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Research Paper

EXPERIMENTAL INVESTIGATION ON PERFORMANCE AND EMISSION ANALYSIS OF CI ENGINE FUELLED WITH METHYL ESTER OF SILK COTTON OIL AND VARIOUS DIESEL BLENDS

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Alternative fuels have received much attention due to the depletion of world petroleum reserves and increased environmental concerns. Thus processed form of vegetable oil (Biodiesel) offers attractive alternative fuels to compression ignition engines. In this experimental study performance and emissions characteristics of methyl esters of Silk Cotton Oil (SCOME) and diesel blends in a diesel engine were experimentally investigated. For this study, methyl esters of Silk Cotton Oil were added to diesel by volume of 20% (B20), 40% (B40), 60% (B60) and 80% (B80), as well as pure blend 100% (B100). Fuels were tested in single cylinder, water-cooled, direct injection Kirloskar diesel engine loaded by eddy current dynamometer. The effect of blends on engine performance, exhaust emissions were examined at different loads (0%, 25%, 50%, 75%, and 100%) at constant engine speed of 1500 rpm. Engine performance parameters namely brake power, brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature and exhaust emissions of CO, HC, CO2, NOx and smoke density were determined. The test result indicates that there is a slight increase in brake thermal efficiency and brake power up to 50% of load, but at full load condition the brake thermal efficiency increases for neat blend of biodiesel. There is an increase in specific fuel consumption for all the blended fuels when compared to that of diesel fuel. The drastic reduction in carbon monoxide, unburned hydrocarbon were recorded for all the blended fuels as well as with neat biodiesel. However, in the case of oxides of nitrogen, carbon-di-oxide, oxygen there is a slight increase for all the blended fuels and with neat biodiesel when compared to diesel fuel. The drastic reduction in carbon monoxide, unburned hydrocarbon were recorded for all the blended fuels as well as with neat biodiesel. However, in the case of oxides of nitrogen, carbon-di-oxide there is a slight increase for all the blended fuels and with neat biodiesel when compared to diesel fuel. On the whole, Silk Cotton Oil Methyl Ester (SCOME) and its blends with diesel fuel can be used as an alternative fuel for diesel in direct injection diesel engines without any significant engine modification.

Keywords: Performance, Emission, I.C. Engine, Blended fuel.

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INTRODUCTION

Energy is the prime mover of economic growth and is vital to the sustenance of modern economies. The overall growth of a country is dependent upon long-term availability of energy from sources that are affordable, accessible and environmental friendly (Kumar Nirajan *et al*., 2013; Chauhan BS *et al*., 2011). Further, India is importing more than 82% of its crude requirement and spending a huge amount of foreign currency for this import (Jain Siddharth and Sharma M P, 2010).

Compression ignition engines play an important role than spark ignition engines particularly in the field of heavy transportation, industrial sectors, and agricultural applications on account of their high thermal efficiency. The inevitable decline in the fossil fuels, namely coal, petroleum and natural gas has spurred vigorous efforts all over the world to find and develop renewable energy sources. There are several alternative sources of fuel, some of them being biogas, producer gas, hydrogen, alcohol and vegetable oils – all renewable in nature. Among these fuels, vegetable oils seem to be a forerunner as they are renewable and easily available (Sukumar Puhan *et al*., 2005; Senthil kumar M *et al*., 2001).

Alternative fuels are considered very promising to play an important in meeting the world's energy requirements (Berrios M *et al*., 2011). Within the gamut of biofuels, vegetable oils derived fuels are very promising and have the potential to meet growing energy demand I a sustainable as a fuel in diesel engine due to high viscosity and need to be chemically modified to produce biodiesel. Biodiesel is a renewable diesel fuel defined as the mono-alkyl esters derived from vegetable oils or animal fats. It is largely competitive with petroleum diesel as far as technical issues are concerned and can be used as a substitute for mineral diesel without major engine modification. Its production and use have expanded exponentially in many countries around the world in recent years. In addition to being biodegradable and non-toxic, biodiesel is also essentially free of sulfur and aromatics, producing lower exhaust emissions than conventional diesel (Bautista Luis Fernand *et al*., 2009; Enweremadu C C and Rutto H L, 2010).

