THE IMPACT OF THERMAL BARRIER COATING APPLICATION ON PERFORMANCE, COMBUSTION AND EMISSIONS OF A DIESEL ENGINE FUELED WITH CALOPHYLLUM INOPHYLLUM BIODIESEL BLEND

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***Abstract**:* The rapid increase in a fuel price, decreasing supply of high grade fuels in the market, and environmental concerns stimulated research on more efficient engines, and also led to the revolution of using alternative fuels. The efficiency of IC engines can be enhanced by reducing the heat loss. Lower heat rejection from the combustion chamber through thermally insulated components can be achieved by thermal barrier coatings. Calophyllum Inophyllum methyl ester (CIME) biodiesel blends, were tested for their alternate resource in diesel engines. The piston crown was coated with the partially stabilized (ZrO_2) and Alumina (Al_2O_3) coatings with bond coating (Ni-Al) over the piston crown to provide thermal insulation, which leads to better combustion and performance. Coating was done by thermal spray method. Experimental investigation on performance, combustion and emission characteristics are conducted for varying loads 0%, 25%, 50%, 75%, 100% for both coated and uncoated piston. The biodiesel blends prepared from CIME oil is prepared through esterification process. In general, thermal barrier coating improves the efficiency of the engine and reduces various energy losses.

Index Terms-Calophyllum Inophyllum, thermal spray,compression ratio, Biodiesel,Ceramic coating

I.INTRODUCTION

The worldwide energy requirement is on the rise due to ever-increasing population and expansion of the industrial base. The world's energy demands depend heavily on conventional fuels and 90% of which is consumed for energy generation and transportation. Due to usage of conventional fuels the release of CO_2, CO, NO_X and S is on the rise, and that, it is responsible for the global warming [1]. Fossil fuels consumption in India is on rise every day. The cost of petroleum and diesel is also increasing along with crude oil. To augment this problem in India, the focus is now, in development non-conventional fuels [2]. Now, there is a need to focus on alternative fuels which can replace diesel fuels. This has led to explore alternative sources fuel to meet the energy demands considering future. Oils of seed crops have been considered as alternative fuel. However, oil obtained from the seed crops have a higher viscosity than diesel fuel, as well as a distinctive odour in the exhaust, which limits their direct usage in engines as they damage engine components and reduce engine life [3]. This problem has been addressed by converting the oils into esters by transesterification with various alcohols. Transesterified oils are called bio-diesel these bio-diesel exhibit fuel properties similar to that of diesel. Hence, it is wise to use non-edible oil for biodiesel applications. Some non-edible oils are Jatropha (Jatropha curcas), [4,5] Mahua (Madhuca indica), [6], Honne (Calophyllum inophyllum Linn),[7,8] Brassica carinata, jojoba oil and Tamanu (Calophyllum inophyllum seed oil) [9].

To improve performance and efficiency of the CI engines some modifications are done on the engine. The heat carried away by the coolant, and exhaust gases carry considerable amount of fuel energy from the combustion chamber in CI engines, leaving only one third of the total energy for conversion into useful work. Thermal barrier coating technique is used by many researchers to increase the heat insulation inside the combustion chamber, and it paves way to improve the thermal efficiency of the CI engines. Thermal barrier coating improves engine power and result in less specific fuel consumption, reducing the emission levels of Hydrocarbon and Carbon Monoxide and reduces smoke opacity [11]. While selecting any thermal barrier coating, three properties which are required in a material which can be used as a thermal barrier coating material.1) strain compliant, 2) lower thermal expansion coefficient and 3) thermal stability. The diesel engine with its combustion chamber wall insulated by ceramics is termed as LHR engine. This necessitates the development of newer materials which poses low shear strength, high hardness, low friction loss and higher fuel economy. Multi-layer ceramic coatings (MCM) are used which consists of combination of ceramic materials, which fulfils the above mentioned requirement [10]. In this work, multilayer ceramic coatings PSZ/Al_2O_3 with bond coating (Ni-Al) were applied by plasma-spray technique onto the piston crown and the performance, combustion and emission characteristics of a diesel engine was analyzed with CIME blend as biodiesel.

