

Performance and Emission Characteristics of Zirconia Coating on I.C Engine Using Callophyllum Biodiesel as a Fuel for Varying Injection pressure

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Abstract: In this present world, the realization of the available of fossil fuels [diesel] is limited and hence it is necessary for the efficient use of the fuel. The increasingly environmental regulations also make it necessary to improve the functioning of the diesel engine in terms of their durability and efficiency. Thus, there is a high scope in engine technology to increase the engine ratings and reduce fuel consumption.

For this purpose, the Thermal Barrier Coating (TBC) has been extensively used in engine technology. The T.B.C technology has been applied on some parts of Diesel engine (piston crown and cylinder head) Plasma Spray technique was used for spraying process. The piston crown and Cylinder head of the diesel engine were coated for a thickness of 0.25mm. Callophyllum oil was converted into biodiesel by two stage Transesterification process using NaOH as a catalyst.

Several tests have been carried out to examine properties, performance and emission characteristics for different blends such as [B100, B20, B30, B40 and B100] in comparison with pure diesel for varying injection pressures like 160 bar, 180 bar and 200 bar pressure. These tests were conducted on a single cylinder, 4 stroke, water cooled, direct injection computerized compression ignition engine.

Keywords: TBC, Callophyllum oil, Transesterification.

1. INTRODUCTION

Thermal barrier coatings (TBC) have been successfully applied to the internal combustion engine, in particular the combustion chamber, to simulate adiabatic engines. The objectives are not only for reduced in-cylinder heat rejection and thermal fatigue protection of underlying metallic surfaces, but also for possible reduction of engine emissions. The application of TBC reduces the heat loss to the engine cooling jacket through the surfaces exposed to the heat transfer such as cylinder head, liner, piston crown and piston rings. The insulation of the combustion chamber with ceramic coating affects the combustion process and hence the performance and exhaust emissions characteristics of the engines.

A typical TBC system consists of (i) the top coat (TC), a porous ceramic layer that acts as the insulator, (ii) the bond coat (BC), an oxidation-resistant metallic layer between the substrate and the TC and (iii) the super alloy or other material substrate that carries the structural load.

The top coat provides thermal insulation for the underlying substrate. The specifications for this coating require a material that combines low thermal conductivity and a coefficient of thermal expansion (CTE) that it is as similar as possible to that of the substrate, so that generation of stresses during

thermal cycling can be minimized. The preferred material for this application is Zirconia.

The bond coat protects the underlying substrate from oxidation and improves adhesion between the ceramic and the metal. Oxidation occurs due to oxygen reaching the bond coat by diffusion through the lattice of the top coat and permeation through the pores.

2. THERMAL BARRIER COATING

Thermal barrier coatings (TBC) have been successfully applied to the internal combustion engine, in particular the combustion chamber, to simulate adiabatic engines. The objectives are not only for reduced in-cylinder heat rejection and thermal fatigue protection of underlying metallic surfaces, but also for possible reduction of engine emissions. The application of TBC reduces the heat loss to the engine cooling jacket through the surfaces exposed to the heat transfer such as cylinder head, liner, piston crown and piston rings. The insulation of the combustion chamber with Ytria partially stabilized Zirconia coating affects the combustion process and hence the performance and exhaust emissions characteristics of the engines.

Thermal barrier coatings (TBC) are used to protect substrate materials from high temperatures and oxidation. They are usually ceramic, due to the high oxidation resistance

and low thermal conductivity of this material class a large number of ceramic materials have been tried and are used to some extent. The most widely used material for TBC applications is without doubt Yttria-partially stabilized Zirconia (YSZ), i.e. ZrO_2 doped with 7-8 wt. % Y_2O_3 . There are some ceramics which are used for thermal barrier coating as shown below. [5]

1. Zirconates
2. Yttria Stabilized Zirconia
3. Yttria
4. Alumina
5. Spinel
6. Forsterite.

3. PLASMA SPRAY COATING

It is one of the widely used methods for coating of the engine parts. In this method, the surface of the cylinder head and piston crown are insulated by using Yttria Stabilized Zirconia for a thickness of 0.25mm using plasma spray technique.

The surface to be coated such as piston rings, cylinder heads, was first cleaned and degreased with a chemical solvent. A special adhesive bonding material was first coated. The material to be coated Yttria stabilized Zirconia, ZrO which is in the form of powder was fed to the melting zone. The molten material was further heated to a very high temperature leading to plasma stage. Then the plasma jet was impinged on the surface to be coated, the coating material flattened and sticks to the surface. It becomes very hard surface when it was cooled in inert gas atmosphere and sticks to the surface.



