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Partially Stabilised Zirconium Nano Coating Piston and Head Surface Used Experimental Investigation on Ethanol Blend with Peg (7.5) Direct Injection in High Compression Ignition Engine

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Abstract: - **This research article focused on partially stabilised zirconium nano-surface coating for piston head and cylinder head surface to perform the experimental investigation on direct-ethanol blend with 7.5 percent by mass of polyethene glycol (PEG7.5) fuel injection in the high compression ignition (EDICI) engine. NOx and soot emissions should be minimised while still increasing fuel economy. EDICI also removes NOx and soot, resulting in a low equivalence ratio and low flame temperatures. For starters, reaction rates are related to temperature and equivalence ratio. Injection, evaporation, and mixing processes are also involved in combustion. The pollution rating of the engine is used to investigate the engine's effect on emissions. The primary goal of this research article is to improve the engine's thermal efficiency. Just one-third of the energy in the fuel is converted into proper operation. This investigation was carried out in order to carry out this mission. As opposed to the uncoated engine, the coated engine's BTE (BTB) improves. Thermal conductivity is poor in the ceramic coating. Productivity increased as a result of the reduction in a wall surface. The variance of BTE is determined by thermal conductivity. BTE is 6.1 percent for 8YSZ + Al2O3 + TiO2**

Keywords: Surface coating, high compression, compression ignition, direct-ethanol injection

INTRODUCTION

Thermal barrier coatings are becoming increasingly efficient and necessary in developing multi jet engines to improve engine temperatures and performance[1]. The mechanical properties of coated and uncoated stainless steel samples were compared[2]. The coated samples' hardness values are ten times higher than the hardness values of the uncoated samples. Scanning electron microscopy was conducted to measure the coating's microstructure and surface morphology [3][4]. A thermal cycling test tested thermal barrier coating (TBC). Finally, the evaluation of coated and uncoated engines was tested at various load conditions. The BTE of the VCR engine was improved by 5.99 percent[5]. Decreased brake specific fuel consumption by 0.06 kg/kWh while increasing brake wears carbon resistance [6][7]. The thermal barrier coating is improved for engine oil and transformer oil. Nitrogen has removed by zirconia leads to lower emission of nitrogen oxide (NOx)[8].

The diesel engines' thermal efficiency can be raised by decreasing heat transfer to the surrounding heat sink[9]. The heat will move from the combustion chamber to the piston, to the combustion chamber walls and then to the cooling water jacket circulating the engine. The heat transfer from the combustion chamber to the pistons can be reduced in this process. It promotes the design of low internal friction pistons and sleeves[10][11]. Low Heat Rejection engines are highly efficient power plants. It can be understood by applying ceramic-coated aluminium pistons and cylinder walls[12]. They have low thermal conductivity, thus lower heat convection to the coolant, reducing heat transfer to the water. As the cylinder cooling losses are minimised, most of the cylinder's heat is transported outside the engine[13].

Recovering the heat of the exhaust gas can increase the thermal performance of a low heat rejection engine. However, it has also been installed an engine that rejects high heat. However, this should not be for the engine setup. Even without such devices, at least some heat is transferred to work and improves thermal efficiency[14]. It is essential to learn how LHR engines with exhaust heat recovery systems.

The hottest burning gas temperature in an internal combustion engine's cylinder is 1200 degrees Kelvin (K). To ensure the engine is subjected to much lower temperatures than are allowed inside engine cylinders, engine parts need cooling. These conditions create high amounts of heat fluxes into the chamber during the combustion process. Flux varies significantly by locale—these areas of combustion show enormous numbers of ions. The occurrence of fatigue failures will be minimised in regions with high heat flux. Heat transfer affects the engine output. Heat flux to the combustion chamber walls would lower the average combustion gas temperature and pressures and eliminate reciprocating work. The size of engine heat transfer would influence strength and reliability. The temperature of the exhaust affects the speed of the compressors. The air and water pump power demand are determined by the amount of heat rejected by the system: the smaller the fan size, the lesser the cooling demand. During the intake process, some air has entered the system colder than the walls as charge compression increases charge temperature above the wall temperature. Heat transfer is now transferred to the chamber walls from the cylinder gases. During combustion, combustion gases' temperature increases significantly when the heat transfer rates are maximum. As expansion happens, the heat transfer rates also decrease. There is substantial heat transfer from the hot exhaust gases to the engine's valves and ports during the exhaust operation[15].

