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PERFORMANCE OF A CI ENGINE FUELLED WITH CASHEW NUT SEED OIL BIODIESEL- EFFECT OF LOAD

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ABSTRACT
Investigation of the performance of cashew- nut seed oil biodiesel and its blends with petroleum diesel in an internal combustion (I.C.) engine was undertaken. The seeds of cashew-nut were grounded using a grinding engine and pressurized mechanically using manual method to extract the oil. The oil was then transesterified to biodiesel using 1% potassium hydroxide (KOH), as catalyst with 102.2g of ethanol and 282g of oil at 60°C with stirring over water bath maintained for 10 minutes. The biodiesel produced was further blended with diesel fuel in the ratios of 10% - 100% cashew-nut oil biodiesel to petroleum diesel (designated as B_{10} – B_{100}). Thereafter, chemo-physical analysis of the diesels was undertaken. The results of the chemo-physical properties were within the specifications set by the American System for Testing and Materials (ASTM). The biodiesel, petroleum diesel and their blends were further subjected to engine performance tests under a constant speed of 3200rpm and varying loads of between 10% and 80%. The results showed that engine torque increased with load, engine power increased and break specific fuel consumption decreased with load while they both increased with increase in biodiesel in the blends; break thermal efficiency increased with load but decreased with biodiesel concentration in blends. For the engine exhaust emissions, carbon monoxide concentration in the exhaust was found to decrease with increase in load and with increase in biodiesel concentration in the blends; nitrogen oxides (NOx) and exhaust gas temperature increased with load and with biodiesel concentration. Generally, it was concluded that the performance of the CI engine fuelled with the cashew nut seed biodiesel blends, B10-B40, was satisfactory and comparable to petroleum diesel.

INTRODUCTION
The research into alternatives to petroleum diesel fuels has been driven majorly by the depletion of fossil fuels coupled with its attendant environmental pollution, global warming and stricter regulations of pollutant emissions. As a result, biodiesel has been found to be a viable alternative to petroleum diesel. Biodiesel is a mixture of mono-alkyl esters of different chain lengths and fatty acids. It can be obtained through the trans-esterification of oils from various plant and animal sources such as palm oil, palm kernel oil, castor seed oil, rapeseed oil, cotton seed oil, animal fats and waste cooking oil, etc. Biodiesel has considerable advantages over conventional diesel such as its biodegradability, non-toxicity, lower exhaust emissions and the widespread availability of its sources in every country, etc. But as varied as its sources are, their compositions also vary as a result of their different fatty acid profiles which, in turn, affect their chemo-physical properties. These properties affect engine performance parameters such as torque, break power, break specific fuel consumption, break thermal efficiency and engine exhaust emissions. Fuel lubricity and miscibility are also affected. It is, therefore, necessary to study the effects of biodiesels from each source on engine performance in order to determine its suitability as substitutes for petroleum diesels. Consequently, several researchers have worked on the production and use of biodiesels in internal combustion engines such as Pramanik, (2003) who carried out research on comparative study of the effect of castor and jatropha oil source and their methyl esters on the diesel engine and concluded that there is no effect of fuel type on fuel consumption up till 20% biodiesel blended fuel. Rao *et al.* (2008) produced two biodiesels from mustard seed oil and pongamia-ponnata seed oils and blended them with diesel at various mixing ratios. The result of these blends in engine and exhaust emission were examined in a single cylinder direct injection air cooled and high speed diesel engine at varying loads and at constant speed of 3000 rpm. The results showed that thermal efficiency of blends was greater than diesel and emissions of smoke, hydrocarbons and NOx of dual biodiesel blends were higher than that of diesel, but the EGT for dual biodiesel blend was lower than diesel. Other researchers such as Ekrem (2010), Sathiyagnanam *et al.* (2011), Gaba *et al.*(2012), Roy *et al.* (2013), , Iortyer *et al.* (2016; 2017), e.t.c., have worked on several biodiesels produced from different feed stocks and reached various

conclusions regarding their suitability for use as alternative fuels in compression ignition engines. However, it is difficult to find any research work on production of biodiesel from cashew nut seeds which are abundant in some African countries including Nigeria. Therefore, the major objective of this research was to investigate the performance of cashew- nut seed oil biodiesel and its blends with petroleum diesel in a compression ignition engine.

