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International Journal Of Modern Engineering Research (IJMER)

Experimental Investigation of Performance and Emission Characteristics of Biodiesel from Sterculia Striata

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Abstract: *With this increase in population, industry, transportation the cost of fossil fuels will grow dramatically. There is a need of new technologies for fuel extraction using feed stocks that do not threaten food security, cause minimal or no loss of natural habitat. At the same time, the fuel should be environmental friendly so that environmental pollution should be minimized or eliminated. The search of vegetable oils as the fuels for engine has been developed. This paper presents the characterization, results of investigation of combustion performance and emissions characteristics of diesel engine using Sterculia Striata biodiesel. In this investigation, the blends of varying proportions of Sterculia Striata biodiesel and diesel were prepared, analyzed compared with the performance of diesel fuel, and studied using a single cylinder diesel engine. The brake thermal efficiency, brake-specific fuel consumption, exhaust gas temperatures, CO, HC, NOx, and smoke emissions were analyzed. The emission from the engine exhaust is lesser with the biodiesel compared with that of the neat diesel engine.*

Keywords: *Sterculia Striata; Characterization of biodiesel; Combustion Parameters; Emission Characteristics*

I. Introduction

The concept of using vegetable oil as engine fuel is as old in the engine but the recent research shows renewed interest on biodiesel as fuel in diesel engines. The lower cost of the petroleum diesel has so far attracted the world to use it as fuel in diesel engines until now. But now-a-days due to global political turmoil and other reasons, the cost of petroleum diesel has been increasing exponentially. Moreover, the emission norms are more stringent as ever before. In this context, many biodiesels have been used now-a-days. Sterculia Striata biodiesel is one of the most promising biodiesel among them.

Shrirame et al. 2011 proposed that the biodiesel can be used as 20% blend with petro diesel in existing engines without any modification. Both the edible and non-edible vegetable oils can be used as the raw materials for the biodiesel. Xue et al. 2009 developed a process for the trans-esterification of Jatropha curcas L. seed oil with methanol using artificial zeolites loaded with potassium acetate as a heterogeneous catalyst. The optimum reaction conditions for trans-esterification of J. curcas oil were also investigated. Ueki et al. 2011synthesized an efficient fibrous catalyst for the biodiesel fuel production by radiation-induced graft polymerization of 4-chloromethylstyrene onto a nonwoven polyethylene (NWPE) fabric followed by lamination with tri-methylamine (TMA) and further treatment with NaOH. Kamimura et al. 2011 analyzed market means in economic terms to various regions of Brazil. Two regions – North and Midwest still display a high degree of poverty for small farmers. The national biodiesel program may represent an interesting economical alternative for them.

II. Sterculia Striata

Sterculia striata is also known as chichá-do-cerrado. It is a tree subfamily of Sterculioideae. The trees are in the height of 8-15 m and trunk diameter of 40 cm. These trees annually produce red fruits that open and contain nuts, which are consumed by man and wildlife. The Dry fruit of sterculia striata is shown in the Figure 1. It is a type of Pioneer plant fast-growing and tolerant of dry and stony land. Sterculia Striata is commonly known as Chicha oil.

Chicha has its origin in India and Malaysia where the seeds are consumed in dried and roasted form (Mangas et al. 2012). It is also available as a source of vegetable oil. This species is also commonly available in the Northeast of Brazil where it grows as a wild tree. The plant starts to produce fruits within 18-24 months from plantation. As an adult tree it can produce about 40kg of seeds per year. The seeds contain up to 60% kernels that contains lipids at concentrations varying from 28 to 32%.Many experimental studies of Sterculia striata biodiesel as a diesel substitute have been done (Aline et al. 2010, Ana et al. 2004, 2005, Aued et al. 2004, Brito et al. 2004, Dario et al. 2010, Oliveria et al. 2000, Sabria et al. 2004, Silvia et al. 2003, Zeomar et al. 2008). The major properties of Sterculia Striata biodiesel include calorific value, diesel index, flash point, fire point, cloud point, pour point, specific gravity, and kinematic viscosity. The various physicochemical properties of diesel and Sterculia Striata biodiesel are measured and listed in Table 1 for comparison.

