International Journal of Automotive and Mechanical Engineering
ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online)
Volume 16, Issue 3 pp. 6889-6905 Sept 2019
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# Comparative Experimental Study of Base Line and Thermal Barrier Coated Four Stroke Four Cylinder Diesel Fueled Engine with Low Heat Rejection

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## ABSTRACT

The depletion of conventional fuel source at a fast rate and increasing of environment pollution motivated extensive research in energy efficient engine design. In the present work, experimental investigations were carried out on a four-stroke four-cylinder diesel-fuelled Base Line Engine (BLE) by conducting a normal load test and measuring the required Brake Thermal Efficiency (BThE) and Specific Fuel Consumption (SFC) in a 100 HP dyno facility. A six-gas Analyser was used for the measurement of Unburnt Hydrocarbons (UBHC), Carbon monoxide (CO), Carbon dioxide ($CO_2$), free Oxygen ($O_2$), Nitrogen oxides ($NO_x$), Sulphur oxides ($SO_x$) and a smoke meter was used to measure smoke opacity. Low Heat Rejection (LHR) engine was realized by coating the crown of the aluminium alloy piston with the most popular Thermal Barrier Coating (TBC) material, namely 8%Yttria Partially Stabilized Zirconia (8YPSZ), after coating qualification on research pistons, specifically fabricated to retain the piston material specification, and the geometry of the crown contour. A normal load test was conducted on LHR engine to evaluate the performance as well as to determine the concentration of pollutants. A ~30% improvement in BThE and ~35% improvement in SFC was exhibited by the LHR engine at all loads studied (7 to 64%). While UBHC level showed an increase, the CO, $CO_2$ and $O_2$ contents as revealed in the emission test showed a mixed response (high and low) for an LHR engine. Compared with BLE, $NO_x$ and smoke level in LHR engine emission showed an increasing trend with the load. On comparing BLE and LHR engine test results, value addition to the BLE in terms of reduced fuel consumption and pollutants was observed.

***Keywords:*** Base line engine; low heat rejection engine; thermal barrier coating; yttria partially stabilized zirconia; diesel engine; piston crown.

## INTRODUCTION

Among internal combustion engines, the diesel engine offers maximum thermal efficiency and life for the engine. Even in a diesel engine, a considerable amount of energy is unutilized which gets dissipated through the cooling and exhaust system. Minimizing the loss of heat energy from the engine will help to increase the efficiency of the engine. Implementing Low Heat Rejection (LHR) engine concept [1, 2, 3, 4] is one method reported to reduce the heat energy loss. The general conceptual idea of LHR in a diesel engine is realised by insulating its combustion chamber with a suitable high-temperature material, like a ceramic. Inside the combustion chamber, the surface coming in contact with the hot gases or flame is covered with the heat-insulating ceramic material to reduce the in-cylinder heat rejection and protect the underlying metal surface (substrate) from thermal fatigue [5].

Though TBC concept existed in aerospace technologies since the late 1940s and started to be applied on aero-engine turbine blades in 1970s [6], the idea of developing an LHR diesel engine began in 1980s [5]. Due to the difference in the operation of the aerospace engine and the diesel engine, many of the coating methods developed for aerospace applications may not be suitable for diesel engines. Although diesel engine TBCs operate at lower temperatures than TBCs used in aircraft, they are subjected to greater compression loads and more frequent thermal shock. In addition, diesel TBCs have to cope with contaminants often found in low-grade fuels [7]. The major breakthrough in the coating of diesel engine technology came through the pioneering work done by Kamo and Bryzik from 1978 to 1989 as the first persons in introducing TBC systems for engines [5]. A large number of research has been carried out on diesel engine with LHR concept using TBC. A few are experimental and many are theoretical studies. In the case of LHR engine, almost all theoretical studies predict improved performance and fuel economy but a few experimental results disagree with it.

In an engine, the application of a thermal barrier coating reduces the heat energy flow to the cooling medium through the surfaces of the combustion chamber (which comprises of the piston crown, cylinder head and cylinder surface/ liner and piston rings) [4]. The ceramic coating will thermally insulate the combustion chamber, influence the process of combustion, which in turn affects the performance of the engine and exhaust emission characteristics. Among the various ceramic materials, Yttria Stabilized Zirconia (YSZ) has got most of the properties suitable to be used as a TBC on a diesel engine and is the most popular till date [8], though researches are progressing to improve the structure of Yttria Stabilized Zirconia by different processes or structure refinement [9, 10, 11] or to find out a better substitute for YSZ [12, 13]. NiAl or MCrAlY (M = Ni, Co etc.) are normally used as the bond coat material and in a diesel engine the components generally being coated with TBCs are piston crown and cylinder head, although coated cylinder liner and exhaust gas manifold also may contribute to the LHR engine performance. However, the maximum contribution to thermal efficiency improvement is from the combustion chamber [14]. In the combustion chamber itself, the maximum heat loss to the cooling system is through the piston [14, 15].

Most of the research work conducted show improvement of thermal efficiencies in the range of 1% to 8%, reduction in the fuel consumption in the range of 1 to 6% and a reduction in exhaust gases like CO and $CO_2$. Some experiments show an increase in Unburnt Hydrocarbons. Increase in the NOx emissions are routinely reported, although with a change in injection timings, researchers have achieved a reduction in NOx production up to 11% [16, 17]. The current trend in LHR engine research involves low-temperature combustion to [18] reduce in $NO_x$ and soot, although many undesirable effects including the increase in the concentration of UBHC and CO followed by poor combustion is reported to be involved. In other experimental work conducted by coating the piston crown surface with YPSZ materials showed a remarkable reduction in the heat loss to the cooling system and fuel consumption [19]. Research conducted on diesel engine with different coating materials and coating thicknesses also revealed [20] improvement in performance and a reduction in the harmful gases except for NOx.