II. CALOPHYLLUM INOPHYLLUM SEED OIL ESTERIFICATION

Esterification is a chemical treatment process, performed for the conversion of unsaturated fatty acids, to its respective esters. Calophyllum Inophyllum seed oil was used for transestrification process. The process parameters such as reaction condition, type of alcohol, amount of catalysts reaction time and temperature, were controlled and optimized according to their standards. Methanol used as a regent and H_2SO_4 and KOH used as a catalyst, for base reaction. Single stage base catalyzed transestrification was used for various methyl ester blends of CIME (10%, 20%, 30%) which are blended with neat diesel [12]. The fuel properties of CIME oil methyl esters and their different blends with diesel are shown inTable1.

Table:1: Properties of biodiesel blends:

S.No	Fuel blend	Density (kg/m^3)	Calorific value (MJ/kg)	Kinematic viscosity at 40^0C (mm^2/s)	Flash point (^{0}C)	Cetane number
1	Diesel	836	43.60	2.98	52	50
2	CIME 10	841	42.38	3.10	86	52
3	CIME 20	846	41.16	3.42	94	52
4	CIME 30	851	40.14	3.74	104	54

III.PLASMA SPRAY CERAMIC COATING

Several surface coatings techniques are available for depositing Zirconia and Alumina powders, amongst them plasma spraying is considered as superior due to its, high reliability and enhanced adhesion. In plasma spray technique, the coating powder sprayed through plasma gas. Between two electrodes plasma is formed and powder is deposited in the plasma arc. The primary gas is usually argon or nitrogen. In the gun with high frequency electrical current, ionization takes place frequently in the system. Standard plasma guns can reach up to 40 kW. The melted and mixed powder is quickly sprayed on to the substrate. In plasma spraying technique, when argon, hydrogen or nitrogen gases are used, oxidation problem is minimized. For this reason, plasma spraying techniques have found useful applications. Even though this system is expensive, in some purposes there is no way to use other method but plasma spray technique. One of the advantages of plasma spraying is, it is possible to coat with high melting point materials. For coating, surface should be rough, and does not contain any oxide, oil and powder on the surface. Surface roughness can be provided by spraying alumina and sand. Plasma spraying technique can be adopted for coating thickness in the range of 2.5-2500µm.

IV. MULTILAYER CERAMIC COATINGS

Multilayer ceramic coating was applied by using plasma spraying technique. The piston crown was coated with top layer PSZ (Partially Stabilized Zirconia) of thickness 150 microns and Al_2O_3 (Alumina) bottom layer of thickness 150 microns with bonding material. The bonding material used in this study was Ni-Al, with thickness of 100 microns, with total thickness of 400 microns. Photographic view of the uncoated piston and coated piston is shown in Fig.1 and Fig. 2 respectively.

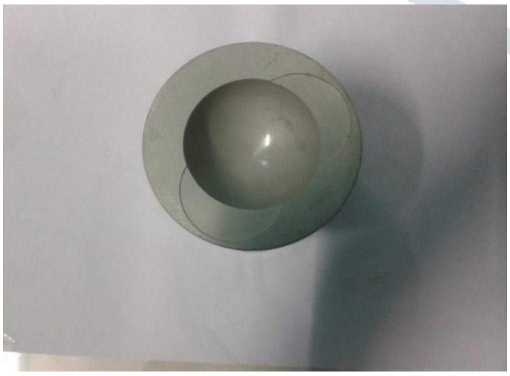
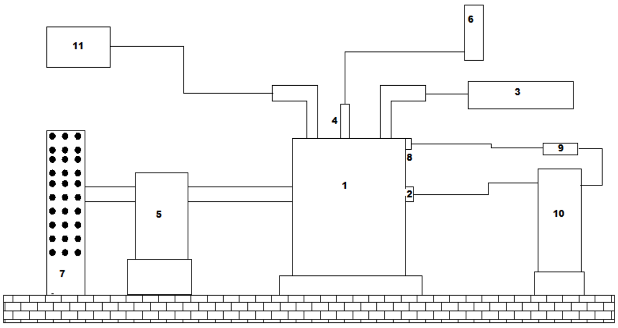


Fig. 1 Photographic view of uncoated piston

Fig. 2 Photographic view of coated piston

V. EXPERIMENTAL SETUP AND PROCEDURE

Figure.3 and 4 shows experimental setup of the single cylinder direct injection diesel engine. Single cylinder direct injection diesel engine, was coupled with the electric dynamometer that applies load on the running diesel engine. The engine specifications are given in Table 2.Personal computer was connected with the engine it helps to analyze the combustion characteristics of an engine. AVL software was used, for combustion analysis.



