# INVESTIGATIONS ON THE PERFORMANCE OF DIESEL IN AN AIR GAP CERAMIC COATED DIESEL ENGINE

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## Abstract

*The world's rapidly diminishing petroleum supplies, their raising costs and budding danger of environmental pollution have led to an intensive search for an alternative fuels or increasing the efficiency of the available diesel engines. It is a known fact that about 30% of energy supplied to the diesel engine is lost through the coolant and 30% is wasted through friction and exhaust and other losses, thus leaving only 40% of energy utilization for the useful purposes. If this lost heat rejection is reduced, the thermal efficiency can be improved. With the insulation of the combustion chamber Walls with ceramics, the transfer of heat can be restricted and can be used further for heating the incoming fresh charge and the same thing can be observed with exhaust gases. This increases the combustion efficiency and reduces the emissions. Hence in the present work, a ceramic coated engine is developed by incorporating air gap between the piston skirt and crown, cylinder liner and jacket, ceramic coating on cylinder head and valves. Therefore, a solemn attempt is made in this research work to investigate the performance and emission characteristics of diesel engine with diesel as fuel. Further the performance of the engine depends on the heat in the combustion chamber. This intends depend on piston material and the turbulence generated in the engine. So, further an attempt is made with brass piston insert and brass insert with six grooves which replaces the aluminum piston in the engine. Among all the pistons tested the brass insert with six grooves is proved to be the best in terms of performance and emissions point of view. But with the higher temperatures in the chamber drop in volumetric efficiency and lubricating oil deterioration are the main problems. However they can overcome by turbo compounding and with the development of new lubricants.*

***Keywords:*** *Ceramic engines, Air gap, New Lubricants, Piston inserts, Low heat rejection engines*

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## 1. INTRODUCTION

Though the researchers claim that the complete recovery of the heat produced in the combustion chamber without sacrificing efficiency and emission standards is possible, in most of their studies, the detailed performance and combustion characteristics have not been disclosed. But for the complete combustion of the diesel in the diesel engine it requires higher pressures and temperatures in the combustion chamber [1]. But this makes the engine bulky. So in the present work a ceramic engine is developed with the insulation of the combustion chamber [2 ,3 and 4]. Ceramics have a higher thermal durability and lower thermal conductivity that controls the temperature distribution and heat flow in the structure. Lower heat rejection from the combustion chamber through thermally insulated components causes an increase in available energy that would increase the in-cylinder work and the amount of energy carried by the exhaust gases, which could also be utilized.

A major breakthrough in the technology of diesel engine has been achieved by the innovative work done by Kamo and Bryzik. R.Kamo et al [6] conducted experiments with 0.13 mm thick thermal barrier coating of PSZ for the piston and cylinder head and 0.5 mm thick coating for cylinder liner. He reported that 5 to 6 percent improvement in fuel efficiency at all loads and speeds. They observed with the experiment higher premix, lower diffusion combustion, reduction heat transfer loss, higher heat release in the combustion chamber. T.Morel [5] et.al achieved higher thermal efficiency at all loads for both heavy and light engines with the various level of insulation at constant peak pressure and A/F ratio. There is 8% improvement in the brake thermal efficiency was observed. Heat rejection is reported to be decreased while exhaust temperature is increased. S.H.Chan and K.A.Khor et.al [8] reported 4 to 7 % improvement in fuel consumption in single cylinder DI diesel engine. This is achieved by using constant air flow rate with boosting pressure with 1 mm thick PSZ coating to the cylinder head face and the valve heads by placing a short solid PSZ cylinder liner in the area above the piston rings and heat insulated steel piston. Y.Miyairi et. Al [7] reported reduction in BSFC by 7% under naturally aspirated conditions in single cylinder DI diesel engine. In this attempt the fuel injection pressure and the amount of fuel injected is kept constant and the cylinder liner is water cooled. The chamber walls are insulated with PSZ. Murthy PVK et.al [9] reported the results of their investigations on LHR diesel engine with 3 mm air gap between piston skirt and insert with Nimonic alloy crown. They revealed that the performance is deteriorated at the available injection timing and pressure. At peak loads the BSFC is decreased by 12 percent while smoke levels by 16 percent but NOx levels are increased by 34 % with an injection timing of 32 $^0$bTDC. Wallace et al [11] have reported the use of a thermal barrier piston in the adiabatic engine and developed the temperature distribution analysis and reported that the piston top temperature were higher by around 400$^0$C for the thermal barrier pistons. From the literature it is observed that much amount of heat is lost through the piston. Hence in the present work for the reduction of heat from the piston and thereby increasing the efficiency, an attempt is made with brass piston crown. The brass crown is also same as the size of the original piston and can be interchangeable [9, 10]. Similarly with the turbulence in the chamber homogeneous mixture can be formed and further the increase in efficiency is possible. Therefore in this work six number of grooves are made on the brass piston and is used for the testing.