It can be noted that the calorific value of Sterculia Striata biodiesel is less than that of diesel. This might be due to the presence of oxygen atoms in the fuel molecule of Sterculia Striata biodiesel. The kinematic viscosity is, respectively, greater in the case of Sterculia Striata biodiesels than that for diesel. The higher viscosity of Sterculia Striata biodiesel could potentially have an impact on the combustion characteristics because the high viscosity affects its atomization quality slightly. The pour and cloud points of Sterculia Striata biodiesel are also favorable. However, the flash point of Sterculia Striata biodiesel is much higher than that of diesel, which makes Sterculia Striata biodiesel safer than diesel from ignition due to accidental fuel spills during handling. It can be seen that the properties of Sterculia Striata biodiesel are found to be within the limits of biodiesel specifications of many countries.

Many researchers investigated the effects of diesel biodiesel blends on performance and emission characteristics in diesel engine and concluded that partial or full replacement of diesel with biodiesel is feasible (alamu et al. 2008, antony et al. 2011, Juhun et al. 2004, kurzin et al. 2007, Thompson, Singh et al. 2010). However, the experimental study of performance and emission characteristics of Sterculia Striata biodiesel on diesel engine is hardly reported. Therefore, such an attempt is made in the present work, to experimentally investigate the performance (brake thermal efficiency, brake-specific fuel consumption, and exhaust gas temperature) and emission (carbon monoxide, unburned hydrocarbon, nitrogen oxides, and smoke) parameters of Sterculia Striata biodiesel and diesel- Sterculia Striata biodiesel blends as fuel in diesel engine.

III. Bio-diesel Processing

Biodiesel is a mono alkyl ester that is derived from vegetable oils or animal fats through trans-esterification. The purpose of trans-esterification is to reduce the viscosity of vegetable oils. All the vegetable oils were trans-esterified with an optimized alkali catalyzed process, which also vary depending on the oil. According to the oil used, the process parameters were adjusted to achieve the maximum ester yield. The process parameters such as alcohol to oil ratio (6:1 molar ratio), catalyst quantity (NaOH, 0.5 wt. %), reaction temperature (65 °C) and reaction time (2 hr) were optimized for a single oil and then subsequently adjusted for other oils. Alkali catalyst was used because of its low cost and also it is easily miscible with methanol. Methanol was used because of its low cost. The biodiesel produced from different oils were washed and dried. Then different biodiesels were blended with different percentage to vary the % of unsaturation. The biodiesel produced were checked for the quality. The important fuel properties were measured as per the ASTM standards and compared with the ASTM limits. It was observed that all the biodiesel fuels have qualified to the ASTM standards.

IV. Experimental Method

Before the present research work was carried out the main technical features of the engine should be studied. The specification of engine and testing conditions are presented in Table 2 and Table 3 respectively. The main objective has been to study the performance and emission characteristics of Sterculia Striata biodiesel as fuel in diesel engine. For conducting the desired set of experiments and to gather required data from the engine, it is essential to get the various instruments mounted at the appropriate location on the experimental setup.

V. Experimental Setup

A single cylinder water-cooled direct injection CI engine developing a power output of 5.2 kW at the rated speed of 1500 rpm was used for the experimental studies. The engine was coupled to an electrical dynamometer. The engine was fitted with all accessories to measure the fuel consumption, air consumption, inlet air temperature, and exhaust gas temperature. The engine was started with neat diesel fuel and warmed up. It was allowed to run for 10 minutes with biodiesel to attain steady condition at its rated speed of 1500 rpm. The engine was gradually loaded to five different load conditions like 20%, 40%, 60%, 80%, and 100% by switching on the load mains. The different biodiesel fuels and their blends were tested in a random order. The speed of the engine was maintained at 1500 rpm and the time taken for 10cc of fuel consumption was measured using a stopwatch. The tests were repeated for five times and the average value of the five readings was taken to eliminate the uncertainty. The in-cylinder pressure, NOX, CO, HC, smoke, and exhaust gas temperature were measured at the entire five loads for different biodiesel fuels blends.The entire experimental work was carried out in the laboratory at room temperature (28.7°C) and atmospheric pressure (1.01325 bar). Before measuring all the engine exhaust emissions and cylinder gas pressure, the instruments such as gas analyzer and pressure sensor were calibrated and verified with the accuracy levels.

VI. Measurement of Emission

The NOX, HC, CO emissions were measured by QROTECH, QRO-401 exhaust gas analyzer. Smoke intensity was measured using a Bosch smoke meter. The temperature of the exhaust gas was measured by using K-type (chrome – alumel) thermocouple with digital indicating unit. The probe that was connected to the exhaust gas analyzer was placed inside the exhaust pipe. HC and NOX were measured in ppm and CO in % by volume and then converted into g/kWh. The smoke intensity was measured in BSU (Bosch Smoke Unit). A "U" tube manometer was used to measure the airflow rate. One end of the manometer was left free to ambient and the other end was connected to the surge tank. The photographic view of test engine is shown in Figure 2 while Figure 3 depicts the pressure and emission measuring setup. The schematic of entire experimental setup is illustrated in Figure 4.

