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Research Article

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Effects of ZrO_2 and CeO_2 coating on piston-performance and emission characteristics of corn oil methyl esters

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ABSTRACT

The rapid depletion of fossil fuels, their ever increasing prices and the harmful effects of their emissions (greenhouse gases) on the environment have necessitated the search for an alternative fuel which is renewable and has comparatively less percentage of emissions .Such properties can be obtained by using biodiesel instead of pure diesel. Increasing the performance and reducing the emissions of the diesel engines using biodiesel could be achieved by coating the piston head with ZrO_2 & CeO_2. These materials have low thermal conductivity and hence can create a thermal barrier. The coating could be done by plasma spray method. Corn oil methyl esters (COME), produced by transesterification process with 75% diesel with 25% corn methyl esters blend (B25) was used as fuel in a Direct Injection Kirloskar, Vertical, 4 Stroke, Single acting, and diesel engine. The performance and emission characteristics at various loads of the engine run at a constant speed of 1500 rpm were studied in both the coated and uncoated engines. The results obtained were compared with those of pure diesel.

Keywords: Kirloskar DI – Diesel engine, Corn oil methyl ester, ZrO_2 & CeO_2 coating, Combustion and emission characteristics.

INTRODUCTION

The world is fast moving towards an energy crisis because of the depleting reserves of fossil fuels. In addition, the rapid rise in the use of petroleum products is favoring the depletion. Moreover, the green house gas emissions have to be controlled as they lead to the depletion of ozone layer. About 98% of carbon emissions results from fossil fuel combustion Balat et al., [1]. Hence the use of alternative fuels such as biofuels has drawn the attention of researchers. Biofuel is renewable and reduces the emissions in the transportation sector. Biodiesel can be produced by various methods. Yusuf et al., [2]. Amongst these methods, transesterification method is the most commonly used. Fukuda H et al., [3] have stated that transesterification using alkali catalyst gives high level of conversion of triglycerides into their corresponding methyl esters in short reaction time. Also, biodiesel leads to the substantial reduction in PM, HC, and CO emissions accompanied by the imperceptible power loss, increase in fuel consumption, and NOx emission on conventional diesel engines. Mofijur et al., [4] conducted experiments using biodiesel from various feed stocks in diesel engines and lowered brake power and brake thermal efficiency but found increases in BSFC than in diesel fuel. Senthil Kumar and Loganathan [5] have stated that corn oil methyl ester (COME) at optimum preheated temperature of 70°C has higher rate of pressure rise and maximum combustion pressure inside the cylinder, higher heat release rate of diesel, decreased ignition delay and combustion duration and higher cumulative heat release rate and mass fraction burnt of COME blends compared with neat diesel. Nathan Kauffman et al., [6] conducted tests on a hectare of corn and stated that a hectare of corn stover subjected to fast pyrolysis for production of bio-oil and then subsequently upgraded to a fuel suitable for internal combustion engines generated a 52.1% reduction in GHG emissions. Tests on vegetable oils were done by Ramadhas et al., [7] who found that the thermal efficiency was comparable to that of diesel with small amounts of power loss while using vegetable oils. The particulate emissions of vegetable oils were higher than those of diesel fuel with a reduction in NOx. Bahattin Iscan and Huseyin Aydın [8] stated that waste corn oil blended with diesel, when tested in diesel engine with ZrO_2 coated piston and valves, produced increased power and torque with simultaneous decrease in the brake specific fuel consumption (BSFC) and many of exhaust emission parameters such as CO, HC, and smoke opacity were decreased. Wang et al., [8] stated that at an engine speed of 1500 rpm, the emissions of nitrogen oxides from vegetable oil and its blends, at various loads, were lower than those of pure diesel fuel and that the carbon mono oxide emissions from the vegetable oil and its blends were lower than those of the diesel fuel at the engine full load, but in the case of lower engine loads, the carbon mono oxide emissions were slightly higher. Also the hydrocarbon emissions of vegetable oil and its blends were lower than those of diesel fuel, except in the case of 50% of vegetable blend. Jinlin Xue et al., [9] conducted a comparative study of power between the coated engine and uncoated engine and the authors reported that the increased values in power for the coated engines were 3.5% and 1.6% for pure biodiesel and its blend, respectively. Although the engine power performances with load or speed were similar for biodiesel engine and diesel engine, there existed a difference in the maximum value of torque for biodiesel compared with diesel. Hanbey Hazar et al. [10] conducted an experimental study with cylinder head, piston, exhaust and inlet valves (which are combustion chamber components) being coated with a ceramic material and concluded that with increase in the proportion of corn methyl ester in the blends for both the coated engine and uncoated engine, smoke density was significantly reduced and that NOx emission increased by 6.2% for 100/D2 and by 8.8% for mixtures in coated engine compared with uncoated engine due to the thermal barrier. The increase in NOx emission for all test fuels in coated engine occurred due to the higher gas temperatures. Tadeusz Hejwowski et al., [11] stated that, Thermal growth of oxides at the top coat/bond coat interface and the decomposition of Al_2O_3 and TiO2 were found to be important degradation mechanisms leading to the spallation of coatings in the diesel engine and the petrol engine exploitation tests. The substrate/bond coat or bond coat/topcoat interface is subjected to the highest stress variations. The developed flame test models start/stop cycles whereas the furnace test can be used to control the production process of coatings. Selman Aydın and Cenk Sayın [12] studied combustion performance and emission characteristics of both uncoated and coated diesel engines tested in the same running conditions. The engine power values for all the test fuels were similar. Generally, petroleum based diesel fuel showed better performance than the biodiesel blends. The coated engine operation resulted in lower BSFC values for all the test fuels including petroleum based diesel fuel operation. CO emissions were considerably decreased and HC emissions were also generally decreased for both diesel and all biodiesel fuel blends in the coated engine. The NOx emissions were also increased in coated engine, for all the test fuels, due to the increased combustion temperature.

