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# Experimental Investigation on 4-Stroke Low Heat Rejection C.I. Engine with Different Piston Crown Materials

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***Abstract:-*** **The prices of the petroleum fuels are rising frequently due to fast depletion of natural resources and particularly in Indian context it is beyond the common user. Therefore, alternate fuels for usage in C.I. Engines are gaining importance. Wide investigation is going on the enhancement of the thermal efficiency of C.I. Engine in the Hi-tech world. Even the most efficient Engine rejects two – thirds of heat energy of the fuel, i.e., one-third to the coolant, other one- third to the exhaust and only about one-third is converted to useful work. The Engine performance can be improved if the energy lost is reduced. Numbers of methods are being recommended by several experts and investigators to enhance Engine performance characteristics. Among them, the Low Heat Rejection (LHR) Engine concept is at the forefront. In LHR Engine, the performance of the Engine can be improved by using thermally insulated components. Such components not only diminish heat transfer to the surroundings but also increase the thermal efficiency.**

**Initially a conventional Diesel Engine is converted to LHR Engine by providing different levels of insulations like different piston crown materials with 2mm air gap insulation and ceramic coating on the inner surface of the cylinder head. The different levels of insulations are tried on the C.I. Engine to accomplish the best one in terms of performance, emissions and other combustion parameters.**

***Key words: Low Heat Rejection (LHR) Engine, compression Ignition (C.I.), Aluminium, Copper, Nimonic alloy, Brass and PSZ.***

## I. INTRODUCTION

In the diesel engines for about 30% of the total energy is lost to the cooling water. This lost energy can be recovered in the form of useful energy by expanding gases in the turbines. The notion of Low Heat Rejection (LHR) Engine or semi-adiabatic Engine is nothing but employing insulation on combustion chamber walls of the Engine. The insulated components include piston, cylinder head, cylinder liner, valves and exhaust ports. In addition to power, enhanced efficiency also occur because a part of the thermal energy, in general vanished to the cooling system, is saved by insulation and due to higher cycle temperatures a large amount of energy is made available in the exhaust gases. The Low Heat Rejection Engine concept is not new. The subject of Low Heat Rejection Engines has be given substantial attention newly as Engine builders struggle to find remaining avenues to improve better performance and lower emissions. Cooling an Engine is a "necessary evil" which designers would gladly forego if it is possible. There is no evidence of a practical LHR Engine, though several investigators suggest the vegetable oils use in these Engines. Therefore in recent times amongst methods for improvement of compression Ignition (C.I.) Engine performance, the rejection of heat loss to cooling medium has been given importance. C.I. Engine has become an important power source in farming activities in rural areas where electrical energy is not available. Hence the need for increasing the efficiency of an internal combustion Engine has been going on ever since the invention of this machine. The reduction of heat loss to the Engine cooling medium can be achieved by insulating the cylinder components by the ceramic thermal barrier coatings.

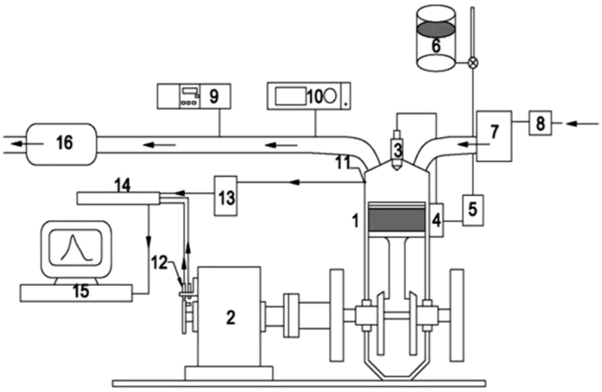
## II. EXPERIMENTATION

Experiments are conducted on the standard Engine with Diesel in different combinations of insulated parts. The Engine is tested under no load for the first 20 minutes and for each load the Engine is operated long enough to stabilize the condition. All the tests are conducted at the rated speed of 1500 rpm. From the observed readings, the parameters of performance, emission and combustion characteristics are evaluated.

### *A. Different Piston Crown Materials*

i. LHR-1: Aluminium Crown Aluminium Piston with 2 mm air gap and PSZ coated inner surface of the cylinder head.
ii. LHR-2: Copper Crown Aluminium Piston with 2 mm air gap and PSZ coated inner surface of the cylinder head.
iii. LHR-3: Nimonic alloy Crown Aluminium Piston with 2 mm air gap and PSZ coated inner surface of the cylinder head.
iv. LHR-4: Brass Crown Aluminium Piston with 2 mm air gap and PSZ coated inner surface of the cylinder head.