VII. Result and Discussion

The results of experimental investigations are compared to identify the best fuel which has a lower emission and less effect on environment. The performance and the emission characteristics are discussed separately.

VIII. Performance Parameters

Fueling the diesel engine with the biodiesel shows some shift in the performance characteristics. The performance parameters like Exhaust gas Temperature, Brake Specific fuel consumption, Brake specific energy consumption, Brake Thermal Efficiency are discussed.

IX. Exhaust Gas Temperature (EGT)

The relationship between exhaust gas temperature (EGT) and load for different fuel blends and diesel has been shown in Figure 5. The results showed that with the increase in the load increases EGT in all the blends of sterculia striata biodiesel and diesel operation. The increase in EGT with increase in load may be due to the increased cylinder pressure due to improved combustion of fuel as a result of improved atomization at warmed-up condition. The increase in EGT with increase in the proportion of sterculia striata biodiesel may be due to the delayed combustion. This may also be due to the slower combustion characteristics of sterculia striata biodiesel.The exhaust gas temperature of biodiesel is comparable lesser than that of diesel. The percentage of biodiesel blends in the decreases the temperature of the exhaust gas to a greater extent.

X. Brake-Specific Fuel Consumption (BSFC)

Figure 6 shows the comparison of effect of load on brake-specific fuel consumption between diesel and sterculia striata biodiesel for different blend conditions. It is seen that brake-specific fuel consumption increases when the load is increased for all operations of diesel and sterculia striata biodiesel and their blends. It can also be observed that brake specific fuel consumption increases when sterculia striata biodiesel proportion in the blend is increased for any given load.At 100% load the sterculia striata shows the maximum brake specific consumption of 0.294 kg/hr compared to other blends of sterculia striata. Similarly the values of other loads are also tabulated, which results that the B100 has maximum fuel consumption and diesel has the least fuel consumption values.

XI. Brake Specific Energy Consumption (BSEC)

Brake specific energy consumption (BSEC) is the product of the brake specific fuel consumption and calorific value. BSEC depends on the fuel consumption rate and the fuel properties. The important property of the fuel is calorific value. It affects the energy consumption to a greater extent. The comparison of the specific energy consumption of diesel and different blends of sterculia striata is shown in the Figure 7.

XII. Brake Thermal Efficiency (BTE)

Brake Thermal Efficiency characteristics of sterculia striata biodiesel, diesel, and their blends are shown in Figure 8. It is observed that at any given load condition, the brake thermal efficiency of neat sterculia striata biodiesel (B-100) and other blends (B-25, B-50, B-75) is lower than that of diesel operation. It can be seen that as the percentage of sterculia striata biodiesel in the blend increases, there is more decrease in brake thermal efficiency as compared to diesel fuel mode, that is, diesel operation. This lower BTE of sterculia striata biodiesel operation is due to the combined effect of higher viscosity, higher density of sterculia striata biodiesel. The efficiency of the engine depends on the properties of the fuel used. The efficiency of the B100 is comparable to the efficiency of the diesel engine. The blend of sterculia striata B25 has a efficiency of 30.96% which is very near to that of the diesel engine.

XIII. Emissions Parameters

The environmental pollution is mainly due to automobile exhaust. To minimize or eradicate the formation of pollutants, biodiesel are used as a fuel for the diesel engines. The effect of reduction in pollutants from the diesel engine is measured. The major emission parameters are discussed here are Smoke, Carbon Monoxide, Hydrocarbon, Carbon-di-oxide, Oxygen, and Oxides of nitrogen.

XIV. Smoke Density (HSU)

Figure 9 shows variation of smoke density for diesel, Sterculia Striata biodiesel, and its blends, respectively, at five various loads. From the figure it follows that smoke density increases with increase in load. It is observed that smoke emissions are higher for diesel and blends compared to bio-diesel sterculia striata oil. The smoke is undesirable from the engine exhaust. The smoke density measured for five different load conditions are compared. In 100% load condition the B100 fuel has less smoke density of 43.96 HSU compared to other fuels. Diesel has the maximum smoke release and its percentage decreases by blending it with sterculia striata bio-diesel.