In this study, the properties of Corn oil methyl esters were compared with those of diesel and analyzed. Owing to their high viscosity, corn oils cannot be used directly with diesel. Transesterification process is done in the presence of methanol added with sodium meth oxide as catalyst. Also, the performance and emission parameters of the engine coated with ZrO_2 and CeO_2 were analyzed and compared with those of an uncoated piston.

Nomenclature:

COME - Corn oil methyl ester
BTE - Brake thermal efficiency
UE - Uncoated engine
CV - Calorific value
CP - Coated Piston
PD - Pure Diesel
BSFC - Brake specific fuel consumption
RCO - Refined Corn Oil

EXPERIMENTAL SECTION

Corn oil was purchased in the local market in Chennai, Tamil Nadu, India. Methanol and NaOH required for the transesterification process were purchased from the suppliers concerned. The materials required for coating the piston, namely ZrO_2 and CeO_2 were purchased in Chennai. The coating was done at Bangalore by Plasma spray coating process. The engine tests were carried out at Sathyabama University, Chennai.

2.1 TRANSESTERIFICATION PROCESS:

The Methyl Esters are formed by transesterification process. One liter of refined corn oil is treated with 400 gms of methanol and 8 gms of sodium meth oxide as catalyst. The methanol is added to the catalyst in the preheated oil at cold temperature (Atmospheric or lower) and the temperature is raised to 80 ºC for reaction while performing transesterification process of oil to reduce high viscosity and it gives pure methyl esters without any soap content. Fig. 1, Fig .2, and Fig .3 show the corn oil, corn methyl esters, and blended fuel (B25).