Research conducted on LHR engine using biodiesel [21, 22, 23, 24, 25] shows a very promising future in the field of better efficiency, lower fuel consumption and reduction of a number of harmful pollutants. Thermal analysis of ceramic-coated aluminium alloy piston using finite element method [26] shows an increased surface temperature on the crown surface which will aid the improvement in efficiency and a reduction in temperature on the substrate material which will help to improve the fatigue life. A theoretical study conducted on the effects of thermal barrier coating on diesel engine combustion and emission characteristics [27] showed improvements in the performance of the diesel engine.

## METHODOLOGY

The present investigative efforts involve the realisation of LHR engine by employing 8YPSZ plasma spray coated piston of a base line engine (BLE). Comparative experimental investigations were carried out on a four-stroke four-cylinder diesel-fueled BLE and LHR engine (piston coated with TBC).

While ceramic coatings are well known and viable means towards realizing LHR engines, it is extremely important to have coated components with coatings that do not spall in the environmental conditions of the engine. To address this issue, a research piston was fabricated simulating the intricate contour of the piston and were plasma spray-coated with 8YPSZ ceramic. Coatings characterisations and developmental steps involved thermal shock and thermal barrier tests and the piston coating parameters were established based on these findings [28, 29].

The BLE with standard uncoated pistons was run for 700 hours for testing and recording of the data. After the BLE testing, the coated pistons were introduced in the engine to realize the LHR engine. LHR engine was tested for 300 hours. The results are compared and presented. The focus of the present work is on the investigation of the effect of a Thermal Barrier Coating (TBC) on thermal efficiency, fuel consumption and emission measurements of unburnt hydrocarbons (UBHC), carbon monoxide (CO), carbon dioxide ($CO_2$), free oxygen ($O_2$), nitrogen oxides (NOx) and smoke density in the exhaust gas. Since the quantity of sulphur oxides ($SO_x$) produced is negligible, it is not considered in this investigation. Technical specification of the BLE used in this research work is given in Table 1.

Table 1. Technical specification of 65 HP class BLE.

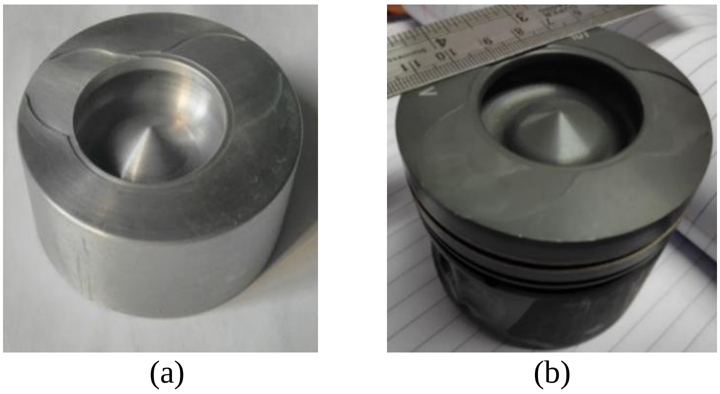
| Engine Type | 4-cylinder inline diesel engine, Turbo charged |
|---|---|
| Fuel Type | Diesel |
| Bore | 76 mm |
| Stroke | 80.5 mm |
| Compression Ratio | 17.9:1 |
| Connecting rod length | 135 mm |
| Cylinders | 4, Inline |

### Coating Qualification on Research Piston

*Research piston*

The ceramic coatings were qualified for its performance (coating thickness, adhesion when subjected to thermal shock tests, thermal barrier effects) by testing the coatings after plasma spraying 8YPSZ on a research piston. The research piston was specially fabricated via casting Aluminium-silicon alloy (Al – 12% Si) and machining, to replicate the composition and contour geometry of the standard piston crown of the diesel engine

(BLE). The photographs of (a) the research piston specifically fabricated for this work and (b) the crown of the original piston is shown in Figure 1.



(a) (b)

Figure 1. Uncoated (a) research piston and; (b) diesel engine piston.

*Coating*

Deposition of a ceramic coating uniformly on the crown surface of a piston with complex contour is a challenging task. This is because the thermal characteristics of metals and ceramics are significantly different from each other: which affects the coating properties during the heating and cooling experienced by the Al piston and 8YPSZ coating. The higher thermal expansion coefficient of the metal substrate allows larger expansion during plasma coating thereby inducing the less expanding ceramic material under stresses. To alleviate the thermal expansion mismatch, the grit blasted and degreased research piston crown surface was coated with a bond coat (intermetallic compound NiAl of ~ 50 µm thicknesses) and the ceramic overlay (top coat) was deposited over the bond coat. In order to assess the coating characteristics (thermal barrier effect, durability at service temperature etc.) different top coat thicknesses of 150 µm, 250 µm and 350 µm were deposited on the crown face via Air Plasma Spray (APS). Photograph of a few typical coated research pistons is shown in Figure 2.

Figure 2. Thermal barrier coated research pistons.

*Coating characterisation*

Coating qualification of the coated pistons was done using thermal barrier and thermal shock tests, simulated in the laboratory by employing oxy-acetylene flame. Coating durability was studied via thermal shock cycling the coating through 550 °C (flame temperature) and ambient, several times. The number of times the ceramic coating successfully endured the 1-minute heat and 1-minute cool cycle was termed as number of thermal shock cycles endured before failure. While both: the 150 and 250µm thick coating successfully withstood 200 thermal shock cycles, the 350 µm thick-coated research piston did not survive the test.

Cross-section metallography performed on the as-spray coated and thermal shock cycled research pistons (150 and 250µm thick coating) revealed the coating integrity especially at the piston crown area. Details are not within the scope of this paper [28, 29]. Coatings with higher thicknesses introduce a stronger thermal barrier effect than those with lower thicknesses: hence a 250µm thick coating was used to coat the actual diesel engine piston for further evaluation of the LHR concept.

### *Coatings on engine piston*

4 numbers of diesel engine pistons were plasma spray-coated with 50 µm bond coat of nickel aluminide (NiAl) and 250 µm top coat of 8YPSZ. One among the 4 spray coated diesel engine pistons is shown in Figure 3. Partially completed assembly of the coated piston to realise LHR engine is shown in Figure 4.