MATERIALS AND METHODS

The cashew nuts (i.e tall variety of anacardium *occidentale* nuts) were obtained from the open market and sun-dried to reduce moisture and the seeds manually extracted from the nuts. The *anacardium occidentale* seeds were crushed into a paste using a corona hand grinding engine. The paste was mixed with hot water to ease the flow of oil. 10ml of hot water was mixed with 100g of cashew seed paste and manually squeezed to obtain the oil. The oil was collected in a container. 50kg of cashew nuts produced 2litres of oil. The oil collected was trans-esterified to obtain biodiesel at the chemistry laboratory of the University of Agriculture, Makurdi, Benue State, Nigeria. The resulting biodiesel was blended with petroleum diesel to obtain blends of B10, B20, B30 up to B100. Chemo-physical analysis of the petroleum diesel, *cashew* seed oil biodiesel, biodiesel blends and oil was carried out according to ASTM recommended procedures. Engine performance tests were conducted on a 3.2 kW Bhojson 165F single cylinder, four stroke, direct injection, bowl-in-piston combustion chamber, compression ignition, diesel engine to which a dynamometer was connected. Tests were conducted at constant speed and varying loads for all fuel samples. The experiment was conducted at 10%, 20%, 30%, 40%. 50%, 60%, 70% and 80% load respectively. Engine speed was kept constant at 3200rpm. The performance parameters investigated were engine torque, brake power, brake specific fuel consumption, brake thermal efficiency, exhaust emissions and exhaust gas temperature. Exhaust gas temperature was measured using K-type thermocouples while exhaust emissions such as NOx, CO, HC were measured using gas analyser and smoke opacity was measured using the smoke meter. Some selected chemo-physical properties of the diesel and biodiesel, schematic layout of the test system and engine specifications are given in table1, figure 1 and table 2 respectively.

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

Parameters	AGO B0	Biodiesel B100
Flash Point °C	60	166
Moisture Content %	0.02	0.84
Heat of Combustion mJ/kg	43.6	29.1
Kinematic Viscosity@ 40°C	5.5	5.9
Specific Gravity @15°C (g/cm^3)	0.87	0.90

1) Test engine
2) Dynamometer
3) Fuel flow meter
4) Fuel pump with filte
5) Fuel tan
6) Cooling tower
7) Exhaust pipe
8) Exhaust gas analyzer unit
9) Control unit.

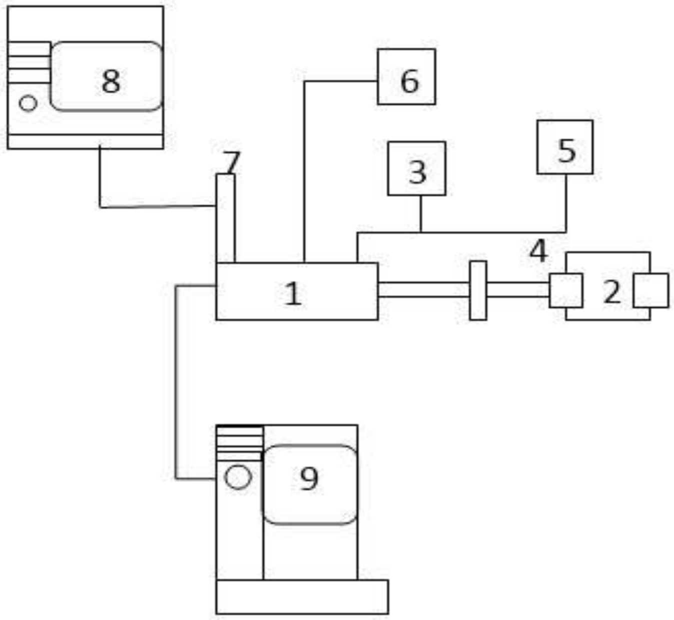

Fig. 1: Schematic Layout of the Test System

TABLE 2: TECHNICAL SPECIFICATION OF ENGINE USED FOR TEST

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

RESULTS AND DISCUSSION

Effect of load on Torque (T)