XV. Carbon Monoxide (CO)

The effect of load on carbon monoxide (CO) emissions for diesel, neat sterculia striata biodiesel, and their blends is shown in Figure 10. It can be seen from the figure that the lowerer CO emissions were obtained with blends of sterculia striata biodiesel and diesel and neat sterculia striata biodiesel mode of operation. The Co is 0.04, 0.037, 0.034, 0.31, 0.28 % by volume for diesel, B-25, B-50, B-75, and B-100, respectively, at 100% load. CO emissions in the exhaust gas of the engine may be attributed to the polymerization that takes place at the core of the spray; this also caused concentration of the spray core and decreased the penetration rate. Low volatility polymers affected the atomization process and mixing of air and fuel causing locally rich mixture, which leads to difficulty in atomization and vaporization of neat sterculia striata biodiesel due to improper spray pattern produced. The CO emission is also undesirable one from the exhaust of the engine. The CO emission of the biodiesel sterculia striata and its blends with diesel and the pure diesel fuel is compared to identify the less emission fuel. The B100 has the less CO emission of 0.028% compared to other fuels.

XVI. Unburned Hydrocarbon (UHC)

The effect of load on unburned hydro-carbon (HC) emissions for diesel, neat sterculia striata biodiesel and their blends is shown in Figure 11. It can be seen from the figure 11that the lower HC emissions were obtained with blends of sterculia striata biodiesel and neat sterculia striata biodiesel. HC emission is 44, 41, 30, 24, 18 ppm for diesel, B-25, B-50, B-75, and B-100, respectively, at 100% load. Lower HC emissions in the exhaust gas of the engine may be attributed to the efficient combustion of sterculia striata biodiesel and blends due to the presence of fuel bound oxygen and warmed-up conditions at higher loads. On the comparison biodiesel B100 has the least emission of 18 ppm whereas the diesel has the highest emission of 44ppm which is very dangerous pollutant.

XVII. Carbon Monoxide (CO_2)

The CO2 emission from a compression ignition engine is the result of better combustion, while HC and CO are of poorer combustion. The CO2 emission of diesel and different blends of sterculia striata biodiesel is shown in the figure 12.The CO2 emission of the B100 is more compared to other fuel which makes it a desirable fuel for engines. B100 has the 6.9 % of carbon di oxide emission. The diesel has lesser value of 6.3 % by volume.

XVIII. Oxygen (O_2)

O2 emissions are oxygen particles released into an exhaust system. Oxygen release is required for an engine to work properly, as it supports the combustion process that makes an engine run. Too much oxygen means there is not enough fuel and will cause stress on the engine, which will result in damage to the engine. Too little oxygen means there is too much fuel saturating the engine's cylinders, which will result in bad fuel efficiency and possible loss of horsepower. O2 emissions are measured and controlled by an O2 sensor. The oxygen emission of diesel and various blends of sterculia striata under different load conditions are shown in the Figure 13.There is no much difference in the oxygen emission. From the figure it is clear that the emission by using the different blends of the biodiesel gives nearly similar values only.

XIX. Oxides of Nitrogen (NOx)

Oxides of Nitrogen (NOx) is generally formed at a temperature higher than 1500◦C. High temperature, especially in the regions containing O2, and time spent at these temperatures are very conducive to NOx formation. The amounts of N2 and O2 existing in the region are also factors in NOx formation. Figure 14 shows NOx variations depending on the load of the engine. It was observed that NOx emissions were higher for neat Sterculia striata biodiesel and blends compared to diesel at almost all loads. The increase in NOx emissions with increase in the proportion of Sterculia striata biodiesel may be due to the delayed combustion. Also the higher oxygen content of biodiesels leads to more complete combustion resulting in greater combustion temperature peaks which caused higher no emissions. However, the higher viscosity and density of biodiesel caused delayed combustion phase which results in the slower combustion characteristics of Sterculia Striata biodiesel.The NOx emission of diesel is less than the biodiesel and its blends. Sterculia striata shows the maximum emission of 676 ppm and the diesel shows the minimum of 625 ppm.

XX. Conclusion

The performance characteristics like brake thermal efficiency, brake specific fuel consumption, and exhaust gas temperature and emission characteristics, carbon monoxide, unburned hydro-carbon, nitrogen oxides, and smoke of a single cylinder four stroke vertical direct injection Kirloskar TV-1 engine using sterculia striata biodiesel and diesel- sterculia striata biodiesel blends as fuels were experimentally investigated. The following conclusions are made based on the experimental results.