Figure 1: Coated piston crown and Cylinder head



Figure 2: UnCoated piston crown and Cylinder head

4. BIODIESEL PRODUCTION

Biodiesel can be produced from straight vegetable oil, animal oil/fats and waste oils. There are three basic routes to biodiesel production from oils and fats:

- Base catalyzed transesterification of the oil.
- Direct acid catalyzed transesterification of the oil.
- Conversion of the oil to its fatty acids and then to biodiesel.

4.1 Transesterification Process of Callophyllum oil



Figure 3: Transesterification Set Up

Figure 3 shows the transesterification set up, in which a 2000 ml three necked round bottom flask, was used as a reactor. The flask was placed in heating mantle whose temperature could be controlled within ± 2 °C. One of the two side necks was equipped with a condenser and the other was used as a thermo well. A thermometer was placed in the thermo well containing little glycerol for temperature measurement inside the reactor. A blade stirrer was passed through the central neck, which was connected to a motor along with speed regulator for adjusting and controlling the stirrer speed. 1000ml of esterified Callophyllum oil was measured and poured into a 2000 ml three necked round bottom flask. This oil was heated upto 600 °C. In 250ml beaker a solution of potassium meth oxide was prepared using 0.5 wt% sodium hydroxide pellets with 1:6 molar ratio of oil to methanol. The solution was properly stirred until the potassium hydroxide pellet was completely dissolved. The solution was then heated upto 60 °C and slowly poured into preheated oil. The mixture was stirred vigorously for one and half hour. Finally FFA was checked and mixture was allowed to settle for 24 hours in a separating funnel. Thereafter, upper layer biodiesel was decanted into a separate beaker while the lower layer which comprised glycerol and soap was collected from the bottom of separating funnel. To remove any excess glycerol and soap from the biodiesel, hot water was used to wash it and then allowed it to remain in separating funnel until clear water was seen below the biodiesel in the separating funnel. The PH of biodiesel was then checked. The washed biodiesel sample was then dried by placing it on a hot plate and excess water still in the biodiesel removed.

Table 1 shows the fuel properties of biodiesel determined as per ASTM standards.

Table 1: Properties of Callophyllum biodiesel

Parameter	Callophyllum biodiesel(Methyl Ester)
Density (kg/m ³)	900
Kinematic viscosity (Cst)	7.1
Flash Point °C	165
Fire Point °C	175
Calorific value (kJ/kg)	36957.2

5. ENGINE TEST PROCEDURE

A four stroke, single cylinder water cooled diesel engine is employed for the performance study.

Five gas analyzer was used to measure the concentration of gaseous emissions such as Oxides of nitrogen, unburned hydrocarbon, carbon monoxide, carbon dioxide and oxygen level. The performance and emission tests are carried out on the C.I. engine using various blends of diesel-biodiesel blends as fuels. The tests are conducted at the constant speed of 1500rpm at various torque and at different injection pressure such as at 160 bar, 180 bar and 200 bar for normal standard engine as well as coated engine. In this experiment, engine parameters related to thermal performance of engine such as brake thermal efficiency, brake specific fuel consumption, brake specific energy consumption, exhaust gas temperature are measured. In addition to that the engine emission parameters such as Oxides of nitrogen, unburned hydrocarbon, carbon monoxide, carbon dioxide and oxygen level.



Figure 4: The photograph of diesel engine with pressure thermocouple for sensing exhaust gas temperature as shown in figure

6. RESULTS AND DISCUSSION

The studies were therefore, conducted on methyl esters transesterification process for Callophyllum biodiesel B100 and blends of different percent volumes of Biodiesel B20, B30, and B40 were carried out. The fuel consumption

test and rating test of a constant speed CI engine was also conducted to evaluate the performance of the engine on diesel and methyl esters of Callophyllum biodiesel B100 and blends of different percent volumes of Biodiesel B20, B30, and B40.

In this chapter the characterization of fuel is analyzed by drawing different graphs, some of the important properties like kinematic viscosity, the density and calorific value of different blends on the addition of biodiesel, was also studied with comparing with the diesel and 100% biodiesels.

Also the engine performance and emission characteristics were also discussed and different Graphs of showing the performance and emission characteristics were drawn and those graphs were analyzed in detailed.