The effect of load on Torque at the various load variations for diesel, biodiesel and their blends, $B_{10} – B_{90}$ are as shown in fig. 2. It will be observed that torque increases for every increase in load (10% - 80%) for all the fuels. The increase in torque is due to higher calorific value of pure diesel, biodiesel and blends with diesel (Ejijah and Asere, 2009). It will be observed that biodiesel, B_{100}, has lower torque when compared with diesel fuel, B_0. This may be because the calorific value of biodiesel is lower than the calorific value of diesel (Wirawan *et al.*, 2008). It will also be observed that the power and torque of the blends are higher than that of biodiesel. If fuel viscosity is high, the injection pump will be unable to supply sufficient fuel to fill the pumping chamber which will lead to power loss for the engine (Knothe *et al.*, 2004). The performance of the blends in the engine shows a significant improvement over both pure cashew seed oil biodiesel and petroleum diesel. This can be attributed to the lower viscosity of the blends when compared with biodiesel and the oxygenated nature of the biodiesel component of the blends which enables better combustion and release of energy thereby giving rise to higher torque values. Also, the higher viscosity of the blends and the volumetric nature of the pump ensures that for the same volume of biodiesel and petroleum fuels, a larger mass of the biodiesel blends is injected into the engine cylinder which releases higher amounts of energy when combusted. The torque of blends increased from B10 to B40 and decreased from B50 t0 B100

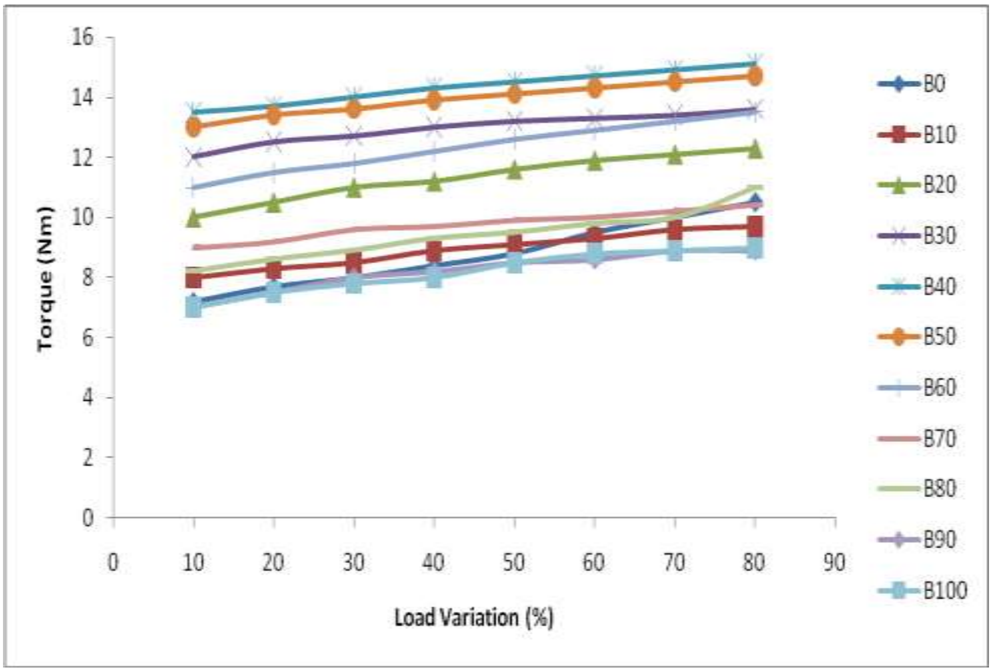

Fig. 2: Effect of Load Variation on Torque at 3200 rpm

Effect of load on Brake Power (B.P)