2. COATING MATERIALS

These two problems most definitely hinder the LHR engine. Higher temperatures are the reason why traditional metal and lubricants usually struggle. This is what has spurred the LUCC research and development by LHR. Principal sources of interest include nitrides, carbides, oxides of silicon, chromium, aluminium, iron, and stabilised zirconium oxide ($ZrO2$, or PSZ). Existing materials like metals have a property called ductility and bending, but new materials may attain similar properties. The conventional piston and cylinder tension makes the application of ceramics difficult. The huge piston ring filling produces enormous pressures and forces. New technologies must be developed in the engine, engine management system, and other components to reduce these powers. Different experimentalists have developed both monolithic ceramics and chemical coatings for LHR engines. It is another thermoplastic resin that can withstand high temperatures. This coating is used to provide thermal insulation for some industries like power generation, transportation and energy. It has been found to improve thermal efficiency and reduce NOx levels in diesel engine's piston heads.

3. PARTIALLY STABILISED ZIRCONIA (PSZ)

Partially stabilised zirconia comprises two solid ones: cubic Zirconia (cZrO2) and metastable tetragonal Zirconia (MStZrO2), a medium between them called partially stabilised zirconia. Significant addition of stabiliser can introduce a tetragonal structure to the pure zirconia when it is heated above 1,000°C and can bring cubic and monoclinic structures at lower temperatures. It is also called partly stabilised Zirconia (TZP). A typical PSZ would have more significant amounts of MgO, CaO, and YO3; and less MgO. PSZ is resilient. Driven tension and micro-cracks may be two approaches to explain the fracture toughness improvement of partially stabilised zirconia. Micro crystallite appears due to the disparity of the thermal expansion between cubic crystallite and monoclinic form. The In-Cylinder coefficient of thermal expansion is 6.5 to 6.6/°C for the monoclinic form and 10.5 to 10.6/°C for the cubic form. This lead to the quivering decrease of the frets of propagating cracks. This model explains the induction stress as a monoclinic transition starting at 1200°C. In PSZ, PZO is metastably held at high temperature and takes the tetragonal step. Compressive force holds the tetragonal solids. Effects of propagating stress fractures from mining or road travel may affect the Metastable tetragonal transition to the stable monoclinic zirconia. This change would slow down the spreading of cracks. Partially Stabilised Zirconia is used where it is needed very high temperatures and pressures. The low thermal conductivity (about 8 Btu/ft2/in/°F at 1800°F) means low heat losses, and the high melting point allows the Stable Zirconia to be used at temperatures of about 2,200°C (4000°F) in neutral or oxidising environments. Above 4000° C, in contact with the carbon, zirconia becomes zirconium carbide. Zirconia is outstanding crucible steel; plus, many metals do not wet it. I have used it on alloys and rare metals. Paz (refractories) are also available in many industries and fields. This source is often used experimentally as cylinder liner, piston cap and valve seat parts.

4. EXPERIMENTAL SETUP

A schematic figure in the study is seen in fig.1 and 2. Experimental works were performed on a four-stroke, single-cylinder, water-cooled, and direct injection diesel engine coupled on an eddy current dynamometer. To measure exhaust temperature, nitrogen oxide, carbon monoxide and unburned hydrocarbons are measured in the exhaust pipe. The temperature of the exhaust gases of the engine is calculated using a digital thermocouple form. The NOX concentration is calculated using the NOX analyser in carbon monoxide measurements and unburned hydrocarbon using the infrared analyser. We used an optical stopwatch and a burette to calculate the fuel intake. These trials are done at