6.1 Performance Characteristics

1. Brake Specific Fuel Consumption

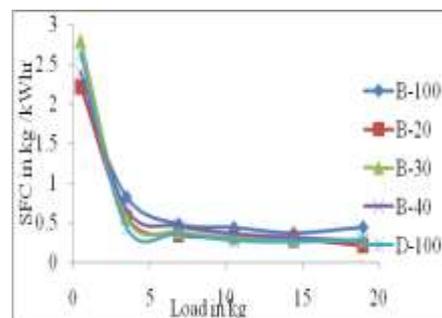


Figure 5: Variation of Brake Specific Fuel Consumption with Load at 200 bar pressure before coating

The variation in BSFC with load for different fuels at 200 bar pressure for before coating of the engine is presented in Figure 5 Brake-specific fuel consumption (BSFC) is the ratio between mass fuel consumption and brake effective power, and for a given fuel, it is inversely proportional to thermal efficiency. BSFC decreased sharply with increase in load for all fuels. The main reason for this could be that the percent increase in fuel required to operate the engine is less than the percent increase in brake power, because relatively less portion of the heat is lost at higher loads. The maximum BSFC was found in B30 and it is higher than the diesel. As the BSFC was calculated on a weight basis, higher densities resulted in higher values for BSFC.

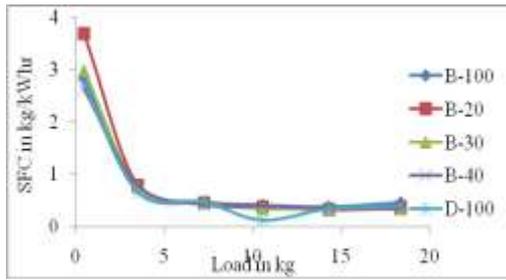


Figure 6: Variation of Brake Specific Fuel Consumption with Load at 200 bar pressure after coating

The variation in BSFC with load for different fuels at 200 bar pressure for after coating of the engine is presented in Figure 6. In this graph also BSFC decreased sharply with increase in load for all fuels. The maximum BSFC was found in B20 and it is much higher than the diesel and biodiesel.

2. Brake Specific Fuel Consumption at 180 bar pressure

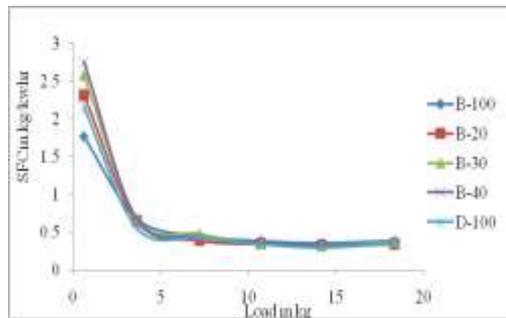


Figure 7: Variation of Brake Specific Fuel Consumption with Load at 180 bar pressure before coating

The variation in BSFC with load for different fuels at 180 bar pressure before coating of the engine is presented in Figure 7. In this graph also BSFC decreased sharply with increase in load for all fuels. The maximum BSFC was found in B40 and it is much higher than the diesel and biodiesel.

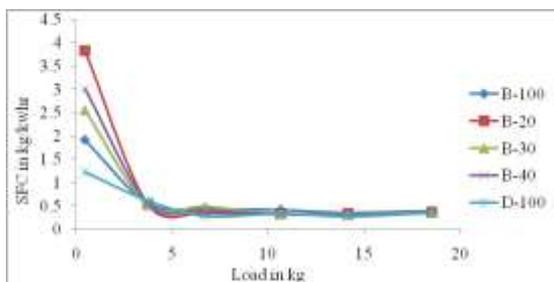


Figure 8: Variation of Brake Specific Fuel Consumption with Load at 180 bar pressure after coating

The variation in BSFC with load for different fuels at 180 bar pressure after coating of the engine is presented in Figure 8. In this graph also BSFC decreased sharply with increase in load for all fuels. The maximum BSFC was found in B20 and it is much higher than the diesel and biodiesel.