CH_2OCOR CH_2OH RCOOR
I   I
CH_2OCOR + 3ROH —catalyst→ CH_2OH + RCOOR
I   I
CH_2OCOR CH_2OH RCOOR

Fig. 1 RCO

Fig. 2Methyl Esters of RCO

Fig. 3 B25 RCO

2.2 PLASMA SPRAY COATING PROCESS

Plasma spray coating process is adopted to coat the piston with ZrO_2 and CeO_2 materials. Its main objective is to reduce the heat transfer occurring in combustion chamber, thereby increasing the temperature of the combustion chamber resulting in more efficient combustion. The piston surface is ground to 150 microns depth and then the coating is done so that there is no change in the compression ratio of the engine. A rough surface is initially created on the piston by shot blasting technique for good adhesion of the coating. The surface is then cleaned with a solvent. It is then preheated to remove the moisture in the surface. Distilled water is circulated in the plasma gun and it acts as the coolant. Argon used as the plasma gas is fed into the plasma torch at the rate of 85 LPM. The temperature and the enthalpy of the plasma gas increase by absorbing energy. Thus a high temperature plasma stream is produced. As a result, the neutrons are subjected to electron bombardment resulting in the ionization of the gas. An ionized gas releases very significant thermal energy due to recombination of electrons. The plasma stream reaches temperatures of 10,000-50,000 ° F. A mixture of 90% ZrO_2 and 10% CeO_2 in the powdered form is mixed with suitable carrier gas and fed into the plasma stream. The mass flow rate of the powdered materials is 45 gm/min. The high temperature of the plasma stream is used to melt the powders which are deposited on the substrate (piston Head). The images of the coated piston, the uncoated piston, and the piston after combustion are shown in figs. 4, 5, and 6 respectively.

Fig.4 Uncoated Piston

Fig.5 ZrO_2.CeO_2 Coated Piston

Fig. 6 after Combustion

Table – 1 Comparison of properties of Diesel, Biodiesel standards & Corn oil

S. No.	PROPERTIES	Euro - IV Bharat stage 1460:2005 Diesel	ASTM D–751 (IS 5607:2005)	CORN OIL	TRANSESTERIFIED B25 CORN OIL
1.	Calculated Cetane Index	51	-	35	53
2.	Density at 15 ° C kg / m^3	820 – 845	860-900	978	873
3.	Kinematic Viscosity at 40 ° C cSt	2 – 4.5	1.9 – 6	29.3	5.02
4.	Flash point ° C min	35 ° C	130 ° C	282	162
5.	Calorific Value kJ/kg	39,000	-	36,364	38,490

It can be seen from the above Table - 1that the cetane index of refined corn oil is higher than that of diesel. The density and kinematic viscosity are also higher compared with diesel and are well within the limit of Biodiesel standards whereas the calorific value of corn oil is slightly lower. The flash point as compared to pure diesel is high and hence the problems in storage and transport are minimized.

Table 2 - Specification of Test Engine

Combustion	:	Direct Injection
Type	:	Kirloskar Vertical, 4S, Single acting, High speed, C.I. Diesel engine
Rated Speed	:	1500 rpm

Rated Power	: 4.3 kW
Compression Ratio	: 17.5: 1
Fuel injection pressure	: 210 bar
Injector type	: Single 3 hole jet injector
Dynamometer	: Eddy current
Cubic Capacity	: 661.5 cm^3

Table 3 - Details of Measuring Systems

Pressure Transducer GH 12 D		
Software Version V 2.0	-	AVL 617 Indi meter
Data Analyzer from Engine	-	PIEZO CHARGE AMPLIFIER
To measure pressure	-	AVL 364 Angle Encoder
Smoke meter	-	AVL 437 C Smoke
5 Gas Analyzer (NOx, HC, CO, CO_2, O_2)	-	AVL DIGAS 444 Analyzer

2.3 EXPERIMENTAL SET-UP:

A stationary kirloskar 4-Stroke, Direct Injection Diesel Engine was directly coupled to an Eddy current type dynamometer. The purpose of the dynamometer is to provide electrically various loadings (0%, 25%, 50%, 75%, 100%) on the kirloskar engine whose piston is coated with ZrO_2 & CeO_2 by plasma spray coating method. Table – 2 shows the specification of the kirloskar 4-stroke diesel engine. AVL DIGAS 444 Analyzer and AVL 364 Angle Encoder were used to measure the emissions and the pressure inside the cylinder respectively. Fuel flow meter was used to measure the brake fuel consumption. A blend of 25% COME and 75% pure diesel was used as fuel for the engine.This set-up was used to evaluate the emission and performance of the refined corn oil methyl esters at various injection pressures and loadings. The main output parameters taken into consideration were the emissions of CO, HC, NO_x, CO_2 gases, performance of the Brake specific fuel consumption, and Brake thermal Efficiency. The schematic diagram of the experimental set-up is shown in Figure 7.

