EFFECTS OF PKO-BIODIESEL BLENDS ON TRACTOR ENGINE PERFORMANCE UNDER VARYING TORQUE CONSTANT SPEED

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ABSTRACTS
Biodiesel as an alternative to fossil diesel is gaining momentum with severe concerns about its effect on engine performance. As a renewable fuel for agricultural tractors, its performance should produce positive results in field tractor operating conditions. Hence this study examines the effect of various blends (B5, B10, B20, B30, B40) and pure palm kernel biodiesel (B100) on the engine performance of a four-cylinder CI diesel engine (David Brown 990: 58 hp; 2WD) at Farm Power and Machinery Test laboratory Centre (FPMTLC), Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka. Each fuel test was performed using the Heenan-Froude hydraulic dynamometer engine-test-bed, and pure petroleum diesel (B0) was first conducted to generate the baseline data. The objective of the study was to determine the fuel consumption rates (FC), energy expended, brake specific fuel consumption (BSFC), and brake thermal efficiency, under varying torque (178 – 227.09 Nm) at a constant speed. The variables calculated were analyzed and compared to determine the differences in the engine performance and the optimum test fuel. The results obtained for the fuel consumption rates showed that B10 was the optimum or preferred fuel to B0 and B100. The fuel consumption (FC), brake specific fuel consumption (BSFC), energy expended, and thermal efficiency for B10 was 3.687 m^3/s, 0.102 l/kWh, 8868.8 kJ, and 98.8%, respectively. The result was similar to earlier studies. Hence, for sustainable fuel consumption in line with IPCC protocol, fuel blends should be encouraged to reduce climate change.

KEYWORDS: Biodiesel Blends, Thermal Efficiency, Brake Specific Fuel Consumption, Engine Performance

1. INTRODUCTION

The growing concern about the problems of over-reliance on fossil fuels as significant sources of energy and associated solutions in our societies requires a systemic approach. The anxiety and awareness about the tendency to exhaust fossil fuels in the nearest future give an avenue for intentional and concerted efforts toward seeking and developing an alternative. Health and environmental hazards are also not left undiscussed due to fossil fuel gas emissions Barman *et al*. (2010). Researchers are attesting that global warming is a result of greenhouse gas emissions emanating from human activities such as fossil fuel uses and attendant gas emissions and deforestation as a recurrent decimal and prevalent (Ofor, 2009).

The apprehension associated with fossil fuels exhaustion with the environmental and health concerns opened the quest for solutions in the energy sector of the economy; it is therefore imperative to develop an alternative or energy mix sources which will be renewable, compatible and eco-environmentally friendly and supportive characteristic to boost Agricultural economy by providing a new market for domestic (oilseed especially non-edible) crops. However, methyl and ethyl esters, a product of catalytic transesterification of vegetable oil sources base popularly known as biodiesel, is established as suitable alternative fuels for diesel engines; its lubricating property removes the need of any lubricate additive and wide acceptance by vehicle manufacturers as an important advantage of the biodiesel fuel (Lawrence *et al*., 2011; Singh and Singh, 2010). Knothe and Steidley (2005) also reported that biodiesel has better lubricity than petrol-diesel hydrocarbons because of the polarity that is introduced with the presence of oxygen atoms lacking in petrol-diesel.

Buyukkaya (2010) investigated the use of rapeseed oil in biodiesel production; studies showed decreased in smoke opacity, reduced CO emissions, and increased brake specific fuel consumption (BSFC) compared with AGO fuel, while the combustion behaviors of rapeseed oil biodiesel and blends with diesel closely followed those of standard diesel. Meanwhile, Igbokwe *et al.* (2015) studied the effects of blend on the properties, performance and emission of palm kernel oil biodiesel. The result showed that diesel fuel showed better fuel economy than the palm kernel biodiesel and its blend because of its higher heating value. Similarly, Oniya *et al.* (2014) worked on performance of a stationary diesel engine using loofah (*Luffa cylindrica*, *L*.) biodiesel and result showed that using 5% loofah ester–AGO blend, 8.5Nm at full load was obtained as the peak value of torque for loofah biodiesel compared to 10.6 Nm (full load) obtained for AGO. The differences in average values of torque, speed and exhaust temperature of the engine for loofah biodiesel and AGO were not significant ($p > .05$). Alamu *et al*. (2009) observed that at all tested engine speeds, the torque outputs of palm kernel oil (PKO) biodiesel in a diesel engine were generally lower than those for petroleum diesel. Biodiesel is regarded as a close substitute and needs to be integrated as a blend (fuel mix) to improve and reduce the hazard effects of fossil fuel gas emissions on the engine without compromising its operation and performance.

