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Engine Performance Analysis Using Biodiesel from Giant Palm *as* a Blending Agent

Rasheed Amao Busari*, Adeshina Fadeyibi, Raheef Kehinde Adebayo

Kwara State University Malete, 241103, Nigeria

ABSTRACT

The continuous reliance on petroleum diesel, coupled with growing concerns about environmental degradation, has propelled the exploration of renewable diesel fuel alternatives. This research study delved into the production of giant palm seed oil methyl ester through transesterification, employed potassium hydroxide as a catalyst. This alternative fuel was then tested in a single-cylinder, direct injection diesel engine commonly used in Nigeria's agricultural sector, where the demand for sustainable energy solutions is crucial. Pure vegetable oils encounter operational challenges in diesel engines due to their high viscosity, low calorific value, and polyunsaturated nature. Transesterification emerges as a more effective method to modify these properties. Comparisons between the physicochemical parameters of giant palm seed oil methyl ester and conventional diesel fuel revealed significant differences. The calorific value of the produced biodiesel stood at 38.470 MJ/kg, slightly lower than pure diesel's 42.00 MJ/kg. Additionally, the kinematic viscosity of the biodiesel was measured at 10.9 mm^2/s. The study also scrutinized engine performance using various biodiesel blends and compared them with conventional diesel. The findings demonstrated the viability of using biodiesel derived from giant palm seed oil in compression ignition engines as a practical alternative to diesel fuel. Lower blends, particularly B5 to B25, adhered closely to ASTM standards, signifying their acceptability. However, as biodiesel concentration increased, both break thermal efficiency and fuel consumption experienced an upward trend. The results showed that the use of biodiesel produced from giant palm seed oil in compression ignition engines is a viable alternative to diesel fuel.

Keywords: Biodiesel, brake specific fuel consumption, brake thermal efficiency, giant palm seeds, single cylinder engine

INTRODUCTION

Biodiesel is an important sustainable renewable energy source that can potentially replace petroleum-based diesel and fulfill environmental and energy security needs without sacrificing operational performance or conditions. The fuel exhibits properties and performs similarly to that of a conventional diesel in terms of engine performance and eco-friendly emissions without any modifications to existing engines (McCarthy *et al.* 2011). Non-edible oils are more suitable to be used for biodiesel production. This is because they are not competing with food

*Corresponding author:
Food and Agricultural Engineering Department,
Kwara State University Malete, Nigeria
Email: rasheed.busari@kwasu.edu.ng

materials; moreover, most non-edible oil seeds are grown in the wild and under-utilized, especially in Nigeria. These wild plants do not require any care but simultaneously will provide a good source of income to rural dwellers through the collection of seeds for biodiesel production. More so, the use of biodiesel as a blending agent in diesel fuel has become a global trend, with many countries passing legislation requiring diesel to contain a minimum percentage of biofuels. Biodiesel produced from non-conventional sources such as vegetable oils, fat, palm oil, soybean, coconut, and others offer a viable alternative fuel for diesel engines. These alternative biodiesel fuels are readily available in Nigeria and can be obtained locally in large quantities (Ajie *et al.* 2023). The blending of pure diesel and even low percentages of biodiesel will contribute to the local economy of the nation and reduce poverty levels. However, the performance of biodiesel blends in compression ignition engines is still a subject of research. Several studies have investigated the effect of biodiesel blends on engine performance and emissions. The results have shown that brake-specific fuel consumption and brake thermal efficiency can increase with biodiesel blends but are likely to produce less power with high fuel consumption than diesel due to its lower gross calorific value. Additionally, the high viscosity of biodiesel can cause fuel flow and ignition problems in unmodified compression ignition engines (Ajie *et al.* 2023).

Borassus aethiopum is called different names by the different ethnic groups in Africa and is a popular palm tree in some regions (Waziri *et al.* 2010). It is a typical savanna tree with a density of not less than 20 palms per hectare and is almost absent in other vegetation (Mollet *et al.* 2000). *B. aethiopum* is widely cultivated and used economically in Nigeria and other African countries. The palms are the most numerous trees in the world after coconut (Asante *et al.* 2011). The plant has various uses and contributes significantly to household incomes in the communities where it is found. In areas where the plant exists, harvesting, selling and palm wine taping provides one of the most important annual incomes (Sambo *et al.* 2002).