Figure 3. Coated diesel engine piston.

Figure 4. Assembly of the coated piston in the diesel engine (partly completed).

## Engine Performance Evaluation

A schematic of the diesel engine R&D test facility is shown in Figure 5. The dynamometer used is of eddy current type and has a loading capacity of 100 HP and is along with dyno controller. A Personal Computer (PC) based Data Acquisition System (DAS) and a software computes the performance parameters and give plots. Upstream injection pressure, as well as combustion chamber pressure, are measured. A water-cooled high-frequency response type (20 kHz) strain gauge is used for combustion chamber pressure measurements. A six gas exhaust gas analyser is used to find out the emissions of various exhaust gases such as UBHC, CO, $CO_2$, $O_2$, $NO_X$ and $SO_X$ in mole fraction units. The Smoke meter used is of optical type and it is used to find out the smoke density of exhaust in Hartridge Smoke Units (HSU) and light absorption coefficient units (K/m). The calibration of the instruments was done by the manufacturer. A fourteen channel Instrumentation is used, and the details are given in Table 2.

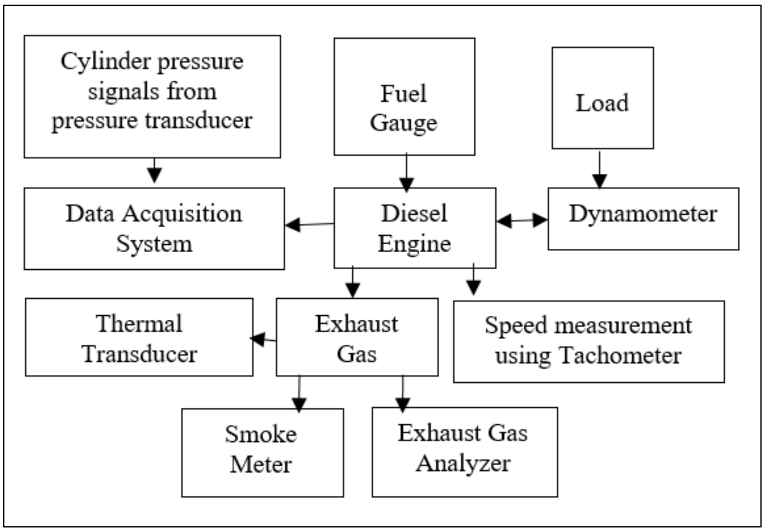


Figure 5. Schematic of engine R&D test facility.

Table 2. Fourteen channel instrumentation details.

| Channel | Parameter | Accuracy |
|---|---|---|
| 01 | Water flow rate to calorimeter | ± 2% |
| 02 | Water flow rate to engine - Accuracy | ± 2% |
| 03 | Ambient Temperature - Accuracy | ± 1% |
| 04 | Exhausts Temperature | ± 1% |
| 05 | Combustion chamber pressure sensor | ±2% |
| 06 | Injection pressure sensor | ±2% |
| 07 | Water inlet Temperature of engine | ±1% |
| 08 | Water outlet Temperature of engine | ± 1% |
| 09 | Water inlet Temperature of calorimeter | ± 1% |
| 10 | Water outlet Temperature of calorimeter | ± 1% |
| 11 | Engine load/Torque sensor | ± 2% |
| 12 | Airflow rate sensor | ± 4% |
| 13 | Engine speed sensor | ± 1% |
| 14 | Fuel flow meter | ±2% |

The engine tests were carried out in an Eddy Current dynamometer test facility for 100 hp class diesel engine equipped with 6 gas Analyser and smoke meter at a constant speed of 2000 rpm and the percentage load varying from 7% to 64%. Details of engine testing are reported elsewhere [30].

## RESULTS AND DISCUSSION

The results on the performance evaluation of the BLE and LHR engine are given in terms of the following. (1) brake thermal efficiency (BThE) (2) brake specific fuel consumption (BSFC) and (3) emissions. The engine was tested between 7% and 64% loading for both: the BLE and LHR engine.

### Brake Thermal Efficiency (BThE)

Thermal efficiency measures the conversion efficiency of chemical energy in the fuel into useful work in the engine. The thermal efficiency of the engine can be improved by reduction of in-cylinder heat transfer and this is a key objective of engine research. Variation of brake thermal efficiency (BThE) with % load (7% load up to 64%) for the BLE and LHR engine is shown in Figure 6. Under the same operating conditions, the BThE of the engine with coated piston (LHR) was found to be higher than that of the BLE: the actual values however increased between a minimum of (+ 3%) and maximum of (~ +32%) between 7% and 58% load from those obtained for BLE values. The BThE values converged at higher than 58% load leading to no variation at 64% load. The salient aspect of this finding is that under no loading condition in the range studied here (7 – 64%), the BThE value for LHR engine fell below that of BLE.

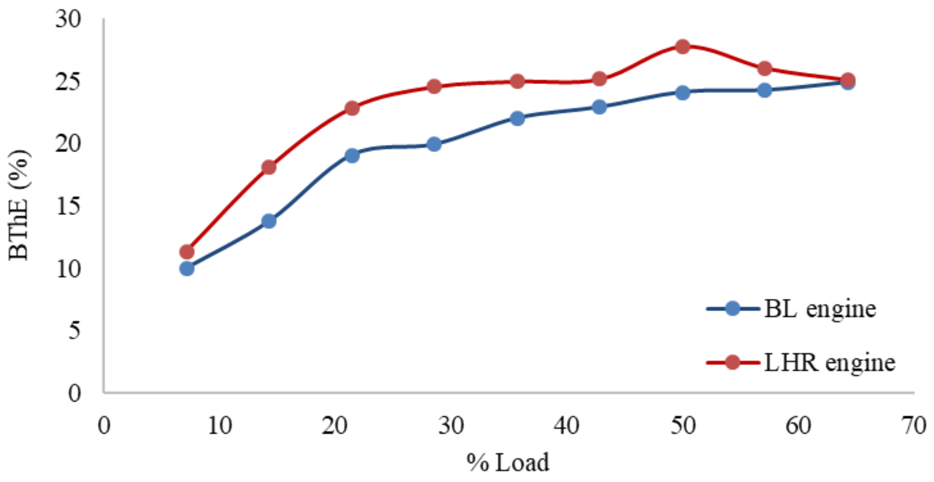


Figure 6. BThE variation with respect to percentage of load.