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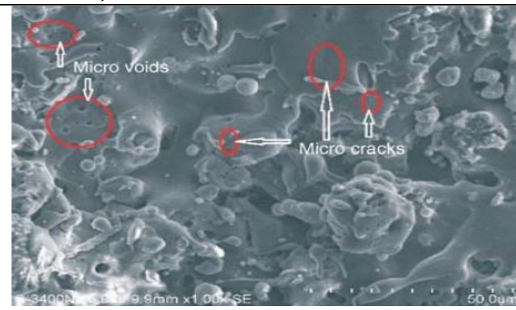
varying g load levels from zero to full load with coated pistons and uncoated pistons with different fuel additives (wet ethanol, diesel).

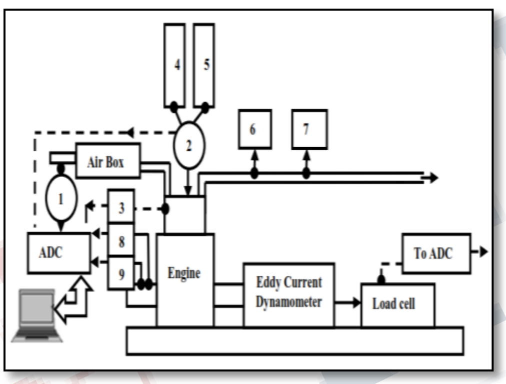
A

Piston before and after coating and coated samples



B The SEM micrographs of Al2O3 + TiO2 + +.8YSZ coated surface

Figure 1 (A and B) Piston before and after coating and coated samples, The SEM micrographs of Al2O3 + TiO2 + +.8YSZ coated surface



A

B

Figure 2 – Experimental layout and single cylinder Test setup

Table 1.1 Specification of Experimental setup

Make & Model	Kirloskar diesel oil Engine, TV1
Research Engine Type	Four strokes/water-cooled / CI engine.
Number of cylinder/ Bore/Stroke	One / 87.5 mm /110 mm.
Compression Ratio Diesel/ Ethanol fuel	Diesel 17.5:1/ Ethanol 28.54:1
Engine Displacement/ Connecting Rod Length	661 CC / 234 mm
In-cylinder pressure limit	0 to 240 bar
Engine Direction of rotation/ Speed	Clockwise/ 1500rpm to 1600rpm
Fuel injection timing Diesel fuel engine	23^0BTDC (Adjustable)
Inlet / Exhaust Valve clearance	0.18 mm /0.20mm
Type /Engine oil Lubricating system	Gear type/ Force feed system
Oil Sump capacity /Lubricating oil pump delivery	2.70 liters/6.50 lit/min