## 2. AIM

The main aim of the present investigation is to find the suitability of the ceramic insulated engine for the complete burning of diesel in the conventional CI engine. The total experiment consists of the following segments.

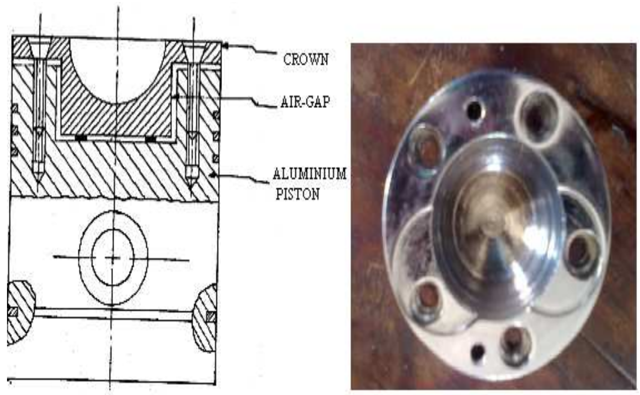
1. Preparation of ceramic insulated engine components
2. Materials and method of conducting the investigations with different piston inserts
3. Results and discussions

### 2.1 Preparation of Ceramic Engine Components

The most complicated part of the work is the design and fabrication of insulated components. The preparation of the components is as explained below.

### 2.1.1 Air Gap Insulated Piston

In the present experiment an air gap of 2 mm is provided between piston crown and skirt based on the existing literature. The crown and skirt is allied with copper and steel gaskets. The air gap between the two components acts as an insulator for the heat transfer through the piston and further provides more heat in the chamber. The following figure 1 show the air gap aluminum piston used in the experiment.




(a) Line diagram (b) Photographic view of aluminum crown

**Fig 1:** Air gap insulated Aluminum crown

### 2.1.2 Cylinder Liner Insulation

The movement of the piston in the cylinder was an impediment for the lagging of the liner on its interior surface. Hence the air insulation is provided on the outer surface the liner. A thin mild steel sleeve was bounded 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. This insulation of the liner reduces the heat transfer from the engine cylinder to the cooling water.

### 2.1.3 Cylinder Head and Valve Insulation

The thermal barrier coatings have better heat and wear resistant characteristics which retains the heat in the combustion chamber and improves the combustion efficiency. This provides the higher thermal efficiencies, improved combustion and reduced emissions. Among all the possible alternative insulating materials, one of the most promising is ceramic. Ceramic is an important material because of its low density, high thermal stability, stability in severe chemical environment, low thermal conductivity and favorable strength and creep behavior. So in the present work this coating is preferred. Ceramic coating is a simpler method of insulation for cylinder head and valves compared with other methods. For the coating of the Partially Stabilized Zirconia (PSZ) the following method is used.

Zirconia is usually produced from the zircon ($ZrSiO_4$). For the production of the zirconia, the zircon is to be added with NaOH and HCl, so that the zircon is converted to zirconyl chloride. Further the reactions are as follows:

$ZrOCl_2 8H_2O$+ Stabilizer ($Y_2O_3$)+ HCl $\longrightarrow$ Solution
Solution + $NH_4OH$ $\longrightarrow$ Zr $(OH)_4$ + $Y(OH)_3$

$Y(OH)_3$
$\downarrow$

(Wash)
Cl-free Precipitate
(Filtration) ↓

Wet Powders $Zr(OH)_4 + Y(OH)_3$
(Freezing Dry (Liquid $N_2$)) ↓

Dry Powder $Zr(OH)_4 + Y(OH)_3$
(Calcination) ↓

Stabilized Zirconia Powder $ZrO_2 + Y_2O_3$

With the available PSZ powder the coating will be done on the cylinder head and valve surfaces. In this the following processes are performed. 1. Pre-cleaning and pre-machining of the cylinder head and valve surfaces to remove rust, scale, sand, paint etc. 2. Application of the PSZ powder on the component surfaces using plasma spraying technique up to the required thickness 3. Final finishing operations like grinding, lapping, polishing and cleaning.