Worldwide biodiesel production is mainly from edible oils such as soybean, peanut, coconut, sunflower, and canola oils. However, biodiesel production from edible oils are not sustainable in India as India is not self-sufficient in edible oil production and imports substantial amount of edible oil for meeting its requirement. In this context, non-edible oils are very promising for biodiesel production in India with abundance of forest and plant based non-edible oils being available in India such as Pongamia (Karanja), Jatrropha curcas (Jatropha), Madhuca Indica (Mahua), Azadirachta Indica (Neem), Schleicheraoleosa (Kusum) and Hevea brasiliensis (Rubber) (Patil B S *et al*., 2012).

Silk Cotton Oil (Binomial name: Ceiba pentandra, Familly: Malvaceae) is a forest-based tree-borne non-edible seed oil (Mahajan R T and Chopda M Z, 2009). The trees grows to 60-70 m (200-300 feet) tall and has a very substantial trunk with buttre-sses. Its natural distribution is uncertain due to extensive cultivation but it is situated in

Southern Asia between Nepal, Pakistan, Bangladesh and India. In India it is cultivated in interior parts of Tamilnadu. The oil is obtained from the seed kernels and is dark yellow in colour. Crude Silk Cotton Oil generally contains high % Free Fatty Acid (FFA). It is used as an alternative to down as filling in mattresses, pillows, upholstery, stuffed toys such as teddy bears and for insulation (Mahajan R T and Chopda M Z, 2009; S. Chaudhary, 2001).

MATERIALS AND METHODOLOGIES

Various methodologies such as heating, blending, pyrolysis and transesterification are employed to use vegetable oil as a fuel in diesel engines. Out of these options, transesterification process to produce biodiesel from vegetable oil is the most documented and explored method for direct engine application. However, transesterification is a sophisticated process and needs reaction vessels, catalysts, chemicals, heating and agitation arrangements and skilled manpower which may not be feasible in rural and remote areas. Moreover, most of the non-edible oils are transesterified in two increased production cost and carbon footprints. Therefore, vegetable oil in neat form blended with some other carbon of the vegetable oil may be a promising breakthrough for energy security and sustainability.

TRANSESTERIFICATION

Transesterification is also called alcoholysis, is the displacement of alcohol from on ester by another alcohol in a process similar to hydrolysis. This process has been widely used to reduce the viscosity of triglycerides. The transesterification reaction is represented by the general equation

$$R\ COOR' + R'' \rightarrow R\ COOR'' + R'OH$$

If methanol is used in the above reaction, it is formed as methanolysis. The reaction of glycerides are readily transesterified in the presence of alkaline catalyst at atmospheric pressure and at a temperature of approximately go to 70°C with an excess of methanol. The mixture at end of the reaction is allowed to settle. The lower glycerol layer is drawn off while the upper methyl ester layer is washed to remove entrained glycerol and is then processed further. The excess methanol is recovered by distillation and sent to rectifying column for purification and recycled. The transesterification works well when the starting oil is of light quantity. However, quite often low quality oils are used as raw materials for biodiesel preparation. In cases where the free fatty acid content of the oil is above 4%,difficulty arise due to formation of soaps which promote emulsification during the water working stage and at an FFA content above 2% the process becomes unworkable . If the free fatty acid content of the oil is below 4% single stage process is adopted. If the free fatty acid content is greater than 4% double stage process is adopted.