1. Engine
2. Magnetic pickup
3. Exhaust gas analyzer
4. Fuel injector
5. Dynamometer
6. Fuel tank
7. Dynamometer controller
8. Piezo electric transducer
9. Charge amplifiers
10. Storage amplifier
11. Air box

Fig. 3 Experimental setup

Fig. 4 Photographic view of the test engine set up

Experimental investigations of CIME, is carried out in a four stroke single cylinder air cooled direct injection diesel engine bore, of 87.5 mm and stroke length 110 mm. CIME mixed, with diesel to form fuel blends, testing fuels blend contains 10%, 20%, 30% of CIME. Electric dynamometer was used for application of loads gradually changing from 0%, 25%, 50%, 75%, 100% load conditions. Tests have been carried out, for both coated and uncoated pistons to study the combustion and performance characteristics, of the oil blends under the partially stabilized zirconia and Alumina multi layer coating as a thermal barrier coating.

Table: 2: Specifications of a single cylinder direct injection diesel engine:

S.NO	Particulars	Specifications
1	Manufacture	Kirloskar
2	Model	TAF 1
3	Fuel injection type	Direct injection
4	Rated speed (rpm)	1500
5	Number of cylinder	1
6	Bore (mm)	87.5
7	Stroke (mm)	110
8	Displacement volume (cc)	661.45
9	Compression ratio	17.5:1
10	Cooling system	Air -cooled
11	Cubic capacity	0.66 lit
12	Fuel Injection time	23.4 degree bTDC
13	Injector pressure (bar)	200
14	Loading type	Eddy current dynamometer
15	Maximum power (kW)	4.4

VI. RESULTS AND DISCUSSION

6.1 Brake thermal efficiency (BTE)

Deviation in BTE for diesel upon addition of CIME biodiesel is revealed in figure 5. Brake thermal efficiency is observed at all BP (Brake power) for uncoated piston with neat diesel and for multilayered ceramic coated piston with CIME oil blends of C10, C20 and C30. All the fuels require additional fuel for sustaining the combustion process. Brake thermal efficiency of Diesel is higher than C30, C20, and C10 at all loads. The viscosity of diesel is lower than methyl esters Lower viscosity amplifies the efficiency of combustion caused by superior atomization, and influence combustion. Further, calorific value (CV) for diesel is higher than CIME blends this in turn increases the BTE for diesel. At 75% load BTE of C30, C20, C10 and diesel is 26.8, 27.6, 28.2 and 28.9% respectively.

