

Emission and Performance Analysis of ZrO_2 And CeO_2 Coated Piston Using Refined Vegetable Oils

J Hemanandh ^{1,*}, K.V.Narayanan², Vemuri Manoj³

¹Asst Professor, ^{2,3}Student, School of Mechanical Engineering,
Sathyabama University, Chennai-600119, Tamilnadu, India.
Email.Id: hemanandh123@gmail.com, Contact No:+91 9444167753.

* Corresponding author

Abstract. Increase in global warming and pollution leads to look for an alternative fuel. The aim of this paper to improve the performance and to reduce the emissions in DI diesel engine. The 80% of ZrO_2 and 20% of CeO_2 were mixed and coated on the piston head using plasma spray method. The B10 fuel of various refined vegetable oil methyl esters were used as fuel. The test was conducted in the 4-stroke DI diesel engine at a constant speed of 1500 rpm. The results show that the brake thermal efficiency, NO_x and BSFC was increased. The CO and HC were decreased.

1. Introduction

Sivakumar and Senthil Kumar [1] carried out an experimental investigation by using YSZ as the thermal barrier material on the piston and fuelled with diesel by varying the loads the results revealed that TE, CO and CO_2 are increased, BSFC and HC are decreased. Selman Aydin et al., [2] has conducted an experimental study on a diesel engine coated with ZrO_2 and fuelled with biodiesel produced from waste cooking oil and conducted performance tests on both coated and uncoated engines and found that the modification of engine resulted in lower BSFC. The emissions were lowered excluding NO_x emission and the results of the coated engine are better in gas pressure, HRR and HR. Bahattin ISCAN et al., [3] has done an experimental investigation on the diesel engine coated with the ZrO_2 and fuelled with the different blends of cotton seed oil with PD and compared the obtained results with the results obtained by employing the number 2 fuel in uncoated engine and found that all the results are improved for the coated engine except NO_x emission. M. Ekström et al., [4] conducted a experimental study on the coatings of the exhaust manifold with seven different coatings (mullite, forsterite, $\text{La}_2\text{Zr}_2\text{O}_7$, 8YSZ, nanostructured 8YSZ) and two sol-gel composite (one sprayed and one dipped)) and were examined for their thermal insulation properties and oxidation and spallation resistance and found that the reduction of temperature up to 50°C by using TBC UPTO 0.2 mm with thermal conductivity close to 0.1 W/m K, or a 3–6 mm thick TBC with thermal conductivity 1.5–3W/m K. Huseyin Aydin [5] has done an experimental investigation on the diesel in which some of its parts are coated with ZrO_2 and fuelled with the vegetable oils (cottonseed oil and sunflower oil) blended with PD and the results stated that the decrease in the BSFC, CO, HC and smoke opacity. Sunflower oil gives better performance than cotton seed oil fuel. Selman Aydin et al., [6] has conducted an experimental study on a 510 model Lombardini CI engine coated with ZrO_2 , MgO , Al_2O_3 , NiCrAl and fuelled with biodiesel produced from residual frying oil of cotton seed and the fuels D2, B5, B100. The performance, Combustion and the emission tests were carried out and the results show that there is partial increase in the B.P, exhaust manifold temp., engine noise and partial decreases were seen in BSFC and the emissions of CO, HC and smoke opacity while NO_x increases. Naveen.P et al [7] has done an experimental investigation on a diesel engine which was coated with the Al_2O_3 and TiO_2 fuelled with Honge BioDiesel and compared the results with the test conducted on the standard engine with same operating conditions and found that there was reduction in BSFC and increase in Thermal Efficiency in the coated piston. Vedharaj et al., [8] conducted an experimental study on a diesel engine coated with the PSZ and subsequently fuelled with the blends of kme B25