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5. EXPERIMENTAL PROCEDURE

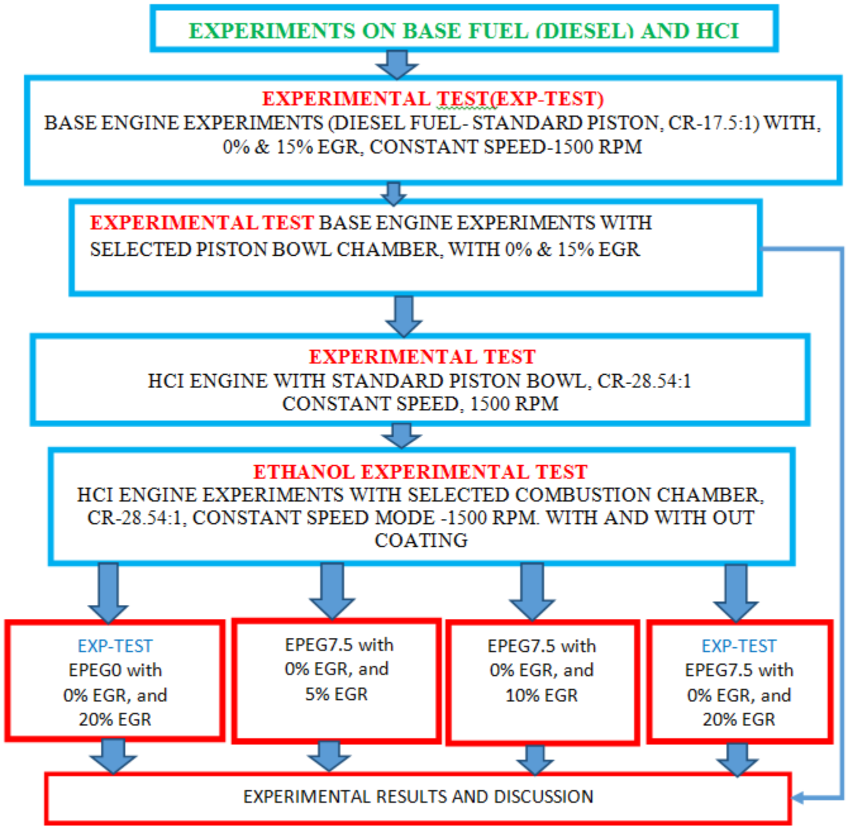

Fig:3 Experimental Methodology

The procedure for setting up the experiments is discussed in detail below. The tanks are loaded correct amount of the requisite fuel from the start. Eddy current dynamometer stator coils, a water pump is turned on. The devices such as the nitric oxide (NOx) sensor and carbon monoxide (CO/HC) detector are attached to the exhaust system. It is turned ON and put in constant torque mode. The engine has been started, allowed to run and attained steady-state status. The time of 25cc standard ethanol intake was measured using a stopwatch. These elements are measured using an infrared analyser and a NOx metre. The temperature of exhaust gas is noted. Operation No. 6, No. 7, No. 8 was repeated for diesel fuel too. This is the procedure replicated with different load, and respective readings are taken. In this way, the engine parts were taken apart. The constructed cylinder head, piston heads and chambers were completed. The same experiment was done to estimate the efficiency of a new engine built with a zirconia coating.

5. RESULTS AND DISCUSSION

Based on this experimental investigation, the following conclusions are arrived at and showed in Figure 4. The variation of BTE of base fuel engine and EPG7.5 mode test showed in Figure 4.

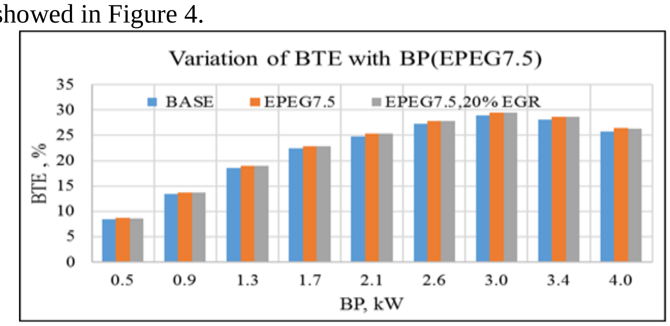

Fig: 4 Brake thermal efficiency Vs Brake Power kW

In Fig. 4, the difference of BTE with break Power for both uncoated and thermal barrier coated engines is seen. The coated engine's BTE (BTB) rise as it is compared with the uncoated engine. The ceramic coating has poor thermal conductivity. Due to the decrease in a wall surface, productivity was improved. The variation of BTE depends on

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the thermal conductivity. For 8YSZ + Al2O3 + TiO2, BTE reaches 6.1 percent. In fig.6, the difference of brake specific fuel consumption with brake power with differing load for the coated and uncoated engine is shown. Engine efficiency decreased strongly with increased load on the engine, applied to either coated or uncoated engine. TBC coating hurts the performance of the TBC engine. This is because of elevated temperatures in-cylinder gas and walls, resulting in higher temperatures in the combustion chamber. As the burning period becomes more desirable, decreasing ignition latency, chemical and physical reactions are accelerated, causing the BSFC to be lower than uncoated engines. The engine with the BSFC coating thermal barrier seemed to grow compared to the engine without any thermal barrier. For 8YSZ + Al2O3 + TiO2, the thermal efficiency is decreased by 0.06 kWh.