The effect of load on brake power for is shown in fig 3. It will be observed that the brake power increases as the load increases from 10% - 80% for the diesel, B_0, biodiesel, B_{100}, and blends, $B_{10} – B_{90}$. The power increase agrees with the trend observed in results obtained by Godiganur *et al.* (2009) and Mustapic *et al.*(2006). They explained this in the following ways:

1) High content of oxygen in biodiesel fuel which enables more complete combustion.
2) Increase in fuel density by blending biodiesel with fossil diesel.
3) The fact that fuel injection pump is volumetric and so more fuel mass can flow in the same volume which further results in more engine power. According to Usta (2004), despite the negative effect of increased kinematic viscosity on the atomization process and air-fuel mixing, a slight increase can affect positively the engine performances since it enables less internal fuel leakage and spray penetration.

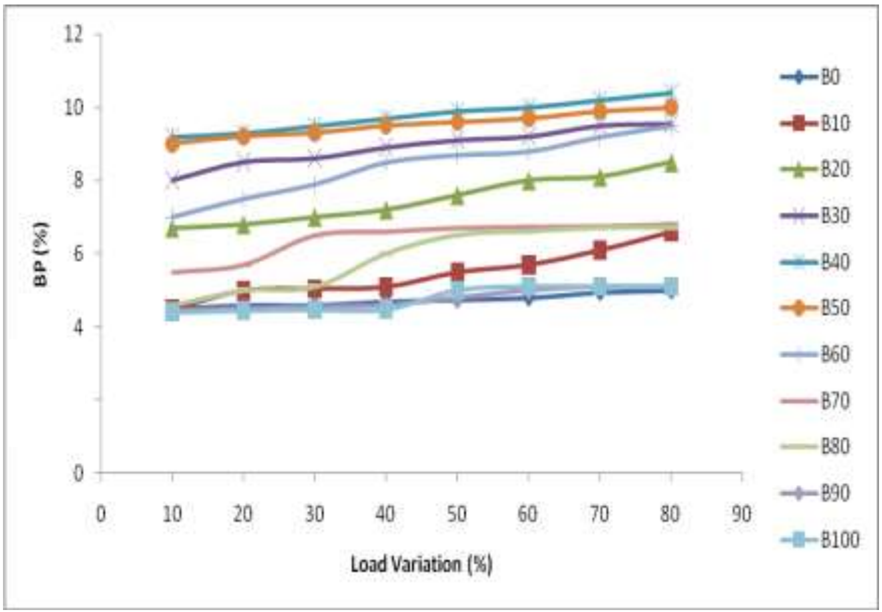

Fig 3: Effect of Load Variation on BP at 3200 rpm

Effect of Load on Brake Specific Fuel Consumption, BSF.
The effect of varying load on brake specific fuel consumption is shown in fig 4. BSF is the ratio of mass flow of the tested fuel and effective power. It will be observed that the BSF decreases with increase in engine load. This may be due to good atomization at higher pressure which helps in faster rate of heat release (Serada *et al*., 2010). Also on observation, the BSF decreases with increase in load while the BSF values of the biodiesel and its blends are seen to be higher than those of diesel fuel under almost all range of engine load. This is because, according to Ekrem (2010), the BSF of diesel depends on the relationship between volumetric fuel injection system, fuel density, viscosity and lower heating value. He continued that more biodiesel and its blends are needed to produce the same amount of energy due to its lower heating value in comparison with diesel fuel. Therefore, BSF increases with increasing proportion of biodiesel in the blends.

