ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
Vol 2, Issue 6, June 2017

Analysis of In-Cylinder Pressure, NOX Formation with CA of EPEG5.5-7.5% Fuel HCI Engine with Surface Coating

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Abstract: - **The research paper focused on analysing in-Cylinder pressure, NOx formation of three different fuel combinations like EPEG 5.5, 6.5 and 7.5. The combustion process in a CI engine is divided into four stages. These are as follows, Ignition Delay, Rapid pressure rise or period of uncontrolled combustion, Controlled or constant pressure rise, burning of the expansion stroke. The variation of in-cylinder pressure with crank angle plotted concerning CA. Experimentally analysis of In-Cylinder pressure and heat release rate for the single-cylinder engine. NOx emissions of the EPEG7.5 fuel engine are 10.23% lower than the base fuel engine and 2.5% lower than the EPEG6.5 fuel engine. NOx emissions of the EPEG7.5 engine are 5.39% lower compared to the EPEG5.5 fuel engine. NOx emission of four ethanol test fuels follows a similar trend for without EGR mode when load increasing from 0.5 to 3.99 kW. In-Cylinder Pressure variation concerning crank angle for CFMs of 0.0256, 0.0327 and 0.0338 g/cycle. It can be observed from the experiments that the in- Cylinder peak pressure are attained near TDC, and the in-cylinder pressure with CA with 20% EGR mode is slightly less than without EGR.**

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

INTRODUCTION

In CI engine air alone, it is compressed and raised to high temperature on the compression stroke, and fuel pressure increases by fuel pump from 310 to 600bar and introduced into the combustion chamber [1]. Performance and emission characteristics of four ethanol test fuels results were used to find the variation of TFC, SFC, BTE, CO, UHC and NOx for all test fuels and plotted with BP and comparison are shown [2]. 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]. Variation of TFC of Base engine, EPEG0, EPEG5.5, EOEG6.5 and EPEG7.5 are obtained from experiment results and plotted with BP shown in Figure 8. TFC of base engine is increased from 0.5 to 1.3 kg/hr. The TFC of the EPEG0 engine is increased from 0.77 to 2.01 kg/hr. TFC of EPEG5.5 fuel engine increased from 0.980 to 2.549 kg/h and TFC of EPEG6.5 engine is increased from 0.85 to 2.21 kg/h. TFC of EPEG7.5 is increased from 0.84 to 2.18 kg/h when the load is increased from 0.5 to 3.9kW.

Based on this experiment results analysis, the following conclusions are arrived: 1) TFC of EPEG5.5 fuel engine is 1.69 times higher fuel consumption than the base fuel engine due to low heat energy per unit mass of the fuel compared to diesel. 2) The TFC of EPEG0, EPEG5.5, EPEG6.5, and EPEG7.5 are higher than the base fuel engine. 3) TFC of the EPEG0 fuel engine is 1.68 times higher than the diesel fuel engine due to low heat energy per unit mass of ethanol test fuels compared to diesel fuel. 4) Based on this investigation, four ethanol test fuel consumptions are nearly 1.67 times higher than diesel fuel engine. 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 (ZrO_2, 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 ($cZrO_2$) and metastable tetragonal Zirconia ($MStZrO_2$), 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 YO_3; 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

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
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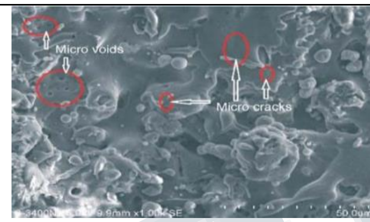
carbide. Zirconia is outstanding crucible steel; plus, many metals do not wet it. I have used it on alloys and rare metals. Paz (refractories) are also available in many industries and fields. This source is often used experimentally as cylinder liner, piston cap and valve seat parts.

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.

