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Research Article

Performance Evaluation of a Ceramic Coated with Air Insulated Four Stroke Diesel Engine

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Abstract

The petroleum crisis of recent years has stimulated a worldwide search for alternate fuels and also emphasized the need for using petroleum fuels with utmost economy. Extensive research is going on in the area of improvement of the engine thermal efficiency. Even the most efficient diesel engine rejects two-thirds of the heat energy of the fuel, one-third to the coolant, and another one–third to the exhaust, converting only about one-third into useful work. By reducing the lost energy and eliminating the need for a conventional cooling system, this engine system will dramatically improve overall performance. One of the methods adopted to achieve this is by going for an adiabatic engine. In an adiabatic engine, the energy loss is avoided by applying a layer of insulating material over the walls of the combustion chamber and by providing air gap insulation. For mainly improving performance of an engine, thermally insulated components may be used. They not only reduce in-cylinder heat transfer but improve thermal efficiency.. Some studies show an improvement in fuel economy while the most of which predicted worse fuel consumption using insulation. Therefore, little progress has been made in explaining the conflicting results and in determining the physical explanation behind the experimented data. At present the concept of low heat rejection engine (LHR) is being attempted by many researchers in India and abroad with a view to develop an efficient one by solving common problems associated with such engines. Initially modifications are carried out by employing PSZ coated cylinder head, valves and air-gap liner on the engine. Then different levels of insulation are applied by changing different pistons. During experimentation four different levels of insulations are tried on the test engine with an objective to find the best one in terms of performance, emissions and other combustion parameters. In all these LHR configurations Diesel is used to find out performance, emissions and combustion characteristics. Out of all LHR configurations tested, one of them (Brass Crown Aluminium Piston with Air gap, an Air gap liner and PSZ coated head and valves) is found to be best in terms of brake thermal efficiency and emissions. All the above investigations are fruitful and these results are expected to lead to a substantial contribution to the development of a Limited cooled engine.

Keywords: *Low heat rejection, PSZ.*

1. Introduction

In an internal combustion engine, approximately one-third of the total fuel input energy is converted to useful work. Since the working gas in a practical engine cycle is not exhausted at ambient temperature, a major part of the energy is lost with the exhaust gases. In addition, another major part of the energy input is rejected in the form of heat via the cooling system. At elevated temperatures, the strength of conventional material drops, creep and fatigue becomes more pronounced and surface burning may result. The performance of mineral lubricants deteriorates at high temperature and carbonization may result. Performance of lubricating oil plays an important role in determining the amount of power output and the improvement in the performance of engine. If the engine can be insulated extra energy will be available at the exhaust. It may then be possible to recover some of this exhaust energy through a compounding system, and redirect it to the engine crankshaft

2. Concept of the Adiabatic Engine

Thermodynamically the adiabatic process is defined as a no heat loss process, hence, the name adiabatic Engine implies a no-heat loss Engine. The insulated high temperature components include piston, cylinder head, valves and cylinder liner. Adiabatic Engine, Semi-adiabatic Engine, un cooled Engine. Limited cooled engine, low heat rejection Engine and differentially cooled Engine are the terms being applied today to the heat insulated Engine. When the combustion chamber of a diesel Engine is insulated by using high temperature

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materials to allow hot operation with minimum heat transfer, only about one – third of the heat saved is given out as useful power output and the remaining part goes out as exhaust heat. Hence the exhaust energy is increased in the case of adiabatic engine compared to that of the conventional engine. Therefore, more technical innovations must be developed to extract useful energy from the exhaust and to derive the maximum benefits from this adiabatic engine concept. Additional power and improved efficiency derived from an adiabatic engine are possible because thermal energy, normally lost to the cooling water and exhaust gas, is converted into useful power through the use of turbo machinery and high temperature with standing materials.

3. Concept Review

The available research results on low heat studies are quite comprehensive. As might be expected innovative nature of this research area creates disagreements among researchers. Research studies are directed at many phases in low heat rejection (LHR) engine development including, but not limited to, heat transfer models, finite element analysis of the components, and optimization of exhaust heat utilization systems.

Brandish, Myers and Uyehara have reported an interesting investigation on the effect of deposit properties on volumetric efficiency, heat transfer and pre-ignition in internal combustion engines, which perhaps was the first attempt towards the development of an adiabatic engine. Moreover Kirloskar also attempted for development of an adiabatic engine before 25 years.

