Effective Implementation of low thermal conductivity material Yttrium Stabilized Zirconium Coating on a Diesel Engine Components Fuelled with neat Waste Cooking Oil-An Assessment Study

E.Sangeethkumar¹, M.Jaikumar¹, P.Vijayabalani², N. Sasikumar¹, V. Ramanathan¹

¹ Department of Automobile Engineering, Hindustan Institute of Technology and Science, Chennai-603103, Tamil Nadu, India.
² Department of Mechanical Engineering, Hindustan Institute of Technology and Science, Chennai-603103, Tamil Nadu, India

Email: esangeeth@hindustanuniv.ac.in

Abstract. In this study, an attempt was made on the consumption of neat waste cooking oil (WCO) in a thermal barrier coated (TBC) diesel engine. During the first stage of the study, the standard engine fuelled with diesel and WCO with different power outputs (25%, 50%, 75% & 100%) to measure the performance, combustion and emission parameters. In the second stage of the study, the engine components coated with 8% yttrium stabilized zirconium (8%YSZ) ceramic coat and NiCrAl bond coat using plasma spray coating. In the third stage of the study, the base engine convert to TBC mode and fuelled with diesel and neat waste cooking oil and reading were compared. From the experimental study, it came to know that, the brake thermal efficiency of uncoated diesel and WCO, 31.2%, and 25.7% were as for TBC diesel and WCO it was improved to 32.8 % and 27%. In the combustion side, the cylinder peak pressure for uncoated diesel and WCO 62 bar and 55.8 bar were as for TBC diesel and WCO improved to 63 bar and 57 bar. Further on the emission side, the CO, HC, and smoke were decreased in the TBC mode along with the penalty of increase in the NOx for both diesel and WCO. From the experimental study, the TBC mode reduces the heat flux from the combustion chamber and traps the heat inside the cylinder as an effect it reduces the ignition delay and helps to utilize highly viscous fuel like WCO in a diesel engine.

1. Introduction

In the present situation globally most of the energy demand met with fossil-based fuel. But due to more depletion of fossil-based fuel which has raised the fuel cost very high nowadays and also high exhaust; emission from the internal combustion engine increases the atmospheric pollution day by day[1-3]. Diesel engine most widely used power source to generate this energy in many sectors due to its advantages like high efficiency, low fuel consumption, and durability[4]. At present much research work was made on
finding a promising alternative fuel that should be biodegradable, renewable in nature, and environmentally friendly. Vegetable oil was one such alternative energy resource that can replace diesel fuel due to its properties very close to diesel [5-6]. Vegetable oil usage in two forms which can be edible and non-edible. Mostly non-edible were preferred and edible was not preferred due to ethical problem issues related to food crisis[7]. Waste cooking oil (WCO) from food waste considered as one of the cheapest alternatives for diesel engines compare with the latest edible and non-edible oil because it is plenty available so that environmental problems and health issues due to illegal dumping of WCO in water and soil can be prevented. Example 1 litre of WCO in water can pollute 500,000 liters of water. But the biggest challenge in the handling of WCO due to its high viscosity which increases the spray size during the atomization and pays way to the incomplete combustion which causes more emission [8-9]. Researchers suggested some of the methods reduce the high viscosity and effectively utilize the WCO such as fuel modification methods like blend, transesterification, emulsion, pyrolysis, and engine modification methods like thermal barrier coating, varying compression ratio, the difference in injection pressure and the difference in injection timing [10-11]. Among this engine modification method such as Thermal Barrier Coating(TBC) chosen to be a more effective method because it reduces the thermal loss from the combustion chamber and enhances the thermal efficiency so that low properties fuel like WCO can be successfully utilized in an engine without any fuel modification [12-13].In a TBC method the engine components such as cylinder head, valve, piston crown, and cylinder liner were insulated initially with the bond coat of metal alloy which eliminate the thermal stress induce due to difference in material properties and top of it low thermal conductivity ceramic insulating coat which reduce the heat transfer from the engine so that energy produced during the combustion effectively utilized maximum and emission such as HC, CO, Smoke reduced with the increase in NOx due to high in-cylinder temperature[14-17].

