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Emission and Performance Analysis of Cotton Seed Oil Methyl Esters with Zro_2& Ceo_2 Coating on Piston

Hemanandh.J*, Narayanan K V

Department of Mechanical Engineering, Sathyabama University, Chennai, India.

Abstract: The energy needs of the human society till date have been successfully fulfilled by fossil fuels such as petroleum, coal and natural gas. However, these fossil fuels are being depleted at a very high rate and this has led to the need for an alternative for these fossil fuels. Biofuels are being considered as an effective replacement for fossil fuels by researchers worldwide as they are renewable. In this study, a bio diesel having a blend of 25% cotton seed oil and 75% pure diesel is used in a Direct Injection, Kirloskar engine. The study is exhibited in three phases. In the first phase, transesterification was done to produce Cotton seed oil methyl esters with sodium hydroxide as catalyst. The second phase comprised of coating the piston with ceramic materials (ZrO_2& CeO_2) by plasma spray process to provide a low heat rejection (LHR) engine. In the third phase, the coated engine was run at a rated speed of 1500rpm to obtain the performance and emission parameters at various loads on the engine. The results obtained were compared with i) an uncoated engine and ii) coated engine with pure diesel and cotton seed methyl esters as fuel at the same conditions.
Keywords: Coatings on piston, diesel engine, cotton seed methyl esters, emission and performance.

1.0 Introduction

Crude oil being a non-renewable source of energy is likely to be non-existent in the distant future if not in the near future. Hence efforts have to be made in order to find some alternative fuel. India being rich in agricultural produce has a wide scope for large scale production and usage of many biodiesels. For instance, cotton is produced in abundance in India and hence it can be considered as a replacement.

Kafuku et al., [1] optimized the non-edible Croton megalocarpus oil by adding it to 1% potassium hydroxide, 30% methanol, at reaction temperature of 60 deg C, at 400 rpm and the reaction time of one hour and producing 88% of biodiesel; the properties were within the standards. Metin et al., [2] found that varying the injection pressure at different loads with different biodiesel blends resulted in an increase in CO_2, O_2, BSFC, HC, smoke and NO_x. Sakthivel et al., [3] investigated on using the fish oil as biodiesel being tested in the diesel engine and comparing with diesel fuel found that brake thermal efficiency, CO_2, and smoke increased, whereas NO_x, CO, and HC decreased. Nidal et al., [4] experimented with the almond biodiesel and the palm oil biodiesel fuel and compared with diesel. The almond biodiesel reduced the NO_x, HC, CO, BSFC, whereas it caused an increase in brake thermal efficiency. Kalam et al., [5] experimented with the 5% waste cooking palm oil with diesel and 5 % waste cooking coconut oil with diesel in a compression ignition engine. The result showed reduction in emission and the brake power. Dhole et al., [6] performed the tests on turbo charged 4 cylinder gen set diesel engine using dual fuel such as producer gas and hydrogen. The 20% hydrogen increased the brake thermal efficiency by 7 %, whereas the 30% producer gas decreased by 8%. The mixture of these fuels (60:40) reduced brake thermal efficiency by 3%. Sarvanan et al., [7] found that the 25% rice bran crude oil methyl esters resulted in an increase in specific fuel consumption and performance in all loads. Mohammad Mustufa et al., [8] gave coatings on valves, piston crown, cylinder liner, and cylinder head using fly ash. The rice bran and pongamia methyl esters were used as fuel at different proportions and it resulted in a decrease in brake specific fuel consumption and increase in NOx compared with uncoated diesel engine. Jaichander et al., [9] conducted experiments using torroidal piston having hemispherical re-entrant combustion chamber, in a diesel engine. The 20% pongamia oil methyl esters with diesel blend used as fuel resulted in a decrease in brake specific fuel consumption and increase in NO_x and brake thermal efficiency. Rutto et al., [10] observed decrease in performance and reduction in hydrocarbon and increase in NO_x, when the blends of cooking oil were used as fuel. JinlinXue et al., [11] observed that there was a reduction in carbon deposits and wear tear of the engine key parts when biodiesel was used as a fuel. Mojifur et al., [12] concluded 20% jatropha oil was the best fuel producing lesser emission and it improved performance at full load conditions. Venkata Ramesh Mamilla et al., [13] conducted experiment in a four stroke diesel engine having toroidal combustion chamber using 20% jatropha oil and it resulted in a decrease in hydrocarbon, smoke density and carbon mono oxide and increase in brake thermal efficiency when compared with the other two. Harinath Reddy et al., [14] experimented with the cotton seed methyl esters and jatropha methyl esters and compared with diesel fuel in diesel engine at constant speed. They observed that cotton seed methyl esters produced higher brake thermal efficiency compared with the other. Dilip Kumar et al., [15] found that the smoke and the emission were reduced for cotton seed oil when compared with diesel fuel. Shailaja et al., [16] varied the injection pressure and found that the cotton seed methyl ester used as fuel could improve the performance at 210 bar injection pressure.

