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Investigation Of The Performance Of A Single Cylinder 4-Stroke CI Engine Fuelled With African Elemi Biodiesel And Its Blends With Petroleum Diesel At Constant Load

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Abstract:** Investigation of the performance of an internal combustion engine fuelled with biodiesel from African Elemi (Canarium schweinfurthii) fruit oil was investigated. The oil was obtained from the fruit by mechanical extraction and analyzed for chemo-physical properties. The oil was converted to biodiesel through transesterification process using ethanol with potassium hydroxide as catalyst. A 3.2 kW Bhojson 165F, single cylinder, four stroke direct injection internal combustion diesel generator was used and alternatively fuelled with conventional diesel fuel, biodiesel and biodiesel blends. The performance parameters investigated were engine torque, brake power, brake specific fuel consumption and brake thermal efficiency. Engine performance test was carried out at 80% load, with variation of speed from 1200 to 3200 rpm at intervals of 200 rpm. The experimental results showed an increase in torque, brake power and specific fuel consumption with speed for all fuel types although conventional diesel had higher values of torque and power but lower values of break specific fuel consumption. Also, decrease in brake thermal efficiency was observed for conventional diesel, biodiesel and biodiesel blended fuels over the speed range with diesel having a slightly higher thermal efficiency than the biodiesel and its blends. Based on the parameters measured and analyzed, it was concluded that blends of B10 to B40 can be used without making any engine modifications.

***Keywords:** African Elemi (Canarium schweinfurthii) oil fruit, Biodiesel, Transesterification, Engine torque, brake power and specific fuel consumption, brake thermal efficiency.*

I. INTRODUCTION

The finite nature of the sources of conventional fossil fuels, the increasing demand for fossil fuels coupled with the debilitating effects of the products of combustion of such fuels on the environment have prompted scientists and researchers to look the way of alternative fuels such as biodiesels for diesel engines. Known crude oil reserves are estimated to, at the current rate of consumption, be exhausted in the not too distant future. A number of alternative fuels such as ethanol, methanol, hydrogen, compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG), dimethyl-ether (DME) and vegetable oils have been used as alternative fuels, however biodiesel has received more attention as substitute fuel for conventional petroleum. Biodiesels are produced from the transesterification of vegetable oils. Vegetable oils can also be used in their pure form. However, the use of vegetable oils for engine fuels has undesirable injection and combustion problems caused by their higher viscosities. This has remained the main obstacle in their use as alternative fuels. This problem has been solved by using some suitable techniques like dilution, pyrolysis, transesterification, preheating and emulsion to get methyl esters of such oils. These methyl esters of animal and vegetable oils are called biodiesel and can be used as fuel for modern diesel engines due to their cleaner burning tendency and environmental benefits. Many researchers have reported that biodiesel has higher flash point, higher cetane number, ultra-low sulfur concentration and improved lubricating efficiency as compared to conventional fossil fuels. Biodiesel has received a great attention in many countries over the last decade and its use has been encouraged tremendously (Shah *et al.*, 2009). Several researchers have obtained biodiesel from various vegetable oils and animal fat and evaluated the performances of diesel engines fuelled with them in order to determine the suitability of the fuels for use in such engines. For example Rao *et al*. (2008) carried out research on the property, performance and emission analysis of dual biodiesel for diesel engine, in which six fuel blends in different mixtures of pongamia-ponnata and jatropha biodiesels produced from their oils were mixed in various rations with petroleum diesel. The test fuels were used in a four-stroke single cylinder, direct injection, water cooled diesel under constant engine speed and varying load conditions and their performances were compared. The results indicated that the specific fuel consumption values of dual biodiesel blends were comparable to diesel. The dual biodiesel blends provided less HC and CO than diesel. Oguntola *et al*. (2009) conducted research on "Power and torque characteristics of diesel engine fuelled by palm-kernel Oil biodiesel" in which engine performance tests were carried out on test diesel engine fuelled with Palm kernel oil (PKO) biodiesel. At all engine speeds tested, results showed that torque and power outputs for PKO biodiesel were generally lower than those for petroleum diesel. Iortyer *et al*. (2016) investigated the performance of an internal combustion engine fuelled with biodiesel from palm kernel oil, castor oil and their blends with petroleum diesel using a single cylinder, air cooled, naturally aspirated 4-stroke internal combustion diesel engine to compare the performance of conventional diesel fuel to biodiesel and biodiesel blends and their emissions. They concluded that the biodiesel blends of B10 to B30 are similar in performance to petroleum diesel and can be used in internal combustion diesel engines without making any engine modifications. Africa Elemi oil ester, however, is yet to be explored for use as an alternative diesel fuel. The aim of this research was, therefore, to investigate the engine performance of a single cylinder 4-stroke CI engine fuelled with african elemi biodiesel and its blends with petroleum diesel at constant load.