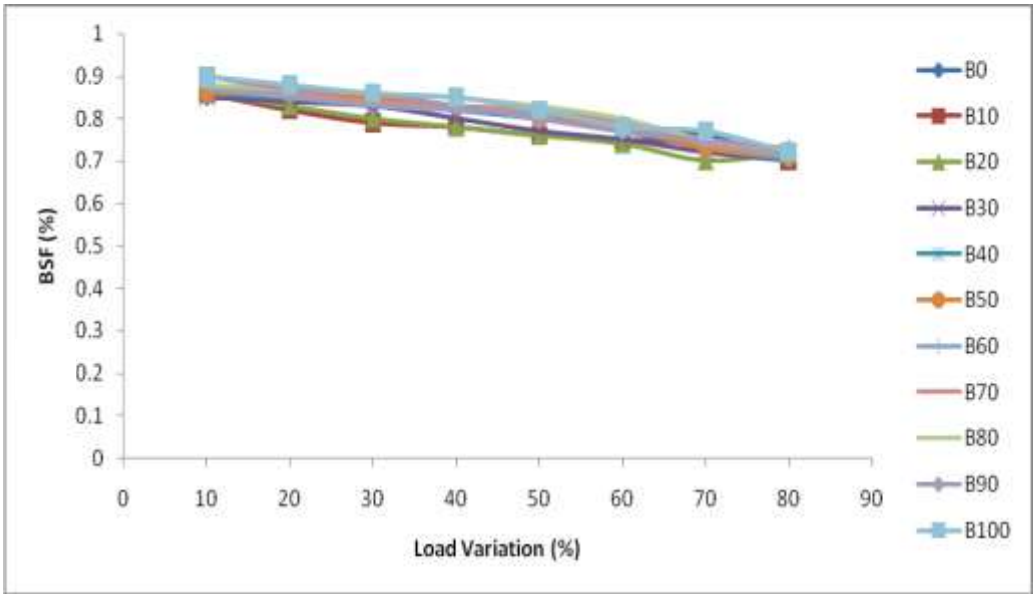

Fig 4: Effect of Load Variation on BSFC at 3200 rpm

Effect of Load on Brake Thermal Efficiency, BTE.

The effect of load on brake thermal efficiency, BTE, can be observed in fig 5. BTE is the ratio of the power output and the energy introduced through fuel injection; the later being the product of the injected fuel mass flow rate and the lower heating value. The reduction in viscosity of the blends leads to improved atomization, fuel vaporization and combustion. It may also be due to better utilization of heat energy and better air entrainment (Ekrem, 2010). The BTE of the diesel, biodiesel and blends increases with increase in load. This shows the converse relationship between the specific fuel consumption and brake thermal efficiency. The increase in break thermal efficiency therefore means that less fuel is injected for same output (Serada *et al.*, 2010).

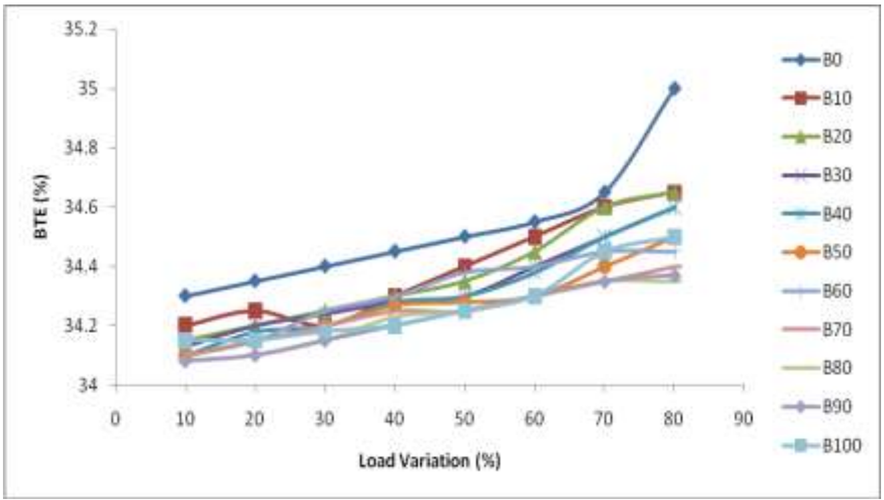

Fig 5: Effect of Load Variation on BTE at 3200 rpm

Effect of load variation on carbon monoxide, CO, emission

Fig 6 shows the effect of load variation on CO emission. It will be observed that the CO emission is higher at low engine load than at high engine load. According to Roy *et al*. (2013), the higher the engine load, the lower the CO emissions for all fuels. This, according to him, is due to better evaporation and mixing of air and fuels at higher loads for higher in-cylinder temperatures. It will also be observed that biodiesel produces lower CO emissions than diesel fuel. This is due to the higher oxygen content of biodiesel as compared to diesel fuel which promotes complete combustion and thus, reduction in CO emissions (Aydin *et al*., 2010; Karabektas, 2009; and Buyukkaya, 2010). Biodiesel may therefore be said to be superior to diesel fuel in terms of CO emission.