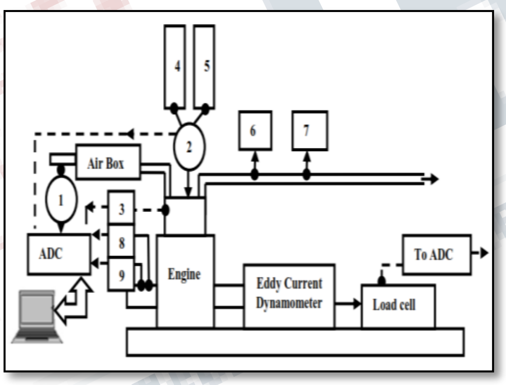
A 

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

5. EXPERIMENTAL PROCEDURE

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International Journal of Science, Engineering and Management (IJSEM)
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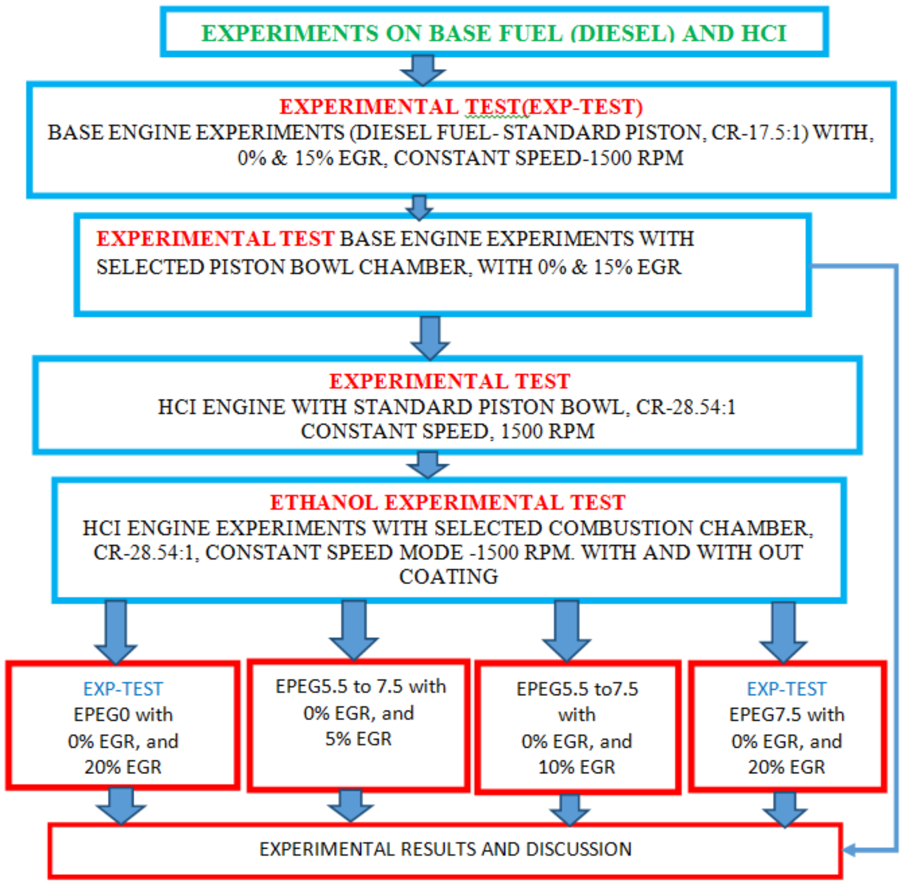

Figure:3 Experimental Methodology

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.

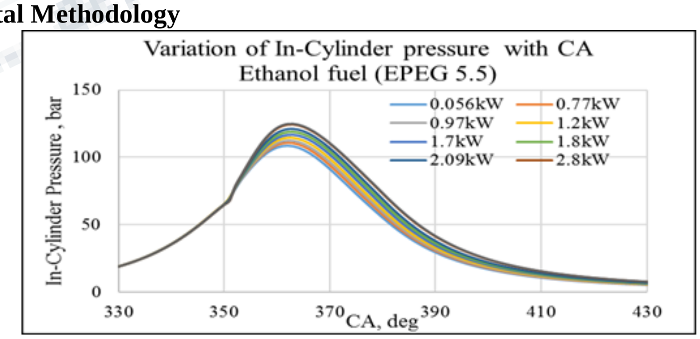

Figure 4 In-Cylinder Pressure Variation with CA of EPEG5.5.

