Performance and Emission Characteristics of Multilayer Thermal Barrier Coated Di Diesel Engine Fuelled With Sunflower Bio Diesel

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Abstract

In the present study the effect of thermal barrier coated piston of air cooled DI engine fuelled with sunflower methyl ester (SFME) are presented. There are many investigations carried out with thermal barrier coatings in the past with different coating material, coating thickness and numerous combinations of fuel blends. The current study is focused to get the combined effect of coating and pure sunflower based bio diesel(100% SFME) with multilayer NiCrAl (150microns) and alumina oxide (Al2O3)-titanium oxide (TiO2:40-45 % by volume) for 200 microns are applied on the aluminium alloy piston crown to study its output characteristics and exhaust emission release. The main objective of the study is to improve the efficiency of engine and to reduce the harmful exhaust emission release from the engine with renewable sunflower based bio diesel on the low heat rejection engines. From the experimental testing, it is predicted 4 % improvement in engine brake thermal efficiency at all loading and 3% decrease in specific fuel consumption at maximum loading conditions for the coated engine with SFME and also noted that 5% reduction SFC at low load conditions. The reduction in HC is reported for wide range of loading and maximum reduction is 27% at peak load operation. A decrease in 18% CO emission is noted in the investigation for medium load operation and it is increased to 20% at peak load. It is also reported in the study that 5% increase in NOx emissions for coated SFME at maximum loading and for all loading the uncoated SFME released 10% lower than standard engine.

Keyword: Diesel Engine, Multi layer thermal barrier coating, Emissions, Thermal efficiency, Sunflower methyl ester.
Introduction

Improving the efficiency of power conversion and reduction of exhaust emission is one of the important researches in recent day’s automotive and stationary engine applications. There are numerous directions available to improve the efficiency and power output of engine with reduced emissions out of which thermal barrier coating plays most attractive because it needs less design modification. The feasibility of using different vegetable oil with and without the blend of conventional fuel is also one of the important applications of thermal barrier coating. The thermal barrier reduces the heat carried away by coolant in case of water cooled engine and air in case of air cooled engine and in turns it increases the operating combustion chamber temperature and it leads to use even with high viscous fuel with the protection of global warming and environment.

Even though a thermal barrier coating prevents heat loss to coolant, it is difficult to convert all available heat due to coating into useful energy. There are many researches carried out in the past with different coating thickness with fuel combinations and investigated both negative and positive impact on power and emission release. Hanbay et al.[1] predicted 26% reduction in smoke density while using the TBE with corn methyl ester in blends for both the coated and standard engine with significant reduction in CO for coated engine compared to standard engine. Their study also concluded that the coating is successful without any major modification in the engine. Taymaz et al.[2] studied and investigated that 30% of engine heat is wasted in the diesel engine which can be utilized if it is coated with ceramics and the same author reported in another study that the coated engine can provide improved engine power and reduced emissions compared to standard engine due to reduction in heat loss. The usability of cotton seed and sunflower bio diesel on zirconium coated diesel engine was experimentally investigated by Huseyin [3] and reported that considerable reduction in CO and PM and improved engine torque is noted for 15% and 35% sunflower oil bio diesel blends with reduction in SFC for coated engine. Increased in brake thermal efficiency and reduction in SFC was noted in an Al₂O₃-TiO₂ TBE engine with 30% honge fuelled diesel engine in the study Naveen et al.[4]. In a study of 0.5 mm PSZ coating in diesel engine with rice brown bio diesel shown improved performance and reduce emissions was achieved by Durga Prasad Rao [5] with proper changes in injection pressure and injection timing.

Ekrem Buyukkaya et al. [6] have investigated the effects of MgZrO₃ and CaZrO₃ thermal barrier on gas emissions with different injection timings and valve adjustments for a turbocharged DI Diesel engines. Their results showed 1-8% reduction in brake specific fuel consumption for the combined effect of thermal barrier coating and injection timing. They also reported that the reduction in NOx emission was decreased by 11% for 18 BTDC injection timing. In the investigation of Maharaja Gasti et al. [7] investigated 20% castor with diesel blend is the optimum blend ratio for PSZ TBC to obtain better improvement in engine power and reduction in emissions.

The important characteristics ceramic material was reviewed and presented in X.Q. Cao et al.[8] and suggested CeO₂, Mullite, and La₂Zr₂O₇ are the best bond material for ceramic coating. The titanium oxide and nickel chromium coating was adopted on
Performance and emission characteristics of multi layer thermal barrier diesel engine and reported 40% reduction in NOx for Al-Ti coated piston in the study of Karuppusamy et al.[9]. In the reviews Piramandhan et al.[10] and Jaichandar et al [11] addressed the most of studies carried out LHR engine and summarized the advantages and pitfalls of LHR engines in the aspects output power, emissions, different coating material, simulations and life of coating. In their review it is suggested that the ceramic coating with different matching fuel combinations will be the potential for obtaining the better improvement in future LHR engines. The coated piston with vegetable oil and bio diesel blends with and without fuel additives are investigated in many studies and obtained improvement in engine characteristics and some of the obtained reduced emission release of HC, CO, smoke and Nox and some research with increased emission level compared to standard engine [15-17].