AND B50. Then the performance and emission tests were conducted and from the results they found that B50 shows increase in BTE, decrease in HC, CO and smoke opacity however there is increase in cylinder temperature and NO_x emissions when compared to uncoated engine. In order to reduce NO_x emission Urea based SNCR system was incorporated in the exhaust pipe through which the NO_x emissions are decreased. Ahmet Necati Ozsezen et al., [9] have conducted an experimental study on the direct injection diesel engine fuelled tentatively with the canola oil methyl ester and waste palm oil methyl ester. The test is conducted at constant speed at full load condition and found that there is reduction in CO, HC, CO₂ and B.P and increase in BSFC and NO_x when compared to PBDF. Muralidharan et al., [10] have done an experimental investigation on a diesel engine working at the constant speed, at constant load by varying the compression ratios. This engine if fuelled with the waste sunflower oil blended with the PD. The various blends were used as fuel and the blend B40 is identified as the best one in terms of thermal efficiency. The usage of these blends has resulted in the reduction of CO, HC emissions and increase in the NO_x emissions. Ertan Alptekin et al., [11] have conducted an experimental study on the DI diesel engine running at the constant speed and the varying load. The biodiesel produced from the pilot plant were blended with certain amounts of diesel fuel and bio ethanol. The tests were conducted on the engine with the biodiesel, diesel and the blends. The results state that BSFC of the biodiesel and the blends containing Bioethanol were higher when compared to the Diesel. The start of the combustion occurred at the earlier crank angles for biodiesel and occurred at later crank angles for bio ethanol when compared to diesel. Biodiesels emitted lower carbon monoxide (CO) emissions, higher carbon dioxide (CO₂) and oxides of nitrogen (NO_x) emissions as compared to diesel fuel. For the blends the HC emissions increased and CO₂ emissions reduced. M. Mofijur et al [12] have carried out a comparative evaluation of biodiesels. They found that many large number of literatures from highly rated journals in scientific indexes are reviewed including the most journals state that the usage of biodiesel reduces the emission of HC, CO, CO₂, PM but results in higher NO_x emissions compared to PD. Biodiesel lowered the B.P, BTE but increased the BSFC compared to diesel. S.M. Palash et al [13] conducted a study on the NO_x reduction techniques in the combustion of biodiesels. Increasing energy demand and reduction in the fossil fuels and the effect of fossil fuels on the environment has prompted for alternative fuels. As an alternative fuel biodiesel reduces the emissions but the NO_x emissions are high compared to PD. In biodiesels the NO_x emissions is high due to many factors such as physicochemical properties and molecular structure of biodiesel, flame temperature, ignition delay, injection timing and engine load conditions etc. The NO_x emissions can be reduced by the both pre and post combustion techniques such as exhaust gas recirculation technique (EGR) and retarded injection timing. Among these EGR is the most effective one which decreases the NO_x by 5-25% and slightly decreasing the HC, CO. I.M. Rizwanul Fattah et al., [14] conducted a study on the biodiesels and reviewed the facts and utilization of biodiesels. Biofuels mainly soybean, rapeseed, palm, jatropha and cottonseed oils reduce engine exhaust gas, noise and petro dependency. Through this study the authors have found that the biofuels have many benefits like reduction of greenhouse gas emissions and many harmful pollutants along with noise emission. Sakthivel et al., [15] have conducted an experimental study on a diesel engine running at constant speed, at variable loads fuelled with the biodiesel produced from the fish oil blended with diesel and the results have shown the decrease in the NO_x, HC, CO with increase in CO₂, smoke and BTE when compared to diesel.

