Experimental Investigation of YSZ Coated Piston Crown on Performance and Emission Features of LHR Diesel Engine with Mahua Biodiesel

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Abstract. Researchers have carried out numerous studies on low heat rejection (LHR) engines. Among the studies reported, some are experimental and many are theoretical in nature. The thermal barrier coatings (TBC) play a prominent role in LHR engines. Ceramic coatings are TBCs, they shield the base material and high temperature protect the source. The present work is focused on Yttria-stabilized zirconia (YSZ) material with a thickness of 500 microns. Is a bond coat which is used a plasma spray Tanique for costed on the required surface. Experimental analysis is carried out on a diesel engine with diesel and Mahua biodiesel with different loading conditions. This study results to expose that brake thermal efficiency is bigger along with lessening of BSFC. The LHR engine reduces the Hydro carbon (HC) and carbon monoxide (CO) emissions drastically but the Nitrogen oxide (NOx) emission is increased.

Keywords: LHR Engine, TBC, YSZ, BSFC, Emissions, HC, CO, NOX

1. Introduction
Various impressions of low heat rejection (LHR) engines are established to using A new techniques like ceramic coating in the preferred components, avoid the air gap in the piston and the other apparatuses etc. It is also found that the coatings on condition that on the engine components are simple with progressive coating techniques. The following journals are referred which forms the basis to carry out the project. Parker et al. [1] developed a monolithic reaction bonded silicon nitride piston for accomplishing low heat rejection to the coolant throughout the load range and reported higher efficiency. Stang et al. [2] bolted the crown, which consisted of a top supported with a conventional aluminum base made of ceramic to the aluminum body of a piston, separated by a very high insulating layer. However, this piston was operated only for 264 hours after which mechanical problems like loosening of the bolt were encountered and further testing had to be abandoned. Krishnan et al. [3] worked on monolithic ceramic piston and evaluated the performance of single cylinder engine and found a drop in brake specific fuel consumption (BSFC) of about 3% with 9% reduction in frictional horse power (FHP). Timoney et al. [4] reported an increased frictional horsepower with insulated engine, with plasma spray coated zirconia piston, with different degrees of air swirl achieved by masked valves, though it improved the fuel economy. Wade et al. [5] reported an improvement in the fuel consumption for un-cooled single cylinder diesel engine, in the range of 4 to 7% with ceramic coated cylinder head, valves, piston and liner in the area above the piston rings, to the baseline water cooled engine. Havstad et al. [6] found small improvements in fuel consumption in the range of 5 to 9% with ceramic insert in the piston and in the liner above the piston rings, when compared with water cooled engine. A constant air/fuel ratio was
maintained for both versions of the engines to ensure similar combustion in both cases. Cheng et al. [7] conducted tests for single cylinder operation on 8-cylinder engine revised, employing a ceramic-coated piston and head. BMEP and airflow rate remained constant, however air–fuel ratio was not kept constant. This resulted in deterioration of the engine performance with insulation, increasing BSFC up to around 17%. Ciniviz et al. [8] clarified that associated with a normal diesel engine, the power of engine was enlarged by 2%, the engine twisting was enlarged by min 1.5% and max. 2.5 %, and brake sfc (B.S.F.C.) was diminished by min. 4.5 and max. 9 %.

2. Methodology
It was divided into different sections namely, Plasma spray Coating, fabrication of an insulated piston, Experimental programme for pure diesel, experimental investigation with LHR engine with mahua biodiesel. The plasma spray coating on piston top shown in Fig.1, and the Normal piston, TBC Insulated piston and Piston de-accumulate and accumulate in Engine are shown in fig. 2.1(a & b) and 2.2 (c & d).

![Fig. 1 Plasma spray coating on piston top](image1)

(a). Normal Piston  
(b). TBC Insulated Piston

![Fig. 2.1 Difference of before TBC and after TBC of piston](image2)
3. Diesel Procedure on Predictable Engine and LHR Engine

Photographic View of the Investigational setup shown in Fig 3 (a & b), used for the surveys of LHR diesel engine with MAHUA diesel is shown in Fig 3 (c), and the Fig 3. (d, e &f) shows reading taken by use of computer. The predictable engine had an aluminium alloy piston with a bore diameter of 87.5 mm and a length of stroke is 110 mm. The esteemed yield of the engine is 5.20 kW at a frequency speediness of engine 1500 rpm. The compression ratio was 17.5:1. The fuel injector required 3 holes of 0.25 mm size.

A direct injection type is involved as a combustion chamber with no different research for swirling motion of air. Electric dynamometer is associated with the engine for finding its BP. Finding fuel consumption of the engine here used Burette method to cut off. Air- consumption of the engine was restrained by the air-box method.