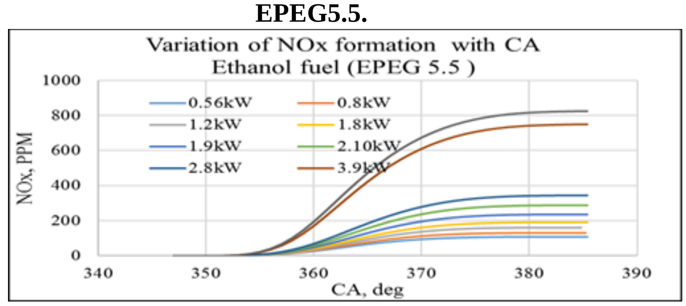

Figure: 5 Variation of NOx formation with CA of EPEG5.5 fuel engine

The variation of NOx plotted concerning brake power (kW) for the BASE, EPEG0 and EPGE0 with 20% EGR engines Brake Power (BP) various from 0.5 kW to 3.99kW. It is found from figure2., that there was an increase from 0.1.6g/kWh to 6.95 g/kWh with an increase in load from 0.5kW to 3.99 kW. EPGE0 fuel test was found from the figure; it can be seen that fuel consumption was higher than base fuel engine due to 1.6 times lower energy compare to base diesel fuel. It can be observed from figure 2 with a 20% EGR mode of operation, fuel consumption slightly increased, but NOx emissions are lower than Base fuel. Variation of NOx plotted concerning brake power can be seen from Figure 2 for the BASE, EPEG0 and EPGE0 with 20% EGR engines Brake Power various from 0.5 kW to 3.99kW.

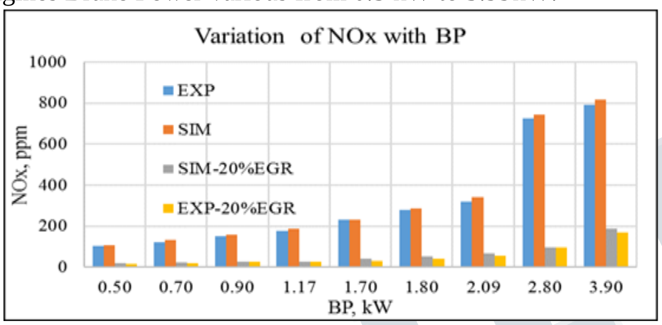

Figure 6 Variation of NOx with BP of EPEG5.5 fuel engine

It was found from figure 6, that there was an increase from 0.1.6g/kWh to 6.95 g/kWh with an increasing load of 0.5kW to 3.99 kW. EPGE0 fuel test was found from the figure; it can be seen that fuel consumption was higher than base fuel engine due to 1.6 times lower energy compare to base diesel fuel. It can be observed from figure 6, with 20% EGR mode of operation fuel consumption slightly increased, but NOx emission is decreased when compared with Base fuel.

5.2 Analysis of In-Cylinder Pressure, NOx Formation with CA of EPEG6.5 Fuel Engine

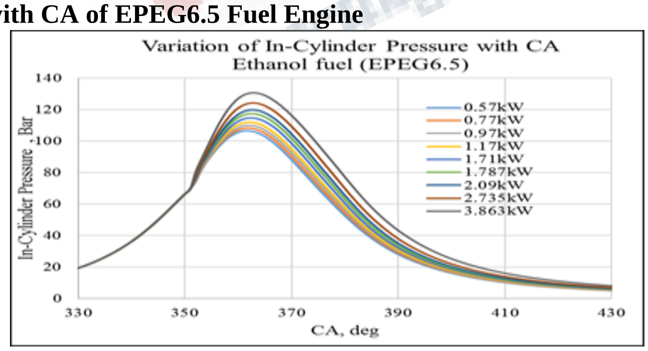

Figure 7 Variation of in-cylinder pressure with CA of EPEG6.5 fuel engine

The variation of in-cylinder pressure plotted concerning CA is shown in Figure 7. Pressure Vs CA diagram was used to compute the heat release rate, ignition delay, and combustion duration. It is found that in-cylinder peak pressure is attained a few angles after TDC and the maximum peak pressure is 130 bar at complete load condition. In-cylinder pressure is increased when increasing load from 0.57 to 3.86kW. It is found from the figure, test fuels, namely EPEG0, EPEG5.5, and EPEG6.5 pressure concerning crank angle, followed the same trend for all four test fuels, but peak pressure is slightly different.

