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PERFORMANCE AND EMISSION CHARACTERISTICS OF THERMAL BARRIER COATING ON DIESEL ENGINE FUELED WITH COTTONSEED BIODIESEL

Badal Kudachi1[a, *], Nitin Satpute2[b], Nilaj N Deshmukh3[a], Bipin Mashilkar4[a]
[a]*Department of Mechanical Engineering, Fr. C. Rodrigues Institute of Technology, University of Mumbai, Vashi, Navi Mumbai, PIN-400703, Maharashtra, India*
[b]*Department of Mechanical Engineering, Faculty of Science and Technology, Vishwakarma University, Pune, PIN- 411037, Maharashtra, India*

*Corresponding author Email: badalkudachi@gmail.com

There is an urgent need to explore substitute for conventional fossil fuel in light of environmental sustainability. Attempts were made to improve engine efficiency and to reduce greenhouse gasses by certain modification in the usage of biofuel. In the present work, experiments have been performed on a single cylinder, four strokes, direct injection, diesel engine with cottonseed biofuel and its blends. In order to ensure complete combustion of the fuel, cylinder head and piston crown have been coated with Yttria Partially Stabilized Zirconia (YPSZ) for a thickness of 0.2 mm. The Plasma Spray Technique has been used for coating engine components. Combustion properties of the cottonseed oil have been improved with the transesterification process. The experimental results showed significant improvement in performance and reduction in emission characteristics of a coated engine. The biodiesel blend B10 and B25 showed good results compared to diesel in an uncoated and coated engine respectively.

***Keywords*:** Diesel Engine, Thermal Barrier Coating, Plasma Spray Technique**.**

1. Introduction

The fossil fuels play a major role in fulfilling the world energy requirement. Fossil fuels are exhaustible energy sources and their ability to supply the energy demands continuously is limited to a few decades. [1] The combustion of fossil fuels emits pollutant gasses such as CO, CO2, SO2, HC, NOX which cause the major impact on the environment. The global warming problem caused by greenhouse gasses (CO2) which traps the heat in the atmosphere [2]. The dependency on fossil fuel has increased enormously due to the growth in the population of the world. The oil crisis in 1973, the subsequent increase in the cost of fuel urges to enhance the performance of IC engine and look for alternative fuels [3]. Increasing efforts are being made to enhance the performance of IC engines and the use of alternative fuels in the view of depleting fossil fuels. An attempt has been made in the present study to increase the efficiency of the engine by the modification of engine parts and using alternative fuel. The thermal efficiency of an engine is about 33% with the major heat loss occurred by cooling and exhaust system. These losses can be minimized by coating certain parts of the engine with the ceramic material which acts as a thermal barrier to the heat produced inside the cylinder, which is also known as Thermal Barrier Coating(TBC) material. Initially, TBC was tested for aircraft engine performance. Furthermore; studies have exhibited and analysed for the effect of inside cylinder thermal insulation. Application of the TBC on IC engine in addition to the reduction of heat loss, it increases gas temperature and combustion wall temperature [4].

The typical TBC system consists of Super alloy/metals, Bond Coat (BC), Thermally Grown Oxides (TGO), and Thermal Barrier Coating (TBC) as illustrated in Fig. 1. The upper layer is TBC which is also called as Top Coat, is the porous ceramic structure which exhibits low thermal conductivity and coefficient of thermal expansion. The properties of TBC resulting lower the heat transfer from the combustion gasses to the components of the system. The BC which acts as a bond/mediator between the supper alloy/metal and TBC. The function of BC is to protect the supper alloy/metal from the oxidation and to improve adhesion property between the TBC and metal. The TGO forms between the TBC and BC at high-temperature exposure. The TGO due to its good adherence and low oxygen diffusivity characteristics, it prevents the underlying material from heat.