### Brake Specific Fuel Consumption (BSFC)

The specific fuel consumption patterns of both: BLE and LHR engine are shown in Figure 7. Contrary to the results found in BThE, fuel consumption pattern for LHR engine was found to be of mixed nature. The BSFC of the LHR engine was found to be higher (up to 220%) than the BLE at loads lower than ~ 43% and favourably lower (up to 35%) at loads above 43% (cross-over of the two patterns where values of BSFC for both the engines were identical). The mixed nature of fuel consumption may be attributed to the higher temperature and pressure existing inside the LHR engine at higher loads which leads to improved combustion within the combustion chamber. At higher loads, BSFC of the LHR engine decreased, reducing the fuel consumption, and thereby realizing the LHR concept.

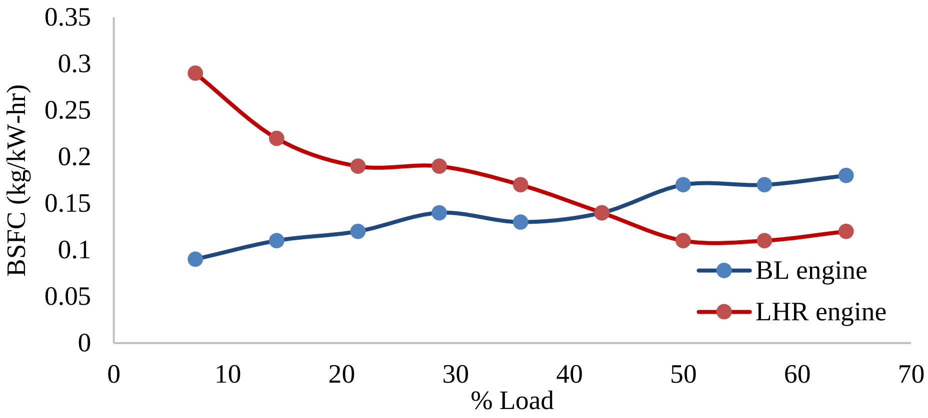


Figure 7. BSFC variation with respect to the percentage of load.

## Emission Characteristics

### *Unburnt hydrocarbon (UBHC)*

The UBHC emission patterns of both: BLE and LHR engine are shown in Figure 8. In an LHR engine, the emission of Unburnt Hydrocarbon (UBHC) is likely to be reduced at medium loads due to reduced quenching distance of the flame and the increased limit of lean flammability. The results of UBHC emission pattern of LHR engine exhibited a pattern somewhat similar to the BSFC pattern, that is mixed results were observed. Although high UBHC emission (up to 250% increase than BLE) was recorded by LHR engine at low loading condition (7% to 20%), both the BLE and LHR patterns were similar to each other at medium and higher loading conditions (20-64% load range). The benefits of the introduction of coating (LHR engine) could only be realized to higher loads. This result is corroborated through the findings reported as well [4].

The high values of UHBC emission at the lower loads (~10%) maybe because the gases inside the combustion chamber of LHR engine may not have the sufficiently high temperature to help the oxidation reactions move close to completion stage. Thus, as expected, increased levels of UBHC emissions were observed at lower loading conditions. Further, the porous nature of the coatings is believed to entrap the fuel thereby not allowing its complete combustion at lower load (lower temperature). At high loading conditions, high wall temperature is believed to promote the complete combustion of fuel but associated with this may be the decomposition of the lubricating oil (different combustion characteristics than diesel) that may have been present inside the combustion chamber. This may be the other reason for increased UBHC level at higher loads. The present investigation shows that in an LHR engine, UBHC level is higher at lower loads (up to 20%), reduces when load increases (between 20 and ~40%) and slightly increases at further higher loads (between 40 and 64%). Thus, in general, UBHC levels are high at low loads in case of LHR engine and low at higher loads.

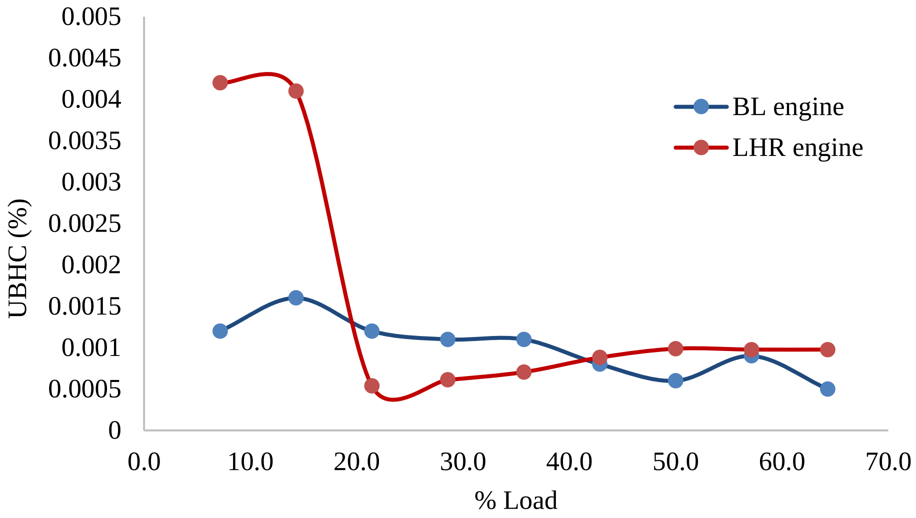


Figure 8. UBHC variation with respect to the percentage of load.

