The Effect of Turbulence on the Emissions of an Insulated DI Diesel Engine With Insulted Combustion Chamber

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Abstract- ***The available petroleum fossil fuels are rapidly depleting and also creating much pollution. As our country is producing sugar cane more, this leads to the recognition of alcohols as an alternative fuels to diesel in diesel engines because these are derived from indigenous sources and are renewable. However due to alcohols lower cetane number and high latent heat of vaporization, it won't vaporize in the existing diesel engines ; it requires higher temperatures in the combustion chambers for the combustion. So in the present work a thermally insulated engine (IE) is developed which reduces the ignition delay and aids combustion. In an insulated engine, the energy loss is avoided by applying a layer of insulating material over the components (air gap piston and ceramic coated cylinder head, valve and cylinder liner) of the combustion chamber. This improved the efficiency of the engine and further reduces the emissions. Tests are conducted on a single cylinder 4-stroke water cooled 3.68 KW diesel engine with alcohol as a fuel. Due to lower viscosity of alcohol the fuel injection pressure is reduced to165 bar for the experimentation. Further the efficiency of the engine can be improved by providing turbulence in the combustion chamber. So in the present work the turbulence is provided in the combustion chamber with grooves on the piston insert. So during the experimentation brass piston with various numbers of grooves is used on the test engine with an objective to find the best one in terms of performance, emissions and other combustion parameters with alcohol as fuel. For comparison the engine is also operated with brass piston. Out of all these pistons tested, one of them (brass Piston with 9 grooves) is found to be best in terms of efficiency and emissions.***

Keywords: air-gap insulation, alcohol, ceramics, grooves and Insulated engine

I. INTRODUCTION

The self-ignition temperature of alcohols is so high that abnormally high compression ratios would be required to use them in conventional diesel engines [1]. So in order to ignite the alcohols in the combustion chambers, producing of high temperatures are necessary.

This can be achieved by the insulation of the combustion chamber surfaces [2, 3 and 4]. Kamo and Bryzik **[5]** have demonstrated the use of partially stabilized Zirconia (PSZ) as the insulating material have also reported reduction in carbon monoxide, carbon particulates and smoke emission levels.

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Wade et. Al [6] have reported the performance of ceramic coated engine with PSZ to 7% improvement in fuel consumption and reduction in HC emissions due to premixed combustion. Wallace et **[7]** 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 400^0C for the thermal barrier pistons.

The insulated high temperature components include piston, cylinder head, valves and cylinder liner. So the insulating materials used in the combustion chamber should have lower thermal conductivity, good mechanical strength and must capable of withstanding for higher temperatures [8,11]. With the insulation of the engine the exhaust energy is increased 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 insulated engine concept. So in the present work the same insulted engine with brass material as piston insert [9,10] is developed and for further increasing the combustion efficiency grooves has been made on the piston.

II. DEVELOPMENT OF INSULATED COMBUSTION CHAMBER COMPONENTS

The design and fabrication of the insulated components for the combustion chambers is the most difficult part of the work. The PSZ material used is having excellent insulating characteristics, adequate strength and thermal expansion characteristics [2, 5, 6].As per the literature the combustion chamber components like cylinder liner, cylinder head and valves are coated with Partially Stabilized Zirconium (PSZ) with air gap piston. Then the engine is tested with various piston metal inserts like Cast iron, Nimonic alloy, Copper and brass. Among all the brass piston gave the maximum performance in the insulated engine. Then various numbers of grooves are made on the brass piston insert and are tested in the insulated engine.

(a) Piston Insulation

In this design, air with its low thermal conductivity is used as the insulating medium. An air-gap of 2 mm (which is optimized based on the literature) is provided between a metallic crown and the standard piston made of Aluminum alloy [9].

Fig1: Aluminum crown with an air-gap insulated piston with brass insert

The two pieces were separated by gaskets made of copper and stainless steel from the aluminum body and is further fastened by suitable materials. Fig 1 shows the air-gap insulated piston with brass insert.

(b) Cylinder Liner Insulation

The reciprocating movement of the piston within the bore is a hindrance to insulate the liner on its inner surface. In this case air with its low thermal conductivity is used as the insulating medium. A thin mild steel sleeve is 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 are sealed to prevent seepage of cooling water into the air-gap region.

(c) Cylinder Head and valves Insulation

Ceramic coating is a simpler method of insulation for cylinder head compared with other methods.