The objective of the work was to study the effects of different blends of palm kernel oil biodiesel and fossil diesel (Automobile gasoline oil) AGO on the performance of a four-cylinder Compression Ignition Engine (David Brown 990: 58hp; 2WD model of a maximum power of 43.268KW). The engine performance parameters determined were fuel consumption rates, brake specific fuel consumption, and brake thermal efficiency of the engine for diesel, with various blends of PKO biodiesel at varying torque and constant speed, to compare the results obtained to determine the fuel blend with the optimum performance.

2. MATERIALS AND METHOD

2.1 Experimental Test Bed

This study utilized a tractor with engine specifications shown in Table 1. The tractor was linked to a dynamometer with the specification shown in Table 2. The dynamometer was connected to a 10 liters' water tank. Other test apparatus included a fuel measuring burette with a bypass pipe. A 100cm^3 measuring cylinder was used to measure the exact quantity of fuel needed. The dynamometer was used to control the torque at a constant value as the engine acceleration was increased. The test engine fuel line was modified to adapt to the calibrated cylinder.

Table 1: Specifications of the test Engine

Engine	Specifications
Name	Tractor
Model	1992 Model
Make	David Brown
Rated Power	58hp
Maximum Power	43.268
Wheel Drive	2WD (2 Wheel Drive)
Type	CI (Compression Ignition)
Number of Cylinders	4 Cylinders
Rated Speed	2600rpm (Hour at 1412rpm)
Fuel type	AGO (Diesel Fuel)
Strokes	Four strokes engine

Table 2: Specifications of the Hydraulic Dynamometer

Dynamometer	Specifications
Size	DPX2
Order Number	BX 34576
Maximum Power (KW)	112KW at Revolution minutes of 4040/7500
Make	Heenan-Froude: Worcester, England
Model	DPX
Serial Number	TE 87/3940
Type	Hydraulic Dynamometer

2.2 Test fuel

The biodiesel was produced at the fuel production plant located at the biodiesel production facility at the Department of Agricultural and Bioresources Engineering, University of Nigeria Nsukka. Palm kernel oil was used as raw material to produce biodiesel through the process of base-catalyzed transesterification. Methanol and sodium Hydroxide were used as reactants in the production. The biodiesel production occurred at 60^{o}C at a pressure of 2 atmospheres; it adequately was purified and allowed to stand for 18 hrs.

ASTM standard fuel test procedure was used in determining the fuel properties. The primary fuel properties of the B100 is shown in Table 3. 50 liters of pure petroleum diesel (BO) was purchased at the Total Fuel Station in Nsukka, Enugu State Nigeria; 25 liters of B100 was produced and used in the experiment. The palm kernel oil biodiesel was blended on a volume basis with pure petroleum diesel to obtain the blends used as (BX), where "B" represents pure petroleum diesel and represent the percentage of PKO Biodiesel. The processing plant that was used in the producing 25 liter of biodiesel as shown in Figure 1. Even other samples were prepared, which includes BO, B5, B10, B20, B30 B40, and B100.