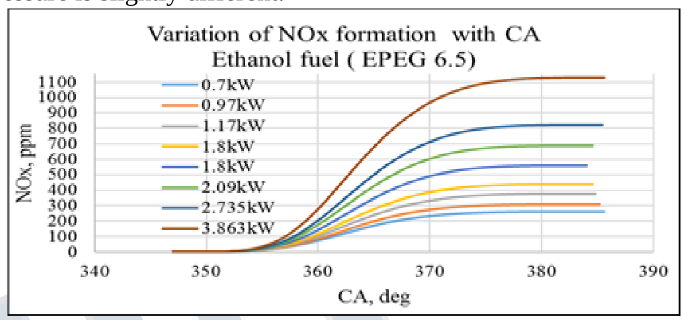

Figure 8 Variation of NOx formation with CA of EPEG6.5 engine

The variation of NOx formation plotted concerning crank angle is shown in Figure 8. NOx of the EPEG6.5 engine varied from 50 to 1131 PPM when the load increased from 0.7 to 3.9kW. It is also observed that the NOx formation rate is increased with increasing load. The experimental and simulation variation of NOx plotted concerning BP is shown in Figure 8

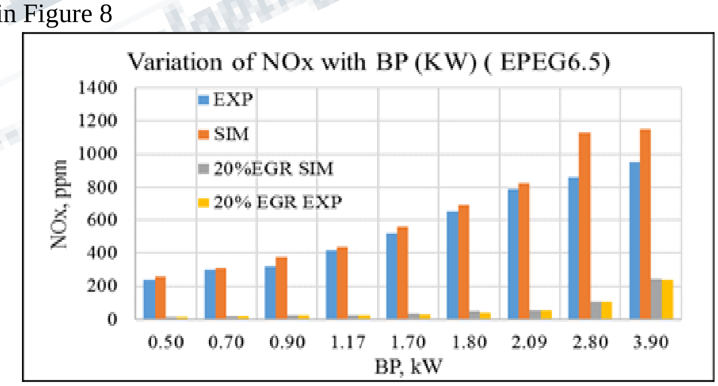

Figure 9 Variation of NOx with BP of EPEG6.5 fuel engine

From Figure 9, the Variation of NOx plotted with BP can be seen in Figure 8.48. Results of simulation, 20% EGR simulation and 20% EGR experimental results are plotted with BP as shown in Figure 8.48. It is found from the figure 8.48 EPEG6.5 with 20% EGR experimental mode is 2.25% lower compared to simulation but 74.7% lower compared to 0% EGR experimental results due to the specific heat of the in-cylinder gas is increased when increasing EGR from 0 to 20%. The results also found that experimental results without EGR mode are slightly lower than its simulation.

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
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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.

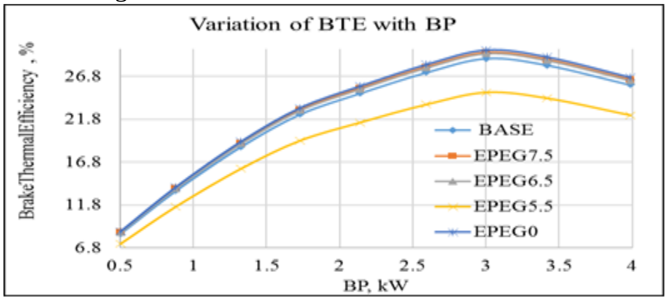

Fig: 10 Brake thermal efficiency Vs Brake Power kW

In Fig. 10, 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 the thermal conductivity. For 8YSZ + Al_2O_3 + TiO_2, 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 + Al_2O_3 + TiO_2, the thermal efficiency is decreased by 0.06 kWh.

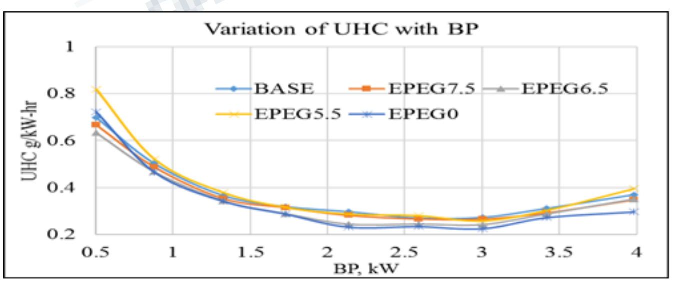

Fig: 11 UBHC Vs Brake Power kW

From Figure 11, it can be shown that the unburned (UBHC) 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 CO_2 emissions due to mixing O_2 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 Al_2O_3 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)

