power} \times 3600} \quad (7)$$

2.6.5. Determination of heat of combustion

The heat of combustion is the energy released as heat when a compound undergoes complete combustion with oxygen under standard condition (Eduardo, 2016). Heat of combustion was calculated from Equation (8).

$$\text{Heat of combustion}(H_f) = \text{Fuel consumption} \times \text{fuel calorific value} \times 1000000 \quad (8)$$

Where, fuel consumption is (kgs^{-1}), fuel calorific value$(MJkgs^{-1})$.

2.6.6. Determination of fuel consumption

The fuel consumption is the rate at which an engine uses fuel, expressed in units such as miles per gallon or liters per kilometer (Eduardo, 2016). The fuel consumption was determined from Equation (10).

$$\text{Fuel consumption is } (kgs^{-1}) = \frac{\text{Pipette volume (mL)} \times \text{Fuel density } (kgm^{-3})}{\text{Time(S)} \times 1000000} \quad (10)$$

2.6.7. Engine torque

It is the force of rotation acting about the crankshaft axis at any given instant of time (Eduardo, 2016). It was determined by Equation (11).

$$T = F \times R \quad (11)$$

Where, T is the engine torque (Nm), F is the force applied to crank (N), and R is the effective crank radius (m).

3. RESULTS AND DISCUSSION

The diesel engine tests results are presented in Figures 2 to 6. The tests were carried out for the B100, B50 and PD. The performances tests were conducted for a range of 2000 rpm to 3000 rpm and the engine characteristics compared with petroleum diesel operations. The effect of speed on thermal efficiency is determined whether the heat during the combustion process is effectively converted to network output. In Figure 2, the variation of thermal efficiency for the mixtures used is presented. For a low speed, when using B50 the thermal efficiency is higher than the other B100 and PD. However, the thermal efficiency of B50 dropped steadily from 33.8 % at the rate of 2400 rpm to 30.20 % at 2600 rpm. When the speed increased to 2800 rpm, the thermal efficiency of the B50 improved to 37.4 % and suddenly drop to 30.56 % at the peak of the speed at 3000 rpm. On the other hand, the PD increases gradually from 17.8 % at 2200 rpm to 27.9 % at 2600 rpm, this continued to increase gradually to 30.56 % at the peak speed of 3000 rpm. The B100 increase steadily from 14.95 % to 23.39 % at 2600 rpm and the maximum thermal efficiency of the B100 at the peak is 27.43 %. From these results, it can be inferred that for low and medium speed, B50 is a better alternative but for higher speed requirements the PD is the best option. The results were similar to findings in Eduardo (2006), where four-stroke diesel engines were used and biodiesel and different biodiesel-diesel mixtures was analyzed. The results showed that all the mixtures B10, B30 and B50 experienced a rise in thermal efficiency when the speed was increased from a low value, but the bio mixtures dropped earlier than diesel. The higher thermal efficiency obtained for B50 was 42.55 % at 2400 rpm, B30 was 44.19 % at 2545 rpm and B10 was 43.47 % at 2107 rpm. The effect of speed on engine power is shown in Figure 3. While the engine is running at low speed the power developed is similar for the three different mixes used. As the speed increases, the difference between the petroleum diesel and biodiesel mixes become significant. It is observed that the effective engine power of B50 is greater than the B100.

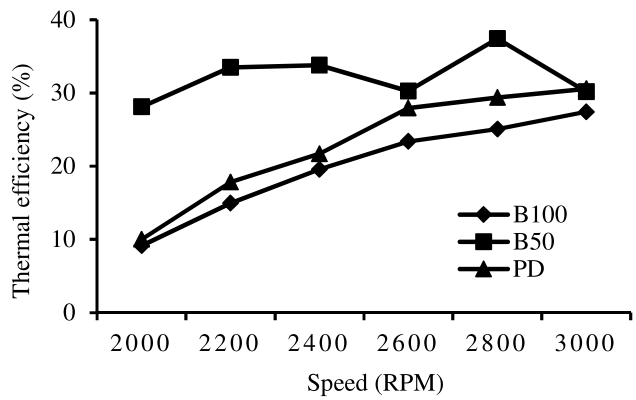

Figure 2: Effect of speed on thermal efficiency (%)

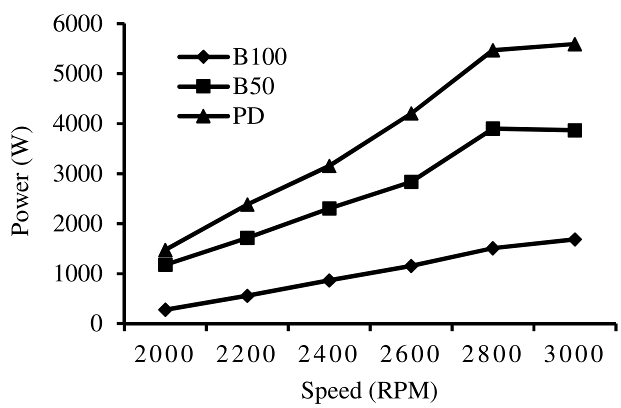

Figure 3: Effect of speed on engine power

The effect of speed on variation of air-fuel ratio between the mixes used is presented in Figure 4. The air-fuel ratio obtained during the test reflects that the biodiesel makes the mixtures “richer” since the values are lower for B100 and B50 at the beginning of the engine performance test. On the other hand, the PD air-fuel ratio is around 10 % higher than 100 % biodiesel for a regular diesel engine performance (2000 rpm). In addition, the air-fuel ratio value decreases gradually with increase in speed since. To increase the speed, it is necessary also to increase the amount of fuel injected for the combustion. However, the B100 tend to increase with about 5 % at 3000 rpm while B50 dropped steadily from 42.2 % at (2600 rpm) to 23.96 % (3000 rpm), an increase in fuel means more air necessary for the mix that will combust in the cylinder.