The results which are obtained during experimentation are found to be productive and these results are predictable to go ahead to a significant involvement to the development of an efficient LHR Engine to run on Bio- Diesel fuels.



| | |
|---|---|
| 1. Kirloskar Engine | 9. AVL Smoke Meter |
| 2. Eddy Current Dynamometer | 10. INDUS 5--Gas Analyzer |
| 3. Injector | 11. Pressure ransducer |
| 4. Fuel Pump | 12. TDC Encoder |
| 5. Fuel Filter | 13. Charge Amplifier |
| 6. Fuel Tank | 14. Indimeter |
| 7. Air Stabilizing Tank | 15. Monitor |
| 8. Air Filter | 16. Exhaust silencer |

Fig. 1 Schematic diagram for Experimental setup

## III. PISTON INSULATION

The insulating the piston is to reduce the heat a loss from the crown to the skirt and the maximum possible area of the crown has to the insulated to fulfill this objective.

The design is adopted based on the use of ceramics as insulating materials. This has certain drawbacks. Ceramics have poor mechanical strength and tend to disintegrate when subjected to high pressures and vibrations. The technology for making ceramic components as Engine parts is complicated and is in the nascent stage. Based on these difficulties, a more rugged and versatile design which would have the same, if not better quality of insulation as ceramics is sought at and an all metallic piston design with air gap insulation is favored.

In this outline, air with its low thermal conductivity is utilized as the protecting medium. An air-gap is given between a metallic crown and the standard piston made of aluminum alloy. The two pieces are detached by gaskets of suitable materials and attached. The metallic crown needs to work at elevated temperatures ($900^0$C - $1000^0$C) under high pressure (90 kgf/cm$^2$) but then its thickness couldn't be high (around 5-6mm). This required a material equipped for withstanding both mechanical and thermal stresses. The material additionally brings to the table imperviousness to erosion and oxidation under those conditions.

In the first instance, an Aluminium crown is 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 is reduced by 7.0 mm at the top by machining. An Aluminium crown of 5.0 mm thickness is turned out of Aluminium alloy rod of 87.5 mm to the shape of standard piston crown. The hemispherical shape is turned using concave and convex turning tool. A thickness of 5mm is maintained on the flange and bowl area of the crown. The recess for valve clearance is provided by end milling. The Aluminium crown is separated by gaskets made of copper and stainless steel from the Aluminium body. Two copper gaskets of each 0.5 mm thickness and a stainless steel gasket of 1.0 mm thickness placed in between the two copper gaskets are used. The total thickness of the three gaskets is 2.0 mm.

The standard height of the piston is 110 mm. The height of the standard piston is reduced by 7mm in order that the total height of the modified piston including the crown (5 mm) and gaskets (2 mm) may be retained at the original value (110 mm).

Fig. 2 Photo Graphic View of Aluminium Piston with Brass Crown and Air Insulation