3. Brake Specific Fuel Consumption at 160 bar pressure

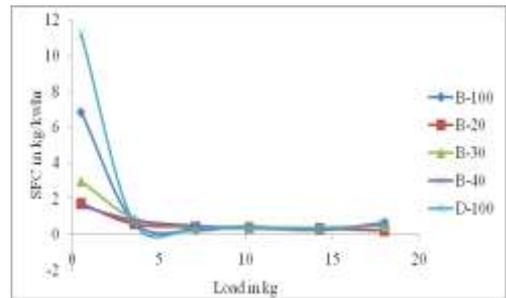


Figure 9: Variation of Brake Specific Fuel Consumption with Load at 160 bar pressure before coating

The variation in BSFC with load for different fuels at 160 bar pressure before coating of the engine is presented in Figure 9. In this graph also BSFC decreased sharply with increase in load for all fuels. The maximum BSFC was found in D100 and it is much higher than the biodiesel and blends.

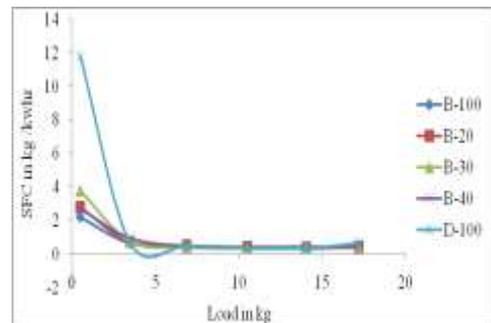


Figure 10: Variation of Brake Specific Fuel Consumption with Load at 160 bar pressure after coating

The variation in BSFC with load for different fuels at 160 bar pressure after coating of the engine is presented in Figure 10. In this graph also BSFC decreased sharply with increase in load for all fuels. The maximum BSFC was found in D100 and it is much higher than the biodiesel and blends.

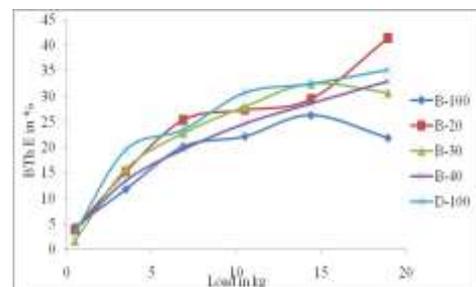


Figure 11: Variation of brake thermal efficiency with Load at 200 bar pressure before coating

The variation of brake thermal efficiency with load for different fuels at 200 bar pressure before coating is presented in Fig 11. In all cases, it increased with increase in load. This was due to reduction in heat loss and increase in power with increase in load. The maximum thermal efficiency for B20

was higher than that of diesel. The brake thermal efficiency obtained for B30, B10, and B100 were less than that of diesel. This lower brake thermal efficiency obtained could be due to reduction in calorific value and increase in fuel consumption as compared to B20.

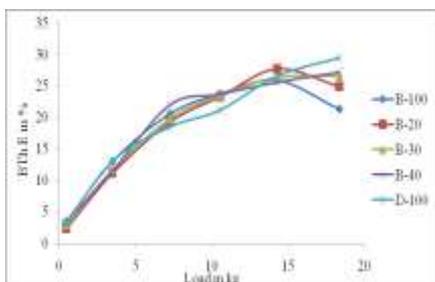


Figure 12: Variation of brake thermal efficiency with Load at 200 bar pressure after coating

The variation of brake thermal efficiency with load for different fuels at 200 bar pressure after coating is presented in Fig 12. In all cases, it increased with increase in load. This was due to reduction in heat loss and increase in power with increase in load. The maximum thermal efficiency is for D100 and was higher than that of biodiesel and blends.

2. Brake Thermal Efficiency at 180 bar pressure:

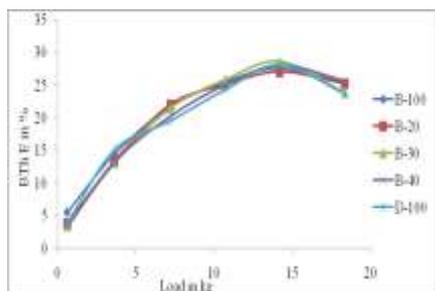


Figure 13: Variation of brake thermal efficiency with Load at 180 bar pressure before coating

The variation of brake thermal efficiency with load for different fuels at 180 bar pressure before coating is presented in Fig 13. In all cases, it increased with increase in load, except for B-100 where the break thermal efficiency decreases for maximum load. The maximum thermal efficiency is obtained in B30.