With the above specified methods, the cylinder head and valves bottom surfaces are insulated by coating the area exposed to the combustion with PSZ. The combustion chamber area of the cylinder head and valves was machined to a depth of 0.5 mm. The surface was then sand blasted to form innumerable pores. The PSZ coated cylinder head and valves are shown in the following figure 2.

**Fig 2:** PSZ coated cylinder head and valves

All these insulated parts described above were interchangeable with the standard engine parts.

## 3. MATERIALS AND METHODS

For the reduction of the heat transfer, a piston is designed similar to that of original aluminum piston which absorbs heat from the combustion chamber and provides the same to the incoming charge. This preheats the charge and increases the combustion efficiency. In the present work a brass piston crown similar to that of normal aluminum piston is designed for experiment. Further the chamber temperature and combustion in the chamber depends on the turbulence generated in the chamber. So in this work an attempt is made with six number of grooves on the brass crown piston. This brass crown piston is further knurled to increase its surface area to facilitate better heat transfer from the gases to the brass crown. The configurations of the brass pistons tried are shown in the following figure 3 and the same is compared with aluminum piston.

**Fig 3:** Photographic view of plain brass crown piston

**Fig 4:** Photographic view of Brass crown piston with six grooves

## 4. RESULTS AND DISCUSSIONS

A long term experimental study has been conducted on a single cylinder 4-stroke, water-cooled 5 B.HP Kirloskar ceramic coated diesel engine by changing piston crowns. The concentration of smoke is measured by Bosch smoke meter; UHC and NOx are measured with non-dispersive infrared (NDIR) AVL exhaust gas analyzer. Air suction rate and exhaust air flow rates were measure with the help of an air box method. Temperatures at the inlet and exhaust valves are monitored using Nickel-Nickel Chromium thermocouple thermocouples. Time taken to consume 20 cc of fuel was noted using a digital stop watch. Engine RPM is measured using an electro-magnetic pick up in conjunction with a digital indicator of AQUTAH make and the analysis of these results are as follows. The following figure 5 shows the experimental set up.

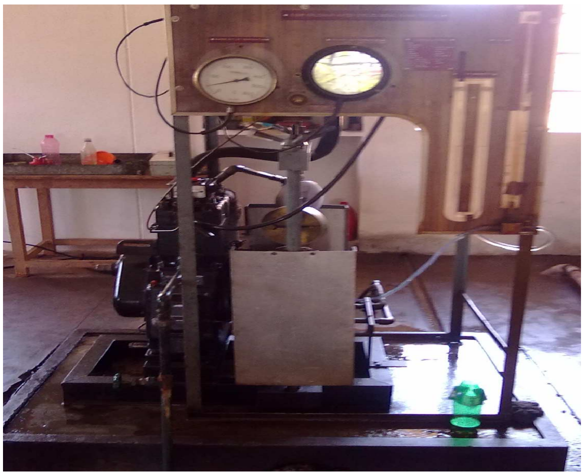


**Fig 5:** Photographic view of experimental setup

### 4.1 Exhaust Gas Temperature

Partially stabilized zirconia is a low thermal conductivity material. It acts as a thermal barrier for the heat transfer to the engine cooling system from the combustion chamber and retains the heat in the chamber. Further the brass crown piston due to its properties restricts the heat transfer through the piston. This leads to the lower temperature difference between the combustion gases and exhaust. Finally it leads to the complete combustion of the fuel in the combustion chamber.

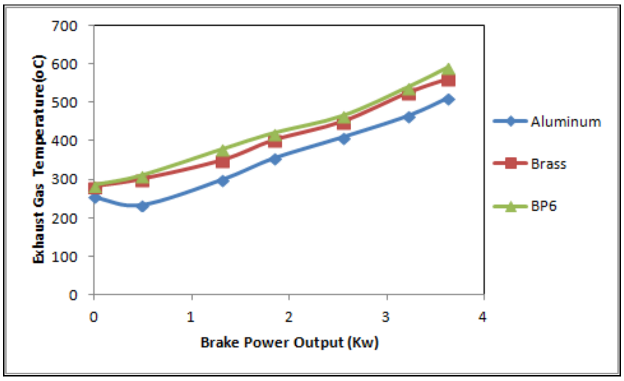



**Fig 6:** Comparison of Exhaust gas temperature with power output

The Fig 6 shows the variation of exhaust gas temperatures with brake power output. At higher loads the insulated engine with brass piston generated maximum temperature and for aluminum it is lower over a wide range of operations. The temperature for brass piston is $560^0$C and for aluminum it is $510^0$C at full load. Further the grooves on the piston crown generate the turbulence in the combustion chamber and increase the combustion efficiency. The insulated engine with BP6 configuration shows maximum exhaust gas temperature at rated loads and it is 5.36% higher than BP. This high temperature exhaust gas energy can be recovered by turbo compounding system.