From Figure 7, it can be shown that the unburned HC emissions are less when the engine is run with the coated piston. When the engine is running without the coating, the unburned HC emissions are marginally higher. At high temperature, the HC in the mixture can increase proportionally. Because of this, the HC will decrease its CO2 emissions due to mixing O2 with it. The braking effect on carbon emissions. Figure 14 shows the difference of brake torque with CO emissions with uncoated and TBC engine. The heat barrier coating in the piston crown shows declining CO emissions compared with uncoated engines. The carbon monoxide is reduced after the coating due to the complete combustion. CO is a test of combustion inefficiencies. At high temperature, carbon readily mixes with oxygen, producing carbon dioxide.

The amount of the 8YSZ is reduced by 4.8 percent due to adding Al2O3 to the NOx engine brake effect. In figure 15, it can be shown that the varying NOx with break power is seen. The major contributor to NOx pollution is gas temperature and residence time. Studies show that NOx output from low heat rejection engines is typically higher than that from high heat rejection engines. This is attributed to higher temperatures and a more extended burning period. However, a more significant reduction in NOx was found because nitrogen is absorbed by zirconia. Generally, diesel has a high amount of oxygen content so that nitrogen can mix with oxygen quickly at high temperatures. Since nitrogen is very scarce, it does not affect the NOx.

5.1 ENGINE PERFORMANCE

Zirconia is a low thermal conductivity material. It will be a barrier for the heat transfer to the engine's combustion chamber's surroundings and reduce the engine's heat loss. Also, in Energy balance in thermodynamics' first law, the heat reduction in heat loss will ultimately increase the engine's power output and thermal efficiency. Out of the four curves shown in the graph, two diesel curves and two curves for ethanol are engine fuel. From fig; 6.1, it is clear that the thermal brake efficiency of the engine for both diesel and ethanol is slightly increased after coating. For ethanol, the thermal brake efficiency is increased by 1.64%. For diesel, the thermal brake efficiency is increased by 3.26%.

5.1.1 TOTAL FUEL CONSUMPTION (TFC)

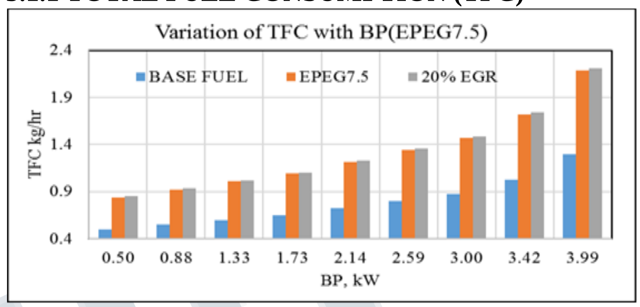

Fig: 4 TFC Vs Brake Power kW

Figure 6 shows that it is clear that the total fuel consumption of the engine after the coating is reduced. This will increase the thermal brake efficiency of the engine. TFC is reduced due to the reduction of the heat loss to the surroundings of the engine. There will be excess heat in the engine compared with the amount of heat without coating, thereby increasing its thermal brake efficiency. Also, it is suggested that the TFC is reduced up to some extent, and it is increased for higher power requirement. For the ethanol, it is low, up to 4kW. After that, it starts increasing. However, in the case of diesel, this problem will not happen.