II. MATERIALS AND METHOD

A bhojson 165F single cylinder four stroke direct injection, bowl-in-piston combustion chamber internal combustion engine attached to a dynamometer and fuelled with biodiesel from African Elemi (Canarium schweinfurthii) oil fruit and its blends with petroleum diesel was used for the engine performance analysis. The biodiesel and its blends with petroleum diesel were characterized for chemo-physical properties using ASTM standards (ASTM 6751 and ASTM 975 for biodiesel and petroleum diesel respectively). The chemo-physical properties and engine parameters are shown in tables 1, 2 and 3 respectively. The engine was mounted on a base plate and started by switching on the ignition switch and pulling the handle of the engine rapidly outwards repeatedly until the engine fired. The engine was allowed to warm-up for three minutes and the choke was repositioned. The air and fuel supplied to the combustion chamber formed a mixture; while the compressed air initiates the combustion processes. The throttle cable and control lever was used to control the inflow of fuel. The power generated from the combustion reaction is transmitted through the power shaft by means of flexible coupling to the dynamometer. The engine drives the dynamometer paddles inside the dynamometer casing. The casing was partially filled with water, which entered through the fine control valves and left through gate valve (coarse control). There is a vent and an outlet leading to the drain. The water in the dynamometer is accelerated by valves in the paddle which push against valves in the casing; this causes shearing of the water, resulting in the resistance to the rotation of the engine giving rise to a force which turns the dynamometer casing on its trunnions (supporting bearings). This force (torque) is measured by the spring balance connected by the torque arm. The load on the engine is dependent on the amount of the water in the dynamometer casing, which is controlled by the two valves. The tachometer is driven by an extension of the dynamometer shaft and used in measuring the speed of the engine. The experiment was conducted by varying the speed from 1200rpm to 3200rpm at 80% load. The experiment was conducted for the eleven different fuel samples i.e B10, B20, B30, B40, B50, B60, B70, B80, B90, B100, and Petroleum Diesel B0. The properties that determine the performance of biodiesel in a stationary diesel engine include; mass flow rate, torque, input power, brake power, brake mean effective pressure, specific fuel consumption, break thermal efficiency and the relationship between pressure and time. These were investigated. From the experiment, the graphs of engine torque versus engine speed, specific fuel consumption versus engine speed, and Brake power versus engine speed, break thermal efficiency versus engine speed were plotted.

Parameters	**AGO B0**	**Biodiesel B100**
Flash Point °C	69	168
Moisture content %	0.02	5.2
Heat of Combustion mg/kg	43.6	25.3
Kinematic Viscosity@ 40°C	4.10	9.32
Specific Gravity @15°C (g/cm^3)	0.86	0.92

Table 1: Chemo-physical Properties of Conventional Diesel and African Elemi Biodiesel

Parameter	Specification
Engine model	Bhojson 165F
Type of engine	Single cylinder, four stroke. Direct injection, bowl-in-piston combustion chamber
Engine brand name	Internal Combustion Engine (I.C. engine)
Injector hole diameter	75 µm
Injector hole number	8
Peak torque	3503 N-m
Exhaust gas temperature	96 oC
Connecting rod length	40 cm
Bore and stroke	87.5 x 110 nm
Stroke	Four –stroke
Cooling method	Air
Rated output	3600 rpm
Injection type	Direct Injection
Injector operating pressure	Direct fuel Injection (Piston sweeps) displacement volume
Oil quantity	4.5Litre
Dry weight	44kg
Compression ratio	10.3:1
Number of cylinder	1
Starting Method	Electric system with Manual Compression release
Rated speed	3600 rpm
Rated power	3.2 Kw
Specific fuel consumption	0.067 (L/kW. hr)
Fuel supply system	Inline pump
Manufacturer	Bhojson & Co. Nigeria Limited
Engine Position	Vertical