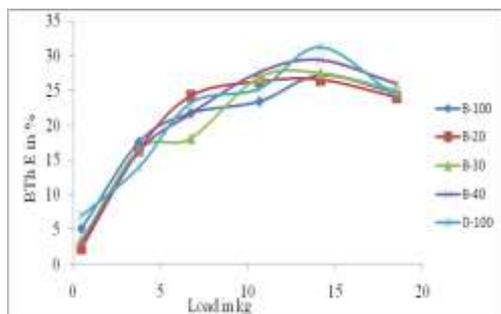


Figure 14: Variation of brake thermal efficiency with Load at 180 bar pressure after coating

The variation of brake thermal efficiency with load for different fuels at 180 bar pressure after coating is presented in Fig 14. In all cases, it increased with increase in load, except for B-100 where the break thermal efficiency decreases for maximum load. The maximum thermal efficiency is obtained in B40

3. Brake Thermal Efficiency at 160 bar pressure:

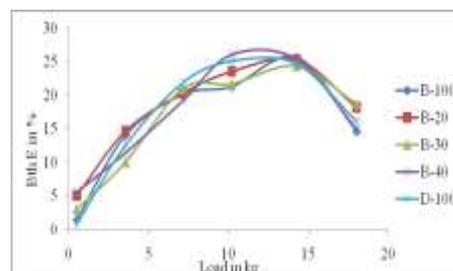


Figure 15: Variation of brake thermal efficiency with Load at 160 bar pressure before coating

The variation of brake thermal efficiency with load for different fuels at 160 bar pressure before coating is presented in Fig 15. In all cases, it increased with increase in load, except for B-100 where the break thermal efficiency decreases for maximum load. The maximum thermal efficiency is obtained in B40.

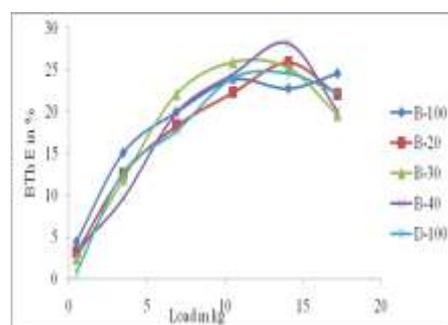


Figure 16: Variation of brake thermal efficiency with Load at 160 bar pressure after coating

The variation of brake thermal efficiency with load for different fuels at 160 bar pressure after coating is presented in Fig 16. In all cases, it increased with increase in load, except for B-100 where the break thermal efficiency decreases for maximum load. The maximum thermal efficiency is obtained in B40

1. Brake power at 200 bar pressure:

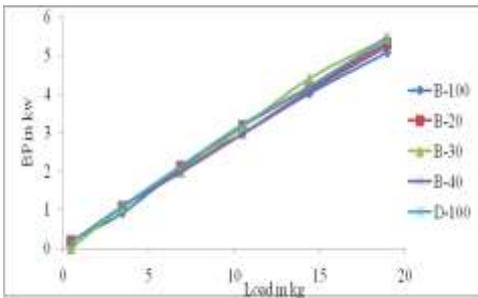


Figure 17: Variation of Brake power with Load at 200 bar pressure before coating

The variation of brake power with load for different fuels at 200 bar pressure before coating is presented in Fig 17. In all cases, it increased with increase in load. The maximum brake power is for D100 at maximum load and was higher than that of Biodiesel. The brake power obtained for B20, B30, B40 and B100 were less than that of diesel

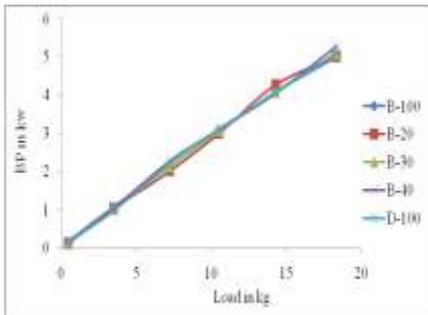


Figure 18: Variation of Brake power with Load at 200 bar pressure after coating

The variation of brake power with load for different fuels at 200 bar pressure after coating is presented in Fig 18. In all cases, it increased with increase in load. The maximum brake power is for B40 at maximum load and was higher than that of diesel. The brake power obtained for B20, B30, B100 and D100 were less than that of B40

2. Brake power at 180 bar pressure

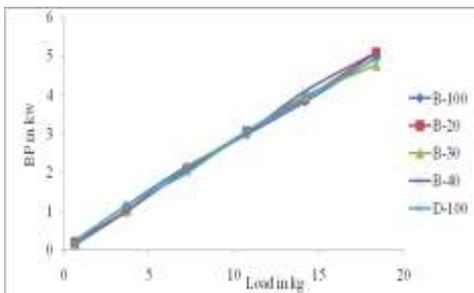


Figure 19: Variation of Brake power with Load at 180 bar pressure before coating

The variation of brake power with load for different fuels at 180 bar pressure before coating is presented in Fig 19. In all cases, it increased with increase in load. The maximum brake power is for B40 at maximum load and was higher than that of diesel. The brake power obtained for B20, B30, B100 and D100 were less than that of B40.