5.2 SPECIFIC FUEL CONSUMPTION (SFC)

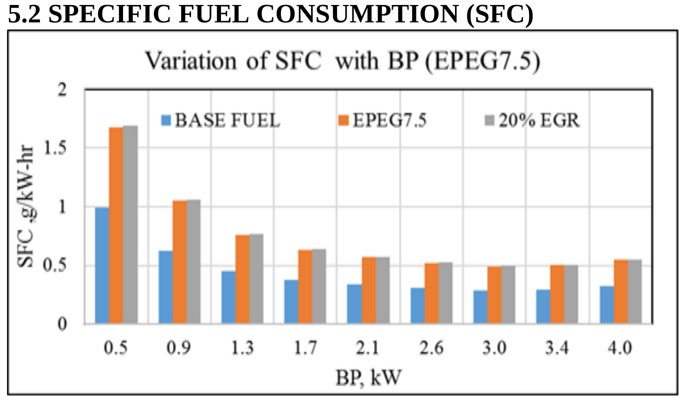

Fig: 5 SFC Vs Brake Power kW

From fig.5, it is clear that SFC is decreasing after the coating due to the reasons that are discussed in the previous headings 6.2, 6.3. There is a slight variation in the curve for ethanol's SFC before and after coating. The reduction in SFC is 0.304 kg/kW hr after coating for ethanol. However, there is a minimal variation in the reduction of SFC (i.e.) 0.033 kg/kW hr.

5.3 NOX EMISSIONS

From fig.4, it is clear that there is a more significant reduction of Nitrogen oxide due to coating because nitrogen has absorbed by zirconia.

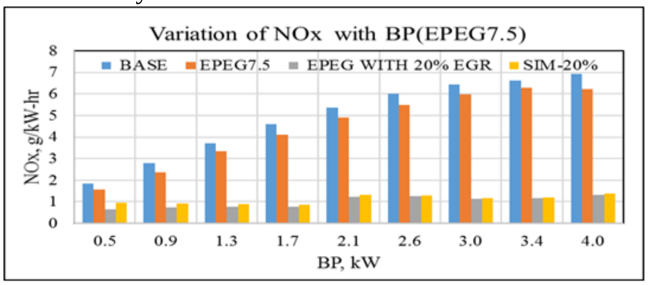

Fig: 6 NOx Vs Brake Power kW

Even though the availability of oxygen high, but the availability of nitrogen is significantly less in the presence of impurities; generally, diesel oxygen availability is high, so nitrogen effortlessly combines with oxygen at high temperatures, but nitrogen availability is significantly less due to coating and produces low NOx. It is investigated that at part load (up to 2 KW), the NOx emissions are slightly increased for the engine with and without coating, but there is a considerable reduction in NOx after coating compared to without coating. There are rapid increases of NOx above 2 KW load and a more significant NOx reduction with coating. For ethanol, it is clear that there is a slight reduction of nitrogen oxide due to coating. It is found that at part load (up to 2 KW), the NOx emissions are almost the same for the engine with and without coating. There are slight increases of NOx above 2 KW load for both cases and considerable NOx reduction with coating. Based on experiments and simulation results analysis, the following conclusions are presented: 1) NOx of EPEG7.5 with 20% EGR mode is 79.4 % less than 0% EGR. 2) NOx of EPEG7.5 with 20% EGR mode is 86.5% lower than the base engine. 3) NOx of EPEG7.5 with 20% EGR is 7.4% lower compared to simulation results

5.4 CO EMISSIONS

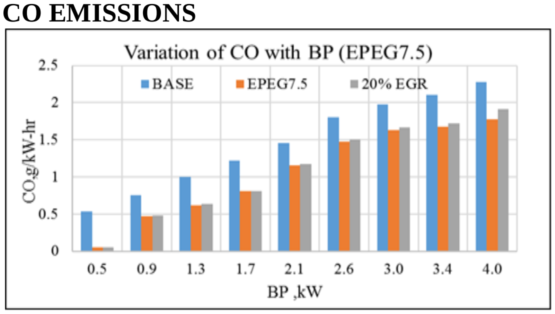

Fig: 7 CO Vs Brake Power kW

From figure 7, it is clear that CO is decreased after the coating due to the complete combustion. Carbon monoxide, which arises mainly due to incomplete combustion, is a measure of combustion inefficiency. Generally, diesel oxygen availability is high, so at high temperatures, carbon effortlessly combines with oxygen and reduces CO emission. It is found that at part load (up to 3 KW), the CO emissions are the same for the engine with and without coating. Moreover, there is a slight increase of CO at complete load condition when it runs without coating conditions. Hence, in the case of an engine with a ceramic coating, the CO emission is reduced. For ethanol also the same process as that of diesel occurs. It is observed that using ethanol with and without coating gives much less CO emission than diesel with and without coating.