The experimental results of Domingo et al.indicate that the higher temperatures of the insulated engine cause reduction in the cylinder heat rejection which is in accordance with the conventional knowledge of convective heat transfer.

Mirari et.al.in a recent experimental work on a single cylinder DI diesel engine, report a 7% improvement in BSFC for a naturally aspirated engine with selected insulation in the combustion chamber. They attribute the measured improvement in fuel economy over a metallic engine to better combustion and not a reduction in heat losses.

4. Fabrication of Insulated Components

A detailed study was carried out as a preliminary to the design of the insulated components. The insulated engine components which include piston, liner, cylinder head and valves are fabricated to constitute the combustion chamber of the low heat rejection engine. There are three major concepts that have been adopted for an adiabatic diesel engine to reduce the heat loss.

4.1. Piston Insulation

The aim of insulating the piston was to reduce the rate of heat transfer from the crown to the skirt and the maximum possible area of the crown had to be insulated to achieve this goal. In this design, air with its low thermal conductivity was used as the insulating medium. An air-gap was provided between a metallic crown and the standard piston made of aluminium alloy. The two pieces were separated by gaskets of suitable materials and fastened.

In the first instance, an aluminium crown was fitted on aluminium piston with 2.0 mm air-gap, in order to investigate the effect of air-gap alone. The total height of the standard aluminium piston was reduced by 9.0mm at the top by machining. An aluminium crown of 7.0 mm thickness was turned out of aluminium alloy rod of 85 mm to the shape of the standard piston crown. The hemispherical shape was turned using concave and convex turning tool. A thickness of 5mm was maintained on the flange and bowl area of the crown. The recess for valve clearance was provided by end milling. The aluminium crown was separated by gaskets made of copper and stainless steel from the aluminium body. The stainless steel gasket is introduced to minimize the heat loss through gasket.

During the later part of the work it was decided to study the performance of the engine with a piston insulated with an air-gap and a crown made of a material of high thermal conductivity and low specific heat. Such a design would increase the rate of heat transfer from the hot combustion gases to the crown during the expansion stroke and from the crown to the fresh charge during the suction and compression strokes of the next cycle. The crown thus had to act as a reservoir of heat. Brass, with its high thermal conductivity was the material suitable to meet the above demand.

4.2 Cylinder Liner Insulation

In this case air with its low thermal conductivity was used as the insulating medium. A thin mild steel sleeve was circumscribed over the cast iron liner maintaining a 2mm layer of air in the annular space between the liner and the sleeve. The joints of the sleeve were sealed to prevent seepage of cooling water into the air-gap region. Fig 2 shows the constructional details of the air gap liner. Insulation of the liner brought about considerable reduction in the heat lost to the cooling water and an increase in overall thermal efficiency of the engine.

4.3 Cylinder Head Insulation

Ceramic coating is a simpler method of insulation for cylinder head compared with other methods. The head was insulated by coating the area exposed to the combustion chamber with PSZ. The combustion chamber area f the cylinder head was machined to a depth of 0.5 mm. The surface was then sand blasted to form innumerable pores for ceramic deposition.

4.5 Insulation of Valves

The bottom surfaces of the valves were machined to a depth of 0.5mm and coated with PSZ material of equal thickness. With the valves assembled on the cylinder head the area of the combustion chamber was about 90-92% of the total area.

5. Experimental Investigations

Experiments were conducted on the standard engine with diesel in various combinations of insulated parts. The standard engine was tested at the recommended injection timing of 27^0 b TDC at various loads. The engine was operated under no load for the first 20 minutes and for each load the engine was operated long enough to stabilize the condition. All the tests were conducted at the rated speed of 1500 rpm.

During experimentation four different levels of insulations are tried on the test engine with an objective to find the best one in terms of performance, emissions and other combustion parameters. After a thorough review of literature, these different levels of insulation are chosen. The Aluminium piston engine is chosen as a base engine. Also, there is no insulation over the piston. As an initial modification to this engine, PSZ coated cylinder head and liner is fitted. Then different insulation levels are tried by changing different pistons. In all these engines Diesel is used for the performance analysis. And the insulation thickness employed is 0.5mm. The notations of these insulation levels are given below.

i) LHR-1 : Aluminium piston with heat dam, an Air gap liner and the heat dam surfaces, head and valves coated with PSZ.
ii) LHR-2 :Aluminium Piston, an Air gap liner and PSZ coated head and valves.
iii)LHR-3 : Aluminium Crown Aluminium Piston with Air gap, an air gap liner and PSZ coated head and valves.
iv) LHR-4 : Brass Crown Aluminium Piston with Air gap, an Air gap liner and PSZ coated head and valves

The experimental investigations are carried out on all these different engine configurations and the processed results are presented in the form of graphs.