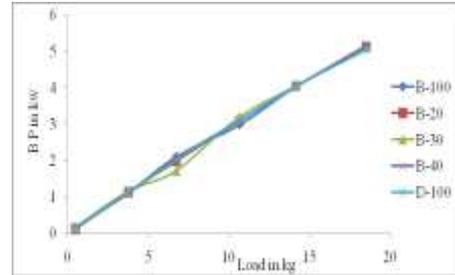


Figure 20: Variation of Brake power with Load at 180 bar pressure after coating

The variation of brake power with load for different fuels at 180 bar pressure after coating is presented in Fig 20. In all cases, it increased with increase in load. The maximum brake power is for B40 at maximum load and was higher than that of diesel. The brake power obtained for B20, B30, B100 and D100 were less than that of B40

3. Brake power at 160 bar pressure:

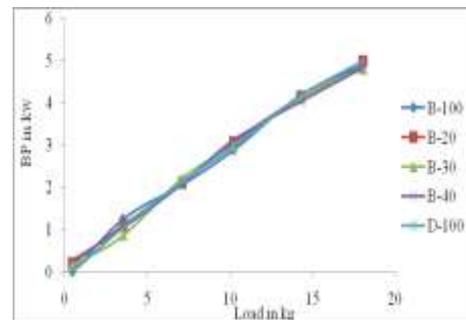


Figure 21: Variation of Brake power with Load at 160 bar pressure before coating

The variation of brake power with load for different fuels at 160 bar pressure before coating is presented in Fig 21. In all cases, it increased with increase in load. The maximum brake power is for D100 at maximum load and was higher than that of Biodiesel. The brake power obtained for B20, B30, B40 and B100 were less than that of diesel

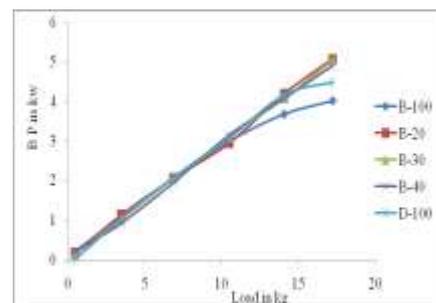


Figure 22: Variation of Brake power with Load at 160 bar pressure after coating

The variation of brake power with load for different fuels at 160 bar pressure after coating is presented in Fig 22. In all cases, it increased with increase in load. The maximum brake power is for B20 at maximum load and was higher than that of diesel. The brake power obtained for B30, B40, B100 and D100 were less than that of B20.

6.2 Emission characteristics

1. Carbon monoxide Emissions at 200 bar pressure:

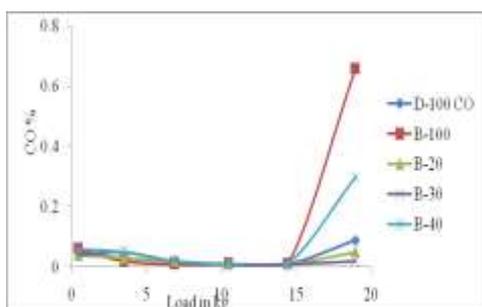


Figure 23: Variation of CO with Load at 200 bar pressure before coating

Variation of CO emissions with engine loading for different fuels at 200 bar pressure before coating is compared in Fig 23. The minimum CO produced was found in B30 and it was observed that a reduction of 50%, as compared to diesel. Also it is observed that the CO emissions for diesel and the blends are lower than the biodiesel fuel. These lower CO emissions of diesel and the blends may be due to their more complete oxidation as compared to biodiesel. Some of the CO produced during combustion of biodiesel might have converted into CO₂ by taking up the extra oxygen molecules present in the biodiesel chain and thus reduced CO formation. It can be observed from Fig. that the CO initially decreased with load and later increased sharply up to full load.