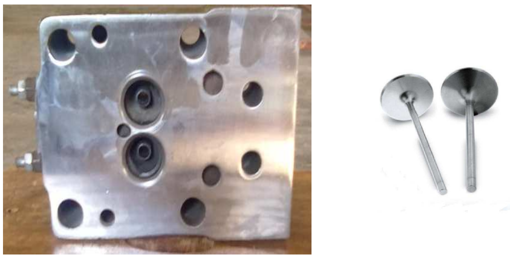

Fig 2: PSZ coated cylinder head and valves

The bottom surfaces of the cylinder head and valves are machined to a depth of 0.5mm and coated with PSZ material of equal thickness [2]. With the valves assembled on the cylinder head the area of the combustion chamber insulated is about 90-92% of the total area. The constructional details of PSZ coated cylinder head and valves are shown in Fig.2.

III. EXPERIMENTAL DETAILS

Experiments are conducted on a 4-stroke, Water-cooled 3.68 KW Kirloskar DI Diesel engine at the recommended injection timing of 27^0 bTDC at various loads. As the self ignition temperature and latent heat of alcohol is more. This will absorb more heat from the combustion chamber and makes it cool. So the engine is tested with liner, Piston, Cylinder head and Valve insulation. The engine is operated 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. The experimental set up is shown in the Fig.3.

Fig. 3. Experimental set up of Insulated Engine Test Rig

Then in the experiments it is observed that among various losses of heat from the combustion chamber, maximum heat loss occurs through the piston. If these losses are reduced, this will increase heat in the combustion chamber and makes the alcohol for complete combustion. So in order to reduce the heat transfer through the piston, a piston is designed (similar to that of original piston) with brass material which is capable of absorbing heat from the hot combustion gases during the peak cycle temperature conditions and gives out the same to the incoming fresh charge during the suction and compression strokes of the next cycle. This improved the combustion efficiency and further thermal efficiency. The combustion efficiency can be further increased with good turbulence in the combustion chamber. So an attempt is made in this work with different number of grooves on the brass crown piston in an insulated engine. The number of elliptical grooves generated on the piston crown depends on the locally available technology (Fig: 4 - 7). The size of the groove is selected in such away that maximum number of grooves can be generated. This brass crown is further knurled to increase its surface area thus facilitating better heat transfer rate from the hot gases to the crown. This can be adapted to any engine without any major modifications to the original design.

Three different number of grooves on the brass crown piston are tried in the present work in order to find the best number of grooves at which the insulated engine gives maximum performance and the same is compared with plain brass piston. The four different configurations of brass piston attempted are as follows.

(i) BP : Plain brass piston

(ii) BP6: Brass piston with 6 grooves

(iii) BP9: Brass piston with 9 grooves

(iv) BP12: Brass piston with 12 grooves

Fig: 4 Photo Graphic View of Plain Brass Crown piston

Fig: 5 Photo Graphic View of Brass Crown Piston with 6 Grooves

Fig: 6 Photo Graphic View of Brass CrownPiston with 9 Grooves

Fig: 7 Photo Graphic View of Brass Crown Piston with 12 Grooves

IV. RESULTS AND DISCUSSION

The clearance volume on the piston increases as the number of grooves on the piston increases. Hence the compression ratio decreases which leads to poor combustion. For 6 grooves the compression ratio is more but the turbulence created in the combustion chamber is less than 9 and 12 grooves pistons. Due this the formation of homogeneous mixture is less and further the combustion is poor. With 9 number of grooves the poor combustion due to reduction in compression ratio is compensated by better turbulence and insulated conditions. But with 12 number of grooves, the relative decrease in compression ratio is more and the turbulence created is more than 6 and 9 groove pistons. Though the turbulence is more, due to lower compression ratio the performance dropped. Further if the number of grooves on the piston is increased the performance further drops. The performance parameters are explained below in detail.

(a) Exhaust Gas Temperature

The turbulence produced in the combustion chamber increases with number of grooves on the piston crown. Exhibit 1 shows the effect of different number of grooves on the piston crown with the exhaust gas temperatures. From the results it is concluded that the exhaust gas temperature of BP configuration is lower than all other piston configurations over a wide range of operation. The insulated engine of BP9 shows maximum exhaust gas temperature at rated loads. BP6 and BP12 also found to be good following the BP9. It is observed that the temperature at rated load for BP9 is 2.32% more than BP.