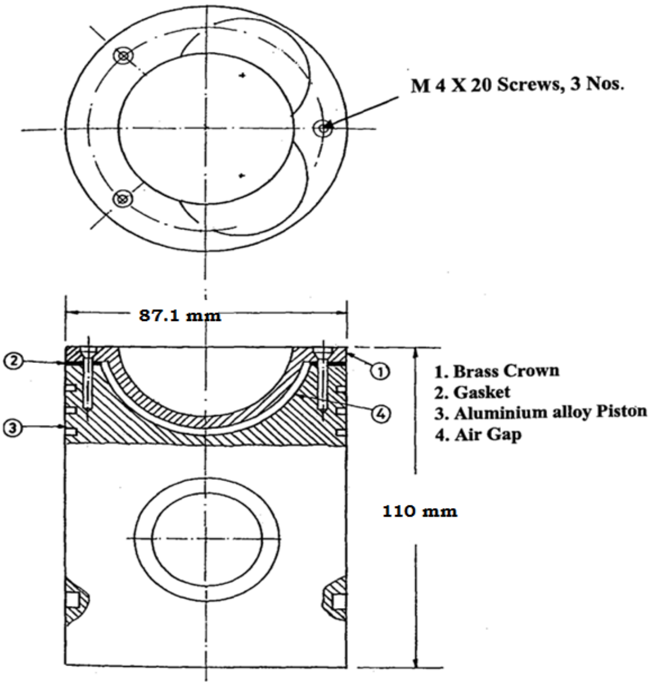


Fig.3 Brass Piston Crown with Air Gap Insulation

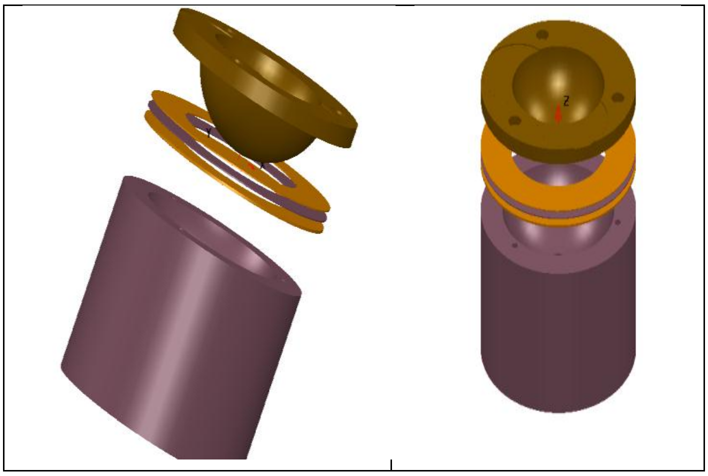


Fig. 4 Three dimensional view of Piston with Crown and Gaskets

Fig. 5 Photographic view of Aluminium crown

Fig. 6 Photographic view of Copper alloy crown

Fig. 7 Photographic view of Nimonic alloy crown

Fig. 8 Photographic view of Brass crown

## IV. CYLINDER HEAD INSULATION

The head is insulated by coating the area exposed to the combustion chamber with PSZ. The combustion chamber area of the cylinder head is machined to a depth of 0.5 mm. The roughened surface is then degreased using chemical agents. By using plasma arc spraying torch a bond coat is applied first to a thickness of 0.075 mm and then the PSZ is coated to a thickness of 0.425 mm. The thickness of the ceramic coating is limited to 0.5 mm due to the expected deterioration in the adherence qualities of ceramic layers over the cast iron surface with the increasing thickness.

On the head demanded exceptionally good adherence of PSZ to the material of the head and the thickness could not be increased further due to deterioration of adherence of PSZ layer over cast iron surface with increased thickness.

The valves and the hole for fuel injector nozzle occupied about 35 percent of the total area of the combustion chamber surface and the remaining area is coated with PSZ.

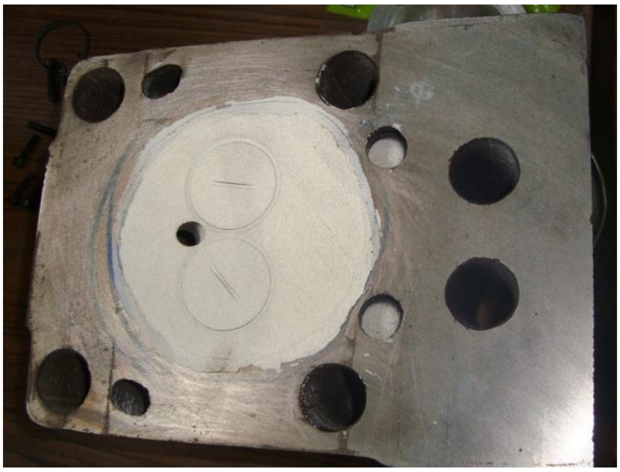


Fig. 9 Photo Graphic View of PSZ Coated Cylinder Head

## V. RESULTS AND DISCUSSIONS

### A. *Brake Thermal Efficiency*

The brake thermal efficiency with power output for four LHR configurations is shown in figure 10.

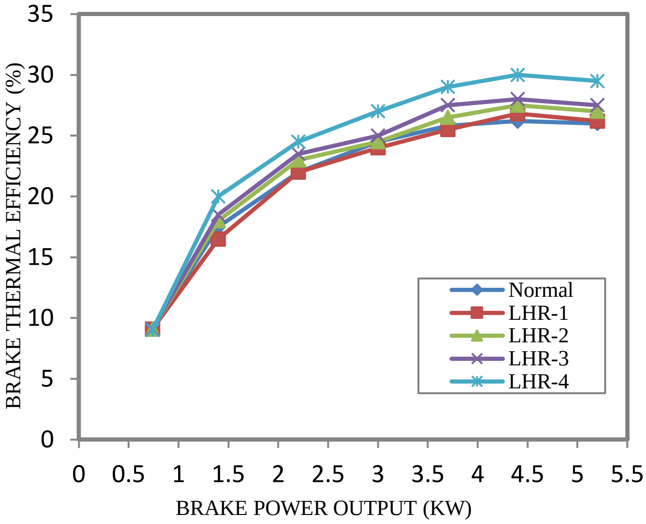


Fig. 10 Comparison of brake thermal efficiency with power output for four LHR configurations.