*Carbon monoxide (CO)*

The Carbon Monoxide (CO) emissions patterns of both: BL and LHR engine are shown in Figure 9. The results are depicted in terms of Concentration of CO in exhaust gas with respect to % load. The patterns of BLE and LHR engine exhibit a similarity: CO emissions are high at low loads (~10%) and drops as the load increases (up to 64%). Regardless of the individual values, it may be precise to record that both BLE and LHR engine emit similar CO values at medium and higher loads (~20 – 64%). The lower amount of CO at lower loads could be due to shorter delay period after injection and better combustion at diffusion stage. At higher loads, the improved temperature and pressure will reduce the ignition delay and will promote smooth combustion reducing the formation of CO.

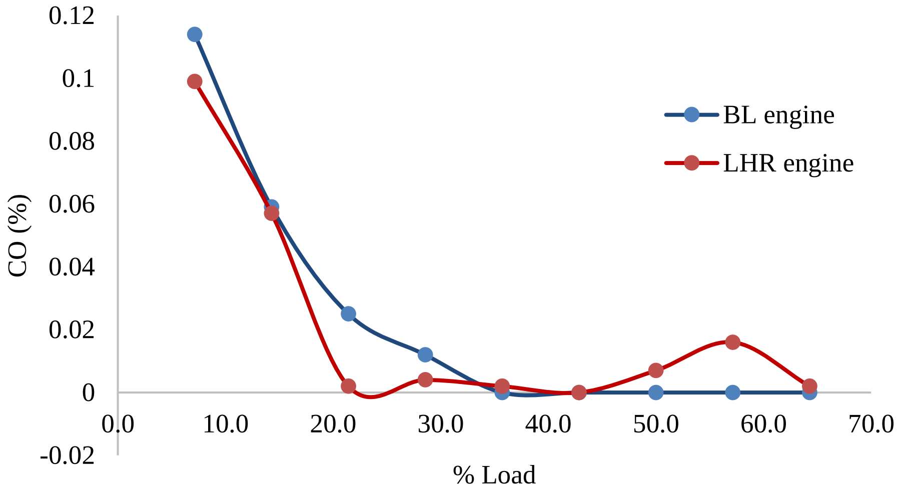


Figure 9. Percentage of CO variation with respect to the percentage of load.

Theoretically, the engines produce less CO, for similar reasons of UBHC production (improved combustion). Many investigations also show a reduction in the level of CO emissions in an LHR engine [19, 20]. This attributed to the higher temperature of the gas inside the cylinder and higher cylinder wall temperature which will support combustion.

### *Carbon dioxide ($CO_2$)*

The carbon dioxide ($CO_2$) emissions patterns of both: BL and LHR engine are shown in Figure 10. The patterns showed a trend similar to that shown by CO versus % Load (Figure 9): that is: both the engines behaved in a similar manner. The $CO_2$ emission was lower at lower loads and increased gradually with the load. In both the engines the $CO_2$ level is increased on increasing load due to the conversion of more CO into $CO_2$ and this is matching with the literature [19]. It is expected [31] that LHR engines would produce less $CO_2$ than standard engines due to the high temperature experienced by the gas within the chamber and the chamber wall. This aspect is observed to some extent in the patterns. The $CO_2$ emission of LHR engine is lower (0 % to 35%) than the BL engine (Figure 10) although no significant improvement may be assigned to LHR engine based on this result alone. The reduction may be due to enhanced soot oxidation by high combustion temperature inside the LHR engine cylinder.

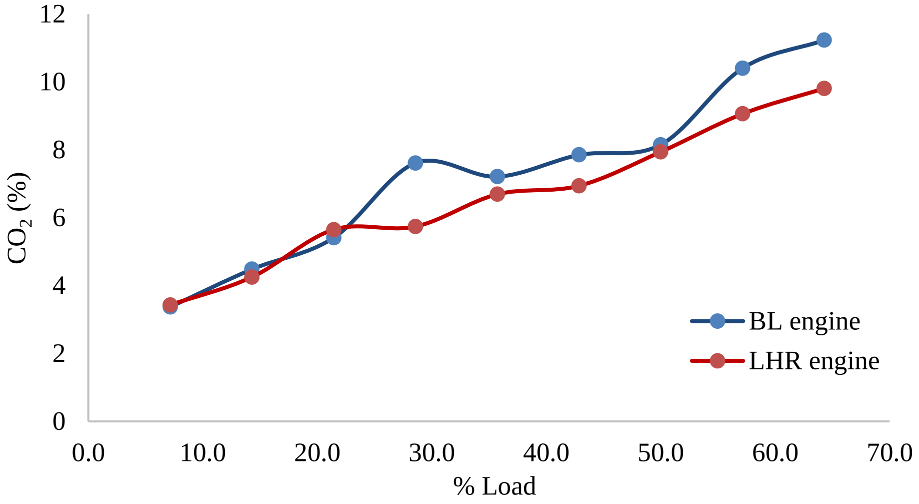


Figure 10. Percentage of $CO_2$ variation with respect to the percentage of load.

### *Oxygen ($O_2$)*

The findings of CO and $CO_2$ emissions (Figure 9 and Figure 10 respectively) is further verified by Analysing the $O_2$ vs. load pattern which is shown in Figure 11. The pattern shows the presence of higher un-reacted oxygen at the exhaust at lower loads. This is expected because the combustion chamber temperatures are low at lower loads and are not consumed for $CO_2$ production. CO level is higher at low loads in both the engines because of low temperatures present in the combustion chamber resulting in the incomplete conversion of CO into $CO_2$.