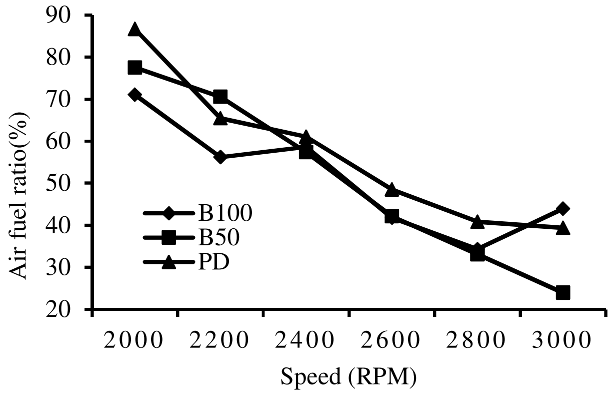

Figure 4: Effect of speed on variation air-fuel ratio

The effect of speed on specific fuel consumption is the ratio of fuel mass flow by effective power and the fuel density. It represents the fuel efficiency with respect to a thrust output for PD, B100, and B50 when changing the speed is as shown in Figure 5. As speed is increased, specific fuel consumption decreased for B100 at 2200 rpm and it reduces steadily and maintains steady rate until around 3000 rpm. The values obtained during the test show that B100 represent a higher fuel consumption and while B50 and PD are similar in fuel consumption with a little different even though as the speed increases the B50 increases in fuel consumption. This fact can be explained by the higher B100 density. The higher density has higher mass injection for the same injection pressure at the same amount of volume. Consequently, the B100 has lower heating value compared to PD. Eduardo (2006) reported that for 2500 rpm, a common performance of engine diesel cars, the specific fuel consumption of B100 is 18 % greater than the value obtained when the engine is running on diesel. This explain why the specific fuel consumption will be higher for B50.

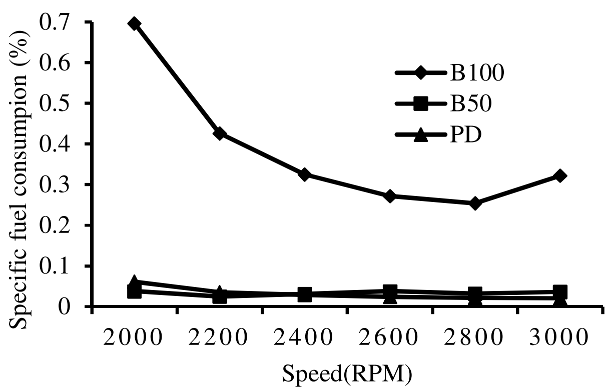

Figure 5: Effect of speed on fuel consumption

The exhaust temperatures for the different mixes of B100, B50, and PD is represented in Figure 6. The highest temperature obtained was reached when the engine was running using B50 while the lowest exhaust temperature was obtained using B100.

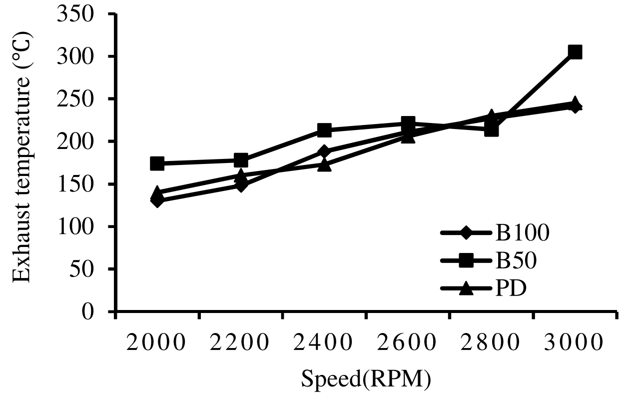

Figure 6: Effect of speed on exhaust temperature

4. CONCLUSION

The performance evaluation of the engineering characterization of biodiesel B100, B50 produced from African breadfruit oil was carried out using the engine testbed, and the data obtained for the biodiesels were compared with PD. They were found to have similar performance in terms of thermal efficiency, specific fuel consumption, engine power, exhaust temperature, and air-fuel ratio at various speeds between 2000 and 3000 rpm. Biodiesel effectiveness is higher when the engine is running at low speed, while its operation at medium and high speeds are good. However, there is a slight difference in air-fuel ratio and specific fuel consumption when petroleum diesel and biodiesel are compared, but this fact is explained by higher calorific value of the petroleum diesel compared to biodiesel and their mix.

5. ACKNOWLEDGMENT

The authors appreciate the TETFUND Research Committee for their effort in making sure that quality research emanates from MAPOLY through TETFUND research funding.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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