Table 2: Technical specification of engine used for test

Parameters	Data
Type	Single cylinder, four stroke.
Direct injection,	bowl-in-piston combustion chamber
Maximum operating capacity AC	170
Dynamometer	Eddy current
Injector opening pressure	250 bar
Injection timing	23°bTDC
Torque arm radius	4.4 cm
Maximum speed	3600 rpm
Nominal power	2.67/3.6 Kw/HP
Manufacturer	Bhojson & Co. Nigeria Limited
Oil capacity	4.5 Litre

Table 3: Dynamometric specification

III. RESULTS AND DISCUSSION

EFFECT OF ENGINE SPEED ON TORQUE

Fig.1 presents the effects of biodiesel, blends and conventional diesel fuel on engine torque with respect to the engine speed. It can be observed that engine torque increased as the engine speed increased until it reached a maximum value and then decreased with further increase in engine speed The conventional diesel B0 presented higher torque value of 96 Nm during engine testing at maximum speed of 3200 rpm, while the engine torque for B10, B20, B30, B40, B50, B60, B70, B80, B90 and B100 at 3200 rpm had values of 90, 88, 86, 84, 82, 82, 80, 78, 76 and 70 Nm lower compared to conventional diesel B0. The reason for this could be due to higher calorific value of conventional diesel fuel in comparison to the biodiesel fuel (Mohammed *et al*., 2009). The behavioural pattern exhibited by the graph shows that, initially more torque was required for operating the engine as speed increased. Further examination shows that torque produced by diesel was more than that of biodiesels and blends at all varying engine speeds. Engine torque is a function of engine speed (Abu Zaid, 2004). Torque increases with increase in engine speed with maximum torque occurring at high engine speed which is said to be typical of diesel engine (Mamat *et al*., 2009). Increase in torque with speed could also be as a result of increase in combustion temperature causing the fuel density to decrease and improving the fuel atomization leading to more complete combustion.

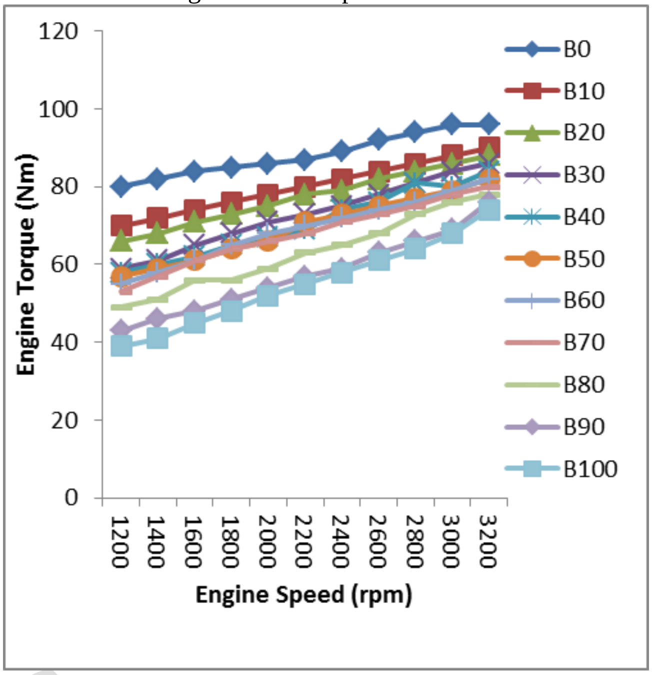

Figure 1: Variation of Engine Torque with Engine Speed At 80% Load

EFFECT OF ENGINE SPEED ON BRAKE POWER (KW)