Nomenclature —

CO	-	Carbon monoxide
CO ₂	-	Carbon Dioxide
HC	-	Hydro Carbons
PD	-	Pure Diesel
RPM	-	Refined Palm oil
RCF	-	Refined Corn Oil
BSFC	-	Brake Specific Fuel Consumption

RSF	-	Refined Sunflower oil
BTE	-	Brake Thermal Efficiency

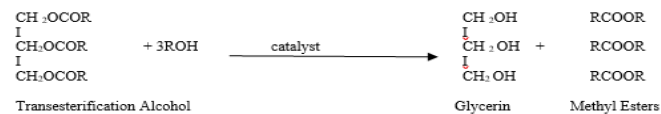
2. Materials and methods

2.1 Plasma Spray Coating

Plasma spray process is a thermal resistance technique. The thermal conductivity of this process ranges from 0.5w/mk to 1.5w/mk. This process is mainly used to improve the performance characteristics of various components which are subjected to high temperature in this process Argon and Hydrogen are used as arc gases. A high power source is required for this process. The mixture of ZrO₂ and CeO₂ 80% and 20% are fed to the arc gun in the form of powder which are supplied to the piston surface. Arc is generated between the electrodes. Due to the high temperature attained by the arc the powder supplied gets melted and the splat formation takes place which is followed by condensation, solidification and adhesion. The formation of the coating on the substrate is due to the KE.

2.2 Transesterification process

The reaction of a triglyceride which is a combination of fat or oil with an alcohol to form glycerol and esters is called transesterification. During this reaction process a catalyst like Sodium Hydroxide (NaOH) is used. The alcohol reacts with fatty acids to form methyl esters and glycerol. In most processes methanol is used. A successful transesterification reaction is identified by the separation of the methyl ester and glycerol layers after the reaction time. The heavier, co-product, glycerol settles down. First vegetable oils which are brought from the local market are checked for the FFA. If the free fatty acids are less than 5% then the one litre of refined Vegetable oil is treated with 250ml of methanol and 2.5gms of NaOH as catalyst. At first the oil is preheated up to 20 °C to 40 °C and is allowed to cool down naturally. At cold temperature i.e atmospheric temperature or lower than that Methanol is added to the catalyst in the preheated oil. While performing Transesterification process of oil the temperature is raised to 70 °C to 80°C the process performed to reduce high viscosity and give pure methyl esters without any soap content.



After the completion of the process the glycerol and the methyl esters are separated even after separation obtained methyl esters contains small amount of water. so for removal of water from these esters they are heated up to 1hr at 20°C and then esters and water are separated. This process is followed for PM, CF, SF. Then these oils are blended with the pure diesel and the blends obtained are B10, B25, B40. These blends are studied for the emission characteristics in the Kirloskar diesel engine.

Table 1. Specification of Test Engine

Type	: Kirloskar Vertical, 4S, Single acting, Diesel Engine
Combustion	: Direct Injection
Rated Power	: 4.3 kW
Rated Speed	: 1500 rpm
Compression Ratio	: 17.5: 1
Injector type	: Single 3 hole jet injector
Fuel injection pressure	: 210 bar

Table 2. Details of Measuring Systems

Pressure Transducer	- GH 12 D
Data Analyzer from Engine	- AVL PIEZO CHARGE AMPLIFIER
To measure pressure	- AVL 364 Angle Encoder
Smoke meter	- AVL 437 C Smoke

5 Gas Analyzer (NOx, HC, CO, CO₂, O₂) - AVL DIGAS 444 Analyzer

2.3 Experimental Setup

The table shows the experimental setup. A kirloskar 4-Stroke, Direct Injection Diesel Engine is used to evaluate the Emission and performance characteristics of the various Refined Vegetable oils at various injection pressure and loading. by using this setup we measure the emissions of various vegetable oils from the engine at different loads. The emission parameters that we evaluate are (CO, HC, NOx, CO₂) and performance of the Brake specific fuel consumption, and Brake thermal Efficiency. These parameters are measured by the Gas analyzer (AVL DIGAS 444 Analyser).The eddy current dynamometer is coupled to the engine to obtain the various loads (0%, 25%, 50%, 75%, 100%).