2.0 Materials and Methods

Cotton seed oil was purchased from the local market and transesterification process was done to obtain cotton seed oil methyl esters. The Methanol and NaOH were purchased from the supplier concerned. ZrO_2 and CeO_2 were purchased in Chennai and the coating was done by plasma spray process at Bangalore.The experiment was conducted in three phases. In the first phase, the piston was coated with ZrO2 and CeO2 in the ratio 90:10. The second phase involved transesterification of the cotton seed oil. In the third phase, a direct injection kirloskar engine with a coated piston was run at a constant speed of 1500 rpm with transesterified oil as fuel.

2.1 Plasma Spray Coating

Plasma spray is a versatile thermal spray processes. Like the other thermal spray processes the plasma spray process also requires a highly concentrated power source. The piston surface is ground to 150 microns before the coating is applied. The material to be coated (mixture of 90% ZrO_2 and 10% CeO_2) is fed to the plasma arc gun in the form of powder. An arc is formed in between the two electrodes consisting of argon and hydrogen in a plasma spray device. The plasma gas gets heated by the high temperature of the arc.The gas then expands and accelerates through a shaped nozzle which is capable of creating high velocities. The temperatures in the plasma jet reach up to 18,000°F (10,000°K) few meters form the nozzle exit. Here the Zirconium dioxide and Cerium dioxide are melted and accelerated on the piston crown to form the coating. The coating is formed by overlapping many thin layers of the materials on the substrate. This is followed by the solidification of these layers and the locking of the layers into one another. The splats easily spread over the substrate because of the kinetic energy of the particles. The thermal conductivity of the coating formed by plasma spray process ranges from 0.5 W/mK to 1.5 W/mK which is ~~way~~ less than that of electron beam physical vapour deposition.

2.2 Transesterification Process

Transesterification can be defined in simple words as a chemical reaction in which the vegetable oils react with any short chain alcohol to form a bio-diesel.Generally this reaction is extremely slow or doesn't happen at all unless a catalyst is included. Thus NaOH is used as the catalyst here. Heat treatment also takes place in order to make the reaction faster. The process is carried out as following:

One liter of cotton seed oil is treated with 400 grams of Methanol and 8 grams of NaOH which plays the role of the catalyst. The catalyst and methanol are charged in the cotton seed oil and temperature is then raised to 70°C for the reaction while performing transesterification process. This is followed by pouring the oil in the separator and is allowed to stand for 24 hours. The methyl esters of cotton seed oil are thus obtained. This process is done to remove the viscosity of the oil.

The reactions are presented as follows:

CH 2OCOR			CH 2OH		RCOOR
I			I		
CH2OCOR	+ 3ROH	catalyst →	CH 2 OH	+	RCOOR
I			I		
CH2OCOR			CH2 OH		RCOOR

2.3 Comparison of properties of cotton seed oil:

The Table 1 shown below gives the comparison of the properties of diesel with those of the cotton seed oil.

It is noticed that the calorific value of cotton seed oil is increased when compared with pure diesel. The high difference in the flash point and the kinematic viscosity are indicated as well. However, the density of the cotton seed oil is slightly more than that of the other bio-diesels.

Table - 1 Comparison of Properties Of Diesel, Biodiesel Standards, Cotton Seed oil and Transesterified cotton seed oil.

S. No.	Property	Euro - IV Bharat stage 1460:2005 Diesel	ASTM D–751 (IS 5607:2005)	Cotton Seed Oil	Transesterified cotton seed Oil
1.	Calculated Cetane Index	51	-	37	52
2.	Density at 15 ° C kg / m3	820 – 845	860-900	925	846
3.	Kinematic Viscosity at 40 ° C cst	2 – 4.5	1.9 – 6	55.6	4.63
4.	Flash point ° C min	35 ° C	130 ° C	207	68.2
5.	Calorific Value kJ/kg	39,000	-	38000	42,256

3.0 Experimental set-up

The Kirloskar 4-stroke diesel engine was used to test the coated piston and the cotton seed methyl esters. The specifications of the engine have been shown in Table – 2. The Eddy current dynamometer was used for loading which was coupled to the engine for providing various loadings such as 0%, 25%, 50%, 75%, and 100%.The blend of oil used here was 25% cotton seed oil and 75% PD.The exhaust gas emissions from the engine measured by using 5 gas analyzer was AVL DIGAS 444 Analyser (NO_x, HC, CO, CO_2, O_2) as shown in Table – 3.