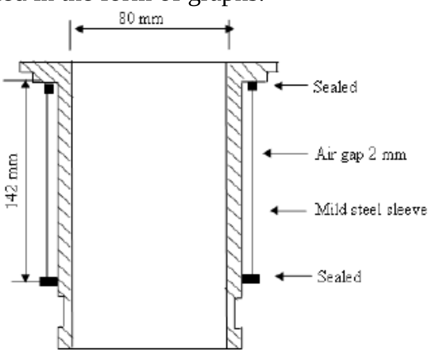

Figure 1 Brass Crown Piston with Gap

Figure 2 Air Gap insulated Liner

6. Results

A set of experiments are conducted with Diesel to evaluate the performance differences between LHR engines and a conventional base engine.

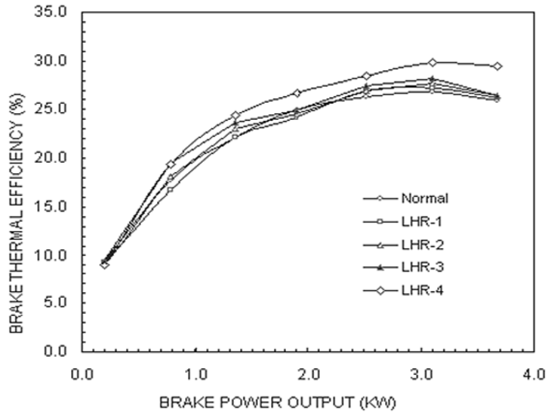

Fig.3 Comparison of brake thermal efficiency with power output for four LHR configurations.

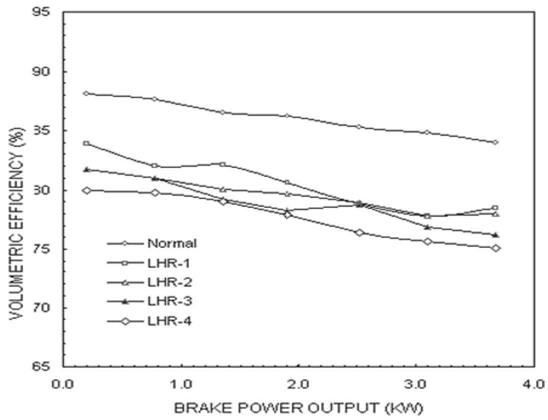

Fig.4 Comparison of volumetric efficiency with power output for four LHR configurations.

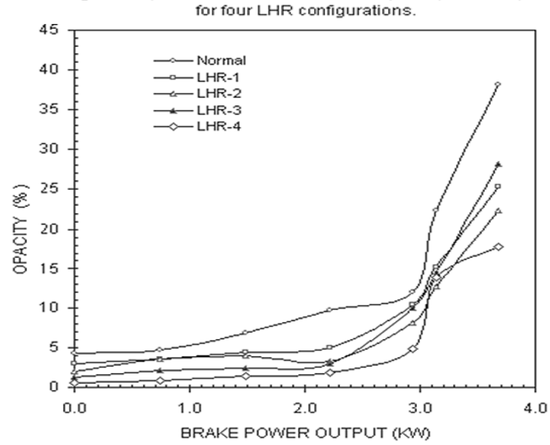

Fig.5 Comparison of Opacity with power output for four LHR configurations.

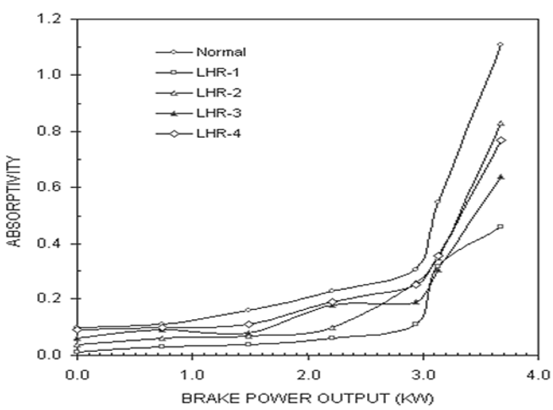

Fig.6 Comparison of Absorptivity with power output for four LHR configurations.