1. As the proportion of sterculia striata biodiesel increases in the blend, the brake thermal efficiency decreases. For B-100, the brake thermal efficiency was less than that of diesel at full load.More the proportion of sterculia striata biodiesel in the blend more is the increase in brake specific fuel consumption for any given load.
2. The carbon monoxide emissions are reduced by 30% with neat sterculia striata biodiesel operation when compared to diesel mode at full load condition.HC emissions for sterculia striata biodiesel and blends are quite low compared to diesel. At higher loads, as the quantity of sterculia striata biodiesel in the blend increases HC emissions decreases.
3. The NOx CO2 and O2 are higher for neat sterculia striata biodiesel and blends when compared to diesel at almost all loads.
4. The smoke density CO and HC emissions are lesser for neat sterculia striata biodiesel and blends when compared to diesel at almost all loads.

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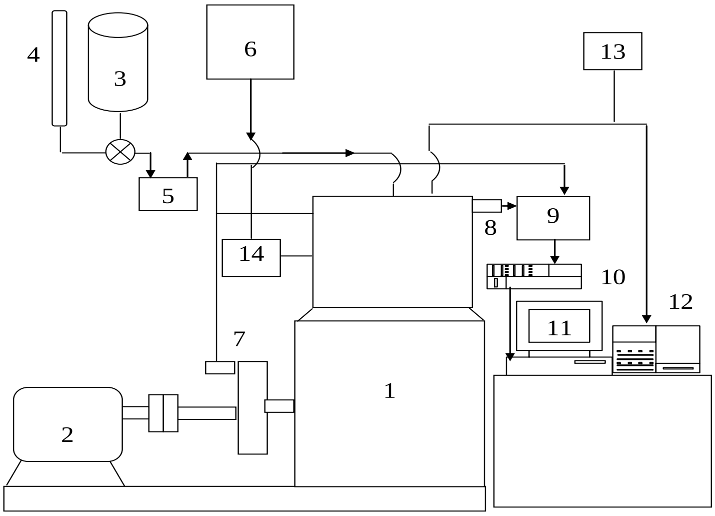
Figures

Figure.1. Seeds of Sterculia striata (Chicha oil)

Figure.2. Photographic view of test engine

Figure.3. Photographic view of pressure and emissions measuring setup



1. Test engine	8.Pressure transducer
2. Dynamometer	9.Charge amplifier
3. Biodiesel tank	10. Analog to digital converter
4.Burette	11.Computer
5.Fuel filter	12.Exhaust gas analyzer
6.Air surge tank	13.Exhaust gas temperature indicator
7.TDC pickup	14.Inlet air temperature indicator