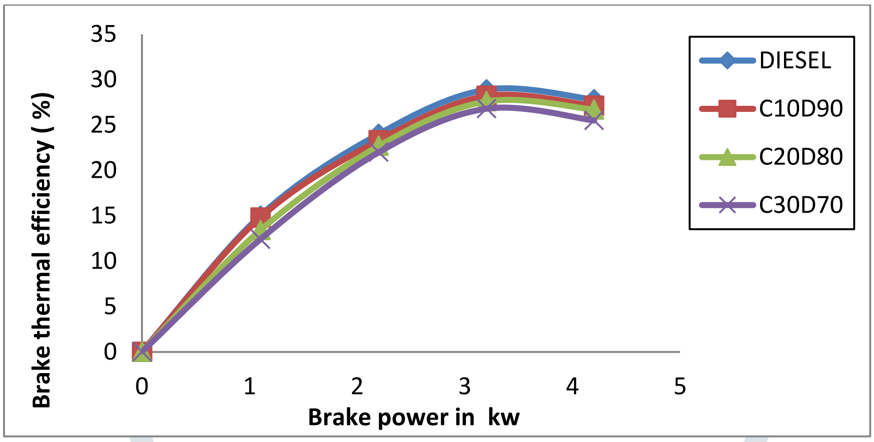


Fig.5 Brake thermal efficiency Vs B P

6.2 Brake specific fuel consumption (BSFC)

BSFC defines the utilization and consumption of fuel per unit time and power. Variation in BSFC by means of BP (Brake power) for, uncoated piston with neat diesel and for multilayered ceramic coated piston with CIME oil blends of C10, C20 and C30 is shown in figure 6. Brake specific fuel consumption of diesel is lower than C10, C20 and C30 at all loads. The viscosity of diesel is lower than CIME. Lower viscosity increases the combustion efficiency due to improved atomization and reduces the fuel requirement. Further, calorific value of CIME is very much lower than diesel. This increases brake specific fuel consumption than diesel. At full load, Brake specific fuel consumption of C30, C20, C10 and diesel is 0.3095, 0.3048, 0.3041 and 0.291 kg/kw-hr respectively.

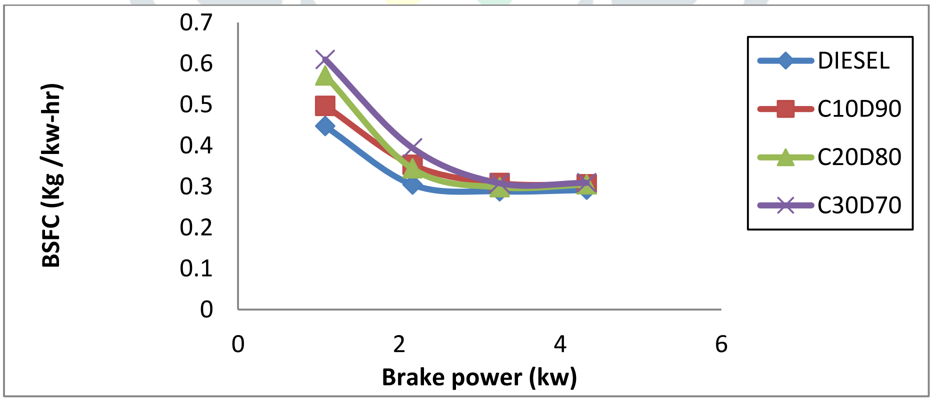


Fig. 6 Brake specific fuel consumption Vs B P

6.3 Carbon monoxide emissions (CO)

CO is formed in rich and lean combination. Lean combination leads to incapable flame propagation. Rich combination guides to short supply of oxygen. Further, Oxidation of CO takes place in recombination reaction between CO and different oxidants present during combustion. Variation in CO emissions for, uncoated piston with neat diesel and for multilayered ceramic coated piston with CIME oil blends of C10, C20 and C30 is shown in figure with BP is shown in figure.7. CO emissions from diesel are higher than C30, C20, and C10. Diesel has lower oxygen content routing lofty CO emissions. Puhan et al [13]. At full load, CO emissions of C30D70, C20D80, C10D90 and diesel is 0.03, 0.06, 0.07 and 0.08% respectively. The obtained result conforms to the result obtained by Sadhik Basha et al. [14].