A. Single Stage Process

In single stage process the raw oil is taken and it is preheated up to 60°C and the mixture of catalyst and methanol is added to the oil and it is heated and stirred well. The mechanical stirred at speed approximately 700 rpm. After some time there will be a phase separation. In which the glycerol settles down and ester control in the upper layer. The glycerol layer is drained off and the biodiesel is collected and it is washed with distilled water for two or three times to remove the alkali matter. The pure bio diesel is now available. To remove the water content, the biodiesel is heated from 105 to 110°C. The biodiesel is cooled and it is stored.

The present experimental investigation deals with the preparation of five sets of blends comprising 20% Silk Cotton Oil and 80% Diesel (B20), 40% Silk Cotton Oil and 60% Diesel (B40), 60% Silk Cotton Oil and 40% Diesel (B60), 80% Silk Cotton Oil and 20% Diesel (B80) and 100% neat Silk Cotton Oil (B100). Fuel properties were evaluated and exhaustive engine trial was conducted to evaluate performance and emission characteristics.

PROPERTIES OF FUEL AND ITS FUEL BLENDS

Performance of CI engine greatly depends upon the properties of fuel, among which viscosity, density, cetane number, volatility, calorific value, etc. are very important. The physic-chemical properties of biodiesel were tested in Eta laboratories, Chennai. Table 1 gives the comparison of physical properties of biodiesel obtained from Silk Cotton Oil and neat diesel.

Table 1: Comparison of Physico-chemical Properties of Biodiesel Derived from Silk Cotton Oil with Diesel

Properties	Diesel	Silk Cotton Oil	Silk Cotton Oil Methyl Ester
Density @ 15°c	830	860	858
Viscosity @40°C(cSt)	1.428	18.86	17.88
Heating value, (MJ/Kg)	42.00	34.17	36.37
Flash point(°C)	44	315	42
Fire point(°C)	49	350	47

Table 2: Physico-chemical Properties of Biodiesel Blends

Properties	B80	B60	B40	B20
Density @ 15°c	852.4	846.8	841.2	835.6
Viscosity @40°C(cSt)	14.590	11.299	8.009	4.718
Heating value, (MJ/Kg)	37.790	38.84	39.895	40.947
Flash point(°C)	42.4	42.4	43.2	43.6
Fire point(°C)	47.4	47.8	48.2	48.6

ENGINE TEST RIG DEVELOPMENT

The diesel engine is a High speed, four strokes, vertical and air cooled type. Figure 2 shows the schematic representation of the experimental set up and the technical specification of the engine are given in Table 3. The loading is by means of an electrical dynamometer. The fuel tank is connected to a graduated burette, to measure the quantity of fuel consumed in unit time. An Orifice meter with

U-tube manometer is provided along with an air tank on the suction line for measuring air consumption. An AVL415 Smoke meter is provided for measuring the exhaust gases.

Figure 1: Photograph of Experimental set up

A five gas analyzer is used to obtain the exhaust gas composition. An AVL444 Di gas analyzer showed the measurement of the HC, CO, CO2, NOx emissions when the probe of the analyzer was inserted, and kept for a few minutes in the exhaust pipe. The fuel flow rates were obtained by noting the time taken for 10cc of fuel consumption. The engine was started and allowed to warm-up for about 10 minutes. The engine was tested under five discrete part load conditions viz: 0%, 25%, 50%, 75%, 100%.For all load conditions, engine speed was constant at 1500 rpm. The time taken for 10cc fuel consumption was noted at each load for Diesel, B20, B40, B60, B80, and B100.