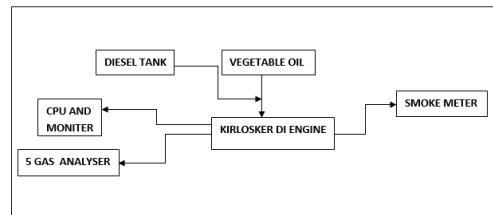


Figure 1. Schematic diagram of the Experimental Set- up

2.4 Test Procedure

This experiment is conducted by running the engine at a constant speed of 1500rpm. Initially the engine is run at no load condition for ten minutes before applying load for every vegetable oil. The various blended oils are injected at various injection pressures (180 bar, 210 bar, 240 bar) and then the load is increased gradually (up to 100%) and the various emission and performance characteristics are measured using the 5 Gas analyzer at the exhaust stream of the engine. The properties of vegetable oils are compared with Diesel, ASTM and BIS standards as given in Table -3.

Table 3. Comparison of properties of Diesel, Biodiesel standards & Vegetable oils

S.No.	Properties	Diesel	BIS standard Bio Diesel	ASTM D – 6751(IS15607: 2005	PM	CF	SF
1.	Cetane Index(Min)	46	51	-	36	35	38
2.	Density at 15°C kg/m ³	820 -845	860-900	860 – 900	874	923	917
3.	Kinematic Viscosity at 40°C cst	2 – 4.5	2.5 – 6	1.9 – 6	4.9	5.02	4.98
4.	Flash point °C min	35°C	262°C	130°C	220	162	163
5.	Calorific Value kJ/kg	42,000	-	-	37,037	36,824	39,8284

3. Results and discussion

3.1 Carbon Mono Oxide (CO)

The fig. 2 shows the CO emissions of the RPM, RSF, RCF, PD at various load conditions. When the emissions of the vegetable oils are compared with the petroleum diesel the emissions of the CO. At the full load condition is reduced by 35.71% by using RCF but RSF reduce by 21.42% and RPM reduce by 28.57%. This may be due to the adequate supply of oxygen.

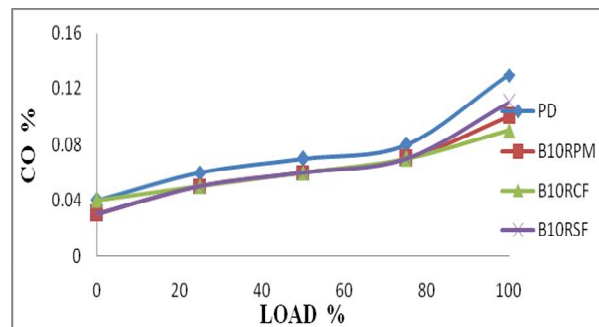


Figure 2. Variation of CO with respect to various vegetable oils

3.2 Hydrocarbon (HC)

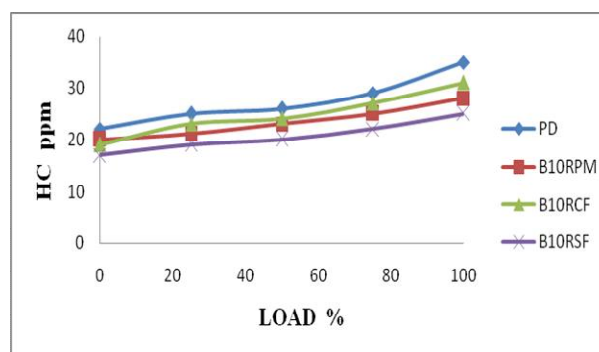


Figure 3. Variation of HC with respect to various vegetable oils

The fig.3 show the emissions of HC in the various vegetable oils and petroleum diesel. At the full load condition the emission of HC is reduced when compared to PD and the rate at which they reduce are in RPM by 20%, in RCF by 14.28% ,in RSF by 37.14%. There is reduction in the amount of HC in vegetable oils due to the difference in viscosity values of PD and vegetable oils.