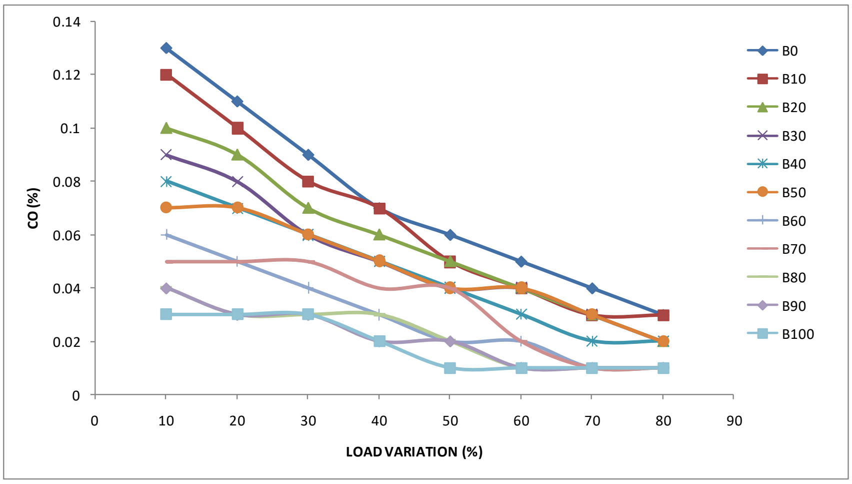

Fig 6: Effect of Load Variation on CO at 3200 rpm

Effect of load variation on NOx emission

The effect of load variation on NOx emission at 3200rpm can be observed in fig 7. It will be observed that the NOx emission for diesel fuel is less than that of cashew seed oil biodiesel. The high temperature of combustion and the presence of oxygen with biodiesel cause higher NOx emissions especially at high engine loads (Sathiyagnanam *et al*., 2011). The NOx of the blends are also higher than that of diesel. Nabi *et al*. (2009) attributed this to the presence of extra oxygen in the molecules of biodiesel blends. The main factors therefore affecting NOx emissions are oxygen concentration, combustion temperature and time. NOx emission is also seen to increase with load. This is confirmed by Obeweis *et al*. (2010) who stated that NOx emissions increase moderately with load similar to the effect of load on exhaust gas temperature but not at the same rate of increase. At low load, diesel has NOx of 80ppm while biodiesel has NOx of 150ppm and at maximum load, NOx emission is 95ppm and 166ppm for petroleum diesel and biodiesel respectively.