(b) Brake Thermal Efficiency

The variation of brake thermal efficiency with power output for brass piston with different configurations is as shown in Exhibit 2. The brake thermal efficiency of the insulating engine depends on the combustion efficiency of the engine. This further depends on the formation of homogeneous mixture with turbulence in the combustion chamber. The brake thermal efficiency of BP9 is increased by about 2.53% compared to BP at rated loads. Similarly the brake thermal efficiency of BP6 and BP12 are 0.9% and 1.58% more than BP.

(c) Volumetric Efficiency

The effect of brass piston with different configurations on the volumetric efficiency depicts in Exhibit 3. Due to higher operating temperatures, with insulated components, the intake air is heated to a higher temperature and consequently the mass of air drawn in each cycle is lower, resulting in a decrease in volumetric efficiency. For BP9 of the insulated engine the drop in volumetric efficiency is more and is about 1.2% as compared to BP at rated load. It is observed that the volumetric efficiencies of BP6 and BP12 lie in between BP and BP9. So the drop in power output of an insulated engine can be compensated by supercharging or turbocharging.

V. COMBUSTION CHARACTERISTICS

Insulation to the combustion chamber components results a significant increase in temperatures and reduced knock. This makes the engine to operate with alcohol easily. The combustion efficiency in the combustion chamber can be further enhanced with the turbulence in that. The combustion characteristics are explained as below.

(a) Ignition Delay

The general phenomenon is that with increasing the load the ignition delays are reduced. The variation in ignition delay with power output is illustrated in Exhibit 4. It is observed that the ignition delay of insulted engine of brass piston crown with different number of grooves is lowered as compared with Plain brass piston due to higher turbulence. The effect of this is to reduce the time lag for initiating combustion, bringing down delay periods. The BP9 showed the lowest ignition delay among all the configurations tested and BP shows marginally higher ignition delay. The ignition delay of an insulated engine with BP varies from 20^0CA at no load to about 17^0CA at full load. The reduction in the ignition delay of BP9 is 6.25% at rated load compared to BP. The ignition delay of BP6 and BP12 lies between BP and BP9.

(b) Rate of Pressure Rise

Exhibit 5 depicts the rate of pressure rise with power output. It is observed that the maximum rate of pressure rise is with BP9 and minimum for BP. Due to insulation of various combustion chamber components and higher turbulence, complete combustion occurs and the combustion efficiency increases, consequently higher rate of pressure. At rated load increase in the rate of pressure rise is 1.6% and 3.6% for BP6 and BP9 compared to BP. However the pressure rise for BP12 is marginally lower than BP9.

(c) Smoke density

The variation of exhaust smoke emissions for different piston configurations is as shown in Exhibit 6. The higher prevailing operating temperatures due to higher turbulence in the insulated combustion chamber result better combustion and oxidation of the soot particles which further reduce the smoke emissions. Due to the complete combustion of alcohol with excess air the smoke emissions are marginal. At the rated load, the smoke emissions of BP9 in the insulated engine are reduced by about 9% compared to BP. It is seen that the reduction in the smoke emissions of BP6 is 4.34% and for BP12 it is 6.62% compared to BP.

(d) Hydrocarbon Emissions

The variation of the hydrocarbon emissions for the insulated engine with different number of grooves on the brass piston is as shown in Exhibit 7. The hydrocarbon formation in the insulated engine is less compared to normal engine because of hotter combustion chamber with insulation and turbulence by the grooves on the piston and the presence of oxygen with alcohol. At the rated load with BP9 a maximum reduction of hydrocarbon emission level is observed and is about 9.26% compared to BP. It is also observed that with BP6 and BP12 the reduction in hydrocarbon levels is about 2.9% and 7% compared to BP.

(e) Carbon Monoxide Emissions

With the higher turbulence and temperatures in the combustion chamber the oxidation of carbon monoxide is improved due to the presence of oxygen in the alcohol fuel which reduces the CO emissions. Exhibit 7 shows the effect of different number of grooves on the carbon monoxide emission levels in the insulated engine. The lowest carbon monoxide emission is with BP9 configuration compared to BP configuration and about 8% by volume at rated load. For the other configurations the values varies in between these two extremes.

(f) Nitrogen Oxide Emissions

The variation of NOx emissions with various configurations of the insulated engine is illustrated in Exhibit 8. With the higher temperatures in the combustion chamber the rate of NOx formation is more. But with the evaporation of alcohol the temperature reduces in the combustion chamber. So the NOx formation is more with BP9 and is about 3.4% more than BP at rated load. Compared with BP the increase in NOx emissions by BP12 and BP6 are 0.9% and 1.4% at rated load.