Figure.4. Experimental setup

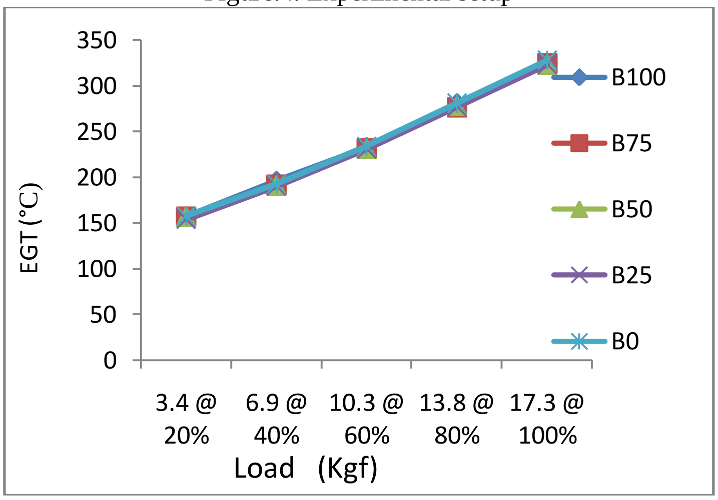


Figure.5. Comparison of EGT of diesel and different blends of sterculia striata

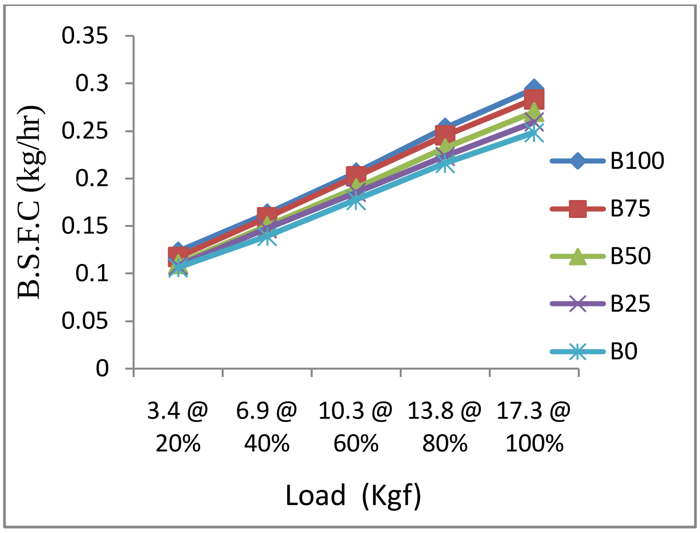


Figure.6. Comparison of B.S.F.C of diesel and four blends of biodiesel (sterculia striata)

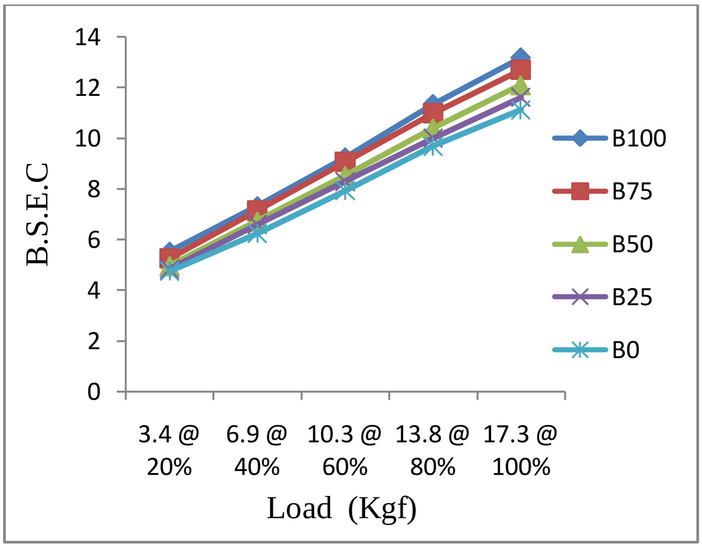


Figure 7 Comparison of B.S.E.C for Diesel and different blends of sterculia striata

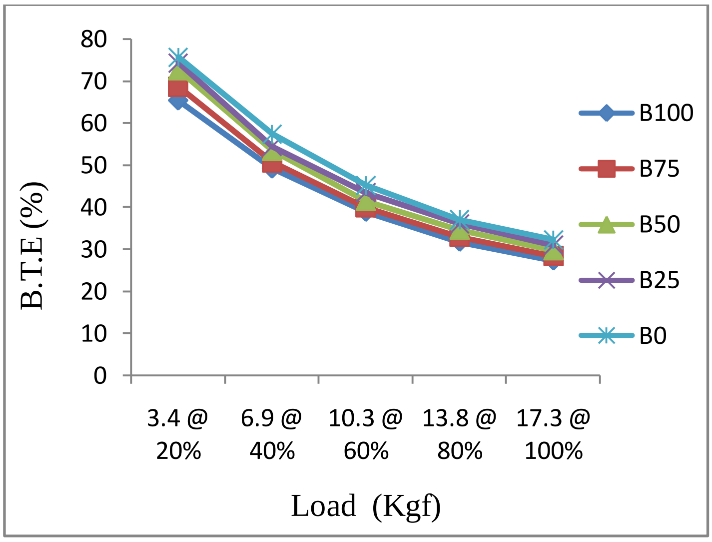


Figure.8. Comparison of BTE of diesel and different blends of sterculia striata

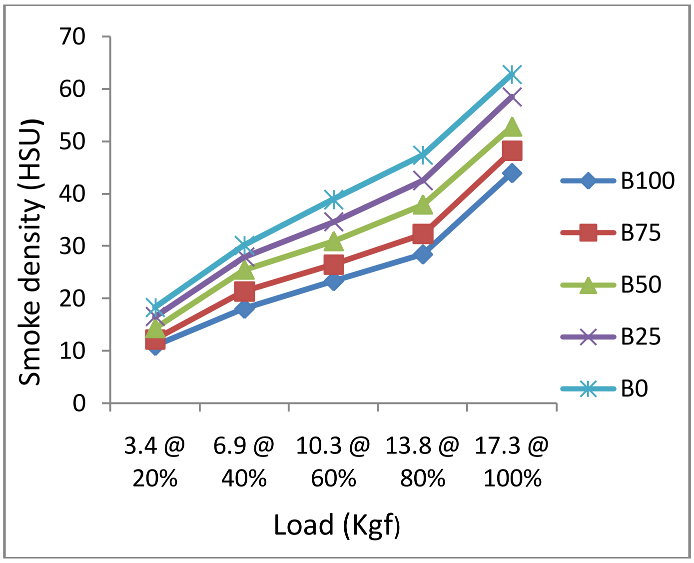


Figure.9. Comparison of smoke density of diesel and different blends of sterculia striata