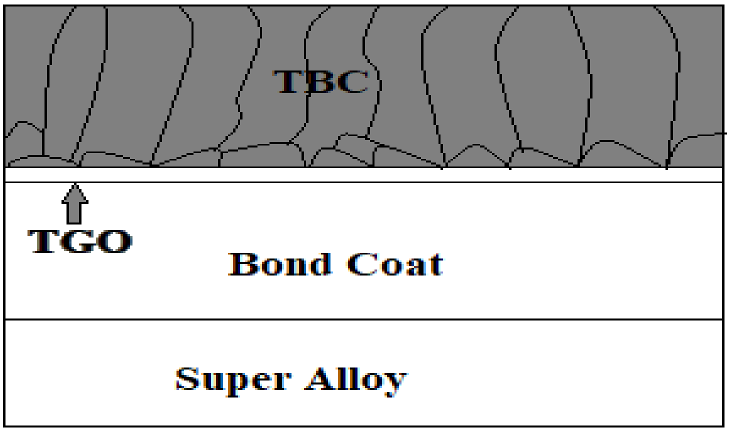

Fig. 1: TBC system. [5]

1.1 Plasma Spray Technique

The schematic diagram of the plasma spray is shown in the Fig. 2. It is a high frequency arc method, which ignites between the tungsten cathode and an anode. The gas which flows between the anode and cathode electrodes (H2, He, N2 or mixtures) ionized in a way that plasma plume several centimetres in length develops. The powder zirconia material is fed into the plasma plume where it gets melted and propelled towards the work-piece at a high speed. They form splats by spreading, cooling and solidifying. The TBC porosity by plasma spray technique is in the range of 3-20% [7]. The porosity of TBC material is desirable since it decreases the thermal conductivity.

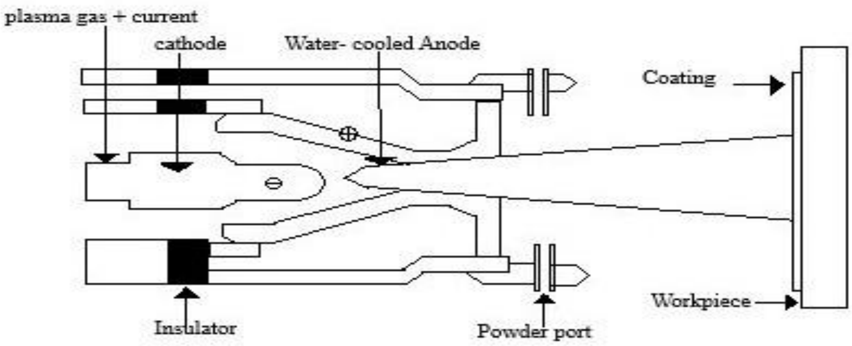

Fig. 2: Schematic diagram of plasma spray technique. [8]

The standard piston crown and cylinder head of diesel engine (Kirloskar made Type TV 1) were machined to remove material equal to the desired thickness of coating in order to maintain the engine compression ratio after the assembly of same on the engine. The optimum thickness of coating varies between 0.2 mm to 0.5 mm. The thinner coatings applied to the engine result in better performance [9]. Hence, the coating of thickness 0.2 mm was applied to the engine parts for this study.

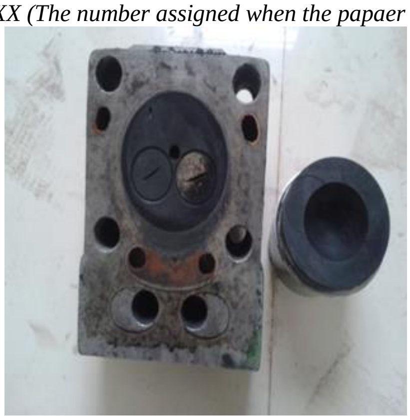

Fig. 3(a): Uncoated engine parts cylinder head and piston crown.

Fig. 3(b): Coated engine parts cylinder head and piston crown.

1.2 Biodiesel

The cottonseed biofuel converted into biodiesel by the trans-esterification process. Figure 4 shows the Experimental set up of trans-esterification. The sodium hydroxide (catalyst) is dissolved in the methanol (alcohol) using standard agitator. The cottonseed oil is added to the mixture of catalyst and alcohol. The two major products glycerin and biodiesel formed after the complete reaction. The mixture is then transferred to the separating funnel. Since the glycerin is much denser than biodiesel, it settles at the bottom of the vessel and is taken off. The excess alcohol from both the phases was distilled off under vacuum. The glycerin neutralized with an acid and can be stored as crude glycerin. The biodiesel in the upper phase separated from glycerin was purified by washing gently with warm water to remove the traces of unreacted catalysts, soaps and glycerine formed during the trans-esterification process.