All the LHR configurations are shown in figure10, have higher brake thermal efficiencies compared to base Engine. The LHR-4 configuration gives higher efficiency 30% at optimum load 4.4 kW and normal Engine at that load 26%. The study recommends that the insulation provided on the Engine decreases the heat losses and in turn increases the brake thermal efficiency of the Engine. The brake thermal efficiency increases around 4% for the LHR-4 configuration at optimum load. The brass crown piston has been designed for internal regeneration of heat as brass has high thermal conductivity. The brass crown is able to absorb heat from the hot gases during peak cycle temperature condition and gives out the same to the fresh charge during the suction and compression strokes of the next cycle, there by acting as a reservoir of heat. This is the reason that the thermal efficiency of the LHR-4 insulation with brass crown piston is higher than with the partial insulation.

### B. *Brake Specific Fuel Consumption*

The brake specific fuel consumption with power output for four LHR configurations is shown in figure 11.

All the LHR configurations are shown in figure 11 have lower brake specific fuel consumption compared to base Engine. The LHR-4 configuration gives lower brake specific fuel consumption 0.2 kg/kW-hr at optimum load and for normal Engine 0.34 kg/kW-hr. The brake specific fuel consumption principally depends upon the consistent mixture formation and complete combustion of the fuel.

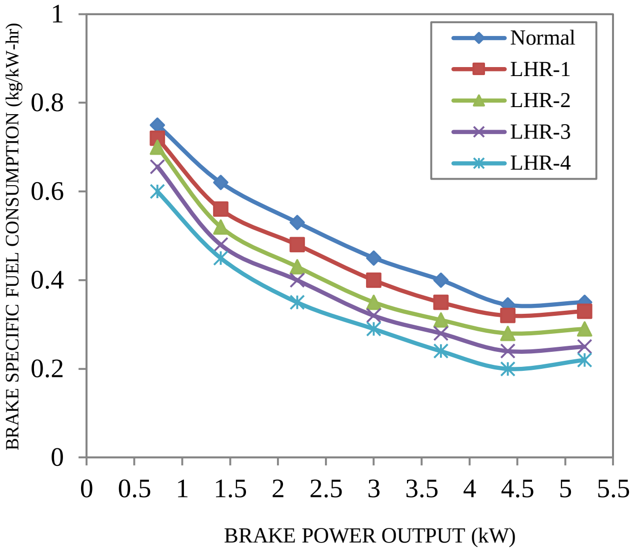


Fig.11 Comparison of Brake Specific Fuel Consumption with power output for four LHR configurations.

With the better vaporization of the fuel, the charge becomes homogeneous and the combustion of fuel can be improved. Due to the air insulation between piston crown and skirt, the LHR-4 configuration Brass Crown Aluminium Piston with 2 mm air gap and PSZ coated inner surface of the cylinder headacts as heat reservoir, the heat within the combustion chamber will increase and the combustion potency is improved. The rise in combustion potency provides fuel economy. The brass crown piston acts as a good heat reservoir, with its better thermal properties. This will increase the temperature of the incoming air and any the combustion potency.

### C. *Hydrocarbon Emission*

The Hydrocarbon emissions with power output for four LHR configurations is shown in figure 12.

The LHR-4 configuration has shown in figure12 the maximum reduction in hydrocarbon emission levels and is about 100 ppm at rated load when compared to base Engine.

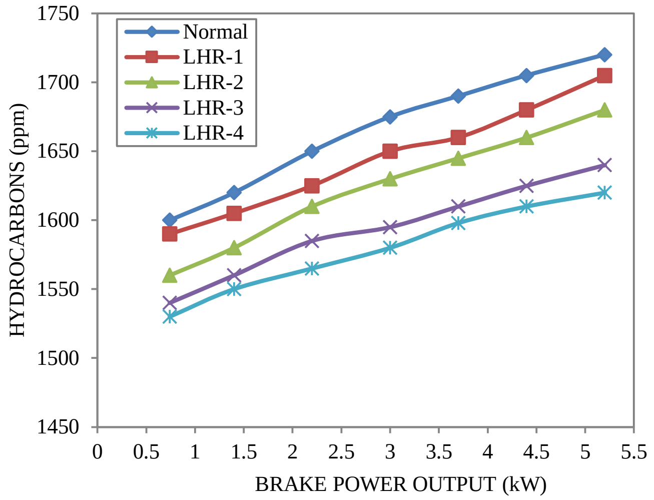


Fig.12 Comparison of Hydrocarbons with power output for four LHR configurations.