In the present study multilayer of NiCrAl and Al2O3-TiO2 are coated on the substrate of aluminium alloy piston. This combination having excellent resistance to wear, high corrosion resistance and thermal fatigue along with toughness due to doping of 40-45 TiO2 additions in alumina. The test was conducted with standard operating conditions for both coated and uncoated engines with diesel and SFME bio diesel. The compression ratio of coated engine for its piston crown coating thickness is compensated by increasing thickness of the gaskets.

**Experimental set up and Coating process**

In the present investigation a single cylinder air cooled diesel engine with computerized combustion analyzer, emission measurement and fuel consumption measurement set up with electrical dynamometer included as shown in Fig.1. The engine was coupled with eddy current water cooled swing-field electrical dynamometer with load varying options in the control panel. The airflow measurement is carried out with help of manometer set up in the surge tank to enable proper flow and electronic fuel measuring is included in the set up. The computerised digital data acquisition system has been used to acquire the in-cylinder pressure and TDC signals to store them in the digital form on the personal computer.

![Figure 1](image-url)

**Figure 1**: Experimental set up computerised record database
The exhaust emission was measured with the help of CRYPTON 295 exhaust gas analyzer (5-gas analyzer). It works on NDIR (Non Dispersive Infra Red) principle. The exhaust gas sample was passed through a moisture separator and filter element to prevent water vapor and particulate matter from entering the analyzer. In this analyzer unburnt hydrocarbon (UBHC), NOx were measured in parts per million and carbon monoxide (CO), oxygen (O\textsubscript{2}), carbon dioxide (CO\textsubscript{2}) were measured in percentage by volume. The AVL smoke meter was used to measure the smoke value of the engine in the system.

The atmospheric plasma spraying technique is adapted to coat the piston. The cleaned piston is set on the table before start the bond coat spraying process. The optimized plasma coating parameters are used to coat the piston in order to get uniform layer of coating on the piston with proper shield gas and plasma gas flow. The bond coat thickness is 150 microns and the Al\textsubscript{2}O\textsubscript{3}-TiO\textsubscript{2} with particle size of 10-25 microns with stand-off distance of 100-120 mm for the plasma flame.

**Test case and observations**

The experimental test is performed for both standard engine with specification listed in Table-1 and ceramic coated engine with diesel and sunflower oil bio diesel (SFME). First the normal piston (uncoated) with diesel fuel engine is tested and noted the data for the engine output and emissions for the various loading. Then the coated piston is installed in the engine with increased gasket thickness to compensate the variation in clearance volume due to piston coating thickness and also to keep the same compression ratio. Then the test output observations for the same set of loading with diesel and 100% SFME fuel are noted.

Four different test cases are performed in the present investigations for five different loading idle load, 20%, 40%, 60%, 80% and 100% of load. For fuel measurement 4 trials are taken to get average time to estimate the fuel consumption accurately. The four test cases are uncoated piston diesel fuel (D), uncoated piston with SFME (SF), coated piston with diesel (CD) and coated piston with SFME (CSF).

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Kirloskar TAF 1</th>
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<tbody>
<tr>
<td>Cooling</td>
<td>Air cooled</td>
</tr>
<tr>
<td>No. Cylinder and stroke</td>
<td>Single,4S</td>
</tr>
<tr>
<td>Rated power</td>
<td>4.4 kW</td>
</tr>
<tr>
<td>Rated speed</td>
<td>1500 RPM</td>
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<tr>
<td>Bore dia.</td>
<td>87.7 mm</td>
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<tr>
<td>Stroke</td>
<td>110 mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>17.5:1</td>
</tr>
<tr>
<td>Office diameter</td>
<td>13.6 mm</td>
</tr>
<tr>
<td>Coefficient of discharge, Cd</td>
<td>0.6</td>
</tr>
<tr>
<td>Swing-field electrical dynamometer</td>
<td>KVA-5, Ph-1, Hz-50</td>
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Results and Discussion
The collected observations are listed and analyzed for engine output power, thermal efficiency, estimation of specific fuel consumption (SFC) and emissions. The comparisons are made for coated and uncoated engines of diesel and SFME. The charts are obtained for clear comparison and analyses.

Thermal efficiency:
The brake thermal efficiency is the important performance measure of engine parameters which indicates the engine conversion capability of input fuel energy. In this present study it is noted that the thermal efficiency is increased by 4% for coated SFME engine compared to standard engine due to high combustion temperature with low calorific value fuel it is shown in Fig.2. At mean load case the coated piston engine works well for diesel fuel because of low diesel fuel consumption when compared to SFME fuel.

Indicated mean effective pressure (IMEP):
In the present study it is has been observed that 12% increase in IMEP for coated piston engine with SFME when compared to baseline engine at higher loading conditions as plotted in Fig.3. The normal piston sunflower oil developed low IMEP due to higher viscosity and lower heat release. At low load conditions the coated piston diesel engine developed more pressure than coated SFME because of more ignition delay period for SFME which can be improved by setting proper injection timing.