Test Method:

The cotton seed methyl esters (B25) and pure diesel were tested in the engine at a constant speed of 1500 rpm at various load conditions. The tests were conducted first for Cotton seed B25 fuel in a coated engine and then for PD in both coated and uncoated pistons. Initially the engine was run at a no load condition for a few minutes without application of load. The loads were increased gradually for test fuel in steps of 25 % upto 100% at a constant speed of 1500 rpm.The emissions were recorded using five gas analyzer.

Table – 2 Specifications of the test engine

Combustion	Direct Injection
Type	Kirloskar Vertical, 4S, Single acting, High speed, C.I. Diesel engine
Injector type	Single 3 hole jet injector
Rated Speed	1500 rpm

Rated Power	4.3 kW
Compression Ratio	17.5 : 1
Fuel injection pressure	210 bar
Dynamometer	Eddy current
Cubic Capacity	661.5 cm^3

Table – 3 Details of Measuring Systems

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

4.0 Results and Discussion:

4.1 Carbon Monoxide (Co):

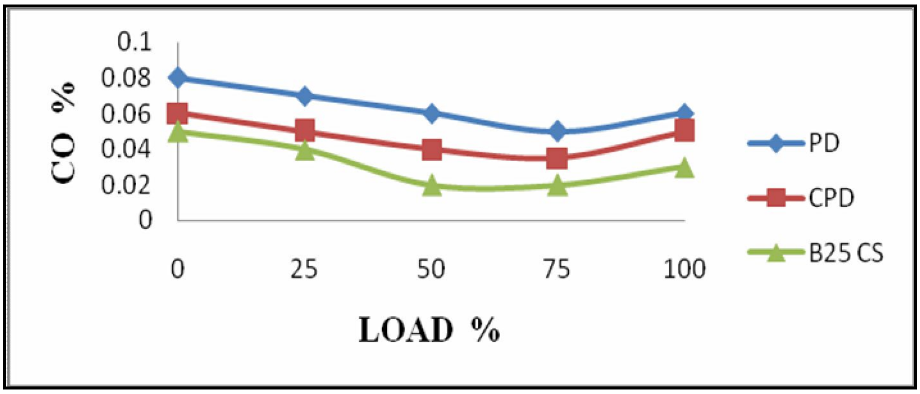

Fig. 1 Variation of CO with respect to coated & uncoated pistons and biodiesel

The variation of CO for coated and uncoated pistons using diesel and biodiesel is shown in fig.1. At full load condition reduction in CO was observed in coated piston using diesel by 33.33% and using cotton seed methyl esters (B25) by 42.8% compared with uncoated piston. This could be due to the higher oxygen content in the fuel.

4.2 HYDRO CARBON (HC):

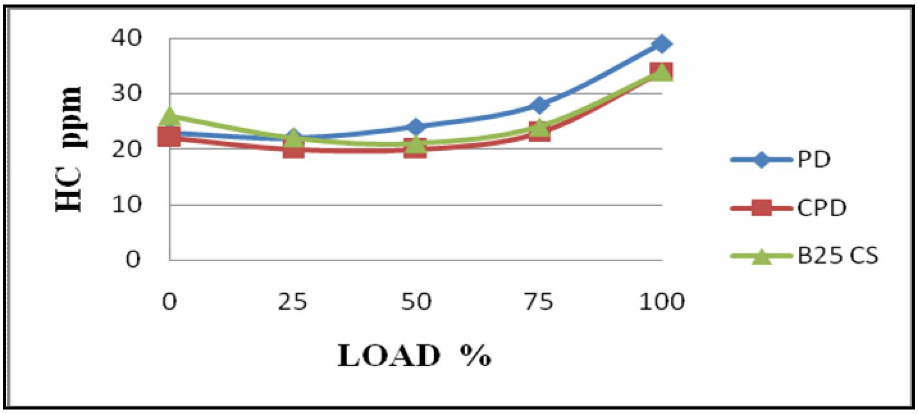

Fig. 2 Variation of HC with respect to coated & uncoated pistons and biodiesel

Fig. 2 shows the variation of HC for coated and uncoated pistons at different loads. The figure shows a reduction of HC for coated piston using diesel and using cotton seed oil. The reduction in HC was observed for coated piston using diesel fuel by 12.5%. In coated piston using B25 CS fuel, at no load conditon HC emission was higher and as the load was increased, HC emission was decreased compared with PD. This could be due to the better thermal conductivity of the coated material and higher cetane index improving the combustion.