The author would like to convey that the neat WCO can be effectively utilized on the TBC mode diesel engine without any fuel modification. In this study performance, combustion, and emission characteristic of diesel and WCO were studied for both unmodified and TBC diesel engines.

2. Materials and Methods

2.1 Test fuel & property study

Diesel was purchased in bulk quantity to reduce the error in the reading. WCO gathered from the hotels very close to the institute and further filtered for the impurity and heated to 60°C to take away the water molecule present in the WCO. Finally, the diesel and WCO tested for the properties specified in the below table 1.

| Property                        | Diesel | WCO | ASTM Standard |
|---------------------------------|--------|-----|---------------|
| Kinematic Viscosity at 30°C (cst)| 3.4    | 18  | D445          |
| Density at 30°C (kg/m³)         | 830    | 921 | D1298         |
| Calorific Value (MJ/kg)         | 44.5   | 39.3| D5865         |
| Cetane Number                   | 42     | 37  | D613          |
2.2 Thermal Barrier coating Employment

The TBC was done on engine components such as cylinder head, valve, and piston crown with the help of plasma spray coating. Plasma spray coating was chosen due to its ability to work with high-temperature material like 8% YSZ. At the start of the coating, the engine components were machined to the 300 microns thickness to maintain the compression ratio after coating, and chemical cleaning was done to remove impurities present on the coating surface. As a first coat 100 microns, NiCrAl bond coating was done on the substrate, and on the top of it, 8% YSZ coating was made. TBC components were shown in figure 1.

![Figure 1. TBC engine components](image1.jpg)

![Figure 2. Kirloskar DM10 Experimental setup](image2.jpg)

2.3 Experimental Setup and Testing Procedure

In this study experimental work was done on a single-cylinder, four strokes direct injection water-cooled Kirloskar make and DM 10 model diesel engine with the constant speed of 1500rpm, compression ratio 17.5:1 and output power of 7.5KW with four different loads of 25%, 50%, 75%, and 100% both in uncoated and TBC mode. The diesel and WCO fuelled in the engine with two different fuel tanks. The engine loading was applied through the eddy current dynamometer. The engine emission such as HC, CO, and NOx was measured using AVL444N and Smoke opacity was measured with AVL 437C Smoke meter. The piezoelectric sensor by the data acquisition system help to obtain the heat release rate and in-cylinder pressure. The exhaust gas temperature measured with the help of a thermocouple fixed in the engine exhaust pipe. The experimental setup is shown in figure 2. During the start of the study, the standard engine was fuelled with neat diesel and WCO at different power output for the engine performance, combustion, and emission parameter. In the second stage of the work, the standard engine was converted into TBC mode and further fuelled with diesel, and WCO in the end results were compared.
3. Results and Discussions

3.1 Performance characteristics

3.1.1 Break thermal efficiency

The Break thermal efficiency (BTE) for diesel and WCO for both uncoated and coated modes shown in figure 3. BTE for uncoated diesel and WCO at maximum power out was 31.2% and 25.7% whereas for coated diesel and WCO it was 32.8% and 27%. The improvement in TBC mode for diesel and WCO was due to heat resistance inside the engine cylinder, lower the heat flux which decreased the ignition delay so that amount of fuel consumption required for each cycle was reduced [18].

Figure 3. Brake power Vs Brake Thermal Efficiency

Figure 4. Brake power Vs Exhaust Gas Temperature

3.2.2 Exhaust Gas temperature

The difference in Exhaust Gas temperature (EGT) of diesel and WCO for both coated and uncoated diesel engines shown in figure 4. The EGT for uncoated diesel and WCO was 375 °C and 426 °C whereas for coated diesel and WCO it was 362 °C and 409 °C the decrease in EGT for TBC mode due to the heat retained inside the cylinder during the previous cycle helps to increase the in-cylinder temperature and reduce the ignition delay which improves the premixed phase and prevent the prolong combustion in the diffusion phase and afterburn period.