![Figure 2: Variation of thermal efficiency with brake power](image-url)
Specific fuel consumption (SFC):  
The specific fuel consumption curve is plotted in Fig. 4. It is seen from the graph that for all loading conditions coated piston sunflower oil fuel consumes 3% less fuel than standard engine due to better combustion due to availability of high temperature in coated piston.

The uncoated piston with sunflower oil consumes 14% more than standard engine due to insufficient temperature for vaporization of rich mixture and to overcome the
viscous issues of SFME. It is also seen from the results that the coated engine with SFME consumes less fuel than uncoated engine with SFME at the idle load due to availability of heat to achieve better combustion for high viscous bio fuel.

**Hydrocarbon (HC) and Carbon monoxide (CO) emissions:**

The main reasons for the presence of hydrocarbon and carbon monoxide in the exhaust of diesel engines are due to incomplete combustion and both are having negative impact on environment. The HC emission release is presented in Fig.5. It shows 27% reduction in HC emissions for the coated piston with SFME at peak load and approximately 20% for all loading cases. The coated piston diesel fuel releases more HC for all loading cases and found 40% higher than standard engine and it can be the result of higher temperature and very shorter delay period for diesel fuel in the vicinity of high crown temperature. The coated piston temperature intensity provides complete combustion for the sunflower oil engine which interns in turn releases low HC for all loading.

**Figure 5:** Effect of brake power on hydrocarbon release

The CO emission of coated SFME at no load releases 18% less than standard engine and 35 % less than uncoated SFME as shown in Fig.6. At peak load, CO emission is 20% more than standard engine due to insufficient time for achieving complete combustion. It is also shown in the graph that normal piston sunflower oil engine releases more CO for all loading conditions as a results of poor spray characteristics of SFME in uncoated conditions due to high viscosity.
The CO\textsubscript{2} emissions is shown in Fig. 7, the coated piston with SFME releasing less CO\textsubscript{2} emissions than standard engine due to complete combustion of fuel mixture with the availability of high temperature in the combustion chamber due to coating. The coated piston with diesel fuel shows more CO\textsubscript{2} at peak load conditions due to decrease in delay period resulting from incomplete combustion. It is also noted that at medium load, both coated diesel and SFME releases same level of CO\textsubscript{2} emission.

**Oxides of Nitrogen Release (NO\textsubscript{x}):**

The primary reason for releasing of NO\textsubscript{x} in diesel engine is due to availability of oxygen with high combustion temperature. Diesel engine normally releases more NO\textsubscript{x} due to high compression ratio and high combustion temperature compared to gasoline engine. The NO\textsubscript{x} emission for different loading is plotted in Fig. 8. It is
observed that 5% increase in NOx at maximum load for coated SFME compared standard engine and also noted 10% reduced NOx level in normal piston with SFME operation for all loading due to consumption of heat for the vaporization of uncoated condition running.

![Graph showing variation of oxides of nitrogen with brake power.](image)

**Figure 8:** Variation of oxides of nitrogen with brake power

**Smoke emissions:**
The smoke emission is increased by 28% and 12% for coated diesel engine and coated SFME engine respectively compared to baseline engine at higher load due to lower calorific value of sunflower oil as shown in Fig.9. For all the cases, it is noted that the smoke opacity is increased, while increasing the engine load. At an average load, the coated piston sunflower oil releases 7% less than uncoated diesel engine due to good combustion capability of coated engine. Around 14% reduction in smoke is noted for coated sunflower fuel when compared to coated diesel engine. It shows coated piston with SFME fuel is better compared to coated piston diesel engine in the aspect of smoke release.

![Graph showing variation of smoke release with brake power.](image)

**Figure 9:** Variation of smoke release with brake power
Conclusion
The multilayer of NiCrAl and Al₂O₃-TiO₂ coating is successfully applied and tested for the air cooled engine piston without any major modification of the existing engine and obtained improved thermal efficiency and considerable reduction in brake specific fuel consumption. The feasibility of using 100% bio diesel fuel SFME is tested without blending it with conventional fuel for improving engine efficiency and to reduce harmful emissions.

The improvement in thermal efficiency at maximum loading condition is found to be 4% and increase in indicated mean effective pressure is noted as 12% which concludes that the coated engine with sunflower based bio diesel is more suitable for stationary engine compared to variable speed engine. It is also concluded that the coated engine with SFME will consume less fuel for wide range of loading conditions. The investigation also showed reduction in HC emission for all loading condition and the maximum reduction is 27% at peak load and 18% reduction of CO emission at no load to medium load. The increase in NOx and smoke is 5% and 12% respectively for coated SFME engine which can be reduced with adding EGR to the engine. The present study also shows that the thermal barrier coating with high viscous vegetable bio diesel fuel is more feasible in stationary engine when compared to variable speed engine because most of the time the stationary engine will operates on peak load.

The effect of coated piston engine performance can be still tuned with different proportions of bio diesel and diesel blends instead of running only with 100% SFME to improve engine power output. Also the harmful emission level can be reduced further by testing the engine with optimum fuel injection pressure and injection timing with optimum SFME blend which is the future planned investigation in this area of study.

References