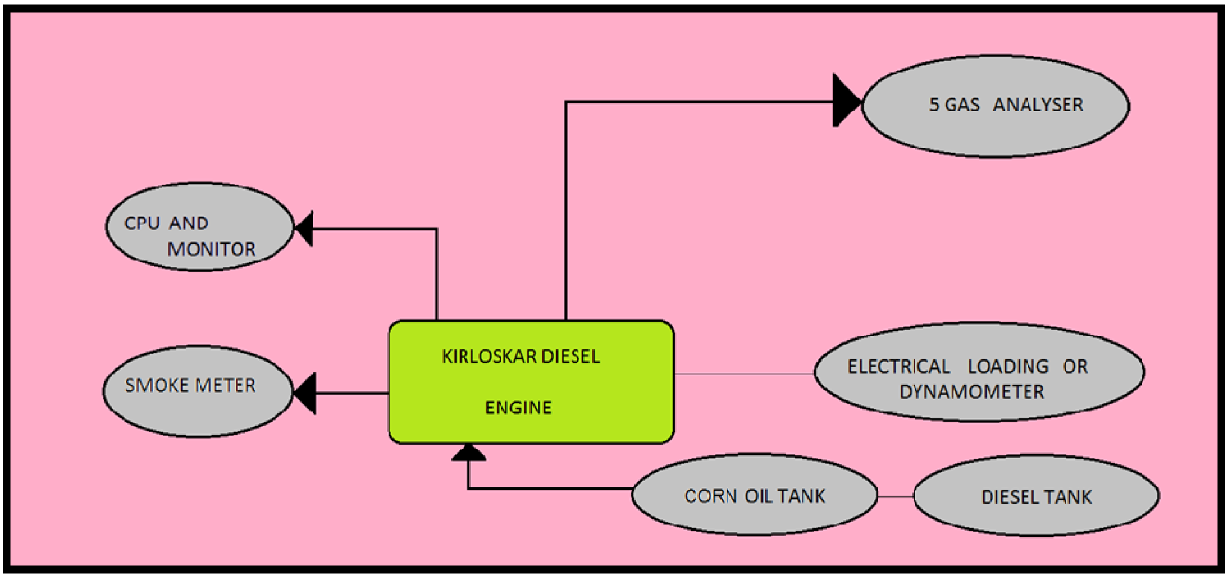

Fig. 7 Schematic Diagram of the Experimental Set-up

2.4 TEST PROCEDURE

The experiments were conducted at different load conditions, with different Injection pressures with COME blend (B25) and PD as fuels. The tests were conducted at a constant speed of 1500 rpm on coated and uncoated engines. Sufficient amount of material was removed from the surfaces of the coated piston so that the thickness of the coating would not result in a change in the compression ratio of the engine. Tests were conducted first for the COME(B25) and PD uncoated engines and then for the coated piston. The engine was allowed to run at 'No load' condition for 10 minutes, before applying the load. The loads were increased gradually in steps of 25 % upto 100% maintaining the constant speed of 1500 rpm. The exhaust gases were measured for both the coated and the uncoated engines by exhaust gas analyzer from the exhasut stream of the engine. The CO, CO_2, HC, and NO_x were measured by exhaust gas analyzer and the results obtained were comparitively studied. The smoke emitted was measured by the smoke meter. The performance parameters such as BSFC and BTE were also measured and compared with those of the uncoated piston. The details of the emission measurements as shown in Table – 3.

RESULTS AND DISCUSSION

3.1 CARBON MONO OXIDE (CO):

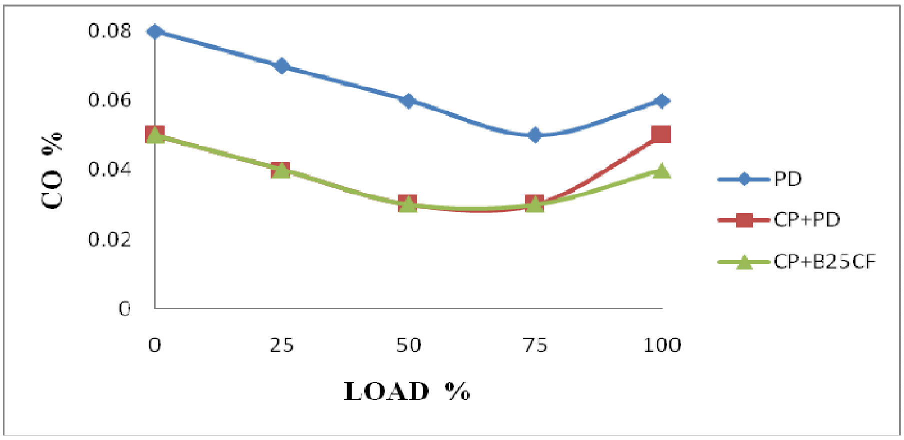

Fig. 8 Variation of CO with respect to PD, CP+PD, CP+B25CF FAME

The variation of CO with respect to different load conditions has been shown in fig.8. At full load condition it was observed that for the B25CF of the coated piston CO decreased by 42.85 % and in coated piston petro diesel it decreased by 14.25 % compared with petro diesel. This could be due to the higher oxygen content in the fuel and the better thermal expansion.