3.2 Emission Characteristics

3.2.1 Unburnt hydrocarbon emission

The unburnt hydrocarbon (UHC) for diesel and WCO for both uncoated and coated engines shown in figure 5. The UHC for uncoated diesel and WCO was 80 ppm and 154 ppm whereas for coated diesel and WCO it was lower side 69.3 ppm and 140 ppm because the heat loss from the combustion chamber was reduced with TBC mode which raises the temperature inside the
engine cylinder due to this higher amount of unburn charge present during the combustion processes [18-19].

![Figure 5: Brake power Vs Unburnt Hydrocarbon](image1)

![Figure 6: Brake power Vs Carbon Monoxide](image2)

3.2.2 Carbon monoxide emission
The carbon monoxide (CO) for Diesel and WCO uncoated and coated were shown in figure 6. For the uncoated diesel and WCO, the CO was at the higher side 0.13 % and 0.23%, whereas for TBC mode it was decreased to 0.1 % and 0.19 %. The decreases in CO for the TBC mode due to the decline in thermal loss from the combustion chamber, which increases the in-cylinder temperature and pressure due to this more CO oxidation, take place [20].

3.2.3 Smoke emission
The smoke emission for Diesel and WCO for uncoated and coated mode shown in figure 7. The smoke Opacity for uncoated diesel and WCO was found to be 35 % and 57% at maximum power output, whereas for TBC diesel and WCO it was 33.2 % and 54.8%. The decrease in the smoke opacity for TBC mode due to the high in-cylinder temperature and betterment in the atomization and vaporization leads to complete combustion [18].

3.2.4 Oxide of Nitrogen emission
The difference in Oxide of Nitrogen (NOx) emission for uncoated and coated diesel and WCO showed in figure 8. At the maximum power output, the NOx for diesel and WCO was 686 ppm and 430 ppm whereas for TBC mode at maximum power out 724 ppm and 451 ppm. The increase in NOx with the TBC mode due to heat retained inside the cylinder rise the in-cylinder temperature which decreases the ignition delay period and pays way to enhance the combustion efficiency so that complete combustion takes place [17,19].
3.3 Combustion Characteristics

3.3.1 Peak cylinder pressure

The variation of Peak cylinder pressure (PP) for uncoated and coated diesel and WCO showed in figure 9. The PP for uncoated diesel and WCO was 62 bar and 55.8 bar, whereas for TBC mode it was 63 bar and 57 bar. The increase in PP for TBC mode due to a reduction in thermal loss from the combustion chamber reduces the ignition delay and increases the in-cylinder temperature due to this early heat release take place during the combustion. A huge quantity of fuel burned at the time of the premixed combustion phase pays way to increase in PP in TBC mode[18].
4. Conclusions

From the experimental study, the diesel and WCO fuelled in standard and TBC mode engine. The performance, emission, and combustion for both fuels were compared and from the study, the following results were found.

1. BTE for diesel and WCO in the TBC engine improved to 31.8 % and 26% compared with the standard mode.
2. EGT for diesel and WCO in TBC mode reduced to 362°C and 409°C.
3. Smoke emission in TBC mode for diesel and WCO decreased to 33.2% and 54.8%.
4. HC emission reduced to 69.3 ppm and 140 ppm with TBC mode for diesel and WCO.
5. CO emission for diesel and WCO in TBC mode reduces to 0.1% and 0.19 %.
6. NOx emission was higher side as a penalty on TBC mode for both diesel and WCO 724 ppm and 451ppm.
7. The cylinder pressure was found to be 63 bar and 57 bar which was higher side for TBC mode diesel and WCO.

From the above result, the author would like to convey that TBC was one of the effective engine modification methods which help to utilize the high viscous fuel like WCO in a diesel engine without any modification in the fuel. The heat-retaining behavior of the TBC helps in changing the ignition characteristics of the fuel.

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