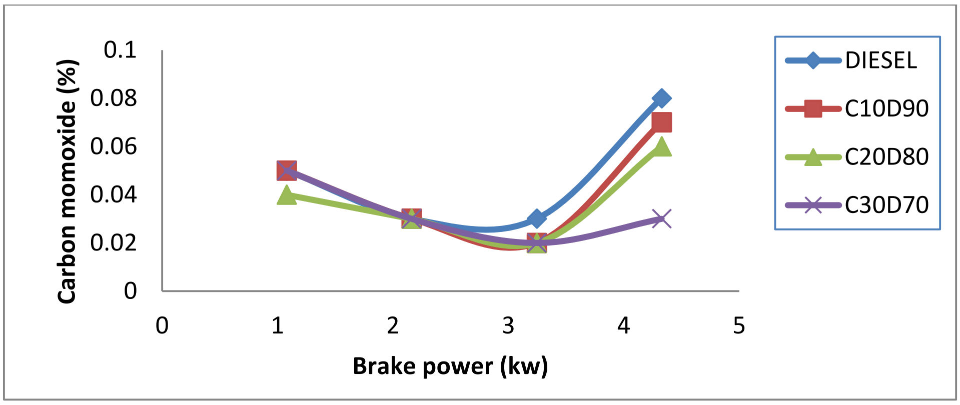


Fig. 7 carbon monoxide emissions Vs B P

6.4 Hydrocarbon Emissions (HC)

HC emission is produced due to non-homogeneity of combination of fuel-air intensification due to shortage of oxidants. Deviation in HC emissions with BP for uncoated piston diesel fueled and for, multilayered ceramic coated piston with CIME oil blends of C10, C20 and C30 is shown in figure 8. HC emissions of the C30, C20, and C10 are fewer than diesel. HC emissions of C30, C20, C10 and diesel are 60, 66, 69 and 74 PPM at 75% load conditions.

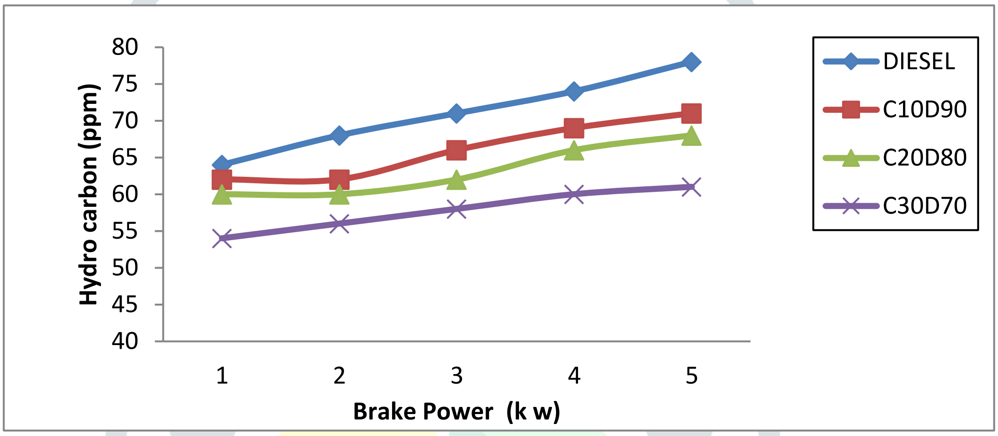


Fig. 8 Hydrocarbon emissions Vs B P

6.5 Oxides of nitrogen (NOx)

NOx emissions with BP for diesel upon addition of CIME biodiesel is shown in figure 9. According to Zelodvich NOx thermal mechanism, higher BP generates more NOx. NOx emissions from diesel are lesser than C30, C20, and C10. Further, thermal barrier coating adds to, increase in high peak cylinder temperature. Biodiesel blends have lower oxygen content which boosts the oxidation reaction between blends and air and result in higher NOx emissions. Puhan et al. [13] found that higher in NOx emission of about 27% for bio fuel. At 75% of BP NOx emissions of the C30, C20, C10 and diesel is 1621, 1333, 1224 and 1035 PPM respectively. The obtained result conforms to the result obtained by Sadhik Basha et al [14]