3.2 HYDROCARBON (HC):

The variation of HC with respect to various loads has been shown in fig.9. Compared with PD, the coated piston PD caused a decrease in HC by 25% at full load. The lowered HC emissions of the biodiesel fuel could be attributed to the high oxygen content in the molecules of biodiesel, which led to a more complete and cleaner combustion. The reductions might be due to changes in the stoichiometry of the spray caused by the oxygen in the biodiesel fuel. The higher cetane index of biodiesel shortened the ignition delay and thus reducing HC emissions.

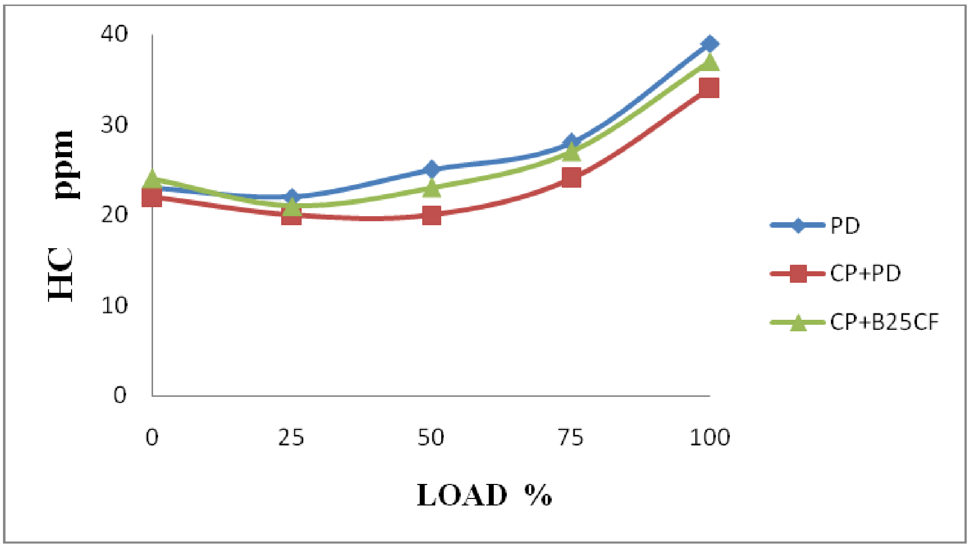

Fig. 9 Variation of HC with respect to PD, CP+PD, CP+B25CF FAME

3.3 NITROGEN OXIDE (NO_X)

The curves of PD, CP+PD, and CP+ CF B25 have been shown in fig.10 at different load conditions. It shows that the NOx emission decreased marginally in the coated piston CF B25 and increased in CP+PD significantly. Owing to the prevention of heat transfer by insulating the engine components, most of the heat was utilized in the fuel evaporation and combustion, and this ought to have increased the combustion chamber temperature. The increase in cylinder temperature and the presence of excess oxygen within the fuel had promoted the formation of NO_x in coated engines. The decrease in NO_x in CFB25 might be due to the higher density of corn oil.