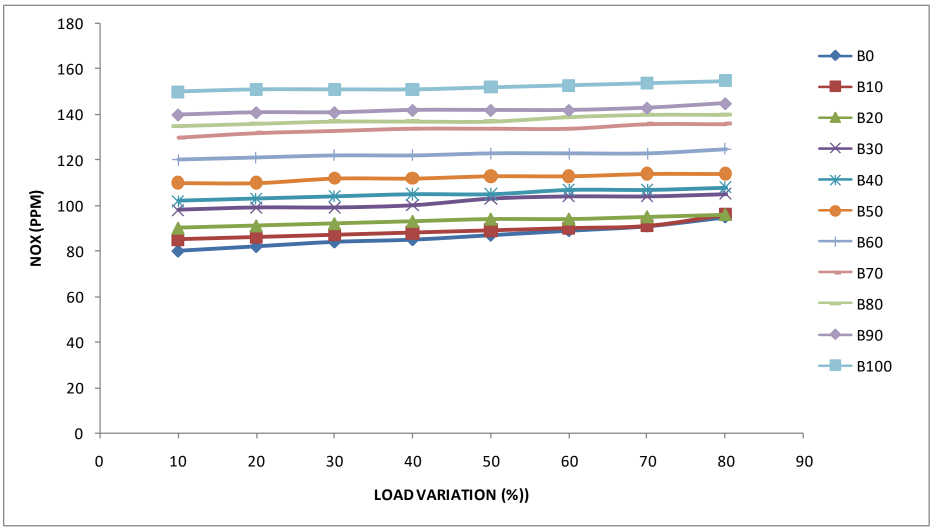

Fig 7: Effect of Load Variation on NOx at 3200 rpm

Effect of Load variation on Hydrocarbon, HC

The effect of load variation on Hydrocarbon at 3200rpm can be observed in fig 8. Diesel fuel produces more HC emission when compared with biodiesel, B_{100}. The emission of HC decreases with increase in load. The low HC emission observed with increase in load can be attributed to better mixing of air and fuel due to higher evaporation at higher engine loads for higher in – cylinder temperature.

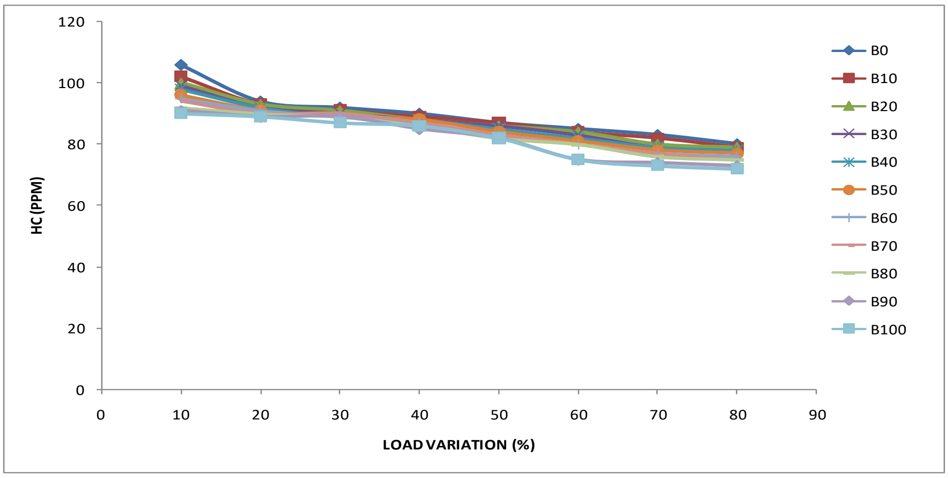

Fig 8: Effect of Load Variation on HC at 3200 rpm

Effect of Load Variation on Smoke Opecity, SC

Fig. 9 describe the effect of load variation on smoke opacity (SC) at 3200rpm. It can be observed that the smoke opacity increased with increase in load. This according to Raheman *et al.* (2007), is due to the decreased air-fuel ratio at higher loads when larger quantities of fuel are injected into the combustion chamber, much of which goes unburnt into the exhaust.