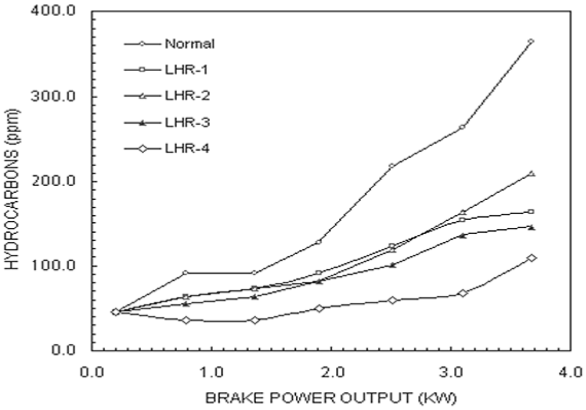

Fig.7 Comparison of Hydrocarbons with power output for four LHR configurations.

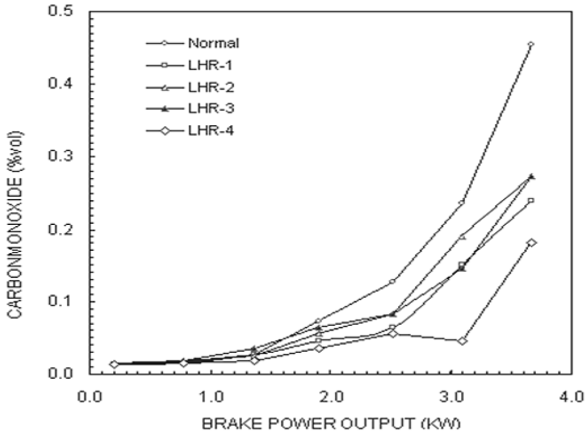

Fig.8 Comparison of Carbonmonoxide with power output for four LHR configurations.

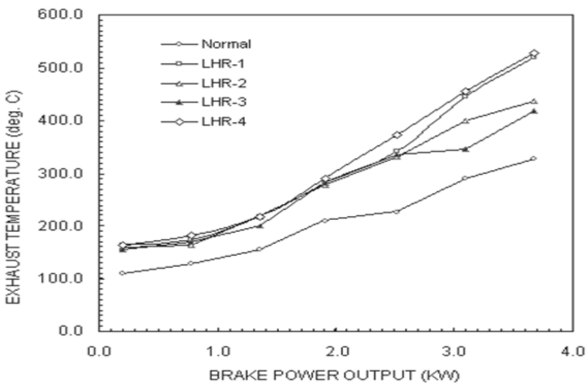

Fig.9 Comparison of Exhaust temperature with power output for four LHR configurations.

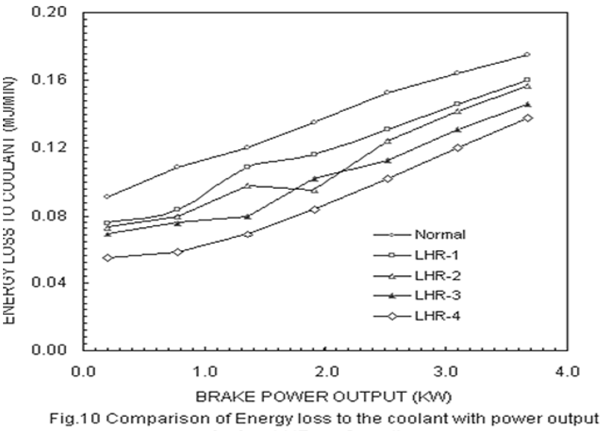

Fig.10 Comparison of Energy loss to the coolant with power output for four LHR configurations.

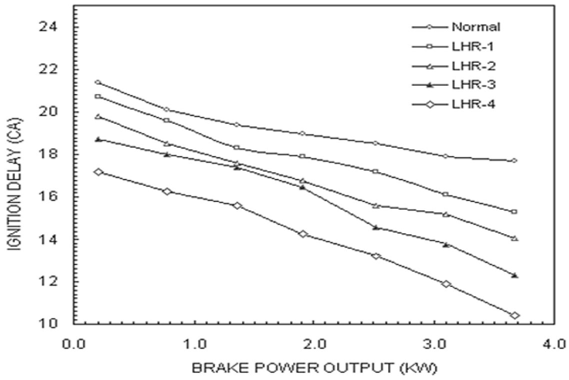

Fig.11 Comparison of Ignition delay with power output for four LHR configurations.