3.3 Carbon Di Oxide (CO₂)

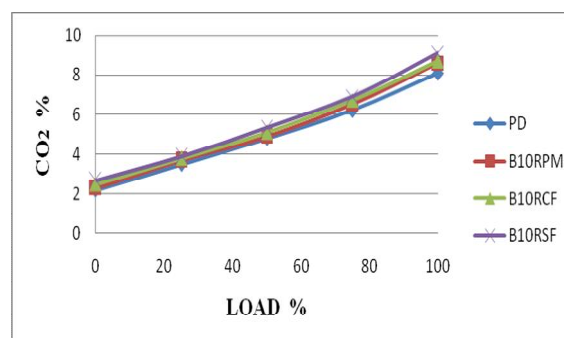


Figure 4. Variation of CO₂ with respect to various vegetable oils

The fig. 4 show the emission of CO₂ for PD and the 3 vegetable oils. There is marginal increase in the emission of CO₂. This may be due to the incomplete combustion.

3.4 Nitrogen Oxide (NO_x)

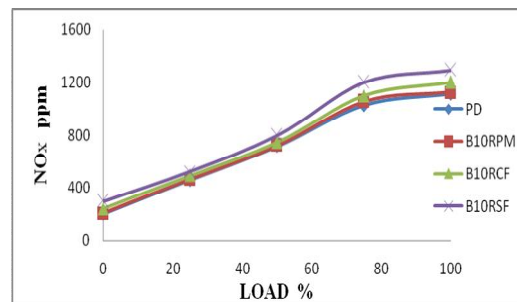


Fig. 5 Variation of NOx with respect to various vegetable oils

The fig.5 shows the emission of NOx at various loads of different oils. At full load condition the emissions of NOx is increased by 4.5%,8.33%,12% for RPM , RCF and RSF respectively. The emission of NOx is more in vegetable oils the reason for this may be due to the higher peak temperature.

3.5 Break Specific Fuel Consumption (BSFC)

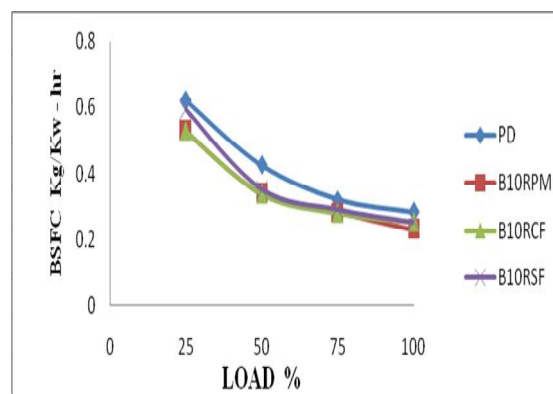


Figure 6. Variation of BSFC with respect to various vegetable oils

The fig.6 shows the BSFC of various vegetable oils at different load conditions. The BSFC decreases marginally for vegetable oils when compared to PD. This may be due to the calorific value of the blends.

3.4 Break Thermal Efficiency (η_{bt})

The fig.7 shows the BTE of various vegetable oils at the different load conditions. The BTE keeps increases as the load on the engine increases. The BTE of the vegetable oils are more than the PD . Among the RPM produces the maximum BTE i.e 23.07%.The amount of the BTE is more for biodiesels than the Diesel due to the better combustion of biodiesels

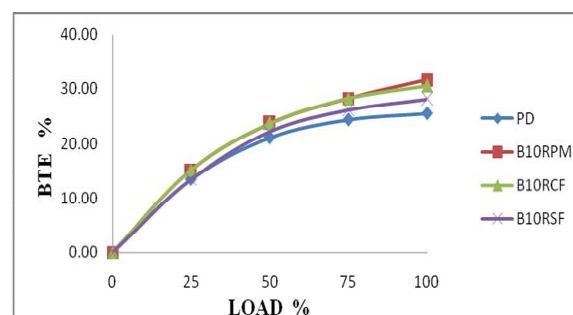


Figure 7. Variation of BTE with respect to various vegetable oils

4. Conclusions

The Engine was tested with various blends by varying load at constant speed. The properties of the biodiesel were analyzed and the following conclusion were arrived from the graph.