Almost all the parts of the palm plant are used for various purposes including food, building materials, household items as well as medicinal purposes. The fruits are major source of food, and it is also an income earner for many households through the sale of fans and mats weaved from the leaves. Asante *et al.* (2011) reported that the processing of palm tree products generates food and income for craftsmen and households in villages where the plants are available. The stems can be split into timber and the leaves are used for the construction of houses in local settings. Figure 1 and 2 shown bunches of giant palm fruit on a tree, and giant palm seeds, respectively. Transport sector plays a key role in the socio-economic development of any country. The number of trucks in Nigeria increases tremendously on daily bases, which has further demand for eco-friendly fuels.

As a result, there is a rapid increase in the consumption of fossil fuels and this has contributed to climate change which is considered the most important environmental problem of the present century (Dwivedi *et al.* 2013). According to recent studies, the emission of greenhouse gases has caused an increase in the global mean temperature by approximately 0.8 °C over the past century (Dwivedi *et al.* 2013). This has led to the need for eco-friendly and renewable energy sources such as solar, wind, hydro, and biomass. Renewable energy sources, particularly biomass energy, can reduce Nigeria's dependency on imported petroleum products. Biodiesel, a liquid biofuel, can replace conventional diesel and generate new economic opportunities in rural areas while protecting the environment. In evaluating materials for biodiesel production, it is important to consider their availability, similar properties to conventional diesel, and economic value compared to fossil diesel. Non-edible oils is

Figure 1 Bunches of giant palm fruit on a tree.

Figure 2 A tropical giant palm seeds.

more suitable for biodiesel production as they do not compete with food sources (Lapuerta *et al.* 2008). By utilizing renewable energy sources and biodiesel, we can reduce our carbon footprint and protect the environment while creating new economic opportunities. Most of the seeds of non-edible oils are wasted in the wild. These wild plants do not require any care but simultaneously provide a good source of income for local people through the collection of seeds for oil production (Shojaeefard *et al.* 2013). Giant palm seeds are promising feedstock for biodiesel production and were considered for this research work. Today, oil from giant palm seeds has not been established whether is edible or not, and some researchers have worked on the medicinal part of the seed and fruit. Biodiesel has the following major advantages; it can be blended with diesel fuel at any proportion, can be used in a diesel engine without any modification, does not contain any harmful substances, and produces less harmful emissions to the environment. This research work provides useful information to designers, engineers, industrialists, and researchers who are interested in biodiesel production from vegetable oils. The objective of this study was to determine the suitability of using biodiesel derived from giant palm seed oil and investigate the effect of giant palm biodiesel addition in volume and compared with conventional diesel fuel using a single-cylinder stationary diesel engine.

MATERIALS AND METHODS

Biodiesel Sample Preparation

A wild giant palm seed was collected and dried under ambient temperature, and oil was extracted using a designed roaster expeller. The extracted oil was converted to fuel using an alkaline transesterification process with potassium hydroxide as a catalyst and methanol as a solvent. Two percent catalyst was dissolved in methanol for the experiment, and the mixture was added to the measured giant palm oil. The prepared mixture was then stirred at the required temperature and time. The reactant product was put into a clear container and allowed to settle for nearly 6 hours at room temperature. Glycerin was left on the bottom of the container while methyl ester was on top, and biodiesel was poured into another vessel that had been cleansed and filtered after the mixture had settled. To eliminate liquid remnants, the collected fuel was heated for 10 minutes at 110 °C. After that, the recovered fuel was allowed to cool to ambient temperature. The finished product (biodiesel fuel) was mixed with diesel fuel in the following proportions: 5%, 10%, 15%, 20%, 25%, 50%, and 100%, designated as B5, B10, B15, B20, B25, B50, and B100, respectively. Biodiesel blends were used to test engine performance while the performance indices were used to calculate some of the parameters. Table 1 present fuel properties of giant palm seed oil and giant palm methyl ester (biodiesel) in comparison with mineral diesel.