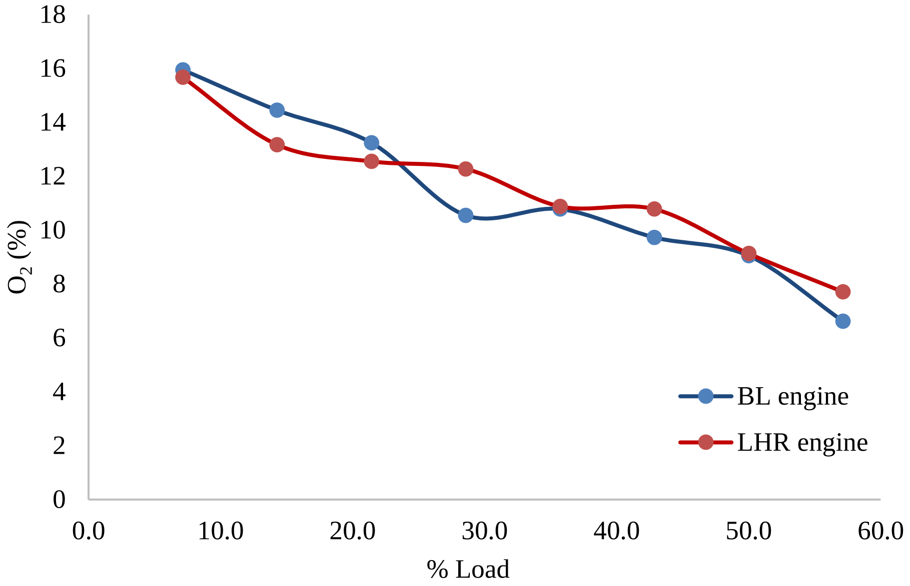


Figure 11. Percentage of $O_2$ variation with respect to the percentage of load.

*Nitrogen oxides ($NO_x$)*

The Nitrogen Oxide ($NO_x$) emissions patterns of both: BL and LHR engine are shown in Figure 12. Formation of NOx is by the chain reactions of nitrogen and oxygen present in the air in the combustion chamber. These reactions mainly depend on the temperature inside the chamber. Diesel engines are designed to operate with excess air and generation of $NO_X$ is mainly a function of gas temperature and residence time of the reactants. Higher combustion temperature and longer duration of combustion will promote reactions between nitrogen and oxygen. Earlier investigations indicate that NOx emission from an LHR engine is generally higher than that in conventional water-cooled diesel engine [4]. A few investigations attribute the increase of NOx emissions in the LHR engine to the diffusion burning which acts as the controlling factor for the production of NOx. Some investigations report a declining trend in the level of NOx emission in an LHR engine. This is due to the reduction in the ignition delay which will decrease the proportion of the premixed combustion. The present investigations show that in the LHR engine, NOx level at different loads is more when compared to BL engine. The results are similar to what has been reported extensively [19, 20] [31].

## Smoke Meter Reading

Figure 13 shows the hartridge smoke unit (HSU) with load for both BL and LHR engine. It can be seen that in an LHR engine, HSU is higher compared to an uncoated engine and nearly constant irrespective of the load. This may be associated with the porous nature of the coating and the decomposition of lubricating oil at higher temperature prevailing inside an LHR engine. In a BL engine at lower loads, the smoke density is less but increases rapidly with the load. This may be due to the degradation of lubricating oil at the higher temperature. The smoke level of BLE engine shows an increasing trend (compared with LHR engine) with an increase in loading conditions (beyond 64% in this experiment). The increasing smoke density obtained for the coated piston engine is supported by the literature [20].

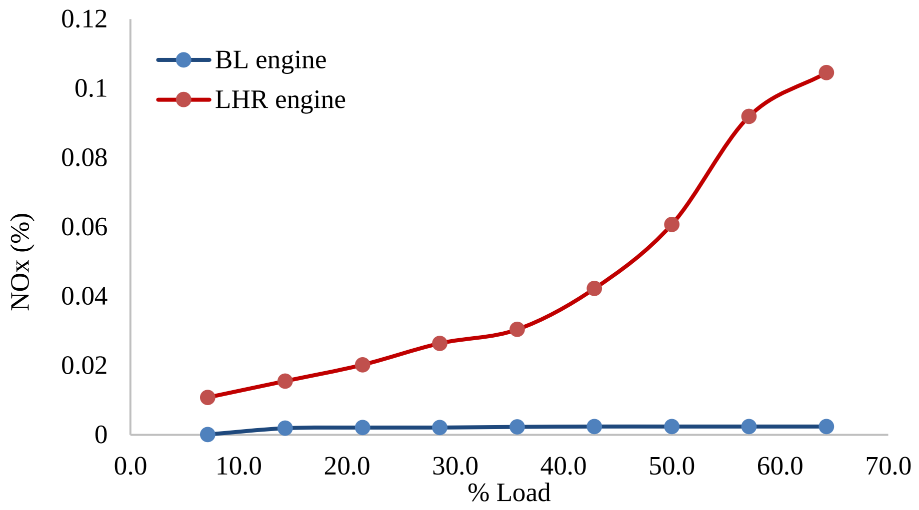


Figure 12. Percentage of NOx variation with respect to the percentage of load.

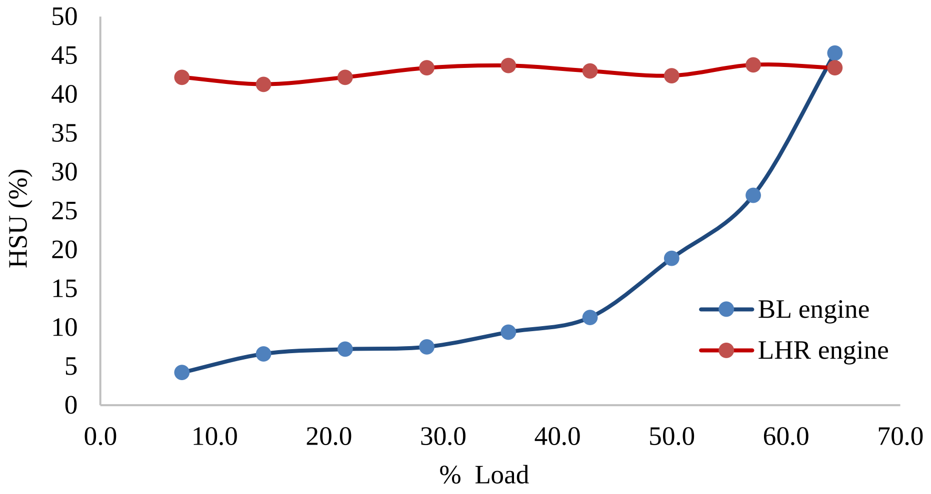


Figure 13. Percentage of HSU variation with respect to the percentage of load.