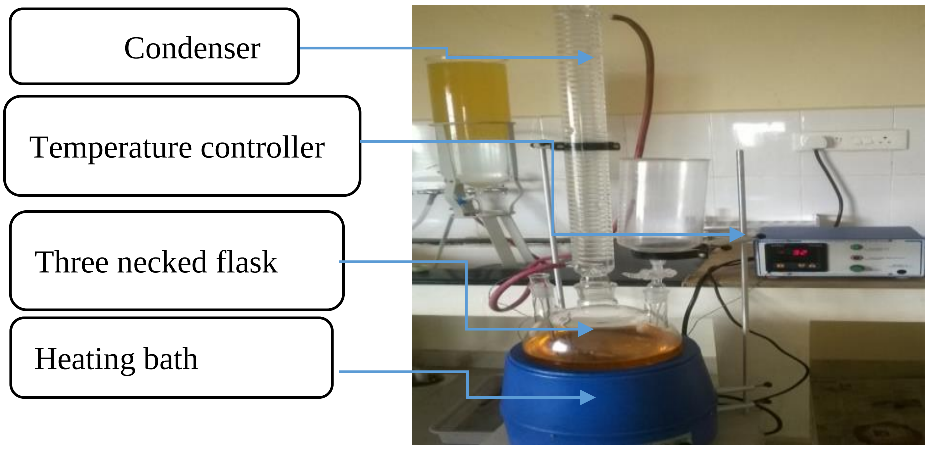

Fig. 4: Experimental set up of trans-esterification.

The biodiesel blends were prepared with different proportion like B100 (100% biodiesel), B10 (10% biodiesel, 90% diesel), B15, B20, B25 for the testing. The calorific value of fuel is the measure of heat or energy produced. The higher calorific value results in higher energy produced inside cylinder [10]. The calorific value of biodiesel is found to less than diesel. The viscosity is the important characteristics of the fuel, higher viscous oil results in poor atomization. The biodiesel is viscous than the diesel and it increase with the concentration of biodiesel in the mixture. The density values helpful for quantity calculation and assuming ignition quality. The density of biodiesel increase with the increase in concentration of the biodiesel in the mixture. The properties of diesel and cottonseed biodiesel are given in the Table 1.

Table 1: Properties of diesel and cottonseed oil

S.N.	Property	Diesel	Cotton Seed
1	Calorific Value (kJ/kg)	42500	34936.4
2	Flash Point (°C)	44	192
3	Fire Point (°C)	49	234
4	Viscosity (cst)	3.07	4.6
5	Density (kg/m3)	840	875

2. Experimental Setup for Engine Performance Test

The experiment was conducted in the laboratory of PDA College of Engineering, Gulbarga Karnataka on the single cylinder, four strokes, water cooled diesel engine. The specification of the engine given below in Table 2.

Table 2: Specification of engine

Parameters	Specification
Engine make	Kirloskar made TV 1
Rated power	5.2 kW
Speed	1500 rpm
Injection timing	23° bTDC
Compression ratio	16.5:1
Bore	80mm
Stroke length	110mm

The test conducted by varying the load and keeping the constant speed of 1500 RPM, the pressure at 180 bar on the normal standard uncoated engine and coated engine. The experiment set up of diesel engine is shown in Fig. 5.

2.1 Uncertainty Analysis

The uncertainty in experimental measurements of individual engine parameters arises from instrument selection, calibration of equipment, experimental conditions, observation, and environmental conditions. Uncertainty analysis required to justify the accuracy of experimental results. The uncertainty in the measurement of an individual parameter (u) and percentage of uncertainty (U) of engine parameters like BP, BSFC, BTE, CO, HC, and NOx were determined using following Eq. (1) and (2).

$$u = \frac{s}{\sqrt{n}} \quad (1)$$

$$U = \frac{u}{\sqrt{n}} * 100 \quad (2)$$

Where, s = standard deviation and n = number of trials.

$$s = sqrt\left\{\frac{\sum(Xi-\bar{X})^2}{n}\right\} \quad (3)$$

Where, Xi = i^{th} measurement $\bar{X}$ = mean of measured value.

Table 3 shows the uncertainties of the measured performance characteristics i.e. BP, BSFC, BTE and emission characteristics CO, HC, NOx.