Experimental Setup for Biodiesel Evaluation

An experimental setup was developed to evaluate an engine's performance using biodiesel from giant palm seed oil. The experiment unit consists of various structural and instrumental panels listed in Table 2. A JUMBO stationary diesel engine, single cylinder, four strokes, vertical and cold starting totally enclosed, water-cooled CI engine was used for experimental investigations. This type of stationary engine is commonly used for farming operations in Nigeria. The engine specifications are shown in Table 3. The engine was coupled to a dynamometer to measure the engine torque. The setup was installed at the Farm Power and Machinery Laboratory, Food and Agricultural Engineering Department, Kwara State University, Malete, Nigeria. Experiments were conducted first with conventional diesel to establish reference parameters and various blends of giant palm biodiesel were used to run the engine for 30 minutes each. The speed of the engine was measured in RPM with a handheld tachometer. The engine fuel tank was disconnected, and the fuel was consumed only from the calibrated burette. An electrical alternator (Table 4) was connected to the engine to vary the engine loads, which contained a load bank. The load bank consists of thirty bulbs of 200 W each, the bulbs were grouped into six with five bulbs in each group, and each group was controlled with a switch. Figure 3 shows the experimental setup used for the performance evaluation of biodiesel blends and load bank.

Table 1 Fuel properties of giant palm seed oil and giant palm biodiesel in comparison with mineral diesel.

Properties	Giant palm seed oil	Giant palm biodiesel	Mineral diesel (Acharya *et al.* 2016)
Density at 20 ºC, (g/cm^3)	960.0	913.6	0.824
Kinematic viscosity (mm^2/s)	23.87	10.90	2.300
Calorific value (kJ/Kg)	35.68	38.47	42.00
Flash point (ºC)	270.0	150.0	53.00
Specific gravity	0.962	0.955	-
Acid value gKOH/g	6.680	4.480	-

Table 2 List of structural and instrumental panels for experimental setup in biodiesel evaluation.

S/N	Items	Requirements
1	Foundation	2, engine and alternator base
2	Lister engine	1
3	Alternator	1
4	Load panel	1
5	Dynamometer	1
6	Tachometer	1
7	Burette (100 mL)	1
8	Giant palm seed oil Biodiesel produced	

Table 3 Engine technical specification panels for experimental setup in biodiesel evaluation.

Item	Technical data
Model	JUMBO stationary diesel engine
Type	Four stroke, vertical and cold starting enclosed
Horsepower	8
Bore (mm) x stroke (mm)	114.3× 139.7
Rotation	Clockwise
Combustion principle	Compression ignition
Cubic capacity (CC)	1432.71
Rated RPM (rpm)	850
Flywheel diameter (mm)	590
Flywheel width (mm)	90
No. of cylinder	One
Method of cooling	Water
Starting	Hand start with a cranking handle
Bearing	Taper roller bearings
Lubrication system	Splash lubrication system

Table 4 Alternator specifications panels for experimental setup in biodiesel evaluation.

S/N	Particular	Specifications
1.	Model	Delmax
2.	Output	7.5 KVA
3.	Volt	230
4.	RPM	1500
5.	Frequency (Hz)	50
6.	Type of cooling	Fan cooled