Table 3: Some Fuel Properties of the methyl ester PKO biodiesel and Premium Diesel

Properties	PKO Biodiesel	Premium Diesel (PD)
Density @ 15^{o}C (kg/m^3)	876.75 (ASTM-D4052)	873.9
Cetane Index	62.4 (ASTM-D613)	50
Kinematic Viscosity (m/s^2 @ 40oC	3.250 (ASTM-D445)	3.276
Flash Point (^{o}C)	131.2 (ASTM-D93)	68
Heating Value (MJ/kg)	37.9 (ASTM-D4809)	45.86
Oxygen Content (wt%)	13.57	-
Cloud point (^{o}C)	21 (ASTM-D2500)	8

Figure 1: 100 Liters per hour biodiesel Plant used for the biodiesel production

2.3 Experimental Procedure

The tractor was coupled to the dynamometer using a PTO propeller inserted in the PTO shaft as shown in Figure 2. The engine was started and allowed to idle until the average operating temperature of 80^{o}C. The rack was then adjusted to an optimum position and the fuel tests carried out using a measuring burette with by-pass pipes attached to the engine. The constant engine speed used for the fuel tests was 550 rpm with the input torque from the dynamometer varied between during 227.09, 178.06 and 129.03 the test.

Experiments were carried out initially using pure petroleum diesel fuel (B0) to generate the baseline data. The dynamometer had different weight in varying torque for test involving engine performance. After recording the data for the reference fuel, other tests were carried out for B5, B10, B20, B30, B40 and B100 and recorded. Record items include all data necessary to calculate the required results as well as all data necessary to reproduce the test. However, before running the engine with new test fuel, it was necessary to change the fuel filters and bleed the fuel system. This was done to ensure a complete transition from one test fuel to another and to escape all traces of air from the system. After each test interval, various parameters such as time, volume, torque and speed were measured and recorded at the various engine speeds at constant torque. Nonetheless, to measure the fuel consumed in each test, a two-way valve fitted with a burette was attached to the engine and the fuel consumption rate determined by recording the time "t" taken for 500ml of fuel to flow under gravity into the engine. The variables calculated were analyzed using tables, plots (graphs) and statistical tools and compared with each other in order to determine the differences in the engine performance and also to determine the optimum test fuel. Each test was repeated three time for accuracy.

Figure 2(a) the tractor coupled to the dynamometer

Figure 2(b) the setup of the fuel measuring system connected to the tractor

The performance parameters such as fuel consumption, brake power, energy expended, brake specific fuel consumption, brake thermal efficiency, fuel consumption rate were calculated using Equation 1 as stated in Nwakaire *et al*. (2020).

$$T = RW \tag{1}$$

where,
T = torque (Nm)
R = Length of Torque arm (m)
W = Effective Load = S + w
S = Spring Balance Reading (N)
w = Static Load (N)

The fuel consumption rate was calculated using Equation 2 as presented by Nwakaire *et al*. (2020)

$$FCS = \frac{v}{t} \tag{2}$$

where,
FCS=fuel consumption rate (l/h)
v = Volume of fuel consumed (L)
t = Time (s) taken to consume 250ml

The brake power was calculated as:

$$P = 2\pi\tau N = T\omega \qquad (3)$$

where,

P = brake power (kW)

τ = torque (Nm)

ω = Angular Velocity = $\frac{2\pi N}{60}$

N = Revolution per minutes (rpm)

Then, the brake specific fuel consumption was given as presented in Equation 4 (Nwakaire *et al*., 2020).

$$BSFCS = \frac{FCS}{P} = \quad (l/kWh) \qquad (4)$$

Similarly, brake thermal efficiency (η_{th}) was given as Equation 5 (Nwakaire *et al*., 2020).

$$\eta th = \frac{P}{FCS * H_v} \qquad (5)$$

where,

H_v = Heating value of fuel

The brake specific fuel consumption when the diesel was performing an operation was given as Equation 6 (ASAE, 2011).

$$BSFCD = (3.91 + 2.6Pr) - 0.203(173 + 738Pr)^{1/2} \qquad (6)$$

where,

Pr = the ratio of equivalent PTO power (PT) to rated PTO power.