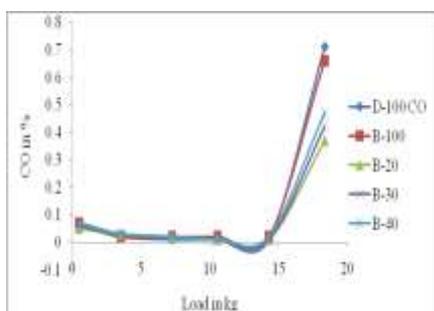


Figure 24: Variation of CO with Load at 200 bar pressure after coating

Variation of CO emissions with engine loading for different fuels at 200 bar pressure after coating is compared in Fig 24. The minimum CO produced was found in B20 and it was observed that a reduction of

30%, as compared to diesel. The maximum CO emission was for Diesel. It can be observed from Fig. that the CO initially decreased with load and later increased sharply up to full load.

2. Hydro carbon Emissions at 200 bar pressure:

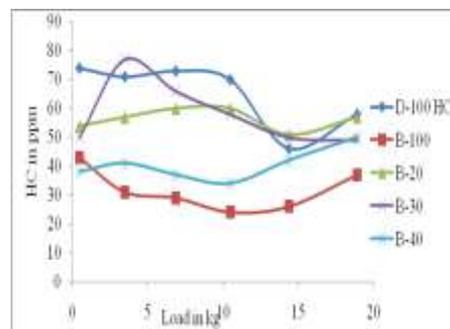


Figure 25: Variation of Hydro-carbon with Load at 200 bar pressure before coating

The hydrocarbons (HC) emission trends for blends of methyl esters and oil and diesel at 200 bar pressure before coating are shown in Fig 25. The reduction in HC was linear with the addition of biodiesel for the blends tested. The minimum HC emission was for biodiesel i.e. B100. There is a reduction from 58 ppm to 37 ppm was obtained resulting in B100 and it is 30%, as compared to diesel at the maximum load.

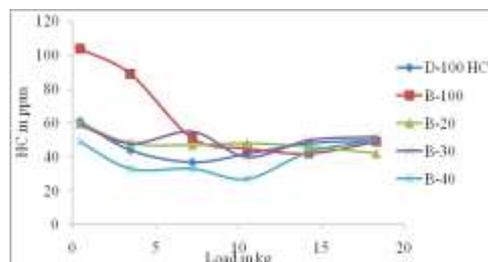


Figure 26: Variation of Hydro-carbon with Load at 200 bar pressure after coating

Variation of HC emissions with engine loading for different fuels at 200 bar pressure after coating is compared in Fig 26. From the fig it can be observed that at initial load HC is maximum for biodiesel B100 and as the load is increased the emission reduces drastically. After coating the HC emission of biodiesel and its blends are less when compared to that of diesel

3. Hydro carbon Emissions at 180 bar pressure:

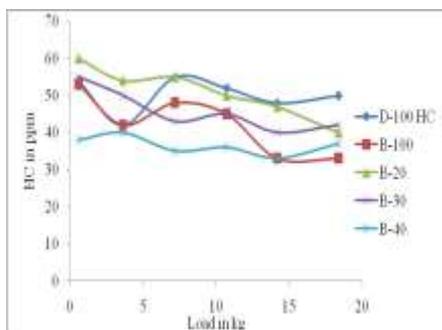


Figure 27: Variation of Hydro-carbon with Load at 180 bar pressure before and after coating

The hydrocarbons (HC) emission trends for blends of methyl esters and oil and diesel for 180 bar pressure before coating are shown in Fig 27. The reduction in HC was linear with the addition of biodiesel for the blends tested. The minimum HC emission was for biodiesel i.e.B100. There is a reduction from 50 ppm to 33 ppm was obtained resulting in B100 and it is 25%, as compared to diesel at the maximum load.

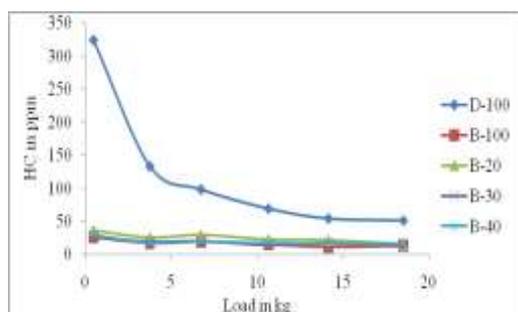


Figure 28: Variation of Hydro-carbon with Load at 180 bar pressure after coating

The hydrocarbons (HC) emission trends for blends of methyl esters and oil and diesel at 180 bar pressure after coating are shown in Fig 28. The reduction in HC was linear with the addition of biodiesel for the blends tested. From the fig it can be observed that at initial load HC is maximum for diesel D100 and as the load is increased the emission reduces drastically. After coating the HC emission of biodiesel and its blends are less when compared to that of diesel.