Fig. 3. (a) Investigational Setup of LHR Engine

(c). Normal piston dis-assemble in the engine

(d). Coated piston was assembled in the engine
Fig. 3 (b). Investigational Setup for LHR Engine Operation

Fig. 3 (c). Preparation of MAHUA bio-diesel

Fig. 3 (d). Reding taken by the computer

Fig. 3 (d). Parameters setting

Fig. 3 (d). Automatic graphs indicated
4. Performance Parameters
LHR engine consisted of a ceramic coating (Yttria stabilized zirconium) of 500 microns on the piston head. Plasma spray coating technique is used in this process. In this a conventional single cylinder CI engine with diesel is used in Test 1 and with mahua is Test 2 then convert the diesel engine to a LHR Engine by coating its piston crown with a 500-micron layer of YSZ by a plasma spray method for Test 3, in Test 4 mahua oil is used with LHR Engine. From the table 1 to 7, Engine parameters, namely Bth η, BSFC, Mech η, vol η, power & emission characteristics were measured. Then include specifications of the coating, specifications of the engine and engine conditions.

Table 1. Specifications of Plasma spray coating.

| Coating parameters | Specifications       |
|--------------------|----------------------|
| Plasma gun         | 3MB plasma spray gun |
| Nozzle             | GH Type nozzle       |
| Pressure of organ gas | 100–120 PSI         |
| Flow rate of organ gas | 80–90 LPM         |
| Pressure of hydrogen gas | 50 PSI               |
| Flow rate of hydrogen gas | 15–18 LPM        |
| Powder feed rate   | 40–45 g per minute  |
| Spraying distance  | 3–4                 |

Table 2. Test Engine specifications.

| Type                  | Specifications                                      |
|-----------------------|-----------------------------------------------------|
| Engine                | Four Stroke, Single Cylinder water-cooled Diesel Engine |
| Rated Speed           | 1500 rpm                                            |
| Bore Diameter         | 87.5 mm                                             |
| Stroke                | 110 mm                                              |
| Compression ratio     | 17.5:1                                              |
| Loading               | Electric loading                                    |
| Orifice Diameter      | 29.6 mm                                             |
| Coefficient of Discharge | 0.6               |

Table 3. Testing Engines and Conditions.

| Testing Engine                  | Condition |
|---------------------------------|-----------|
| Base Line Engine (Diesel)       | Test-1    |
| Base Line Engine (Mahua Biodiesel) | Test-2   |
| LHR Engine With YSZ Coat (diesel) | Test-3 |
| LHR Engine YSZ Coat (MahuaBiodiesel) | Test-4 |

Table 4. Conventional Engine with Diesel.

| Load (kg) | Speed (rpm) | BP (kW) | IP (kW) | FP (kW) | TFC (kg/hr) | SFC (kg/kWh) | BThη (%) | IThη (%) | Mech η (%) | Voη (%) | HBP (%) | HJW (%) | HGas (%) | HRad (%) |
|-----------|-------------|---------|---------|---------|-------------|--------------|----------|----------|------------|---------|---------|---------|---------|----------|
| 1559      | 0.05        | 0.01    | 2.68    | 2.67    | 0.35        | 23.53        | 0.36     | 65.98    | 0.55       | 86.87   | 0.36    | 9.64    | 15.78   | 74.22    |
| 1537      | 4.51        | 1.32    | 3.76    | 2.45    | 0.50        | 0.38         | 22.66    | 64.76    | 35.00      | 86.45   | 22.66   | 18.69   | 17.59   | 41.35    |
| 1520      | 9.11        | 2.63    | 4.89    | 2.26    | 0.75        | 0.28         | 30.19    | 56.07    | 53.84      | 85.58   | 30.19   | 19.36   | 16.54   | 33.90    |
| 1507      | 13.52       | 3.87    | 5.97    | 2.10    | 1.00        | 0.26         | 33.32    | 51.39    | 64.84      | 85.84   | 33.32   | 20.67   | 17.12   | 28.89    |
| 1490      | 17.78       | 5.03    | 6.88    | 1.85    | 1.25        | 0.25         | 34.66    | 47.38    | 73.16      | 85.07   | 34.66   | 21.82   | 20.14   | 23.38    |
show differences of related characteristics. 

rises, hence it cannot consent the heat energy to the coolant and further standard. Then below graphs that, the heat energy available at the exhaust is increased at all loading conditions. It is also observed the reduction in fuel burning and the power output is same to helps increasing the brake thermal efficiency all load periods. Hence, the TBC engine, increasing the vol η of the engine at 28.38%.