### 4.2 Brake Thermal Efficiency

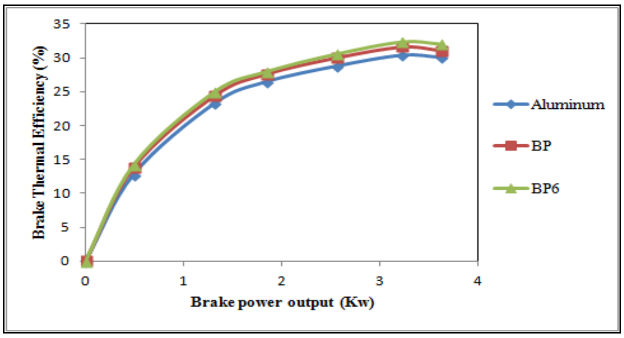



**Fig 7** variation of brake thermal efficiency with power output

The above Fig 7 shows that the variation of brake thermal efficiency of the ceramic insulated engine with the power output for various piston inserts. This is due to the reduction of the heat transfer to the coolant with the ceramic coating and thereby increases the heat in the chamber. The efficiency is further improved with the insulation of piston with air gap and brass piston. As the brass crown piston acts as a good heat reservoir, it maintains the heat in the chamber and further combustion completes. Further with the grooves on the piston it is more. So the brake thermal efficiency of BP6 is increased by about 3.16% compared to brass piston at rated loads.

### 4.3 Volumetric Efficiency

The volumetric efficiency variation for different piston materials depicts in the Fig 8. As the combustion chamber temperature with the brass pistons is more than aluminum piston, higher amount of heat will be transferred to the incoming air which reduces the density and in turn drops the volumetric efficiency. This cut down the amount of air available for the combustion and further plunge the power output. This reduction of the power can be compensated by turbo charging

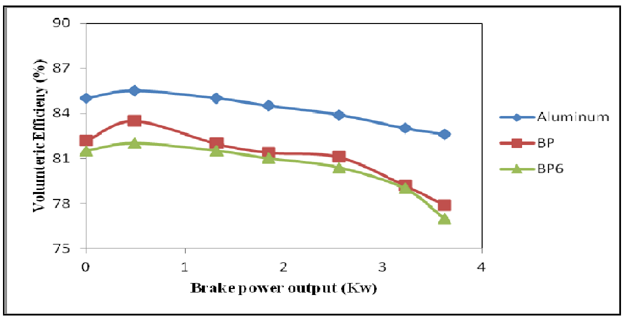



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**Fig 8:** Variation of Volumetric Efficiency with power output

The volumetric efficiency of aluminum piston varies from 85% at no load to 82% at full load. The fall in volumetric efficiency with brass piston is more. The absolute drop is 3.35% compared to the aluminum piston at the rated load. This trim of volumetric efficiency further depends on the turbulence and temperatures in the combustion chamber. So the drop of volumetric efficiency with BP6 is highest and is about 1% compared to BP.

### 4.4 Smoke Density

The variation of exhaust smoke intensity (Bosch units) for brass piston material is shown in the Fig 9. The smoke in the engine exhaust is due to incomplete combustion. The lower prevailing temperatures in the chamber and with the

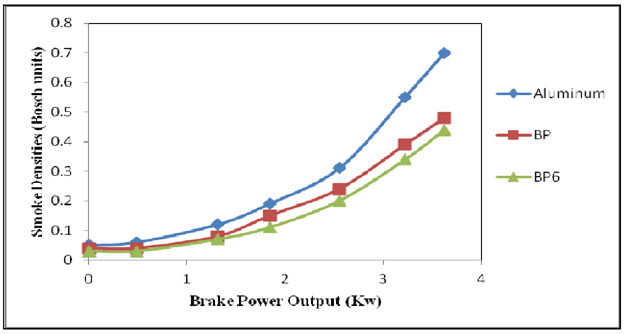


**Fig 9:** Comparison of Smoke intensity with power output

Comparison of Smoke intensity with power output lack of oxygen, there will be incomplete combustion. With the grooves on the brass material it provides homogeneous mixture in the chamber and there by higher temperatures. This higher operating temperatures in the combustion chamber result better combustion and oxidation of the soot particles which reduce the smoke emissions. From the above graph it is observed that the brass piston showed the lowest smoke emissions over the entire operating range and the reduction is to be about 19.8 percent. This will increase further with BP6. The drop is about 16 percent compared to BP.