5.5 UNBURNED HYDROCARBON EMISSIONS

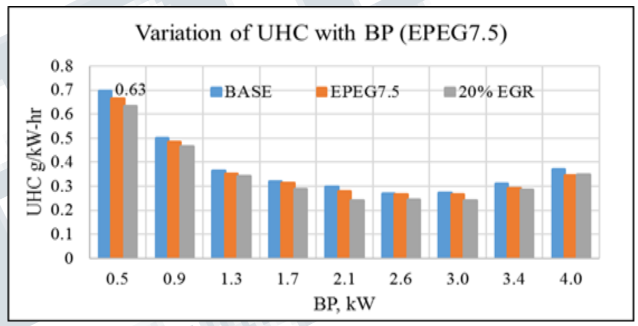

Fig: 8 UBHC Vs Brake Power kW

Figure 8 shows that it is clear that the unburned hydrocarbon emissions are reduced when the engine runs with coating. The unburned HC emissions are slightly higher for both the fuels when the engine runs without the zirconia coating. The main reason for this reduction in the unburned HC emissions is that the engine will have sufficient oxygen at high temperatures, which mixes with the HC emissions. Experimental results showed that the UBHC would split into H and C, which mixes with O2, reducing the HC emissions.

5.6 EXHAUST GAS TEMPERATURE

Figure 7 shows that it is inferred that the exhaust gas temperature is higher for the engine runs under zirconia coated conditions than the engine runs under normal conditions. This is due to the more heat generated inside the engine casing in which all amount of heat cannot be converted into practical work. Exhaust temperature increase under this condition because its heat is mixed with the exhaust gas.

5.7 CORROSIONS

Wet ethanol contains 5% water content. Due to this, the piston top surface and cylinder head bottom surface gets corroded. However, this can be eliminated by applying the zirconia coating on the piston top and cylinder head bottom surfaces. This can be noticed from fig. 6.8 before and after the zirconia coating.

6. CONCLUSIONS

The mechanical properties of coated and uncoated stainless steel samples were compared. The hardness values of the coated samples were surprisingly much higher than the value of the uncoated samples. The estimated value of adhesion power of prepared samples was 65 MPa. As subjected to thermal cycles 100 times, cracks and spallation were observed on the surface and the plastic coating interface. The efficiency of the TBC engine primarily depends on the thermal conductivity of the materials. For 8YSZ + Al2O3 + TiO2 BTE is increased by 5.99%. The BSFC in the TBC engine was decreased. For 8YSZ + Al2O3 + TiO2, the equipment's brake wear is decreased by 0.06 kg/kWh. There was a considerable drop in CO in TBC engines. Nitrogen has removed by zirconia leads to lower emission of nitrogen oxide.

Nomenclature

CFM Cycle Fuel Mass
DI Direct Injection
EGR Exhaust Gas Recirculation
FP Friction Power
GHG Green House Gas
HSU Hartridge Smoke Unit
HC Hydro Carbon
IMEP Indicated Mean Effective Power
IP Indicated Power
ITE Indicated Thermal Efficiency
IDI Indirect Injection
ICE Internal Combustion Engine
ISO International Standard Organisation
MTBE Methyl Tetra Butyl Ether
NWR Near Wall Flow
NOx Nitrous Oxide
NDIR Non-Dispersive Infrared Analyser
PM Particulate Matter
PEG Poly Ethylene Glycol
SFC Specific Fuel Consumption
SOC Start of Combustion
SOI Start of Injection
SR Swirl Ratio
Ut Swirl Tangential Speed
TDC Top Dead Center
TFC Total Fuel Consumption
UHU-Unburned Hydro Carbon

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