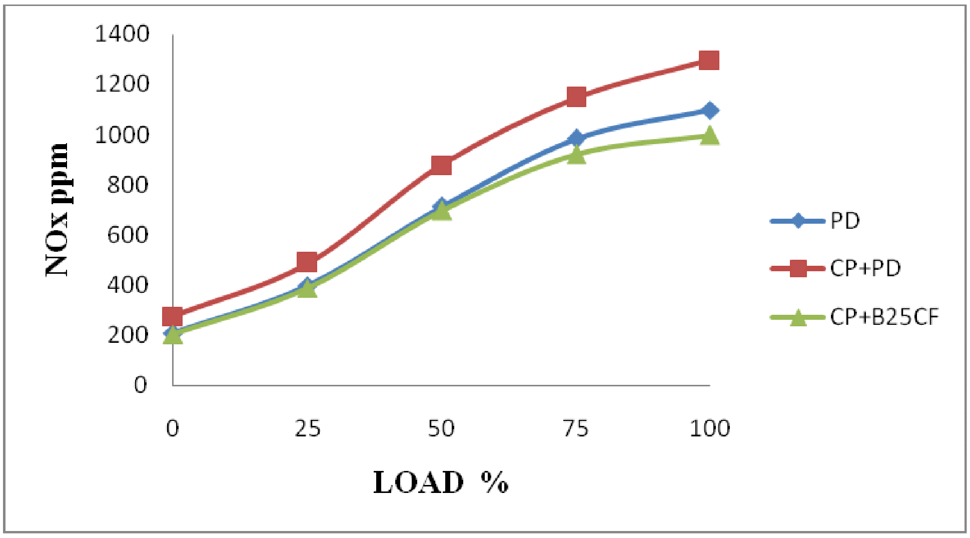

Fig. 10 Variation of NO_X with respect to PD, CP+PD, CP+B25CF FAME

3.4 SMOKE

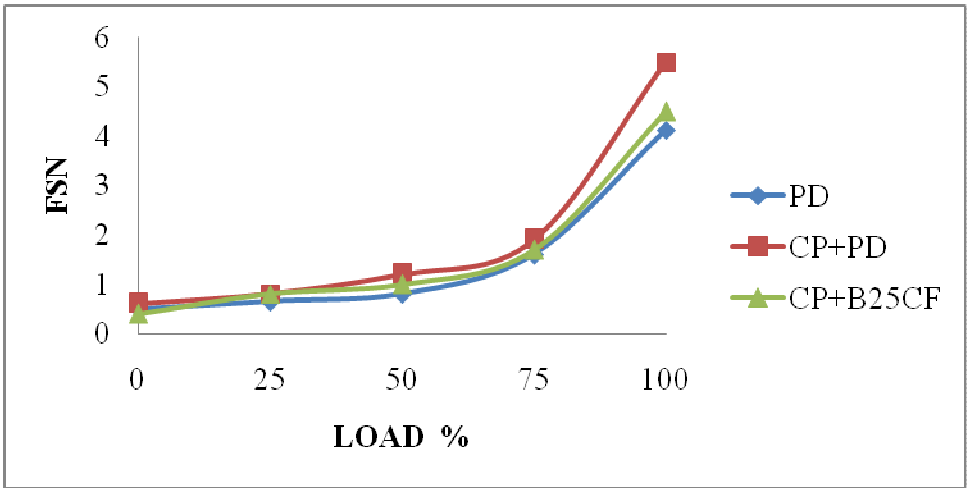

Fig. 11 Variation of FSN with respect to PD, CP+PD, CP+B25CF FAME

The smoke emitted from CF B25, coated and uncoatedPD was compared at various load conditions and it was found that upto 75% of the load, the smoke emitted was almost the same. At full load condition, smoke was marginally increased for coated and uncoated pistons using biodiesel compared with PD.

3.5 BRAKE SPECIFIC FUEL CONSUMPTION (BSFC):

Fig.12. shows the variation curves of BSFC for various loads of coated piston with pure diesel, coated piston with CF B25 methyl esters, and PD. BSFC increased by a marginal value for the coated piston with CF B25 by 11% when compared with the uncoated PD. This could be due to the higher density in the fuel. The marginal decrease in the coated piston was observed when compared with pure diesel.