Table 3: The uncertainties of measured parameters

Measured Parameter	Uncertainty (u)	Percetage of Uncertainty (U)
BP (kW)	±0.008	±0.254
BSFC (kg/h)	±0.008	±0.887
BTE (%)	±0.48	±0.05
CO (g/kWh)	±0.11	±1.39
HC (g/kWh)	±0.003	±0.58
NOx (ppm vol)	±5	±2.50

3. Results and Discussion

3.1 Performance characteristics

Brake power (BP)

The experimental values of BP are shown in Fig. 6(a) and 6(b). The maximum BP was found 5.42 kW for B10 at maximum load in an uncoated engine and it was 0.33 kW (6.4 %) higher than that of diesel. The maximum brake power was found 5.49 kW for B25 at maximum load in a coated engine and it was 0.44 kW (8.7 %) higher than that of diesel. Increase in the brake power was attained by the ceramic applied to the engine parts which prevents heat loss to the cooling and other medium [11].

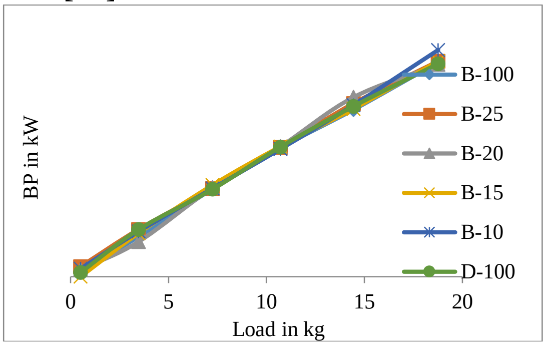

Fig. 6(a)

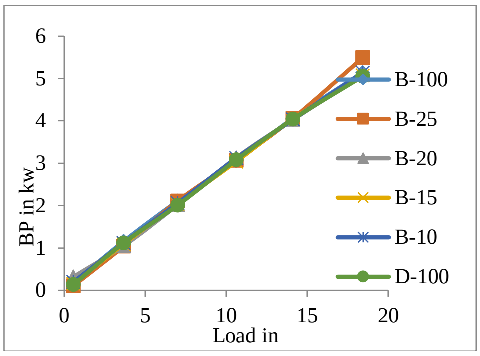

Fig. 6(b)

Fig. 6(a) and 6(b): Variation of brake power with load for uncoated and coated engine.

Brake thermal efficiency (BTE)

The results obtained pertaining to the BTE are shown with the help of graphs in Fig. 7(a) and Fig. 7(b). The maximum BTE was found 29.61 % for B10 in an uncoated engine and it was higher compared to diesel at maximum load. The maximum thermal efficiency was found 33.63 % for B100 in a coated engine which was higher than that of diesel at maximum load. The efficiency is improved because of increase in available power and reduction in heat loss [12].

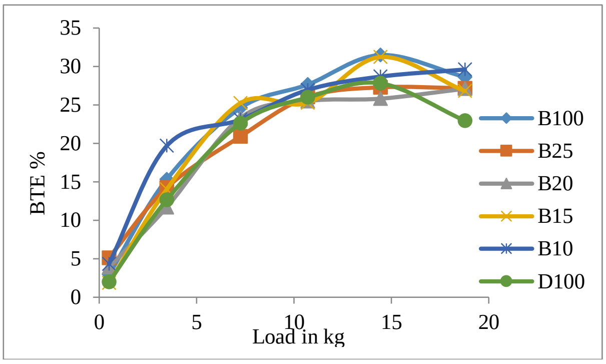

Fig. 7(a)

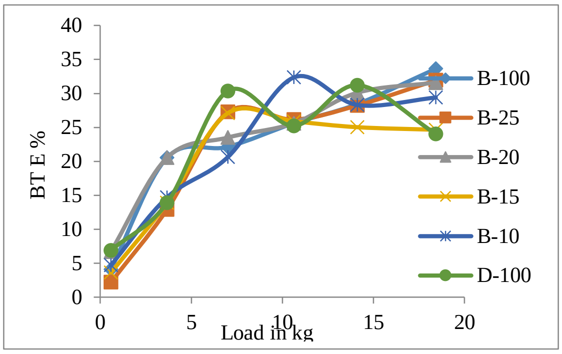

Fig. 7(b)

Fig. 7(a) and 7(b): Variation of BTE with load for uncoated and coated engine.