Fig.2 illustrates the variations in the brake power for conventional diesel fuel, biodiesel and biodiesel blends as a function of the engine speed. It was observed that brake power of the engine increased with increase in the engine speed due to the effect of rise in combustion temperature and pressure created in the engine. Fig.2 shows the engine brake power for biodiesel fuel and biodiesel blends was found to be slightly less than the power generated from conventional diesel fuel as the engine speed increased due to lower calorific value (Chakrabarti *et al*., 2008). It was also observed that as the speed increased, conventional diesel B0 gave better engine power than pure biodiesel and its blends. The reason for this could be as a result of the higher calorific value of conventional diesel compared to biodiesel. Generally, reduction will occur in the engine power when biodiesel of lower calorific value is used in a diesel engine without modification (Celikten, 2003). The main reason for increased brake power at high engine speeds is the increased atomization. At the same time, high engine speeds cause the increased inlet air flow speed or turbulence (Canackci, *et al.* 2009) which enhances the effect of atomization of the fuel in the cylinder, making the mixture more homogeneous as such improving combustion thus increase brake power. Because of this reason, the beneficial effect of biodiesel as an oxygenated fuel was partially lost at high speeds (Usta, *et al*; 2005).

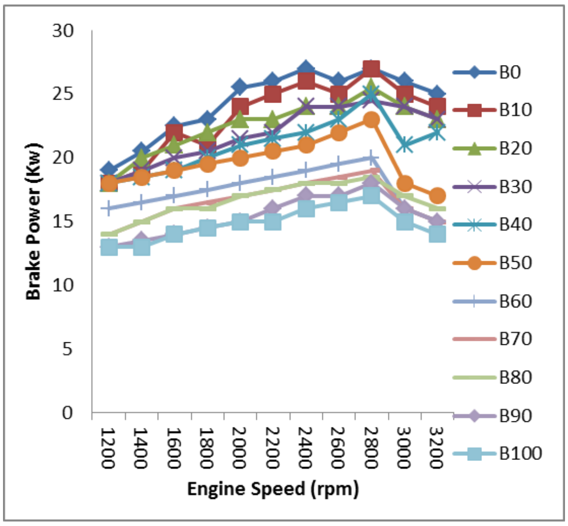

Figure 2: Variation Of Brake Power With Engine Speed At 80% Load

EFFECT OF ENGINE SPEED ON BRAKE SPECIFIC FUEL CONSUMPTION

Fig. 3 presents the brake specific fuel consumption (BSFC) for conventional diesel fuel, biodiesel fuel and biodiesel blends as a function of engine speed. Good engine performance in terms of fuel economy is reflected by the BSFC parameter. It was observed that for all samples tested, BSFC increased with increase in speed at constant engine load. The fuel consumption of biodiesel is relatively higher than conventional diesel fuel due to the lower energy content of the biodiesel such that for the same volume of fuel more biodiesel fuel based on the mass flow was injected into the combustion chamber than conventional diesel fuel due to its higher density (Aydin and Bayindir, 2010; Ozsezen *et al.* 2009; Karabektas, 2009; Murillo *et al.* 2007; Kaplan *et al.* 2006; Choi *et al.* 2006; Ramadhas *et al.* 2004; Canakci *et al.* 1999). It is a known fact that biodiesel has oxygen content which results in the lower heating value. Thus for the same energy output from the engine, it requires larger mass fuel flow which increases BSFC to compensate for the reduced chemical energy in the fuel.

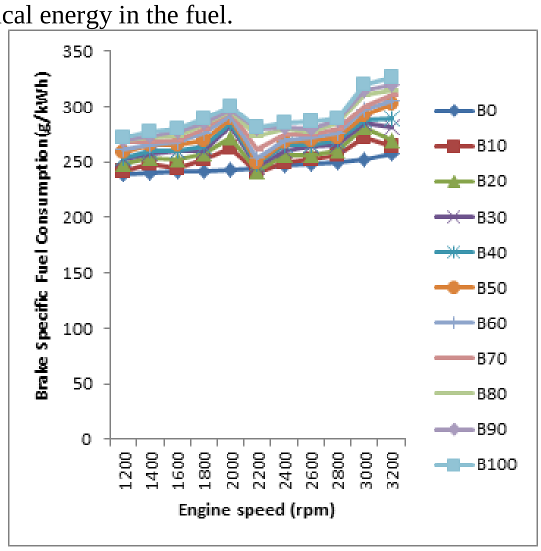

Figure 3: Variation of Brake Specific Fuel Consumption with Engine Speed At 80% Load

EFFECT OF ENGINE SPEED ON BRAKE THERMAL EFFICIENCY (%)