For all other configurations the Hydrocarbon emissions are in between the base Engine and Engine with LHR-4 configuration.It's observed that the HC emission will increase with increase in load on the engine for all piston crown materials utilized in the current work. HC emission of LHR-4 configuration is less than the other piston crown materials. This decrease in HC emission could be due to increase in heat within the combustion chamber as a result of better insulation by brass due to its high thermal conductivity phenomenon.The main sources of these emissions in C.I. Engine are lean mixing, burning of lubricating oil, and wall quenching, because of hotter combustion chamber.

### D. *Carbon Dioxide Emission*

The Carbon dioxide emission with power output for four LHR configurationsis shown in figure 13
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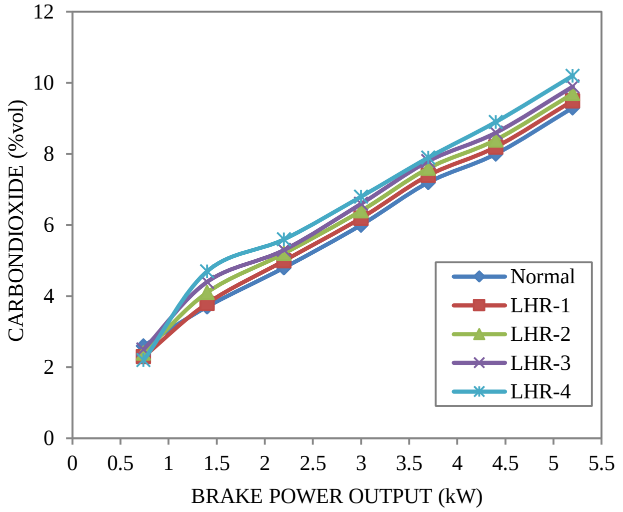

Fig.13 Comparison of carbondioxide with power output for four LHR configurations.

It is evident from the graphs that the $CO_2$ increases with increase in power output. Because of better combustion in the insulated Engines, Carbon dioxide levels are higher for LHR Engines. It indicates that the level of Carbon dioxide is highest10.2% volume at full load for LHR-4 configuration, and 9.3% volume for normal Engine are shown in the figure 13.

### E. *Carbon Monoxide Emission*

The Carbon monoxide emission with power output for four LHR configurationsis shown in figure 14.

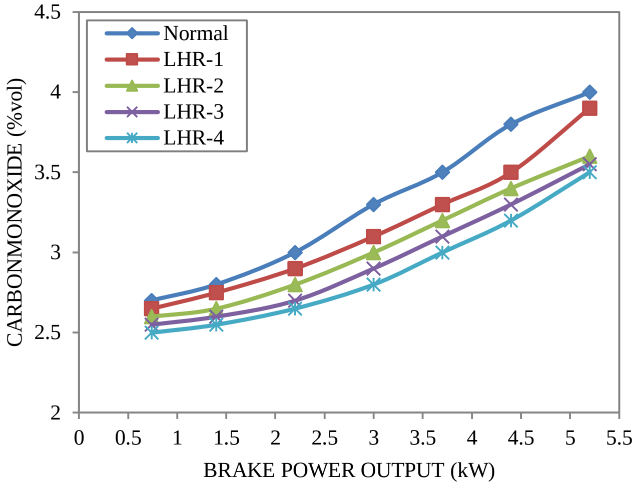

Fig.14 Comparison of carbonmonoxide with power output for four LHR configurations.

Carbon monoxide levels in the exhaust of base engine and all the four LHR configurations are shown in figure 15. Because of better and complete combustion in the insulated engines, the surplus oxygen offered within the LHR-4 configuration converts the some of the CO into carbon dioxide and thus the CO emission is reduced.Lowest carbon monoxide emissions are observed in the case of LHR-4 configurations, the reduction is about 0.28% by volume at rated load. Compared to part loads, the reduction is more at higher loads. LHR-2 and LHR-3 configurations have shown higher levels of carbon monoxide emission compared to other configurations. A good amount of reduction in carbon monoxide levels is observed with LHR-4 configuration.

### F. *Nitrogen Oxide Emissions*

The Nitrogen oxide emission with power output for four LHR configurationsis shown in figure 15.