Also, fuel consumption (FC) when the engine was performing an operation was given as presented in Equation 7 (ASAE, 2011).

$$FCD\ (L/h) = BSFCD \times P \qquad (7)$$

where,

P = brake power or equivalent power

The tests were replicated three times and the means of each measured parameter used to determine the engine performance of the test fuels based on the following variables; fuel consumption rates, energy expended, brake specific fuel consumption, and brake thermal efficiency.

3. RESULTS AND DISCUSSION

The effects of varying torque at constant speed on some selected engine performance parameters were investigated. The varying torque scenario simulates tractor field operating conditions where a known field speed condition exists. A varying field torque or soil resistance is experienced as the tractor pulls the implement through the soil during tillage operation. The performance of the tractor is dependent on the fuel combustion performance and expressed in such parameters as; specific fuel consumption.

3.1 Rate of Fuel Consumption

Rate of fuel consumption is a factor that is associated to engine performance which is a function of fuel density, caloric value (heating value), and viscosity of the fuel Igbokwe *et.al.* (2015). Specific fuel consumption determines the amount of fuel that is use under specific torque or load during an engine operation. From figure 3, the specific fuel consumption rate of B100 was very high with a value of 6.08 m3/s at the maximum torque of 227.09 Nm.

The result is similar with Selvan *et al.* (2022) in which B100 had the highest rate of specific fuel consumption at the maximum test torque for CI engine. Further figure 3 showed B10, B0 and B20 had the lowest rate of specific fuel consumption of 3.687m^3/s, 3.687 m^3/s, and 3.805 m^3/s, respectively for the same experimental torque of 227.09 Nm. Bora *et al.* (2008) showed similar result, where B20 had the lowest specific rate of fuel consumption for Jatropha oil, Karanja oil, Polanga oil biodiesel blends. Hence these authors results validates this study's result that **B10**, B0 and B20 had the lowest specific fuel consumption rates.

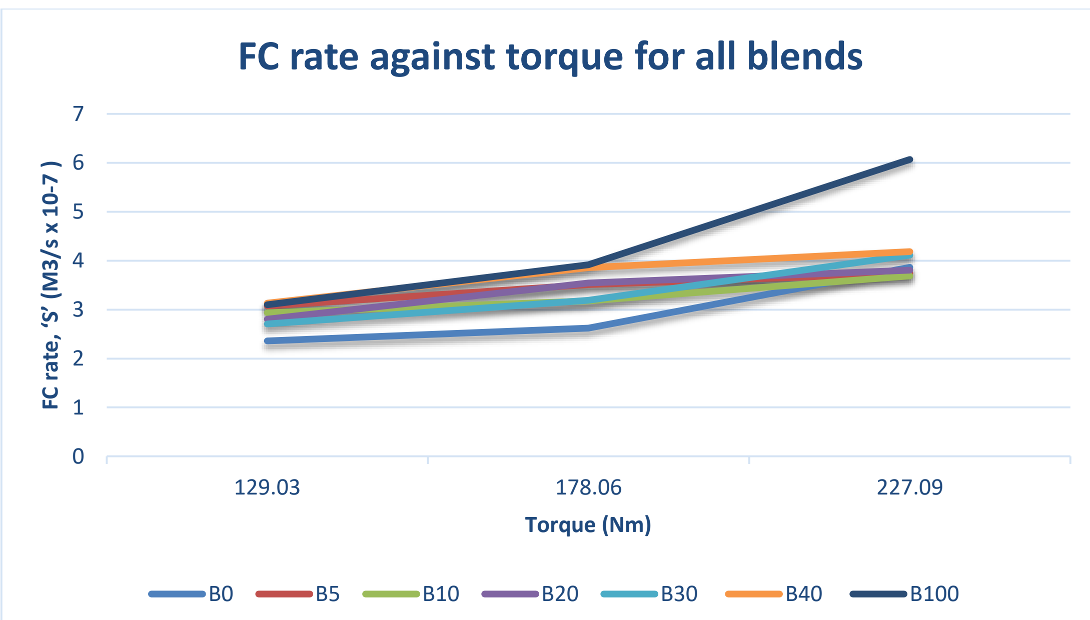

Figure 3: Fuel consumption rate against torques for different biodiesel blend ratios