Table 3: Technical Specifications of Diesel Engine

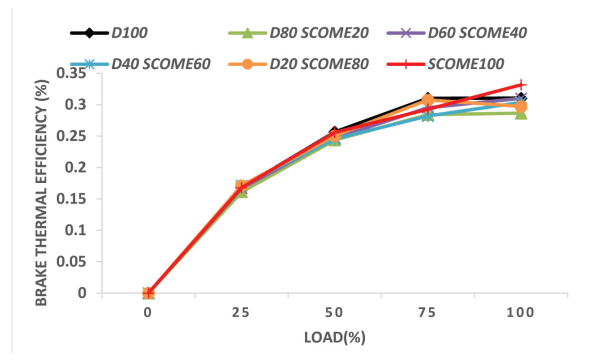
Type	**Kirloskar TAF 1 vertical diesel engine**
No of cylinders	Single
Type of injection	Direct
Rated power @1500 rpm (KW)	4.41
Bore (mm)	87.5
Stroke (mm)	110
Compression ratio	17.5:1
Method of cooling	Air cooled with radial fan
Displacement volume (liters)	0.662
Fuel injection timing BTDC (Degree)	23°
No of injector nozzle holes	3
Coefficient of Discharge (Cd)	0.6

RESULTS AND DISCUSSION

B. Brake Thermal Efficiency (BTE)

The BTE indicates the ability if the combustion system to accept the experimental fuel and provides comparable means of assessing how efficiently the energy in the fuel is converted into mechanical output. The variation in brake thermal efficiency (BTE) is shown in Figure 3 and a comparative assessment has been drawn. From the experiment it has been seen that at 50% load B80 shows slighter variations in BTE when compared to the diesel fuel. This may be cause due to proper combustion of fuel owing higher oxygen content and higher cetane rating than that of baseline diesel fuel. Enriched oxygen promotes the combustion characteristics and better atomization of the test fuels. Neat diesel showed lower full load BTE compare to all the blends.B100 has higher efficiency than that of neat diesel at full load condition however, at part load the difference were insignificant (NurunNabi Md *et al*., 2009; Agarwal Deepak *et al*., 2008).

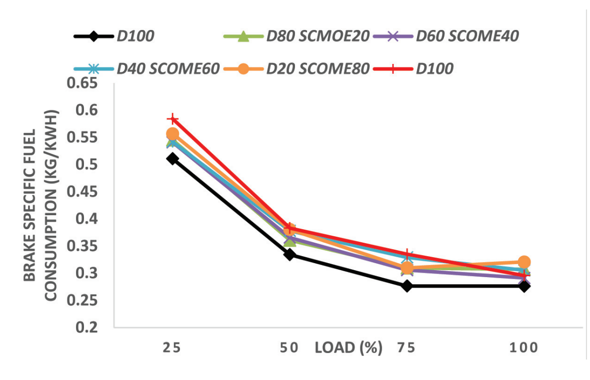
Figure 2: Variations of Brake Thermal Efficiency with Load



C. Brake Specific Fuel Consumption (BSFC)

Brake specific energy consumption (BSFC) is an important parameter of an engine because it takes care of both mass flow rate and heating value of the fuel. Brake specific fuel consumption is an essential and ideal parameter for comparing engine performance of the fuels having different calorific value and density. Figure 4 shows variations of BSFC for neat diesel and Silk Cotton Oil biodiesel blends. It is observed that at full load condition the brake specific fuel consumption is higher for all blends of Silk Cotton Oil biodiesel when compared to the diesel fuel. Mainly B40 and B100 showed better results when compared to other blended fuels. This is mainly because of lower heating value, higher viscosity and density of SCOME. The lower heating value of SCOME requires larger fuel flow rates to maintain constant energy input to the engine. At lower loads significant properties of the fuel inducted through the intake does not burn completely due to the lower quantity of pilot fuel (NurunNabi Md *et al*., 2009; Agarwal Deepak *et al*., 2008).

Figure 3: Variations of Brake Specific Fuel Consumption with Load



D. Exhaust Gas Temperature (EGT)

The exhaust gas temperature indicates how efficiently energy conversation takes place in the engine. Lesser the EGT is Higher the conversion of heat into work and vice versa. The variation of EGT is shown in the Figure 5. At full load condition the exhaust gas temperature is 382°C, 380°C for the test samples B100, B80 respectively high when compared with neat diesel fuel, but rest of the samples also have high EGT. The reduction exhaust temperature substantiates higher BTE of blended fuels as the heat is more efficiently utilized leading to lower EGT (Agarwal Deepak *et al*., 2008).