## Peak Cylinder Pressure

The combustion within the chamber may be improved with an increase in the peak pressure characteristics. In addition to the increase in the temperature, yet another result expected by coating the piston crown by the ceramic material is the increase in the pressure inside the combustion chamber. A higher pressure will result in a better expansion and generation of more power by the pistons. This aspect has been brought out in the pressure indicator diagrams plotted for the two engines (BL and LHR). The comparison of pressure developments within the combustion chambers in the BLE and LHR engine studied in this work, at different percentage of loads. The variation of pressure with respect to crank angle for a BLE is given in Figure 14 and for an LHR engine is given in Figure 15. Both Figure 14 and 15 show the pressure development inside the engine cylinder, typically at 2000 rpm and at varying load conditions from 0° to 720° crank angle.

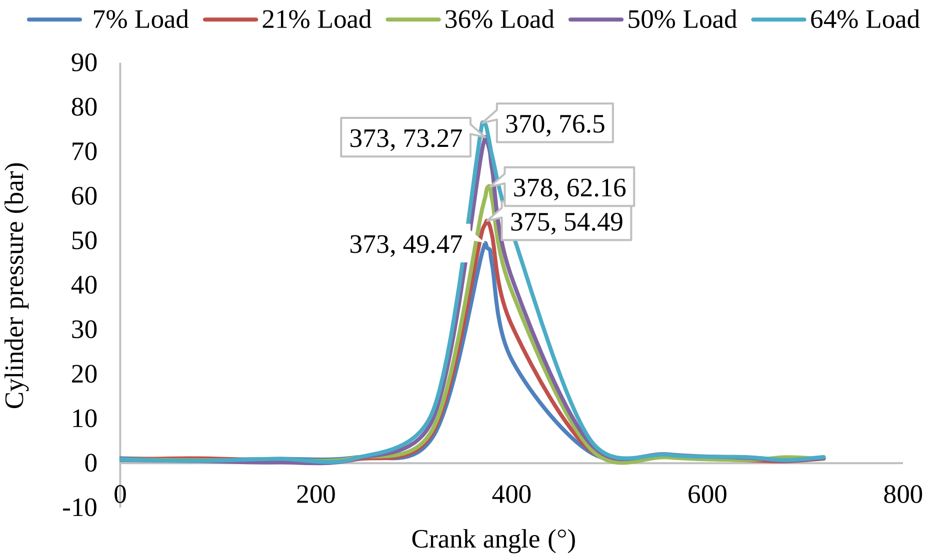


Figure 14. Variation of cylinder pressure with respect to crank angle, BL engine.

It can be seen that for both BLE and LHR engine, the peak pressure increases as load increases and also the peak pressure is reached just after the Top Dead Centre (TDC), which is one important indication of a healthy diesel engine. Moreover, it can be seen that in an LHR engine, the peak pressure is reached at a lower crank angle compared to a BLE, This shows the reduction in delay period which is one of the expected results of LHR concept. This finding is explained further. In both sets of figure (14 for BLE and 15 for LHR engine), diagrams for all the loads (7 to 64%) under study has been shown. The two numbers depicted at the top of the indicator diagram are the (i) crank angle at which the peak pressure is developed and the (ii) value of the peak pressure in bar. Analysing the diagrams further, it is seen that the crank angle at which the peak pressure is developed in the BL is 370 with a peak pressure value of 76.5 bar for maximum (64%) load. The values obtained under the same loading condition in the LHR engine correspond to 369° and 84.21 bar respectively. Comparing the two results, the peak pressure developed for the LHR engine is at a lower crank angle showing lower ignition delay than the BL engine. This favorable result is typically expected from a LHR engine that contributes toward a smoother combustion. Fairly similar results have been obtained for all the pressure indicator diagrams for the different loads.

The pressure indicator diagram covers compression of air, fuel injection, ignition, combustion of the mixture and expansion of the charge. In an LHR engine, the higher temperature aids ignitability of the fuel-air mixture, reduction of ignition delay which helps to release more heat before the pistons reach TDC of the cylinders. The combined effects of the continuation of compression and the enhanced heat availability due to improved thermal insulation of the piston enable to achieve a higher peak pressure in the LHR engine. As the ignition is advanced in an LHR engine, effectively there is an increase in the expansion stroke to produce the positive work.

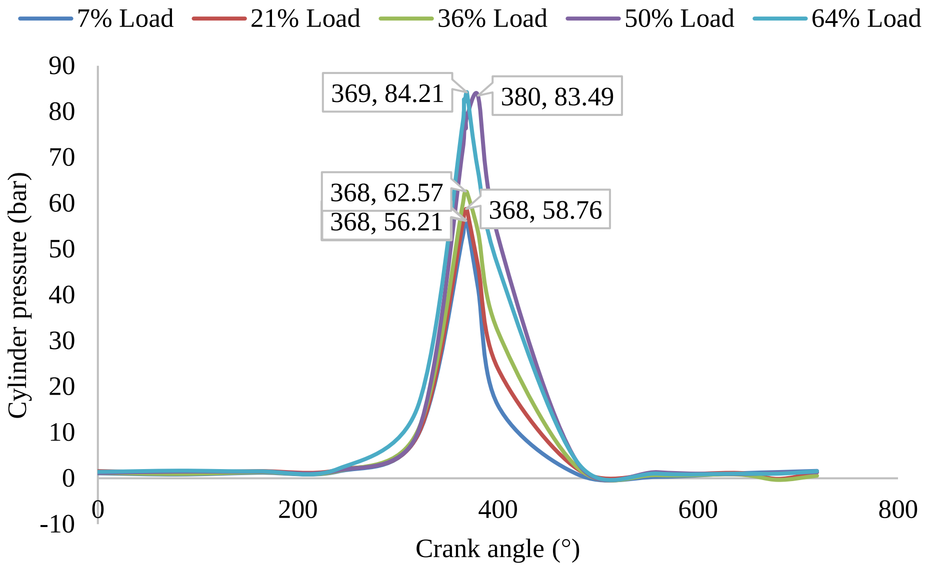


Figure 15. Variation of cylinder pressure with respect to crank angle, LHR engine.