3.2 Brake Specific Fuel Consumption

Brake Specific Fuel Consumption (BSFC) is a measure of the fuel efficiency of any primary engine that burns fuel and produces rotational or shaft power. It is often used to compare the efficiency of an internal combustion engine with the output of the shaft. It is the ratio of fuel consumption divided by power generated. The lower the brake specific fuel consumption, the more efficient the engine is. From Figure 4, B10 had the lowest BSFC of 0.102 l/kWh, followed by B20 with 0.1047 l/kWh and B0 with 0.106 l/kWh at the highest load of 227.09 Nm. B100 had the highest BSFC of 0.167l/kWh at the highest load of 227.09 Nm. This result has similar trend with the work of Krishna *et al.* (2010) and Damanik *et al.* (2018) which showed that B20 and B10 had lowest BSFC for the highest load on the engine during the engine test.

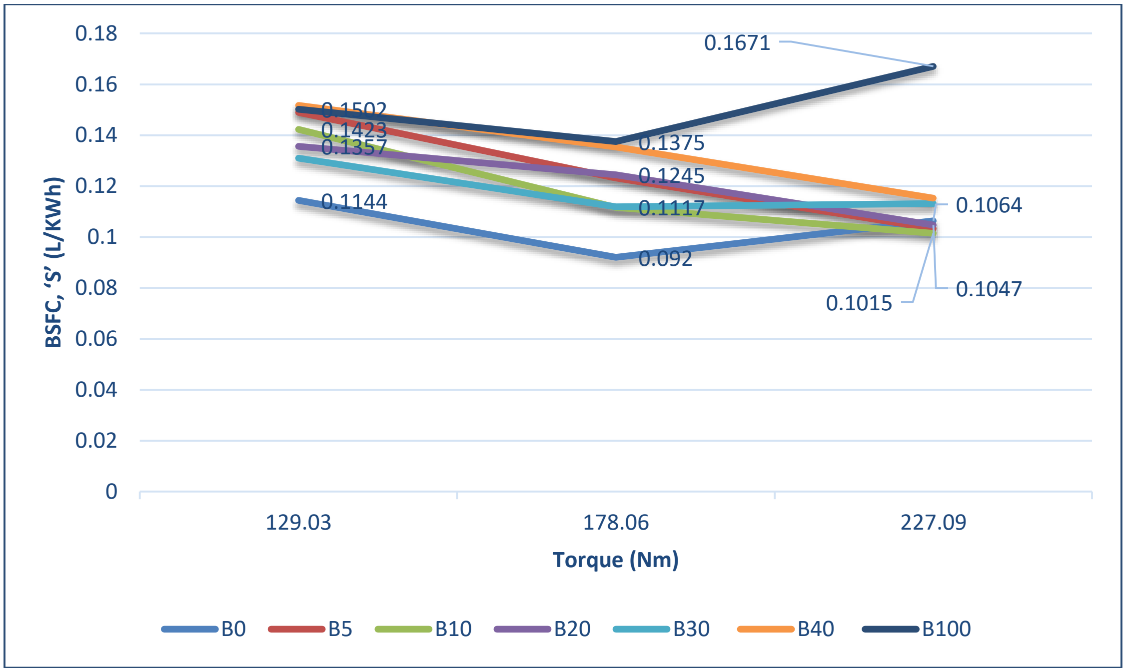

Figure 4: Brake Specific fuel consumption against torques for different biodiesel blend ratios

3.3 Energy Expended

The energy expended is a function of torque or load on the engine. Energy expended describes the engine's energy output under varying loads at a constant speed. Figure 5 shows the graph of energy expended against torque for different blend ratios of biodiesel. B100 had the lowest energy expended at the highest torque, while B10 had the highest energy output of 8868.9 kJ at the highest torque of 2227.09 Nm. B5 and B20 had the next highest energy output, which is similar to the work of Shrivastava *et al.* (2019), which showed that B20 had the highest energy output for the various blend and is higher than B100 and B0. Igbokwe *et al* (2015) showed that energy for B0 reduces as torque increases but output. Blends are hybrid form of chemical fuels used to achieve certain goals like achieving environmental sustainability in line with the recent IPCC. This result shows that for increased load at constant speed during field operation, B10 is the optimum blend of biodiesel to substitute B0 (AGO).