ENGINE EMISSIONS

E. Carbon Monoxide Emissions

The variation of carbon monoxide (CO) emission of diesel and Silk Cotton Oil blends is shown in Figure 6. CO results from

Figure 4: Variations of Exhaust Gas Temperatures with Load

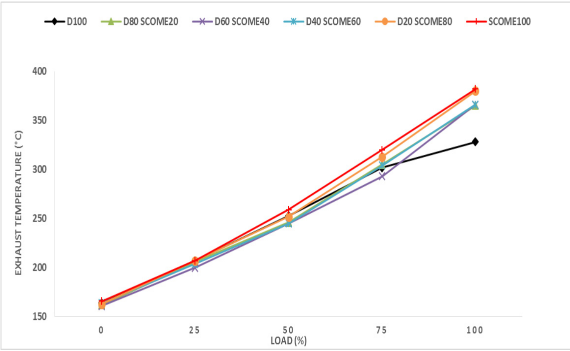
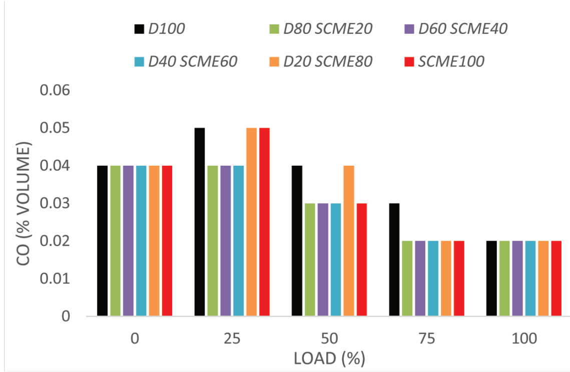


Figure 5: Volumetric Emissions of Carbon Monoxide with Load



incomplete combustion of fuels and it is produced most readily from petroleum fuels, which contain no oxygen intermolecular structure. It has been observed that the CO emission is lower for all the blends of Silk Cotton Oil methyl ester than that of neat diesel. At part load conditions CO emission for B20, B40, B60, B80 are similar but very low when compared with diesel fuel. This may be due to more complete combustion of biodiesel because of its higher oxygen percentage, CO emission level decreases as amount of oxygen content in biodiesel helps in complete combustion and oxidation. CO is an intermediate combustion product and is formed mainly due to incomplete combustion of fuel. If combustion is complete, CO is converted to CO2. If the combustion is incomplete due to shortage of air or due to low gas temperature CO will form. For bio-diesel mixtures CO emission was lower than that of diesel fuel. Because biodiesel mixture contains some extra oxygen in their molecule that resulted in complete combustion of the fuel and supplied the necessary oxygen to convert CO to CO2 (Hoekmana S Kent *et al*., 2012; W H Kemp, 2006).