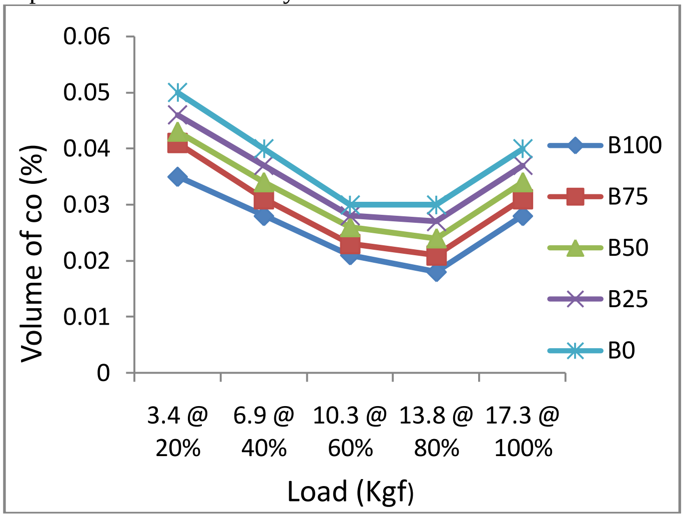


Figure.10. Comparison of CO emissions of diesel and different blends of sterculia striata

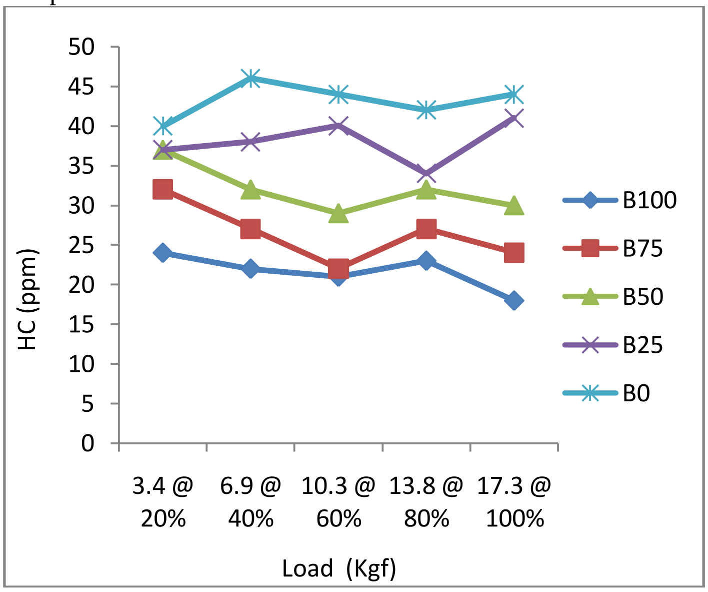


Figure.11. Comparison of HC emissions of diesel and different blends of sterculia striata

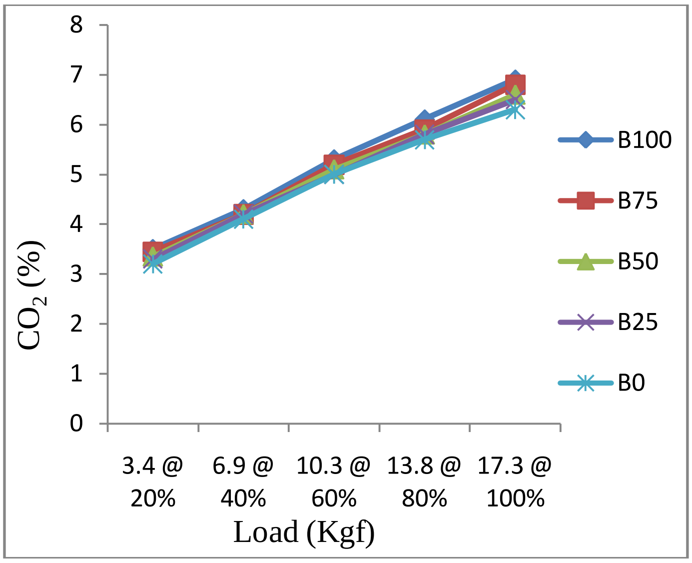


Figure 12 Comparison of CO2 emissions for Diesel and different blends of sterculia striata