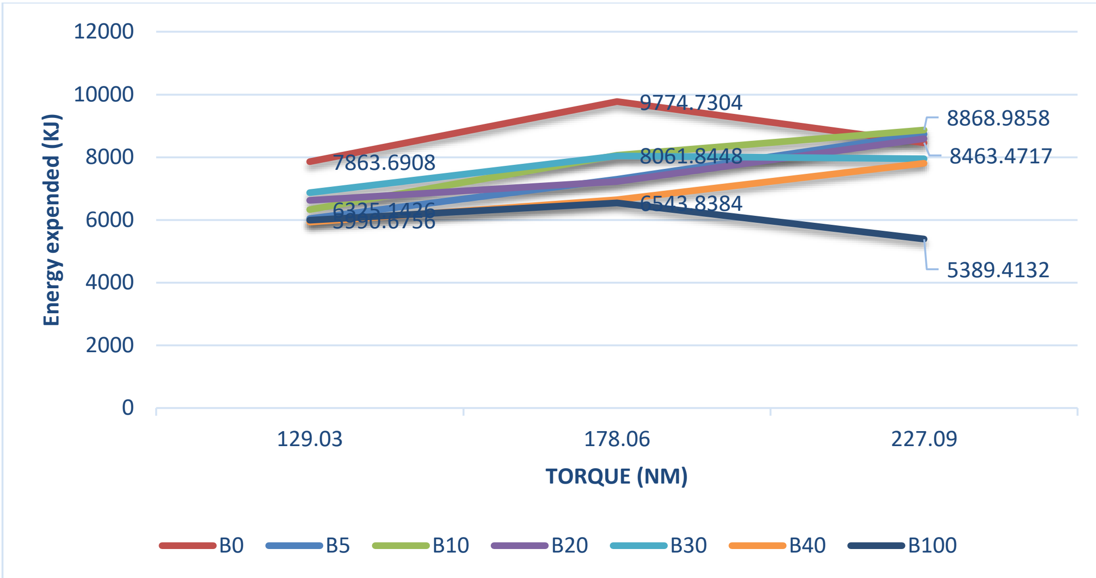

Figure 5: Energy Expended against torques for different biodiesel blend ratios

3.4 Brake Thermal Efficiency

Brake thermal efficiency is a measure of the total efficiency of an engine. Studies show that the thermal efficiency of an engine increases with an increase in engine torque. Figure 6 shows that the thermal brake efficiency increased as the biodiesel content B100 had the lowest thermal brake efficiency (68.5%), while B10 and B20 had the highest thermal brake efficiency of above 97%. The obtained result is similar to the works of Reddy *et al.* (2010) and Azad *et al.* (2013), which showed that B100 had the lowest thermal brake efficiency at the highest load applied to a CI engine. Azad *et al.* (2013) showed that the thermal brake efficiency of B20 was the optimum for all the bends examined; this is similar to the results obtained in this study from B20 and B10, which had the highest thermal brake efficiency. Razzaq *et al.* (2021), Razzaq *et al.* (2022).