### 2.3.5 Hydrocarbon Emissions

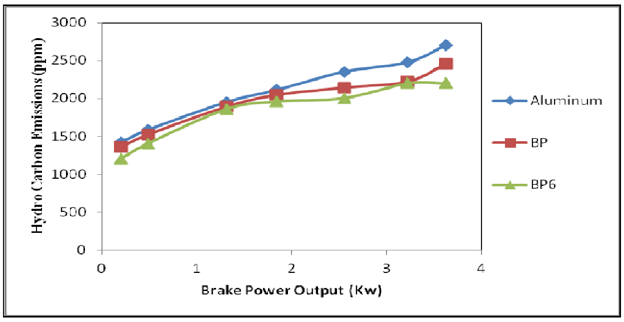


**Fig 10:** Comparison of Hydrocarbon emissions with power output

The Fig 10 depicts the amount of unburnt hydrocarbons present in the exhaust as function of different piston materials. The main sources of these emissions in diesel engine are lean mixing, burning of lubricating oil, and wall quenching. Because of hotter combustion chamber, Hydrocarbon emission formation is found to be less in all the ceramic engines. In spite of rich air-fuel mixture due to the lower volumetric efficiency, the HC emissions are reduced considerably due to the completion of combustion in the combustion chamber. From the graph it is observed that maximum reduction is with BP6 due to its properties and turbulence generated. The reduction is about 6.26 % compared to BP at the rated load.

### 2.3.6 Nitrogen Oxide Emissions

The variation of NOx emissions with various piston inserts of the ceramic engine is illustrated in Fig 11. The formation of the NOx emissions depends on the amount of heat in the combustion chamber and evaporation rate of the fuel. The temperature with BP6 is more due to the turbulence generated in the combustion chamber. This increases the heat transfer between the crown and charge. The formation of the emissions will also increase with the availability of oxygen in the chamber at higher loads. So the increase in NOx emissions with BP6 is about 4% compared with base aluminum piston. The emissions with BP are in between these two extremes.

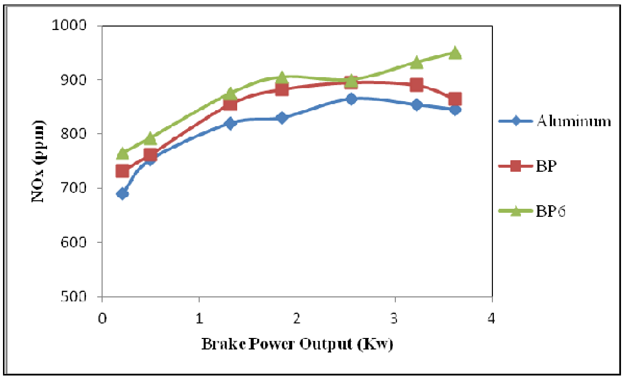


**Fig 11:** Comparison of Nitrogen Oxide emissions with power output

## CONCLUSIONS

1. The bras piston material acts as an insulator with its lower thermal conductivity. With this the heat generated will be stored and supplied back to the incoming fresh charge. This completes the combustion process and increases the exhaust gas temperatures and brake thermal efficiency.
2. With the grooves on the brass piston turbulence is generated in the combustion chamber is more. So the performance of the brass material is good in terms of emissions and efficiency.
3. Lower heat rejection from the combustion chamber through thermally insulated components cause an increase in

available energy that would increase the in-cylinder work and the amount of energy carried by the exhaust gases which could also be utilized.

4. The high temperature of the exhaust indicates the availability of considerable energy in the exhaust gases which could be used to operate a low pressure turbine.
5. Due to the higher prevailing temperatures in the combustion chamber the volumetric efficiency of the engine dropped. This further reduces the amount of air available for the combustion. So the power output is slightly dropped. But this can be compensated with turbocharging system.
6. With the higher temperature in the chamber NOx emissions are more for all the pistons. Among all BP6 generates more emissions with its higher prevailing temperatures in the chamber.
7. With the higher operating temperatures of the ceramic engine, the performance of the lubricating oil deteriorates resulting higher friction. This problem can overcome with new liquid lubricants or solid lubricants.
8. The higher temperature in the chamber enables the use of low cetane fuels and confers the multi-fuel handling capability.

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