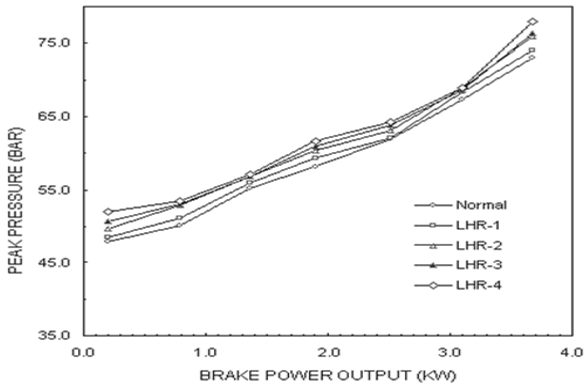

Fig.12 Comparison of Peak pressure with power output for four LHR configurations.

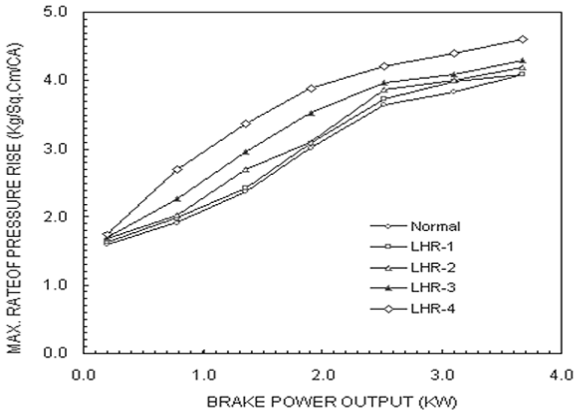

Fig.13 Comparison of the Maximum rate of pressure rise with power output for four LHR configurations.

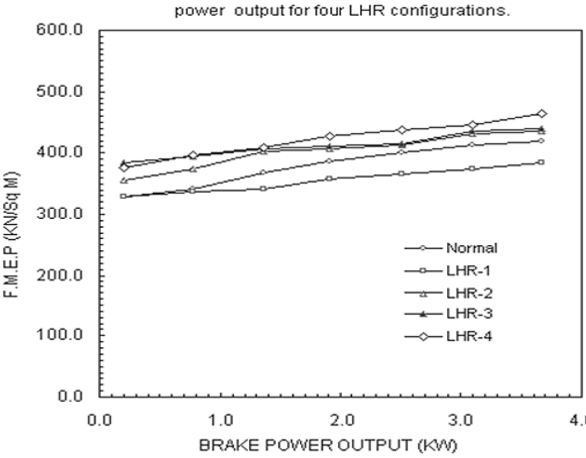

Fig.14 Comparison of Frictional mean effective pressure with power output for four LHR configurations.

Conclusion

The following conclusions can be drawn from the processed results of the experimentation.

- LHR engines performed better when compared to base engine.
- For the LHR-4 configuration (Brass Crown Aluminium Piston with Air gap, an Air gap liner and PSZ coated head and valves) , the brake thermal efficiency improvement is found to be 22% at the full load operation compared with the base engine.
- Volumetric efficiency drop is maximum in the case of LHR-4 configuration. And it is about 12% compared to the base engine.
- All LHR configurations resulted in a good reduction of smoke emissions. The maximum reduction in the smoke emission is for the LHR-4 configuration when compared to the base engine. Though all the four LHR configurations have shown reduced HC emission levels, the maximum reduction is observed for the LHR-4 configuration which is around 250 ppm at the full load when compared with the base engine.
- As a result of better combustion, LHR-4 configuration has shown a significant reduction in the CO emission and is about 0.28% by volume.
- Exhaust temperatures are higher in all LHR configurations when compared relatively with the base engine because of insulation of the engine. The exhaust gas temperature increased by 200^0C for the LHR-4 configuration because of reduction of heat losses to jacket water at full load.
- Due to hot environment in the LHR engines, a reduction in the ignition delay is observed. The ignition delay is lower by 7.3^0CA for the LHR-4 configuration.
- Better vaporization of injected fuel is possible in these engines. Therefore smooth engine operation is possible with this LHR- 4 configuration
- Frictional losses are higher with LHR engines and are proportional to the level of insulation applied.
- From the experimental investigations, it can be concluded that the LHR-4 configuration performs well.

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