*Comparison of peak pressure in BLE and LHR engine*

Comparison of peak pressure developed vs. crank angle at two representative loads is shown in Figure 16 and Figure 17. Figure 16 shows the pressure variation for 7% load and Figure 17 shows for 64% load. The graph shows that at all loads a higher peak pressure is produced in an LHR engine. Higher pressure was produced by the higher temperature inside the chamber due to lesser heat transfer to the cooling media. Moreover it was observed that in a coated piston engine, the peak pressure was attained at a crank angle lesser than the uncoated engine. Overall, there is an increase in pressure in case of LHR engine. Since the walls of engines are very thick, it makes no adverse effect on engine life or performance.

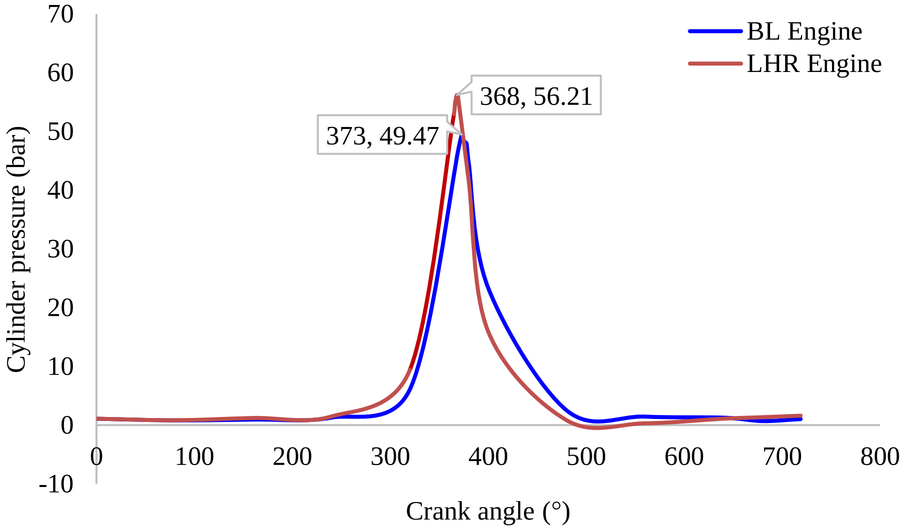


Figure 16. Comparison of cylinder peak pressure vs. crank angle at 7% load.

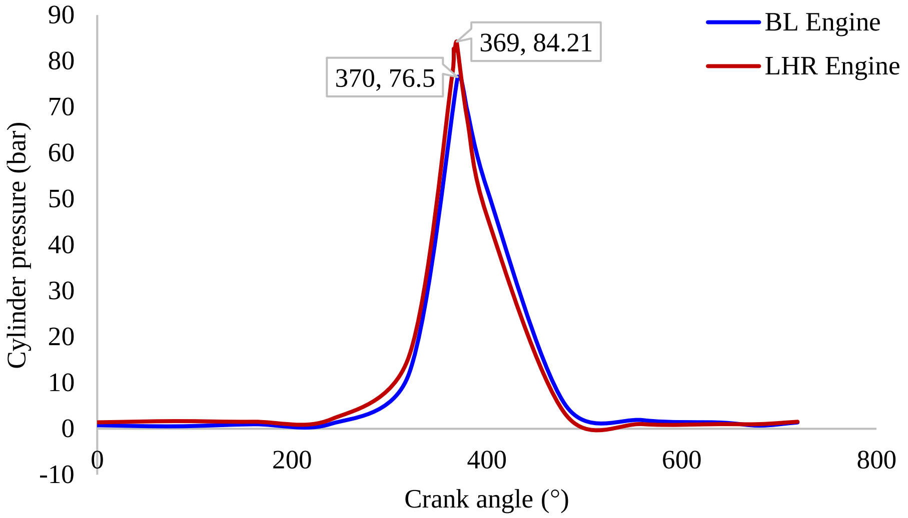


Figure 17. Comparison of cylinder peak pressure vs. crank angle at 64% load.

## CONCLUSION

A 250 µm thick 8% yttria partially stabilized zirconia (8YPSZ), plasma sprayed coating on 50 µm thick NiAl bond coat was applied on (a) Al-Si alloy-based research piston for coating qualification and thereafter on actual pistons pertaining to 4 stroke 4 cylinder diesel engine. The methodology used to coat and develop sound thermal barrier coatings on research pistons was atmospheric plasma spray technique. Extensive developmental efforts were made to plasma spray coat the specially fabricated research piston with complex contours which included a thermal barrier and thermal shock tests. The same spray conditions were employed to coat the actual engine pistons (4 numbers). Experimental results pertaining to thermal barrier coating qualification, performance and emission characteristics of base line engine (BLE) and ceramic coated low heat rejection (LHR) engine (tested at 7 to 64% full load) are compared and presented. Following salient features have been observed.

i. The LHR engine offers value addition to the engine in terms of higher brake thermal efficiency, lower SFC and pollutants with a mixed response when compared with its Base Line engine counterpart.
ii. The favourable results of the LHR engine are accompanied by an increase in the cylinder pressure, which is marginal (7-8 bar in the test range of load) and can be handled by the combustion chamber.
iii. The favourable results obtained as the above were however marred by the increase in NOx levels increase in case of LHR engine. These results were as expected and most likely may be resolved by advancing the injection timing.
iv. Smoke levels in LHR engine were higher in range when compared with BLE although were consistent in its level. A varying pattern was observed in the case of BLE, and the smoke level tended to increase towards and likely beyond the smoke levels of LHR engine.
v. There is a potential for further improvement in performance by coating engine cylinder head, piston and cylinder and exhaust gas manifold and this paves way for future work to realise fully the LHR engine potential.

## ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial and administrative support received from the CHRIST (Deemed to be University) Management and the permission given to publish this paper, and the technical help provided by colleagues in preparing the manuscript.

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