V. CONCLUSIONS

Based on the experimental results with brass crown piston with different number of grooves in an insulated engine, the following conclusions are drawn:

- The brake thermal efficiency of BP9 is increased by about 2.53% compared to BP at rated loads.
- Due to higher temperatures in the combustion chamber with turbulence, the drop in volumetric efficiency of BP9 is more and is about 1.2% as compared to BP at rated load.
- With higher temperatures in the combustion chamber the reduction in the ignition delay of BP9 is more and is about 6.25% at rated load compared to BP.
- Due to the higher operating temperatures and with the oxygen present in the combustion chamber, the smoke, CO, CO2 emissions are reduced for BP9 in the insulated engine compared to BP at rated load.
- Though higher turbulence increases the temperatures in the combustion chamber this is dominated by the higher latent heat of alcohol. So the NOx formation is 3.4% higher for BP9 than BP at rated load.

It is concluded that out of four different number of brass piston configuration tested Brass piston with nine number of grooves proved to be good in all respects.

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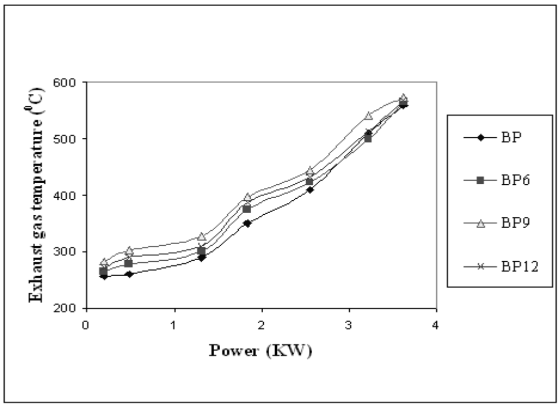

Exhibit 1: Comparison of Exhaust Gas Temperatures with Different Number of Grooves on the Brass Piston

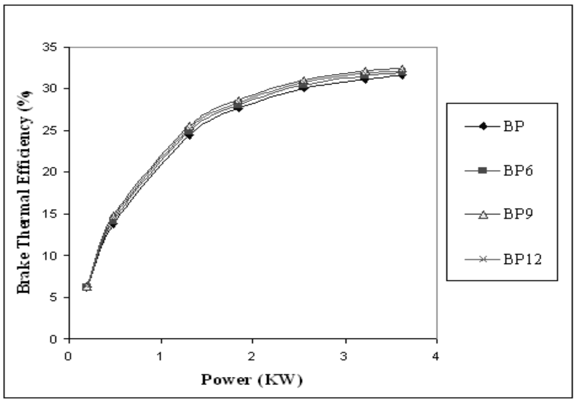

Exhibit 2: Comparison of Brake Thermal Efficiency with Different Number of Grooves on the Brass Piston

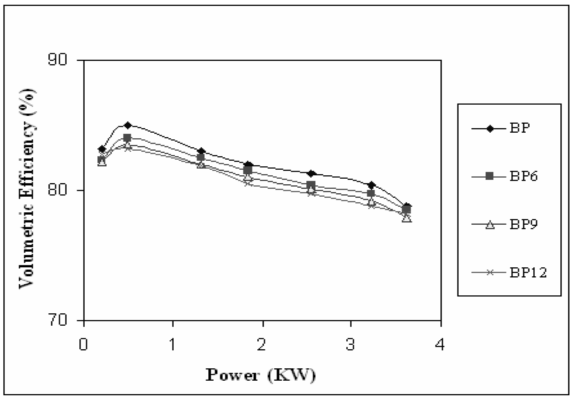

Exhibit 3: Comparison of Volumetric Efficiency with Different Number of Grooves on the Brass Piston

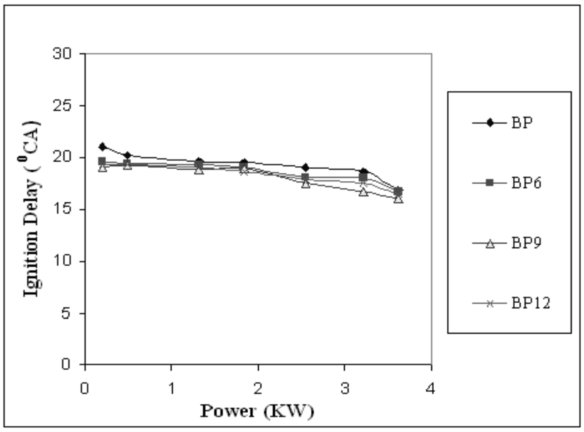

Exhibit 4: Comparison of Ignition Delay with Different Number of Grooves on the Brass Piston