4.3 Nitrogen Oxide (NO_X) :

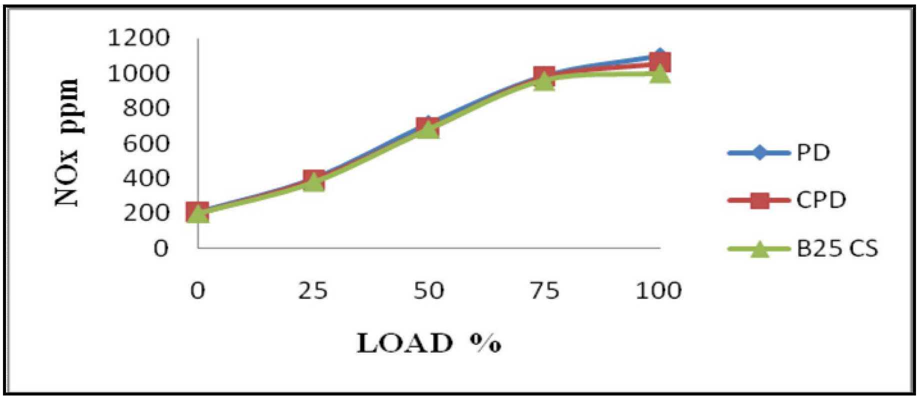

Fig. 3 Variation of NOx with respect to coated & uncoated pistons and biodiesel

The curves representing the variation of NOx for uncoated piston using diesel and coated piston using diesel and B25 CS are shown in Fig. 3. NO_x is mostly formed by the oxidation of atmospheric nitrogen present in the combustion chamber. Its formation is mainly controlled by the temperatures of combustion and the availability of oxygen. The emission of NO_x increases in direct proportion to the size and amount of pilot diesel fuel. The nitrogen oxide emission rises with the increase in cylinder temperature, oxygen concentration, and the time period of combustion. Initially at zero load conditions there is similarity in the NO_x emission. But at full load conditions emission of NO_x was measured to be 980ppm when B25 CS was used while it was 1025ppm for the pure diesel.

4.4 Smoke:

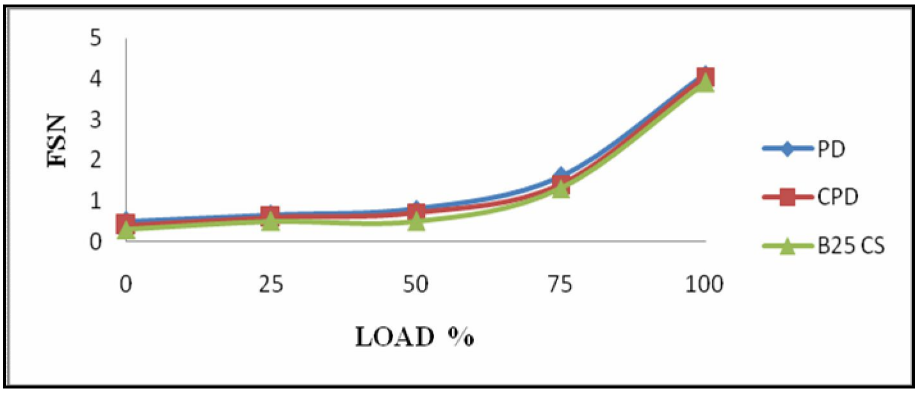

Fig. 4 Variation of smoke with respect to coated & uncoated pistons and biodiesel

Smoke opacity depends upon the amount of air inside the cylinder as well as quantity of oxygen in the fuel. Also the amount of sulphur content in the fuel affects the smoke emission. However, oxygen content in the fuel is important for the reduction in emmission of particulate materials. From the graph shown in fig.4 there is a marginal decrease in the smoke emitted when B25 CS is used as the fuel when compared with pure diesel.