4. Hydro carbon Emissions at 160 bar pressure:

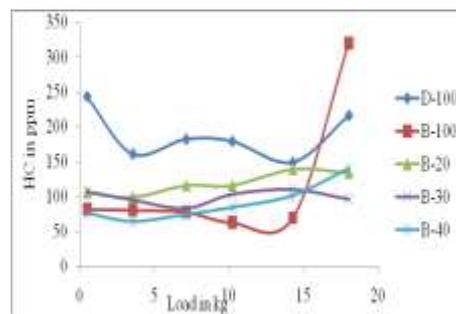


Figure 29: Variation of Hydro-carbon with Load at 160 bar pressure before coating

The hydrocarbons (HC) emission trends for blends of methyl esters and oil and diesel at 160 bar pressure before coating is shown in Fig 29. The reduction in HC was linear with the addition of biodiesel for the blends tested. The minimum HC emission was for biodiesel i.e.B30. The HC emission for diesel and biodiesel is much higher than the blends of biodiesel.

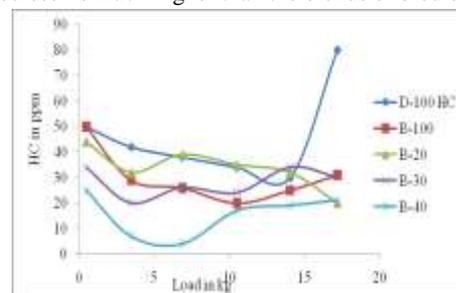


Figure 30: Variation of Hydro-carbon with Load at 160 bar pressure after coating

The hydrocarbons (HC) emission trends for blends of methyl esters and oil and diesel at 160 bar pressure for after coating are shown in Fig 30. The reduction in HC was linear with the addition of biodiesel for the blends tested. From the fig it can be observed that at initial load HC is maximum for diesel D100 and as the load is increased the emission reduces drastically. After coating the HC emission of biodiesel and its blends are less when compared to that of diesel.

7. CONCLUSIONS

1. The production of Callophyllum biodiesel is obtained by two stage transesterification process using NaOH as a catalyst.
2. The Performance and Emission test was carried out for different pressures [160 bar, 180 bar and 200 bar pressures]
3. The C.V of biodiesel (B100) was found to be 36957 kJ/kg and C.V of different blends were also determined according to ASTM standards .The C.V of blends was found to be less than the diesel (42500 kJ/kg)
4. From the experimental investigation the C.V, Viscosity, and Density of B20 is 41,391kJ/kg, 3.1 Cst and 852 kg/m³ respectively which is approximately same when compared to diesel.

5. From the experimental study, the result shows that Brake Thermal Efficiency for B20 is 41.33% and for diesel 35.21%. There is an increase in 6.12% of Brake Thermal efficiency at 200 bar pressure for uncoated engine when compared to diesel.
6. For coated engine, at 180 bar pressure for B40 blend the B.S.F.C decreases by 0.08 kg/kWhr and B.P increases by 0.2 kW with respect to diesel. So, the performance of engine increases for coated engine when compared to uncoated engine.
7. From the emission characteristics graphs, it can be seen that there is a decrease in CO and HC emission for 200 bar pressure after coating. The CO emission of B100 is reduced by 2 % when compared to diesel and HC emission is reduced partially from 45 ppm to 50 ppm.
8. At 180 bar pressure HC emission of B100 reduces considerably for both before and after coating of the engine. Before coating, B100 emits 33 ppm NO_x emission and diesel 50 ppm. After coating, B100 13 ppm and diesel 51 ppm.
9. The CO₂ emission of biodiesel and its blends are much higher than that of diesel for all injection pressure.
10. The performance and emission characteristics of 160 bar pressure are determined. The results obtained are not to the standard values with respect to diesel because the fuel atomization is incomplete due to which incomplete combustion of fuel takes place.
11. From the obtained results, we can conclude that the blend B40 at 180 bar pressure has better performance and Emission characteristics when compared to all other blends with respect to diesel for all varying pressures for TBC engine.

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