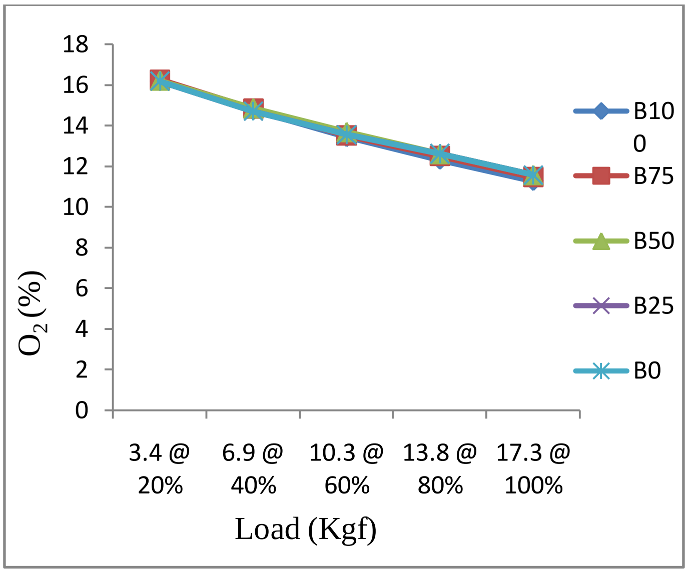


Figure 13 Comparison of O2 emissions for Diesel and different blends of sterculia striata

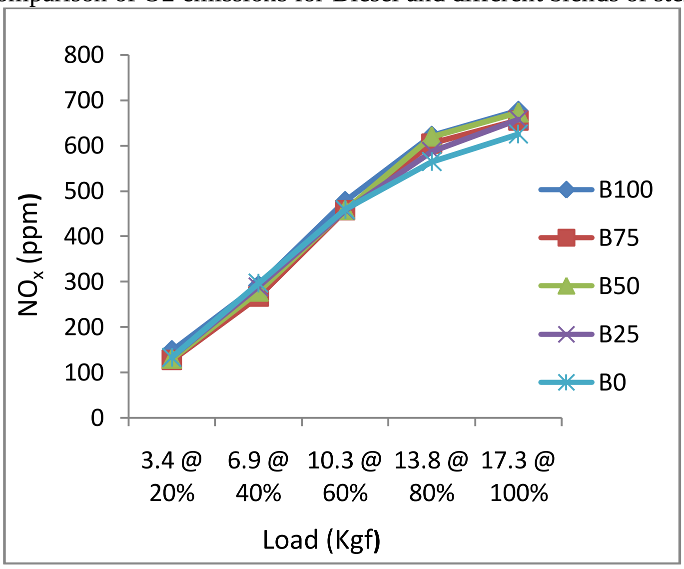


Figure.14. Comparison of NOx emissions of diesel and different blends of sterculia striata

Tables

Table 1 Comparison of Properties of diesel and different blends of biodiesel

Properties	Diesel	Sterculia Striata
Water Content	0.02	0.96
Density (Kg/m3) @ 15°C	820	893.1
Kinematic Viscosity (mm2/s) @ 40°C	2.50	6.31
Conradson Carbon Residue %	-	0.84
Ash Content %	0.01	0.008
Pour Point °C	-16	-10
Flash Point °C	45	56
Acidity (mg of KOH/gm)	-	0.62
Sediments %	-	0.018
Gross Calorific Value (Kcals/Kg)	10,755	10,720
Distillation Range (90% Recovery) °C	330	345
Residue ml	-	3.80

Table.2. Engine Specifications

Type	Kirloskar T.V-1
Cylinder details	Single cylinder,Four Stroke Vertical, Water cooled
Power	7 H.P, 5.2 Kw
Bore	87 mm
Stroke	110 mm
Speed	1500 rpm
Compression ratio	17.5:1
Dynamometer	Eddy Current dynamometer
Model/Srl no	AG-20, 237/2003
Max Kw	20 Kw
Rpm	2450/1000
Dynamometer arm length	0.195 m

Table.3. Engine Load testing conditions

Fuels	Diesel, B100, B75, B50, B25
Compression Ratio	17.5:1
Specific gravity of fuel	0.884
Speed	1500 rpm
Room temperature	28.7°C
Mass flow rate of cooling water	7 Kg/min
Injection pressure	205 kg/cm2