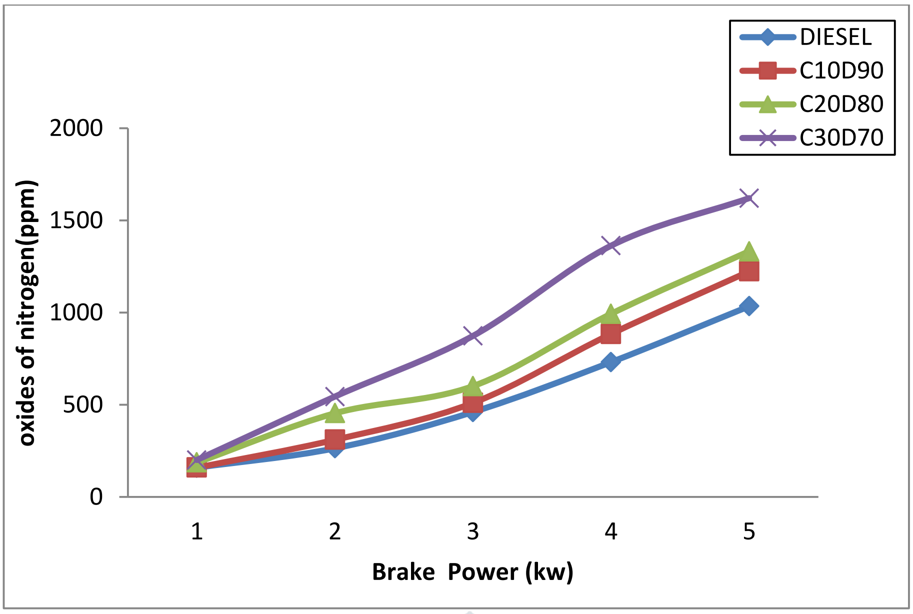


Fig.9 Oxides Nitrogen Vs B P

6.6 Variation of Cylinder Pressure

Figure 10 shows the variation of cylinder pressure with respect to crank angle for the 75% of load conditions, for uncoated piston with neat diesel and for multilayered ceramic coated piston with CIME oil blends of C10, C20 and C30 respectively. The result shows that the cylinder peak pressure of the uncoated piston with neat diesel is 68.13 bar and for multilayered ceramic coated piston with CIME blends are 66.4 bar, 62.21 bar, and 58.03 bar respectively. The peak pressure in the case of multilayered ceramic coated piston for the C10 is maximum and very close to pressure of neat diesel, ceramic coating which retains the heat inside the combustion chamber which in turn, increases the engine operating temperature resulting in increased cylinder peak pressure. Also, in a compression ignition engine, cylinder pressure depends on the burned fuel fraction during the premixed burning phase i.e. at initial stage of combustion.