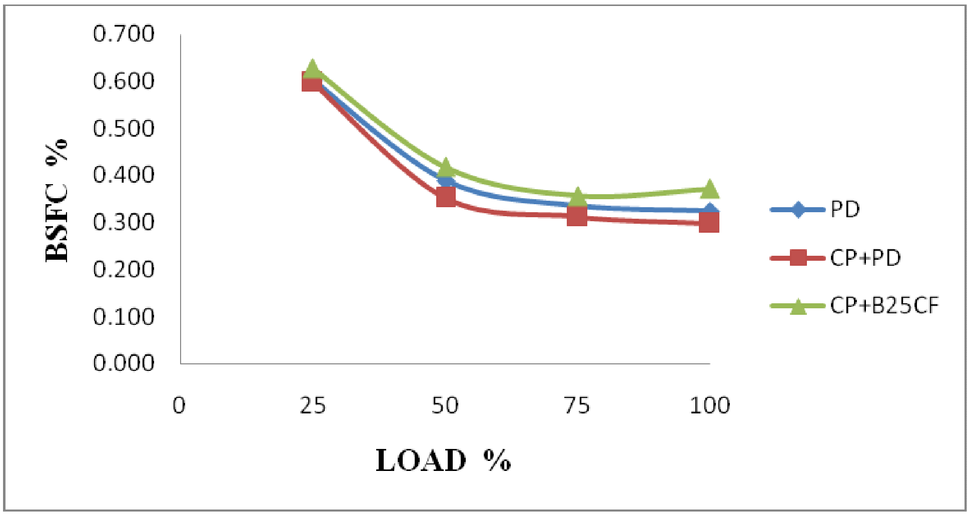

Fig. 12 Variation of BSFC with respect to PD, CP+PD, CP+B25CF FAME

3.6 BRAKE THERMAL EFFICIENCY (BTE)

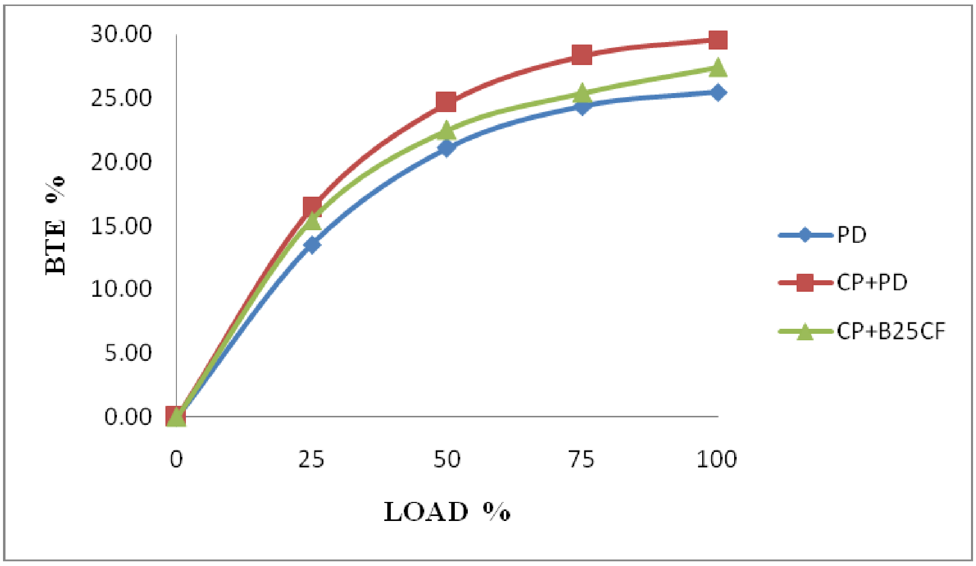

Fig. 13 Variation of BTE with respect to PD, CP+PD, CP+B25CF FAME

The comparison of BTE for the coated piston PD, CF B25 & the uncoated PD at various loads is shown in fig.13. It can be seen from the above cuves that the BTE increases compared with PD. It increased by 13.8% for the coated piston with pure diesel and by 7% for the coated piston with CF B25. This was ~~is~~ because of the heat insulation provided by the coating. This increased the efficiency of the combustion process. The increased combustion enfficiency led to an increased BTE. Hence the performance of the engine could be improved by using biofuel.

CONCLUSION

The engine coated with ZrO_2 and CeO_2 was studied by running it at a constant speed of 1500 rpm with corn oil methyl esters of B25 as fuel. It could be concluded that there was a significant decrease in the emissions of CO and HC gases with a marginal decrease in NO_x emissions. At full load, emission of CO decreased by 42.85% for the coated piston B25, HC decreased by 25% in the coated piston petrodiesel and NO_x decreased by 9% in the coated piston CF B25 compared with PD. The Brake thermal efficiency increased by 7% and BSFC increased by 11% in the coated piston CF B25 compared with diesel. Hence COME(B25) when used in a coated engine can be considered as an effective replacement for diesel. However, many further researches need to be performed when petroleum diesel is substituted completely by biodiesel using coated piston.

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