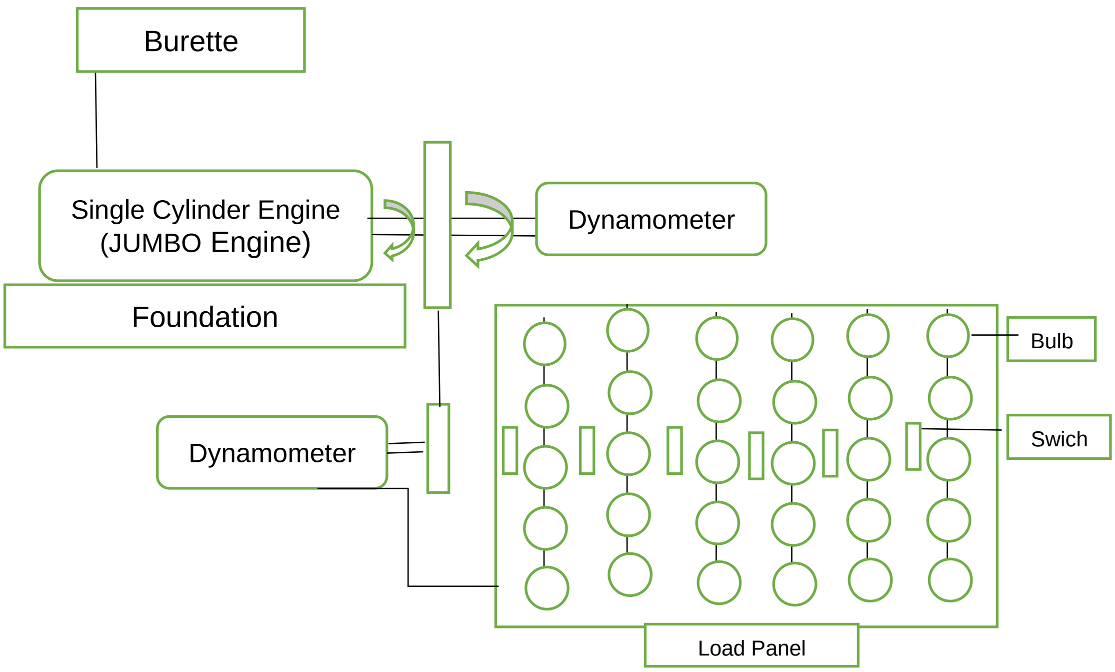

Figure 3 Experimental setup in for biodiesel evaluation.

Experimental Procedure

The engine was first tested using conventional diesel to provide baseline information for the experiment. Thereafter, all measurements were taken after the engine was stabilized. The experiments were repeated with the blends of methyl ester of giant palm seed oil for comparison. The test was conducted in accordance with the standard in the following sequence: pure diesel, B5 (5% biodiesel and 95% diesel), B10 (10% biodiesel and 90% diesel), B15 (15% biodiesel and 85% diesel), B20 (20% biodiesel and 80% diesel), B25 (25% biodiesel and 75% diesel), B50 (50% biodiesel and 50% diesel), B100 (pure biodiesel). The engine fuel consumption was measured using calibrated burette (100 mL). The burette was filled with fuel well above the top marking while the stopcock was locked, after that the stopcock was on to allow the passage of fuel into the engine. The engine was operated for 30 minutes in each case and the fuel consumption was recorded.

RESULTS AND DISCUSSION

Brake Specific Fuel Consumption (BSFC)

Figure 4 shows the findings for the variation in the BSFC as the engine's biodiesel content increases up to the maximum load. Due to its higher density, lower calorific value (heating value), and higher viscosity as compared to petroleum diesel, giant palm biodiesel has a higher brake-specific fuel consumption (BSFC) than regular diesel. In order to compensate the inferred engine's low heating value, extra fuel is supplied, increasing the amount of specific fuel consumed. In contrast, according to Shojaeefard *et al.* (2013), the lower heating value of biodiesel compels the engine to burn more fuel in order to produce the same amount of power as a diesel engine. Moreover, Eze and Ejilah (2010) stated that the amount of fuel introduced into the cylinder for the desired energy input was greater for biodiesel. The results of this test confirmed that the lower heating value exhibited higher brake-specific fuel consumption and vice versa. This indicates higher fuel consumption per unit of power produced due to low combustion efficiency (Eze and Ejilah 2010). The findings are comparable to those of Zheng *et al*. (2008), who found a 23% rise in brake-specific fuel consumption (BSFC) when biodiesel was used as the fuel source. The higher BSFC of the biodiesel blends could be connected to the lower calorific value of biodiesel and its blends, on average by 12.5% of the net calorific value of methyl ester. The higher cetane number of biodiesel fuel and the change in injection timing were two additional factors cited by Buyukkaya (2010). Meanwhile, Sahoo *et al.* (2007) revealed no major difference in fuel consumption between methyl ester and petroleum-based diesel.