4.5 Brake Specific Fuel Consumption:

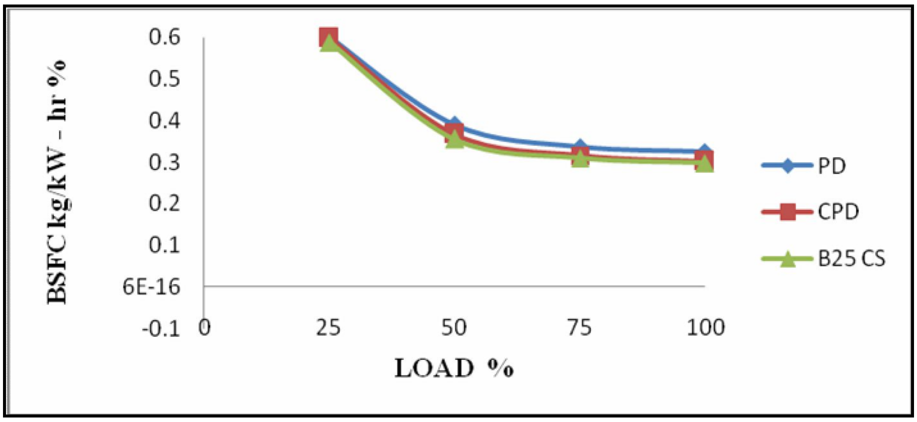

Fig. 5 Variation of BSFC with respect to coated & uncoated pistons and biodiesel

The above graph fig. 5 shows the variation of BSFC for B25 CS, PD, and CPD at different load conditions. It can be seen that at all loads, there are no significant changes in BSFC of B25 CS compared with CPD. When compared with PD, there is a marginal decrease in BSFC for B25 CS at full load condition. This may be due to the high temperatures present in the combustion chamber due to the coating. As a result the fuel consumption is less.

4.6 Brake Thermal Efficiency:

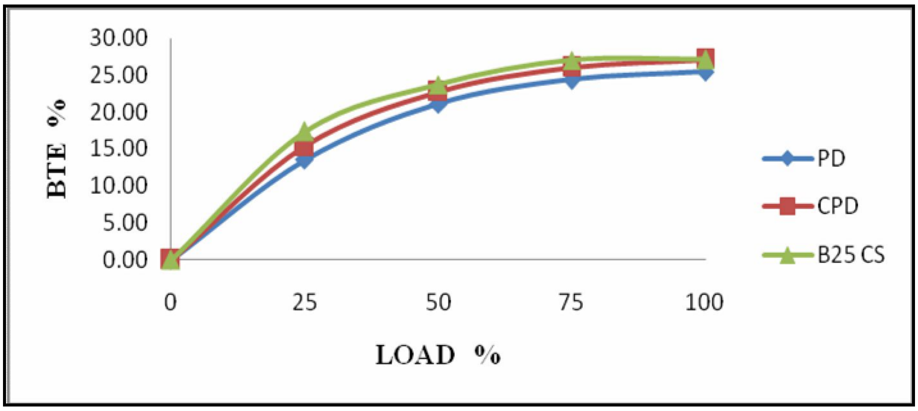

Fig. 6 Variation of BTE with respect to coated & uncoated pistons and biodiesel

Fig.6 shows the variations of BTE at different loads for coated and uncoated piston. It is seen that the brake thermal efficiency of the B25 cotton seed oil is slightly higher than that of pure diesel. This may be due to the presence of unburnt hydrocarbons in the exhaust gas system as a result of the coating. The reburning of these unburnt hydrocarbons increases the BTE. Owing to insufficient oxygen, the efficiency obtained is quite lower for the diesel engine. However, the graph shows that at the full load conditions there is not much difference between the brake thermal efficiency of the coated and the uncoated engines.

5.0 Conclusion:

In this work, the performance and emissions of Cotton seed oil were studied in an engine coated with ZrO2 and CeO_2 and were compared with PD in both coated and uncoated engines. The performance parameters used for comparison were BSFC and BTE. The emissions analyzed were CO, HC, NOx, and smoke. It can be concluded from the tests conducted that there was a 42.8% decrease in CO emissions when Cotton seed oil was used in coated engine compared with Pure Diesel. As far as the emission of HC is concerned, there was a 12.5% decrease for coated piston using diesel compared with uncoated piston. Also marginal decreases in NOx and smoke emissions were observed for B25 CS. The performance of cotton seed oil was similar to diesel with no significant changes observed. There was a slight decrease in BSFC and a marginal increase in BTE compared with PD. Hence Cotton seed oil can be considered as one of the effective replacements for diesel.

6.0 References:

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