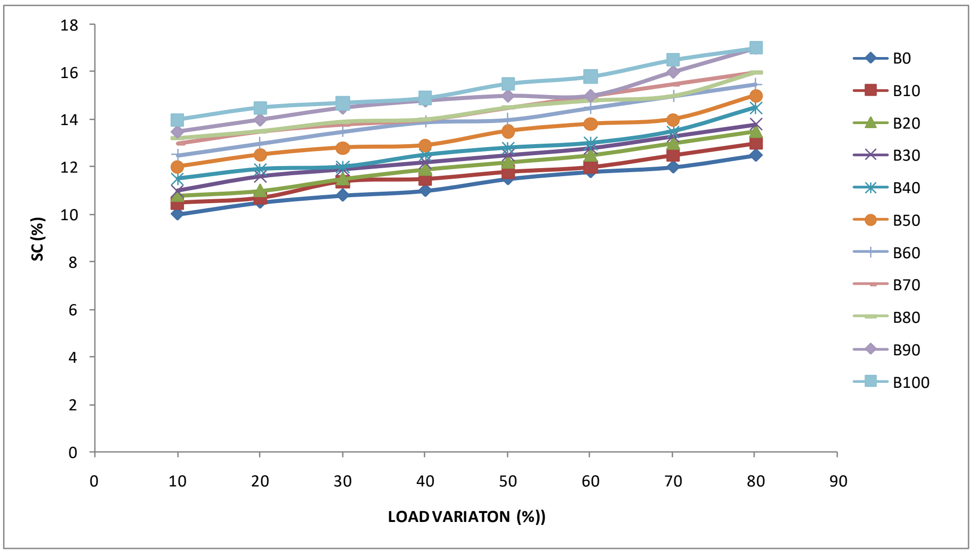

Fig. 9: Effect of Load Variation on SC at 3200 rpm

Effect of Load Variation on Exhaust Temperature, Tg.

Fig 10 shows the effect of load variation on Tg at 3200rpm. It will be observed that the exhaust gas temperature for biodiesel, B_{100}, is highest and lowest for diesel fuel among all the tested sample of fuel. The exhaust gas temperature of engine with biodiesel is higher due to the presence of excess energy supply to the engine (Gaba *et al.*, 2012)

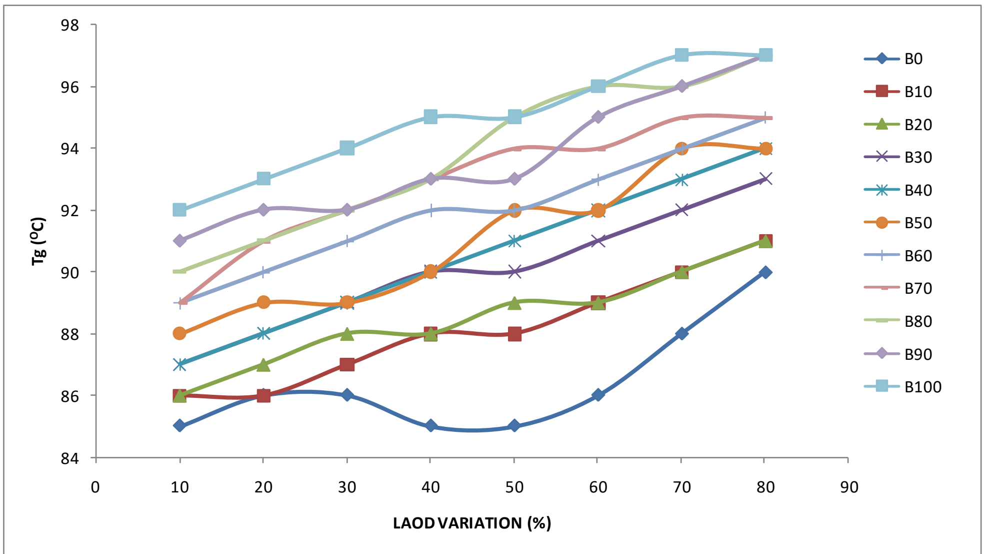

Fig 10: Effect of Load Variation on Tg at 3200rpm

CONCLUSION

In this research, the effect of load on the performance of cashew seed oil biodiesel was evaluated. Cashew nut oil was transesterified into biodiesel which was then characterized for chemo-physical properties and then used to run a 3.2 kW Bhojson 165F single cylinder, four stroke, direct injection, bowl-in-piston combustion chamber, compression ignition diesel engine to which a dynamometer was connected. The following conclusions were arrived at: Engine torque increased with load; Engine power increased and break specific fuel consumption decreased with load while they both increased with increase in biodiesel percent in the blends; break thermal efficiency increased with load but decreased with biodiesel concentration in blends. Carbon monoxide concentration in the exhaust decreased with increase in load and with increase in biodiesel concentration in the blends. Nitrogen oxides (NOx) and exhaust gas temperature increased with load and with biodiesel concentration. Generally, it can be concluded that the performance of the CI engine with cashew seed and the biodiesel blends, B10-B40, have shown potential to be used as fuels in compression ignition engines without modification.

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