Table 5. LHR engine with YSZ coating (diesel)

| Load (kg) | Speed (rpm) | BP (kW) | IP (kW) | FP (kW) | TFC (kg/hr) | SFC (kg/kWh) | BThEff (%) | ITthEff (%) | Mech Eff (%) | VoIeff (%) | HBP (%) | HJW (%) | HGas (%) | HRad (%) |
|----------|-------------|--------|--------|--------|------------|-------------|------------|------------|-------------|------------|---------|--------|---------|---------|
| 1565     | 0.09        | 0.03   | 2.38   | 2.35   | 0.31       | 11.57       | 0.74       | 65.84      | 1.13        | 88.68      | 0.74    | 12.69  | 19.80   | 66.77   |
| 1553     | 4.69        | 1.38   | 3.76   | 2.38   | 0.52       | 0.37        | 22.98      | 62.52      | 36.76       | 88.62      | 22.98   | 13.22  | 18.43   | 45.36   |
| 1526     | 9.03        | 2.62   | 5.16   | 2.54   | 0.72       | 0.28        | 31.08      | 61.19      | 50.80       | 88.11      | 31.08   | 15.29  | 18.50   | 35.13   |
| 1518     | 13.45       | 3.88   | 6.04   | 2.16   | 0.98       | 0.25        | 33.93      | 52.79      | 64.28       | 86.57      | 33.93   | 15.18  | 18.57   | 32.32   |
| 1500     | 17.91       | 5.11   | 7.19   | 2.08   | 1.19       | 0.23        | 36.87      | 51.91      | 71.03       | 85.87      | 36.87   | 16.66  | 20.60   | 25.86   |

Table 6. Conventional Engine with Mahua Biodiesel

| Load (kg) | Speed (rpm) | BP (kW) | IP (kW) | FP (kW) | TFC (kg/hr) | SFC (kg/kWh) | BThEff (%) | ITthEff (%) | Mech Eff (%) | VoIeff (%) | HBP (%) | HJW (%) | HGas (%) | HRad (%) |
|----------|-------------|--------|--------|--------|------------|-------------|------------|------------|-------------|------------|---------|--------|---------|---------|
| 1560     | 0.05        | 0.01   | 2.35   | 2.33   | 0.35       | 23.83       | 0.36       | 57.61      | 0.63        | 88.85      | 0.36    | 1.11   | 19.29   | 79.23   |
| 1540     | 4.79        | 1.40   | 3.75   | 2.35   | 0.56       | 0.40        | 21.89      | 58.60      | 37.35       | 88.29      | 21.89   | 12.03  | 17.54   | 48.55   |
| 1528     | 8.99        | 2.61   | 4.87   | 2.26   | 0.81       | 0.31        | 28.05      | 52.27      | 53.66       | 87.43      | 28.05   | 14.38  | 17.11   | 40.46   |
| 1516     | 13.60       | 3.92   | 6.11   | 2.19   | 1.06       | 0.27        | 32.06      | 49.95      | 64.18       | 86.14      | 32.06   | 16.06  | 17.64   | 34.25   |
| 1496     | 17.92       | 5.09   | 6.99   | 1.90   | 1.36       | 0.27        | 32.42      | 44.50      | 72.86       | 85.50      | 32.42   | 15.84  | 18.01   | 33.72   |

Table 7. LHR engine with YSZ coating (mahua)

| Load (kg) | Speed (rpm) | BP (kW) | IP (kW) | FP (kW) | TFC (kg/hr) | SFC (kg/kWh) | BThEff (%) | ITthEff (%) | Mech Eff (%) | VoIeff (%) | HBP (%) | HJW (%) | HGas (%) | HRad (%) |
|----------|-------------|--------|--------|--------|------------|-------------|------------|------------|-------------|------------|---------|--------|---------|---------|
| 1552     | 0.06        | 0.02   | 2.18   | 2.16   | 0.35       | 19.11       | 0.44       | 52.01      | 0.85        | 88.81      | 0.44    | 7.46   | 18.60   | 73.49   |
| 1540     | 4.45        | 1.30   | 3.62   | 2.32   | 0.66       | 0.51        | 16.75      | 46.56      | 35.97       | 88.40      | 16.75   | 10.89  | 14.66   | 57.70   |
| 1520     | 9.22        | 2.66   | 4.82   | 2.16   | 0.91       | 0.34        | 24.76      | 44.82      | 55.24       | 87.26      | 24.76   | 12.00  | 14.57   | 48.68   |
| 1509     | 13.67       | 3.92   | 5.99   | 2.07   | 1.16       | 0.30        | 28.51      | 43.56      | 65.46       | 86.31      | 28.51   | 12.76  | 15.65   | 43.07   |
| 1492     | 17.95       | 5.09   | 7.14   | 2.05   | 1.52       | 0.30        | 28.38      | 39.80      | 71.30       | 84.89      | 28.38   | 13.00  | 15.80   | 42.83   |