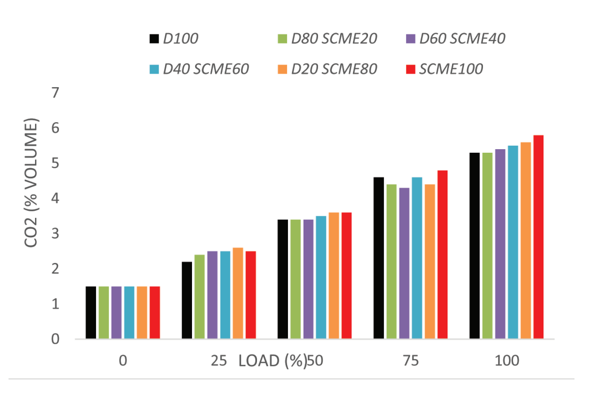
F. Carbon Dioxides Emissions

The CO2 emission for various EGR rates and loads is shown in Figure 7. Carbon-di-oxide in the exhaust gases in an indication of complete combustion. It may be observed that CO2 emissions were higher for all the blends compared to the neat diesel at all loads. At full load B60, B80, B100 showed 9.6%, 9.4%, 9.1%.CO2 emission were higher as compared to diesel fuel. The combustion of fossil fuels produces carbon dioxide that gets accumulated in the atmosphere and leads to many environmental problems. The combustion of Silk Cotton Oil biodiesel also produces carbon dioxide but the crops are readily absorbing these and hence carbon dioxide levels are kept in balance. Thus considering the closed cycle of biodiesel it can be pointed out that the effective emission of CO2 is relatively low. (W H Kemp, 2006; M Senthilkumar *et al*., 2001).

G. Hydrocarbon Emissions

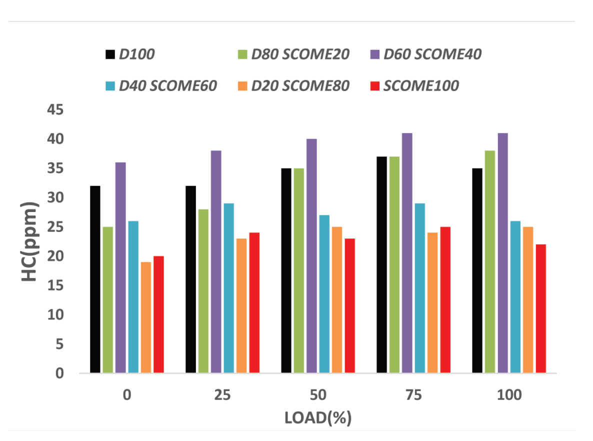
The HC Emissions of different blends are shown below in Figure 8. It is found that the hydrocarbon (HC) emission is lower for all the blends of Silk Cotton Oil methyl ester as

Figure 6: Volumetric Emissions of Carbondioxide with Load



compared to neat diesel fuel. As percentage of biodiesel increase in the blend, HC emission decreases. B100 has 15.9 % less hydrocarbon emission than that of mineral diesel fuel at full load condition when compared to various blends. The significant decrease in HC emission is due to the complete combustion of the fuels (J Nazar *et al*., 2004).

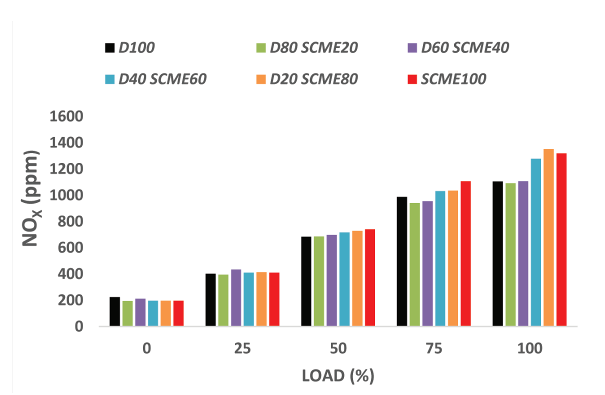
Figure 7: Volumetric Emissions of Hydrocarbon with Load



H. Oxides of Nitrogen Emissions

The exhaust gas emissions like CO, CO2, HC and NOx are measured and analyzed. From the above mentioned emissions NO is the most significant emissions for diesel engine due to high flame temperature and diffusive combustion in the combustion chamber. Since NOx emissions from current diesel technologies are closer to the limits permitted by regulations and limits will be even more stringent in the near future, this emission will be critical factor in the development of new diesel engine. Apart from this, diesel engine produces less CO and HC emissions than the spark ignition engine. The oxides of nitrogen in the exhaust contain nitrogen monoxide (NO) and nitrogen dioxide (NO2). The formation of NO is highly dependent on in-cylinder temperature, oxygen concentration in the cylinder and also dependent on engine technology. At part loads oxides of nitrogen emissions for all test blends is similar to that of the diesel fuel. The NOx emission of diesel at maximum load was 1106 ppm, whereas for B20, B40, B60, B80, and B100 was 1092 ppm, 1108 ppm, 1278 ppm, 1352 ppm, 1320 ppm respectively. This may be due to the reduced premixed combustion rate, which reduces the temperature. B100 fuel had high viscosity resulting in poor atomization, reduced spray