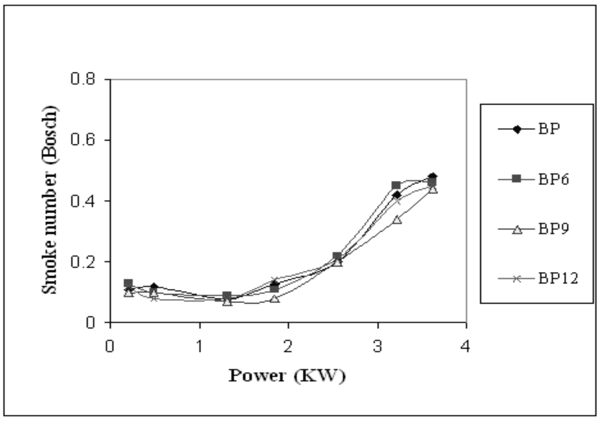

Exhibit 5: Comparison of Smoke Densities with Different Number Of Grooves on the Brass Piston

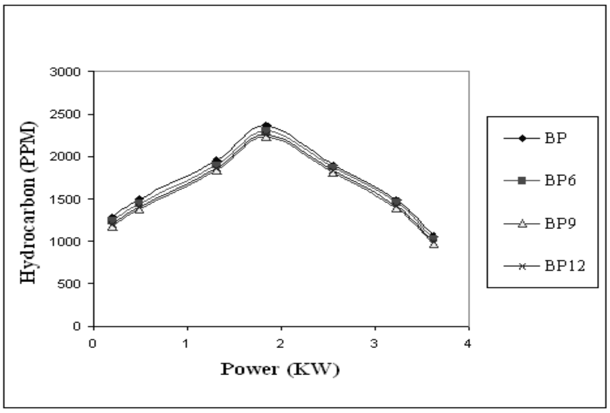

Exhibit 6: Comparison of Hydrocarbon Emissions with Different Number of Grooves on the Brass Piston

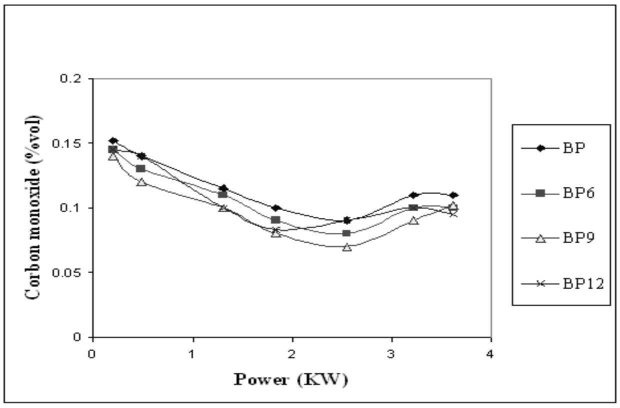

Exhibit 7: Comparison of Carbon Monoxide Emissions with Different Number of Grooves on the Brass Piston

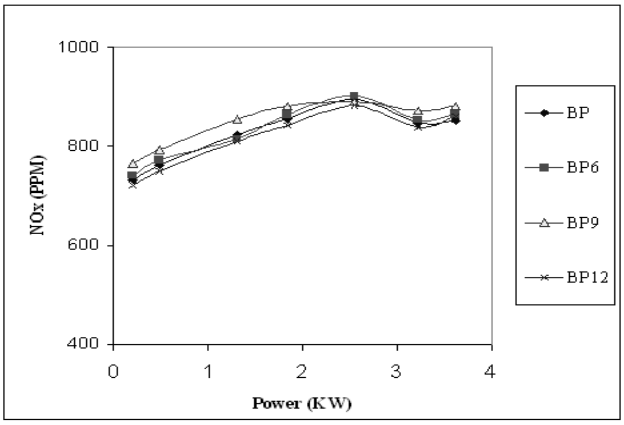

Exhibit 8: Comparison of NOx Emissions with Different Number of Grooves on the Brass Piston