Fig. 4 shows the variation of brake thermal efficiency for conventional diesel, pure biodiesel and varying blends of biodiesel with conventional diesel as a function of engine speed. Brake thermal efficiency is a good measure in assessing how efficient the energy in fuels changes to mechanical output. It was observed that the brake thermal efficiency for conventional diesel, pure biodiesel and varying blends of biodiesel with conventional diesel have similar trends and closely resemble one another which is in agreement with similar works done by (Lapuerta *et al.*, 2008). However, conventional diesel had the highest break thermal efficiency while pure biodiesel had the lowest. The reduction in brake thermal efficiency with biodiesel and blends was as a result of higher viscosity (molecular weight and bulky molecular structure) resulting to larger size fuel droplets injected from the nozzle instead of a spray of the droplets leading to unsuitable pumping, inadequate air-fuel mixing, poor atomization, lower volatility and inefficient mixing of fuel with air contributing to incomplete combustion and lower energy value and hence the thermal efficiency of the biodiesel blends was lower than that of conventional diesel (Lovekush *et al.*, 2012). It has been observed that the fall in brake thermal efficiency and power output in some cases reveals that, specific fuel consumption relates conversely with thermal efficiency and proportional to combustion efficiency (Gopinath *et al.*, 2010). Thermal efficiency is a measure of the combustion process in converting the power in the fuel to mechanical power at the head of the pistons. The mechanical efficiency is a measure of what fraction of that mechanical power that is transmitted to the flywheel. The falling off in thermal efficiency could also be as a result of increase in mechanical losses in engine relative to useful power output, throttling losses and deterioration in combustion efficiency and an increase in concentration of biodiesel in the diesel blends (pathak, 2004; Singh *et al.*, 2007; and Plint and partners, 1984).

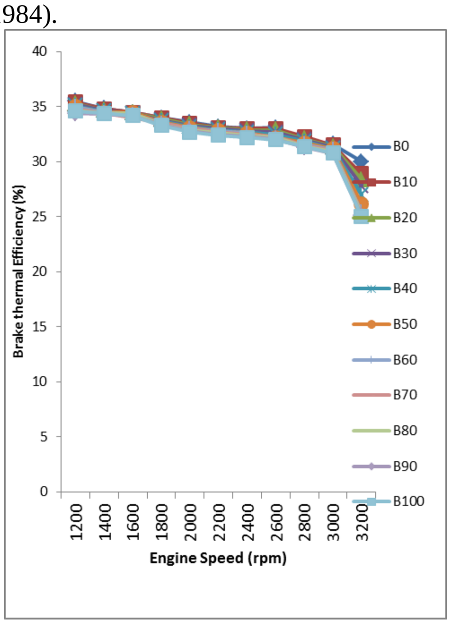

Figure 4: Variation of Brake Thermal Efficiency with Engine Speed At 80% Load

IV. CONCLUSION

- ✓ The behavior of torque with speed variation at constant load showed that the conventional diesel B0 had higher torque value of 96 Nm during engine testing at maximum speed of 3200 rpm, while the engine torque for B10, B20, B30, B40, B50, B60, B70, B80, B90 and B100 at 3200 rpm had values of 90, 88, 86, 84, 82, 82, 80, 78, 76 and 70 Nm which were lower compared to conventional diesel B0.
- ✓ Engine torque decreased with increasing amount of biodiesel in the blends.
- ✓ It was further observed that the brake power of the engine increased with increasing engine speed.
- ✓ The engine brake power for biodiesel fuel and biodiesel blends was found to be slightly less than the engine brake power generated from conventional diesel fuel as the engine speed increased.
- ✓ BSFC of the neat biodiesel and the blended biodiesel fuels increased with increase in speed at constant engine load and has higher break specific fuel consumption values compared to conventional diesel.
- ✓ The brake thermal efficiency of fuel combinations of B10, B20, B30, B40 B50, B60, B70, B80, B90 blends and neat biodiesel B100 were found almost comparable to that of petroleum diesel B0 performance; the performance trend showed that as the speed increased the brake thermal efficiency decreased.
- ✓ Based on the parameters measured and analyzed, it was concluded that blends of B10 to B40 can be used without making any engine modifications.

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