Figure 8: Volumetric Emissions of Oxides of Nitrogen with Load



penetration, decreased cone angle, and greater fuel droplet size than diesel. It results in lower amount of air entertainment and poor combustion, leading to lower combustion temperatures (J Nazar *et al*., 2004; A Murugesan *et al*., 2012).

CONCLUSION

In the present experimental investigation, a set of exhaustive engine trials were conducted on a naturally aspirated, single cylinder diesel engine fuelled with various blends of SCOME and diesel. Several performance and emission characteristics of the engine trials and their comparative assessment with diesel baseline are described briefly below.

1. Full load brake thermal efficiency was found to increase with increase in SCOME percentage in blends as a result of higher cetane rating of biodiesel. From the experiment it has been seen that at 50% load B80 shows slighter variations in BTE when compared to the diesel fuel. This may be cause due to proper combustion of fuel owing higher oxygen content.

2. With increase in percentage of SCOME in the blend a steady increase in BSFC was reported at full load condition. This is mainly because of lower heating value, higher viscosity and density of SCOME. The lower heating value of SCOME requires larger fuel flow rates to maintain constant energy input to the engine.

3. At full load condition the exhaust gas temperature is 382°C, 380°C for the test samples B100, B80 respectively high when compared with neat diesel fuel, but rest of the samples also have EGT comparatively high. The reduction exhaust temperature substantiates higher BTE of blended fuels as the heat is more efficiently utilized leading to lower EGT. However at low loads EGT is similar for all test blends compared to neat diesel fuel.

4. Emission of carbon monoxide was found to reduce with increase in SCOME percentage in the blends. At part load conditions CO emission for B20, B40, B60, B80 are similar but very low when compared with diesel fuel. This may be due to more complete combustion of biodiesel because of its higher oxygen percentage, CO emission level decreases as amount of oxygen content in biodiesel helps in complete combustion and oxidation. Reduction in carbon monoxide emissions at higher blends may be attributed towards better combustion characteristics of high cetane oxygenated SCOME.

5. B20 exhibited parallel hydro carbon emission tendencies as that of diesel baseline. However, other higher blends of SCOME showed reduction in HC emission at all loads compared to that of diesel. Among the various blends B100 exhibited the least hydro carbon content (15.9%) confirming better combustion characteristics.

6. Due to higher cetane rating of SCOME and improved combustion characteristics, the in-cylinder temperature was increased resulting in higher NOx emission for blended fuels as compared to baseline data. Full load NO emission was steeply increased for B80, B100 respectively as compared to diesel baseline. Lower blends exhibited marginal increase in NOx emissions. B100 fuel had high viscosity resulting in poor atomization, reduced spray penetration, decreased cone

angle, and greater fuel droplet size than diesel. It results in lower amount of air entertainment and poor combustion, leading to lower combustion temperatures.

Definitions/Abbreviations

BSFC - Brake Specific fuel Consumption

BTE - Brake Thermal Efficiency

CO - Carbon Monoxide

CO2 - Carbon Dioxide

HC - Hydro Carbon

FFA - Free Fatty Acid

cSt - Centi Stroke

Kg – Kilogram

MJ - mega joule

KW - Kilo Watt

mf - mass flow rate

mm – Millimeter

D100 - Neat Diesel

SCOME - Silk Cotton Oil Methyl Ester

B20 – D80 SCOME20

B40 – D60 SCOME40

B60 – D40 SCOME60

B80 – D20 SCOME80

B100 - 100% SCOME

NOx - Nitrogen Oxides

ppm - Parts per Million

rpm - Revolution per Minute

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