1. It was found that for a blend of diesel of 10% RPM, at full load, the CO, HC decreased by 28.57%, 20.03% and there is marginal increase in NOX and CO₂ than PD.
2. The BTE is increased by 23.07% and there is marginal decrease in BSFC when compared to PD. The performance and emission characteristics for RPM has given better results than other two vegetable oils.

References

- [1] G. Sivakumar, S. Senthil Kumar, "Investigation on effect of Yttria Stabilized Zirconia coated piston crown on performance and emission characteristics of a diesel engine"; Alexandria Engineering Journal ;2014;53, pp. 787–794
- [2] Selman Aydın, Cenk Sayın, "Impact of thermal barrier coating application on the combustion, performance and emissions of a diesel engine fuelled with waste cooking oil biodiesel–diesel blends"; Fuel ;2014; 136 pp. 334–340)
- [3] Bahattin IS, CAN, "Application of ceramic coating for improving the usage of cottonseed oil in a diesel engine"; Journal of the Energy Institute;2015 pp. 1-8
- [4] M. Ekström, A.Thibblin, A.Tjernberg, C. Blomqvist, S. Jonsson, "Evaluation of internal thermal barrier coatings for exhaust manifolds"; Surface & Coatings Technology;2015; pp. 198–212.
- [5] Huseyin Aydın, "Combined effects of thermal barrier coating and blending with diesel fuel on usability of vegetable oils in diesel engines"; Applied Thermal Engineering;2013; 51 pp. 623-629.
- [6] Selman Aydın et al, "Investigation of the usability of biodiesel obtained from residual frying oil in a diesel engine with thermal barrier coating"; Applied Thermal Engineering; 2015;80, pp. 212 - 219.
- [7] Naveen. P et al., "Effect of Titanium Oxide Coating on Performance Characteristics of Bio-Diesel (Honge) Fuelled C.I. Engine"; International Journal of Modern Engineering Research 2012; Vol.2, pp. 2825-2828
- [8] S. Vedharaj et al, Reduction of harmful emissions from a diesel engine fueled by kapok methyl ester using combined coating and SNCR technology, Energy Conversion and management;2014;79 pp. 581-589.
- [9] Ahmet Necati Ozsezen, Mustafa Canakci, "Determination of performance and combustion characteristics of a diesel engine fuelled with canola and waste palm oil methyl esters", Energy Conversion and Management; 2011;52 pp. 108-116.
- [10] K. Muralidharan, D. Vasudevan, "Performance, emission and combustion characteristics of a variable compression ratio engine using methyl esters of waste cooking oil and diesel blends"; Applied Energy;2011;88 pp. 3959-3968.
- [11] Ertan Alptekin et al, "Using waste animal fat based biodiesels–bioethanol–diesel fuel blends in a DI diesel engine"; Fuel;2015;157 pp. 245-254.
- [12] M. Mofijur et al, "A study on the effects of promising edible and non-edible biodiesel feed stocks on engine performance and emissions production: A comparative evaluation" Renewable and Sustainable Energy Reviews; 2013; 23 pp. 391-404.
- [13] S.M. Palash et al, "Impacts of biodiesel combustion on NO_x emissions and their reduction approaches, Renewable and Sustainable" Energy Reviews; 2013 pp. 473-490.

- [14] I.M. Rizwanul Fattah et al, "Impact of various biodiesel fuels obtained from edible and non-edible oils on engine exhaust gas and noise emissions, Renewable and Sustainable Energy reviews", 2013;18 pp. 552-567.
- [15] G. Sakthivel et al, "Comparative analysis of performance, emission and combustion parameters of diesel engine fuelled with ethyl ester of fish oil and its diesel blends", Fuel; 2014;