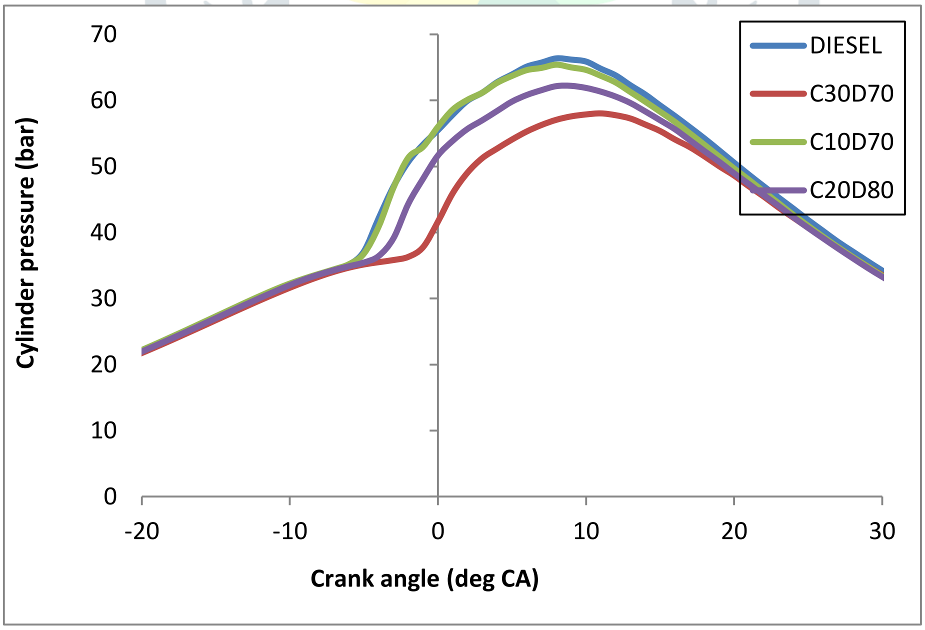


Fig. 10 Cylinder Pressure Vs Crank angle

6.7 Variation of Rate of heat release

Figure 11 shows the variation of heat release with crank angle at 75% load condition. Under identical conditions, fuel in uncoated piston and multilayer ceramic coated piston with CIME blends experiences the rapid premixed fuel burning followed by diffusion combustion. After the ignition delay period the premixed fuel air mixture burns rapidly releasing the heat at a very high rapid rate after which the diffusion combustion takes place. The significance of a higher operating temperature associated with the ceramic coating shows better performance. The heat release rate for C30, C20, C10 and diesel at75% load conditions are 63.75 J/°CA, 67.05J/°CA, 72.3 J/°CA, and 77.25 J/°CA respectively. Since the calorific value CIME is lower, the maximum heat release rate is comparatively less. Further, this is also because of enrichment in combustion (premixed) because of lengthier combustion for the C30, C20, and C10.

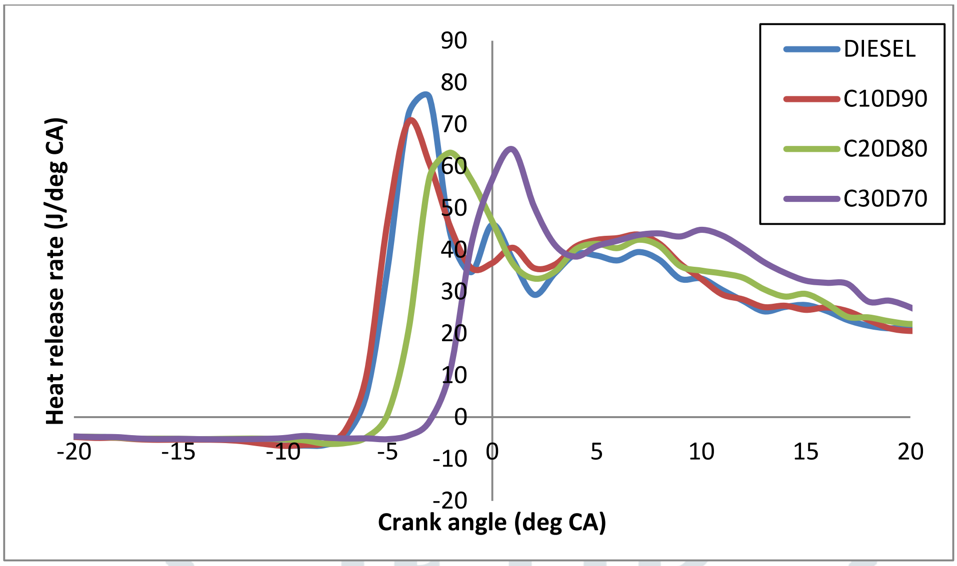


Fig. 11 Rate of heat release Vs Crank angle

VII. CONCLUSION

This present work is intended to discover the surplus information about using Calophyllum Inophyllum oil methyl ester as a potential and promising alternative fuel for CI engine on direct injection diesel engine with the partially stabilized PSZ/Al_2O_3 coatings over the piston crown for thermal performance. The effects of these techniques, on performance, emissions and combustion characteristics of CIME oil blends have been explored in this work.

- Result reveals that BTE of C10 is very close diesel fuel, and less than that of diesel by 2.42%. CO and HC emissions of CIME blend is less than diesel. NO_X emission of coated piston for CIME blend increases with increase in percentage of CIME blend, when compared to the uncoated piston for neat diesel.

- Further, with addition PSZ/Al_2O_3 coatings to the piston, the ignition delay was shorter for CIME biodiesel (10%, 20%, and 30%) than neat diesel. Cylinder peak pressure for C10 blend of the multilayered coated piston is 66.4 bars and 68.13 bars for neat diesel standard piston, the value is very close to neat diesel.

- The heat release rate of the PSZ/Al_2O_3 coated piston was less for CIME biodiesel blends (10%, 20%, and 30%) than neat diesel. For C10 blend it is 72.3 J/°CA and 77.25 J/°CA for neat diesel, this value is very close to diesel.

- From this work, it is concluded that CIME biodiesel and diesel blends subjected to PSZ/Al_2O_3 coatings has a positive impact on reducing various drawbacks associated with the blends.

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