Brake specific fuel consumption (BSFC)

The experimental values for BSFC shown with the help of graph in Fig. 8(a) and 8(b). The energy content of biodiesel and its blends were lower than that of diesel; therefore, The BSFC of diesel and its blends are nearly the same as that of diesel [13]. The minimum BSFC 0.291 kg/kW-hr was observed for B10 in an uncoated engine at maximum load. In case of a coated engine, minimum BSFC 0.278 kg/kW-hr was observed for B25 and it was lower than other biodiesel blends and diesel at maximum load.

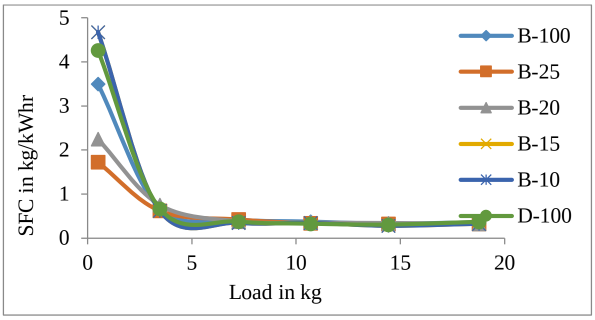

Fig. 8(a)

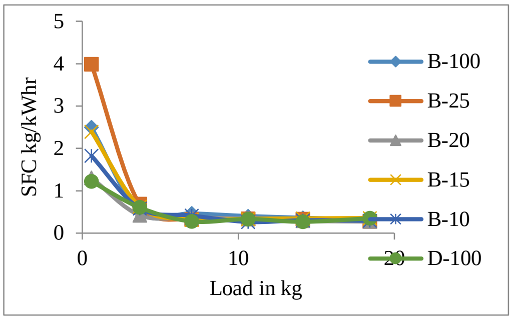

Fig. 8(b)

Fig. 8(a) and 8(b): Variation of BSFC with load for uncoated and coated engine.

3.2 Emission characteristics

Carbon monoxide (CO) emission

The variation of CO emission values is shown with the help of graphs in Fig. 9(a) and 9(b) respectively. In case of an uncoated engine, the minimum CO was observed for B25 and B10 at maximum load and there was reduction of 28.57 % as compared to diesel. On the other hand, the minimum CO was found for B25 at maximum load in coated engine and there was reduction of 51.61 % compared to diesel, which may have attributed to complete combustion. Some of the CO produced during the combustion might have converted into CO2 by taking up the extra oxygen molecule present in the biodiesel chain.

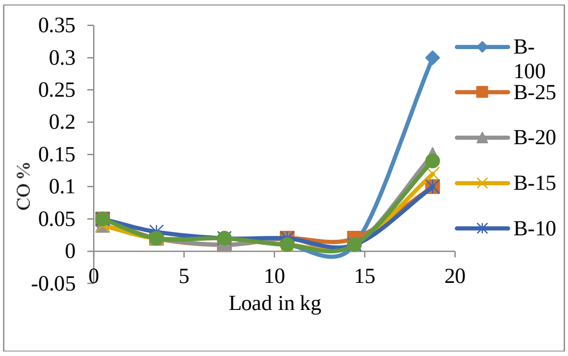

Fig. 9(a)

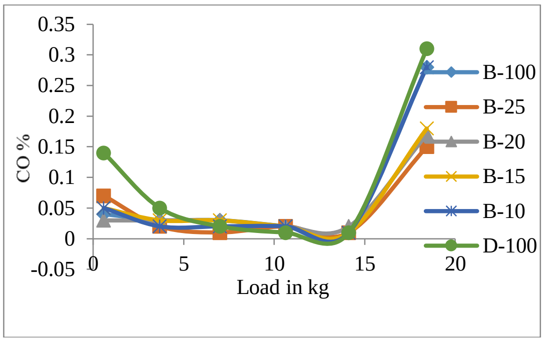

Fig. 9(b)

Fig. 9(a) and 9(b): Variation of carbon monoxide with load for uncoated and coated engine.

Hydro carbon (HC) emission

In case of uncoated engine, the minimum HC emission was observed for B100 and B25 by 68 %, 58 % compared to diesel at the maximum load. On the other hand, the minimum HC was found for B100 and B25 by 84.31 % and 80.4 % at the maximum load in a coated engine, which may be attributed to the better combustion efficiency. The hydrocarbon emission value is shown in Fig. 10 (a) and 10(b).