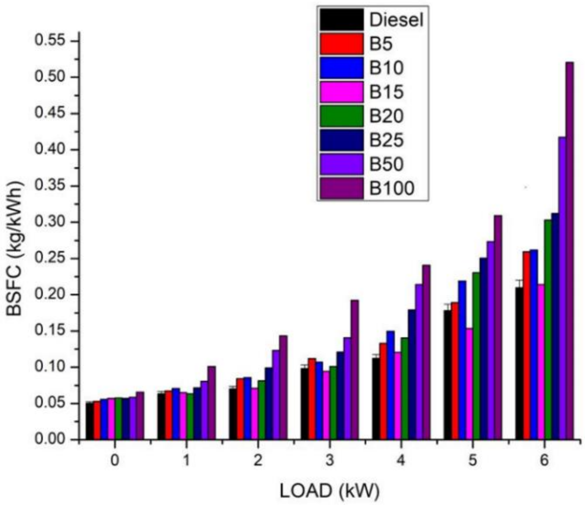

Figure 4 Brake specific fuel consumption variations for different biodiesel blends versus load.

Brake Thermal Efficiency (BTE)

The brake thermal efficiency of all fuel modes decreased as the load increased over the full range of loading circumstances. The BTE of giant palm biodiesel (B100) and biodiesel blends was lower than that of conventional diesel fuel, demonstrating the methyl ester's poor combustion properties as a result of its high viscosity and low volatility. Over time, it was discovered that the BTE from methyl ester was lower than that of regular diesel. The tendency is consistent with previous study (Chauhan *et al.* 2012; Panwar *et al.* 2010). Low heating value, high kinematic viscosity, poor spray characteristics, poor air-fuel mixture, and low volatility as a result of biodiesel from vegetable oils caused a drop in brake thermal efficiency (Nabi *et al.* 2009). Another factor could be the methyl ester's ignition delay, which initiates engine combustion before the piston reaches the top dead center. This can result in heat loss and decrease the engine's efficiency (Rao *et al.* 2007). Moreover, Karanja vegetable oil provided higher BTE at higher loading conditions and higher BSFC with the increase in blending ratio (Ashraful *et al*. 2014). While Canakci (2007) reported no significant difference between methyl ester and petroleum-based diesel, others have found that Karanja biodiesel blend offers higher BTE and BSFC compared to other biodiesels. Nonetheless, biodiesel combustion comes with low thermal efficiency, elevated emissions of nitrogen oxides (NOx), and carbon deposition issues (Ashraful *et al.* 2014). Figure 5 shows how the thermal efficiency of the brakes varies with loads for various giant palm biodiesel blend.

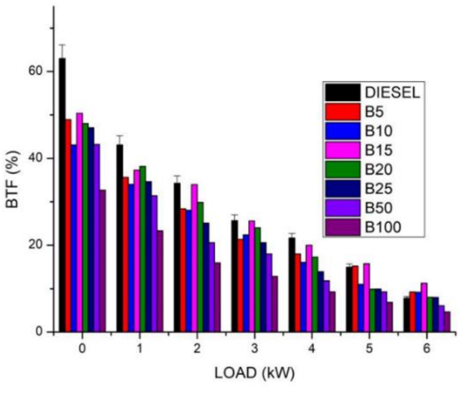

Figure 5 Brake thermal efficiency variation for different biodiesel blends versus load.