5. Results and Discussions

Investigational result shows that a lack of heat refusal to the chilling medium needed to result in an increase in exhaust energy all load periods. Hence, the TBC engine, increasing the vol η of the engine at dissimilar loadings and speed situations. The parameters from the Graph 1 to 7 have different parameters with corresponding to the tables 1 to 7. The discrepancy in brake thermal efficiency vs brake power. TBC coated engine with Test 3 has higher efficiency than Test 1, Test 2, and Test 4 engines. This is due to the low thermal conductivity of YSZ, in the piston crown the thermal resistance rises, hence it cannot consent the heat energy to the coolant and further standard. Then below graphs show differences of related characteristics.

Graph 1, 2 shows the variation in brake thermal efficiency vs brake power. TBC coated engine with Test 3 has higher efficiency than Test 1, Test 2, Test 4 engines. The maximum brake thermal efficiency obtained for TBC coated engines Test 4 and Test 3 respectively. The Test 4 and Test 3 due to the reduction in fuel burning and the power output is same to helps increasing the brake thermal efficiency. Graph 3. shows the variation in volumetric efficiency of baseline engines and TBC coated engines in Test 3 under different load conditions. Graph 3. shows the comparison of thermal balance sheet is made for the baseline engine and TBC coated engines under different loads. It is also observed that, the heat energy available at the exhaust is increased at all loading conditions.
Graph 1. Difference of Bth η of reference engine & TBC engine under BP

Graph 2. Difference of Brake Sp. Fuel Consumption of reference engine & TBC engine under BP

Graph 3. Difference of Volumetric Efficiency of reference engine & TBC engine under BP
6. Emission Features

The appliance is verified the record of ISO 8178-4 “C1” 8 Methods of trial sequence for off-road automobiles, and its emission features. After the investigational results, the emission of HC, CO and NOX emissions is considered. It is initiate of CO and HC emissions are condensed in Test 3 and Test 4 in TBC engines when related to the reference engine in Test 1 and Test 2. The NOX emissions are increased in Test 3 and Test 4 in the TBC coated engines. Graph 5 shows variations in HC emissions with load and Graph 6 shows CO with load.
Graph 7. Difference of Nitrogen oxide emission of reference engine and TBC engine under changed Loads.

In general NOX level is different straight values with in the temperature of inside the cylinder in engine. NOX emissions higher un base line engine compared to TBC engine. Smoke levels increases by 12% and NOX levels increases by 19% in TBC coated engine. In past investigation explained that LHR engine are generally higher NOX emissions. It is to be higher combustion in temperature and curation of combustion is longer. It was experimentally determined that TBC coated engines Test 3 engine higher in NOX emission at various loads. Graph 7 Variation of Nitrogen oxide emission of baseline engines and TBC engines under different Loads.

7. Scope for Future Work
There is sufficient scope for carrying out further work on the following aspects of other materials with low thermal conductivities and high strength can be tried out as crown materials.
- Endurance Tests on the LHR engine may have to be carried out.
- The effect of varying compression ratios on LHR engine can be studied in detail.
- The naturally aspirated engine can be changed to supercharged engine and its effect on the performance of LHR engine can be studied.
- For controlling NOX in LHR engine, catalytic converters can be designed. For reducing smoke levels in LHR engine with pure diesel operation suitable cyclone separators can be designed.
- The multi insulation LHR engine can be used to study its effects in alcohols. 9. Heat Released Rates can be studied.

8. Conclusion
A conventional single cylinder CI engine with diesel is used in Test 1 and with mahua is Test 2 then convert the diesel engine by using coated piston to an LHR Engine with 500-micron film of YSZ ceramic coating a plasma spray method for Test 3, in Test 4 mahua oil is used with LHR Engine. Engine limits, namely $Bth\,\eta$, BSFC, Mech $\eta$, vol $\eta$, power and emission remained measured to inspect the properties of YSZ, and its performance and emission features of the engine. The succeeding conclusions canister be tired from the investigational outcomes. Brake thermal efficiency is enhanced at all loads in the TBC coated engines in Test3 condition. In Test3 brake thermal efficiency is an extreme increase due to low thermal conductivity of YSZ. TBC coated engines in the Test 3 condition reduce the specific fuel consumption, when compared to the reference engines in Test 1. HC emissions were condensed drastically in the TBC coated engines in Test 3, whereas Carbon monoxide emission is condensed in Test 2, Test 3 and Test 4 conditions separately when compared to the baseline engines in Test 1. Smoke levels increases by 12% and NOX levels increases by 19% in TBC coated engine. Finally, Exhaust gas temperature was enhanced charging conditions within chance to improve the NOX emissions of the ceramic treated engines.
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