$NO_x$ levels in the exhaust of base Engine and all the four LHR configurations are shown in figure 15. Because of better and complete combustion in the insulated Engines, Nitrogen oxide levels are higher for insulated Engines.

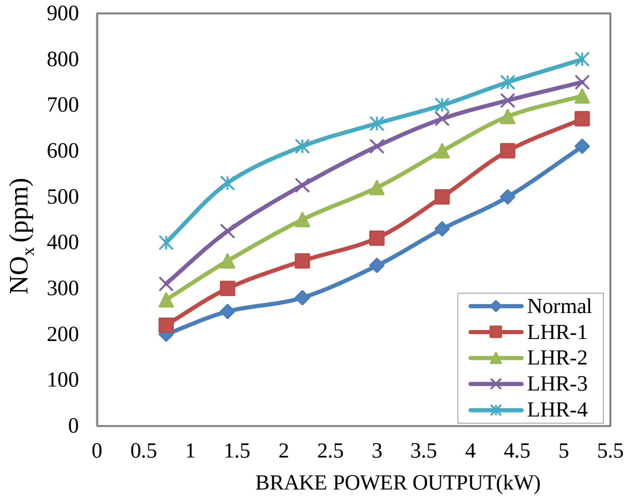

Fig.15 Comparison of nitrogen oxide with power output for four LHR configurations.

It indicates that the level of nitrogen oxide is highest 800 ppm at full load for LHR-4 configuration, 610 ppm for normal Engine. The formation of $NO_x$ depends on the heat available in the combustion chamber. The LHR-4 configuration reduces the heat losses through the piston and increases the evaporation rate of the fuel. This will improves the combustion process and causes to increase in $NO_x$ emission. Higher nitrogen oxide in the exhaust is an indication of complete or better combustion.

### *G. Ignition Delay*

The Ignition delay with power output for four LHR configurations is shown in figure 16.

Reduction in the ignition delay is observed for the Diesel fuel when tested in LHR configurations.

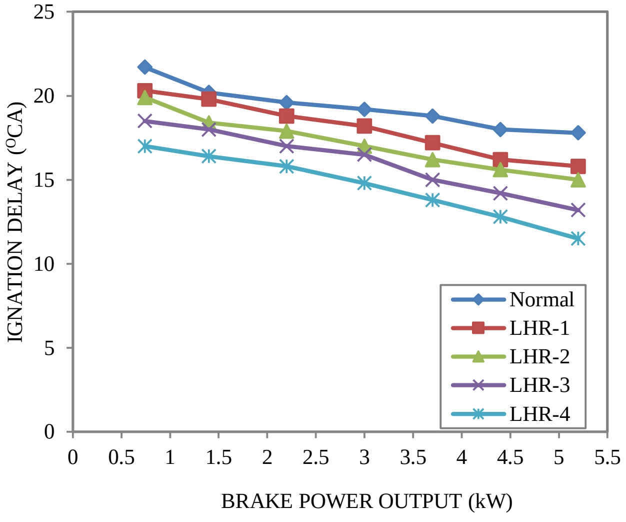

Fig.16 Comparison of Ignition delay with power output for four LHR configurations.

The reduction in the ignition delay is normally expected because of higher temperatures in these configurations. The ignition delay variation with brake output is shown in figure 16.

Lowest ignition delay is obtained for the LHR-4 configuration compared to other configurations. The ignition delay for this configuration is reduced by $6.3^0$CA when compared to base Engine at full load. The reduction in the ignition delay depends upon the level of insulation applied. Short ignition delay is conductive to multi-fuel capability and fuels with low cetane numbers (Vegetable oils) can be used.

## VI. CONCLUSIONS

The following conclusions can be drawn from the processed results of the experimentation. The LHR-4 configuration has shown the best performance.

1. For the LHR-4 configuration (Brass Crown Aluminium Piston with air gap and PSZ coated cylinder head), the brake thermal efficiency increases by 4% at optimum load operation compared with the base Engine.

2. All the LHR configurations have lower brake specific fuel consumption compared to base Engine. For LHR-4 configuration gives reduction in brake specific fuel consumption 41% at optimum load.

3. All the four LHR configurations have shown reduced HC emission levels, the maximum reduction is observed for the LHR-4 configuration which is around 5.8% at the full load when compared with the base Engine.

4. 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.

5. Nitrogen oxide emissions are higher for LHR-4 configuration is around 23.75%.

6. The ignition delay is lower by 6.3°CA for the LHR-4configuration.

## ACKNOWLEDGMENT

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