Brake Power

Figure 6 illustrates how the increase in load affects the brake power for various fuel blends. The figure shows that brake power diminishes for all loading conditions as the load increases. It was observed that the engine power for biodiesel and biodiesel blends is lower than that of the conventional diesel fuel when the brake power at various loads is compared with conventional diesel. It was observed from the graph that at lower blend ratio, brake power is close to conventional diesel fuel but lower. This drop in power output could be caused by the giant palm biodiesel's lower heating value. From the experiment, it was observed when petroleum-based diesel was utilized in the same engine, the power output decreased for B5 to B100 by 3.1–20%. According to Wan Ghazali *et al*. (2015), biodiesel blends have a little lower brake power than pure diesel (3.8–20%). This suggests that the brake power produced will decrease as the percentage of biodiesel in the blends increases. Aydin and Bayindir (2010) also concurred that using methyl ester as a fuel decreased engine output. The low heating value of methyl ester and the engine's incomplete combustion when utilizing biodiesel are the causes of the decline in output power. According to Oner and Altun (2009), the difference in engine power output between methyl ester and conventional diesel is insignificant. The justification offered was that engines provide fuels on a volumetric basis, and because methyl ester density is higher than that of diesel fuel, more methyl ester is supplied to make up for the fuel's lower calorific value (Qi *et al.* 2009). The larger spray droplets will be produced by the higher viscosity of the feedstocks and improve fuel spray penetration due to their greater momentum, enhancing air-fuel mixing (Nwafor 2004). In summary, a significant number of authors discussed power reduction, which was previously linked to high viscosity, the low calorific value of feedstock biodiesel, and incomplete combustion while utilizing biodiesel. In any event, higher fuel consumption would make up for the engine system's use of biodiesel, which has a lower heating value. Hence, the benefits of biodiesel from feedstocks will include decreased fuel leakages in the injection pumping system, advancement of the com bustion process, and higher lubricity of biodiesel.

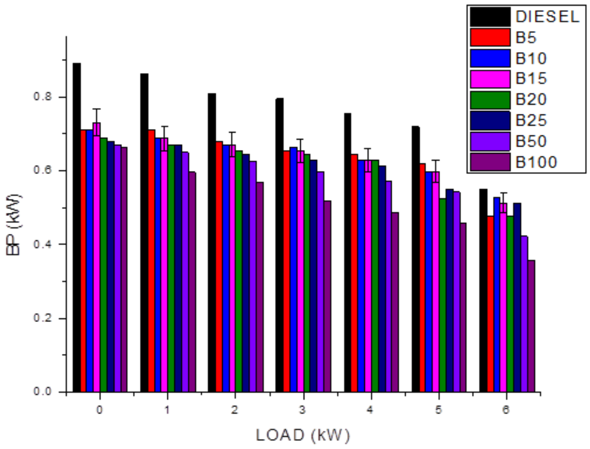

Figure 6 Brake power variation for different biodiesel blends versus load.

Brake Mean Effective Pressure (BMEP)

Figure 7 depicts the variance in brake mean effective pressure under different loading conditions of the engine for the various biodiesel blends. The graph demonstrates how BMEP reduces with increasing loading conditions. The conventional diesel's BMEP was higher than the BMEP of all blends under all loading circumstances. The findings were consistent with research done by Buyukkaya (2010), who examined the performance of a six-cylinder, four-stroke, turbocharged direct injection diesel engine when running at maximum load of 2000 rpm using neat rapeseed oil and its blends. According to reports, adding more rapeseed oil to the blends caused a decrease in the peak cylinder pressure. Therefore, the improvement in air-fuel mixing formation and atomization rate is directly related to the fuel's viscosity and volatility. Giant palm biodiesel and its blend's high viscosity and low volatility had an impact on the brake mean effective pressure. This implies that the brake mean effective pressure of the engine decreases as the biodiesel concentration increases. Other literature reported similar results are Senthil *et al.* 2005; Canakci *et al.* 2009; Devan and Mahalakshmi, 2009b. Devan and Mahalakshmi (2009) confirmed the same tendency when they evaluated diesel fuel with poon oil biodiesel at full load in single-cylinder diesel engines. They claimed that with regular diesel, B20, and poon oil, cylinder pressures of 67.5, 63, and 60 bar were reported. Pressure reduction with the expected effects of methyl ester viscosity on fuel spray, and reduction of air entrainment and fuel/air mixing ratio. However, the brake mean effective pressure of giant palm biodiesel fuels was lower than that of the conventional biodiesel fuel.