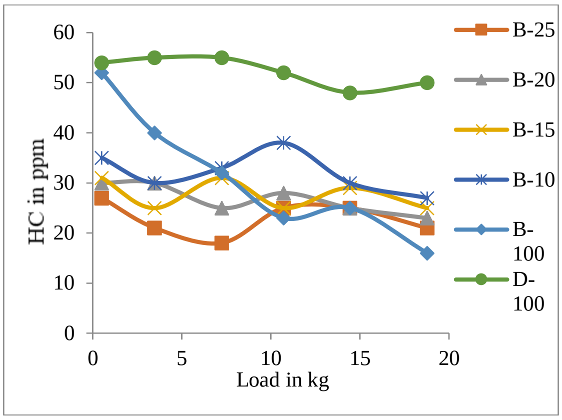

Fig. 10(a)

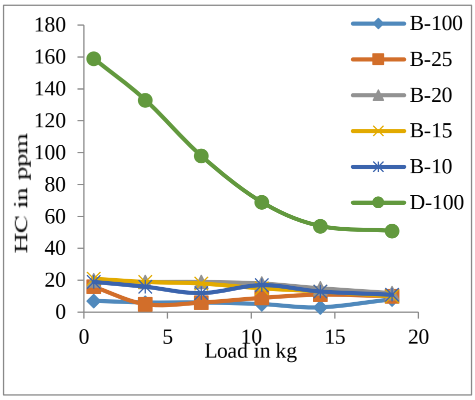

Fig. 10(b)

Fig. 10(a) and 10(b): Variation of hydrocarbon with load for uncoated and coated engine.

Nitrogen oxide (NO_X) emission

The NO_X emissions in CI engines are formed based on two factors, the cylinder gas temperature and the availability of oxygen for combustion [14]. The NO_X emission of uncoated and coated engine are shown in Fig. 11(a) and 11(b). The NO_X emission found to be higher for all the biodiesel blends when compared to diesel for both uncoated and coated engines.

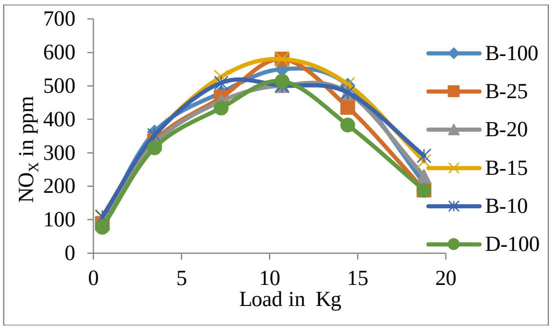

Fig. 11(a)

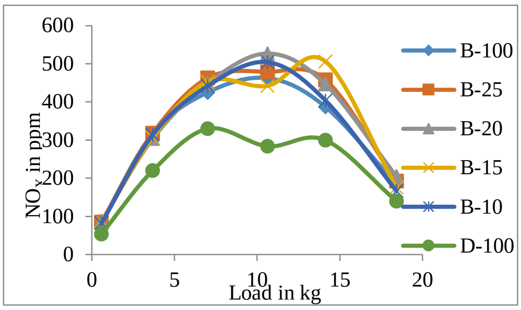

Fig. 11(b)

Fig. 11(a) and 11(b): Variation of nitrogen oxide with load for uncoated and coated engine.

4. Conclusion

The biodiesel blend B10 shows good results compared to diesel in an uncoated engine. The BP, BTE, and BSFC for B10 were observed to be 5.42 kW, 29.61%, 0.291 kg/kWhr respectively. These results were compared with diesel and there was increase in 0.33 kW (6.4 %) of BP, 6.6 % of BTE, decrease in 0.078 kg/kWhr (21.13 %) of SFC. In case of coated engine, B25 showed good results compared to diesel. The results showed that BP, BTE and BSFC for B25 were 5.49 kW of BP, 31.94 of BTE and 0.278 kg/kWhr of SFC respectively. There was increase in 0.44 kW (8.7%) of BP, 32.75% of BTE and reduction of 0.074 kg/kWhr (21 %) SFC compared to diesel. The B25 shows minimum CO emission of 51.61 % compared to diesel at maximum load. The B25 shows minimum HC emission of 80.4% and 84.31% compared to diesel at maximum load. The NO_X emission of all the biodiesel blends were found to be higher than diesel at all the load for both uncoated and coated engines.

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