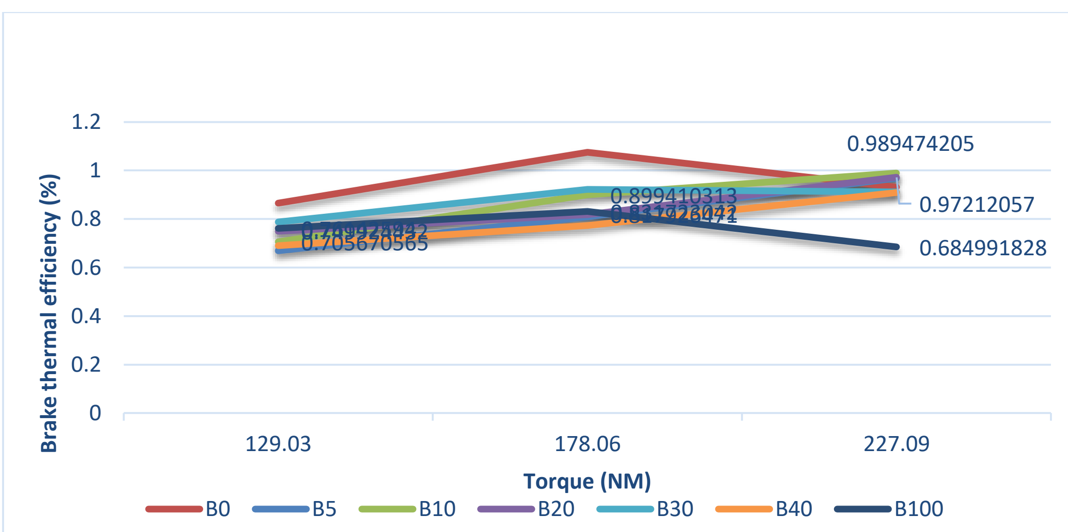

Figure 6: Brake thermal efficiency against torques for different biodiesel blend ratios

3.5 Reasons for the observed trends in the results

Fuel consumption of biodiesel is expected to be slightly higher than petroleum as density of the biodiesels is higher than petroleum diesel (Mittelbach and Remschmidt, 2007). Sources of biodiesel greatly influence the engine performance, such that, the engine fuelled with palm oil biodiesel is more efficient than biodiesel produced from tallow and canola oil (Fogllia *et al.* 1997). Biodiesel is likely to produce less power with high fuel consumption than diesel as the gross calorific value (energy content) of biodiesel is lower than petroleum diesel. Blends of biodiesel with petroleum fuel are widely used in the diesel engine Devlin *et al.* (2008). High viscosity of the fuels causes fuel flow and ignition problems in unmodified CI engines and also decreases the power output (Devlin *et al.* 2008). The lubricity and oxidative stability of the animal fat-based biodiesels are better than soy-based biodiesel (Foglia and Chang, 2002). The composition of animal fatty acid methyl esters is different from vegetable fatty acid methyl (ethyl) esters.

4. CONCLUSIONS

Engine performance for seven different blend ratios of biodiesel fuels (B0, B5, B10, B20, B30, B40 and B100) on a David Brown 990:58hp 2WD Agricultural tractor was studied and the following conclusions were made considering the scenario of high torque requirement in the field:

1. The Specific fuel consumption of B10 and B20 where the lowest for the highest experimental torque shown that the quantity of fuel that will be used when running on B10 or B20 will not be high when compared to the consumption rates of B100, Hence B10 was the optimum for this work.
2. The Brake Specific Fuel consumption of B10 was the most significant for the test results as it had the lowest BSFC of 0.102 l/kWh, followed by B20 with 0.105 l/kWh and B0 with a value of 0.106l/kWh. B100 had the highest BSFC consumption.
3. For energy expended, B10 with a value of 8868KJ was the highest in terms of energy output. B100 was not recommended based on the low energy output
4. The test engine had the optimum efficiency of 98% when running on B10, which shows that B10 is the preferred biodiesel blend substitute for B0.

From the foregoing, B10 is the preferred test fuel selected to replace B0 in the right of all the result of this study.

From the results of experiments, it was recommended that at varying torques, B0 had optimal fuel economy relative to B30 blend ratio. Therefore, B30 was recommended as close substitute to B0 given the operation. Studies on the varying speed at constant torque should also be investigated to arrive at useful conclusion.

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