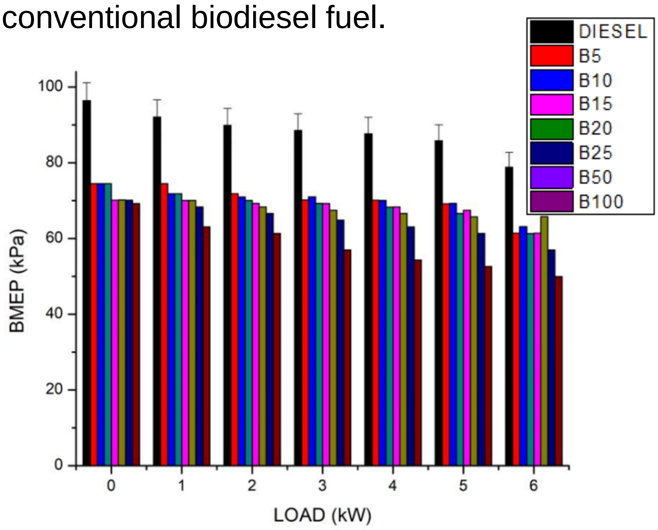

Figure 7 Brake mean effective pressure of different biodiesel blends versus load.

Engine Speed

The engine developed a speed for biodiesel blends that ranged from 750 to 650 rpm under the same conditions when utilizing conventional diesel at a full load (750 rpm). Also, the engine's speed at no load varied between 840 and 800 rpm for all samples made from giant palm biodiesel, whereas the tested engine's speed was 850 rpm. At all loading conditions, it was found that the engine speed dropped as the biodiesel concentration and loads increased. The relationship between load and engine speed is shown in Figure 8, which is consistent with previous research on biodiesel made from various sources such as canola, rapeseed, soybeen and beef tallow. Oniya and Bamgboye (2013) conducted tests on a single-cylinder 2.46 The engine speed remained constant for any increase in engine load after 75% of the full load for all the blends. However, the use of giant palm biodiesel resulted in a reduction in engine speed due to its low heating value, higher kinematic viscosity, poor spray characteristics, poor air-fuel mixture, and low volatility. High viscosity and poor volatility lead to poor combustion of the engine systems, which in turn results in low speed.

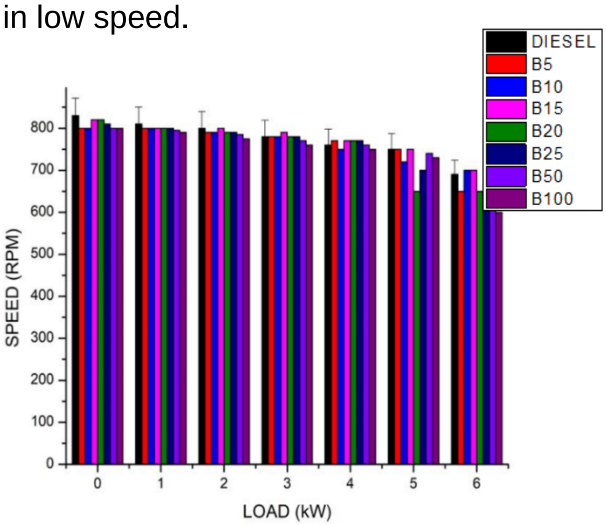

Figure 8 Speed variation for different biodiesel blends versus load.

CONCLUSION

A study was conducted on the production of biodiesel from giant palm seed oil, its characterization, and performance testing on a single-cylinder engine using various biodiesel blends at varying loads. The fuel characteristics of giant palm biodiesel and its blends, except for B50 and B100, were found to be identical to conventional diesel fuel and mostly within ASTM requirements. However, the short-term performance of a diesel engine fuelled with promising giant palm biodiesel showed a slight reduction in power output (brake power) and brake thermal efficiency, along with an increase in brake specific fuel consumption. The lower heating value (calorific value) of the biodiesel may be responsible for this reduction in power output, which ranged from 3.1 to 20%. This implies that the higher the biodiesel concentration in the blends, the lower the engine power generated. The increase in brake specific fuel consumption (BSFC) of biodiesel blends could be due to the low heating values when compared to petroleum-based diesel. Therefore, more quantity of biodiesel will be required to be injected into the combustion chamber for the desired energy output.

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