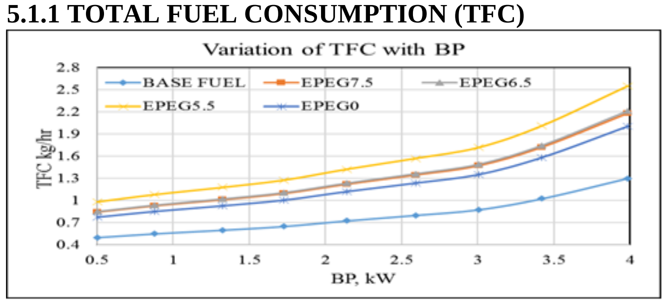

Fig: 12 TFC Vs Brake Power kW

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
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Figure 12 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)

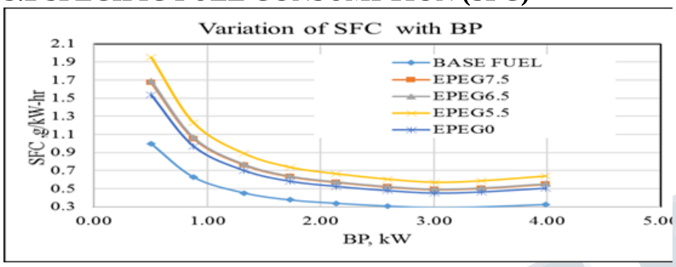

Fig: 13 SFC Vs Brake Power kW

Figure 13 shows that the SFC of the base engine decreased from 0.99 to 0.33 kg/kWh. SFC of EPEG0 engine is decreased from 1.54 to 0.50 g/kWh. SFC of EPEG5.5 decrease from 1.69 to 0.55 g/kW, and SFC of EPEG6.5 varies from1.68 to0.56 g/kWh, SFC of EPEG&7.5 increased from 1.954 to 0.639 g/kWh shown in Figure12. The following conclusion is made from this result analysis: 1) SFC of the EPEG7.5 engine is 1.66 times higher than the base engine. 2) SFC of the EPEG7.5 engine is 10% higher consumption compared to the EPEG0 engine. 3) SFC of EPEG0, EPEG5.5, EPEG6.5 and EPEG7.5 fuels are higher than base fuel due to the low heating value of four ethanol test fuels. Variation of BTE concerning brake power (kW) and varies from 0.5kW to3.99kW. BTE of BASE FUEL, EPEG0, EPEG5.5, EPEG6.5 and EPEG7.5 engines are obtained from experiments shown in Figure 10.

5.3 NOX EMISSIONS

From fig.14, it is clear that there is a more significant reduction of Nitrogen oxide due to coating because nitrogen has absorbed by zirconia. 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.

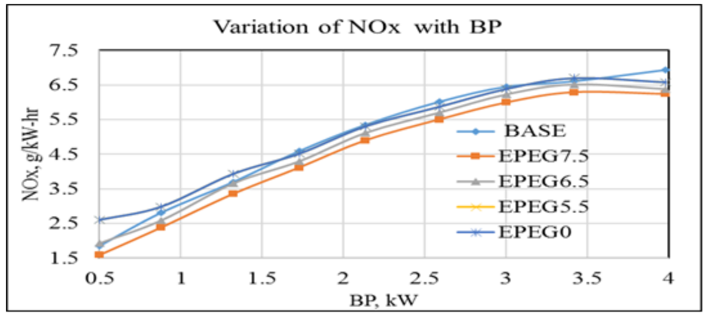

Fig: 14 NOx Vs Brake Power kW

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

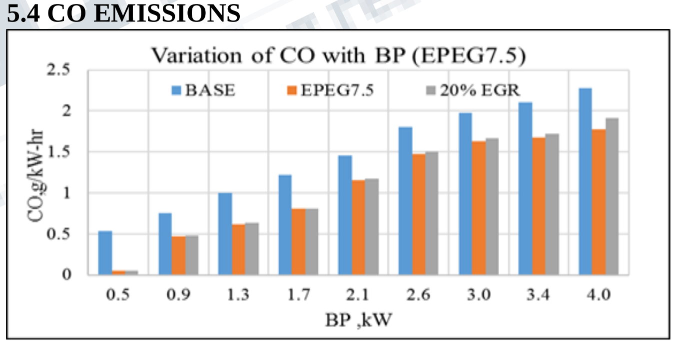

Fig: 15 CO Vs Brake Power kW

From figure 15, 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.

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5.5 UNBURNED HYDROCARBON EMISSIONS

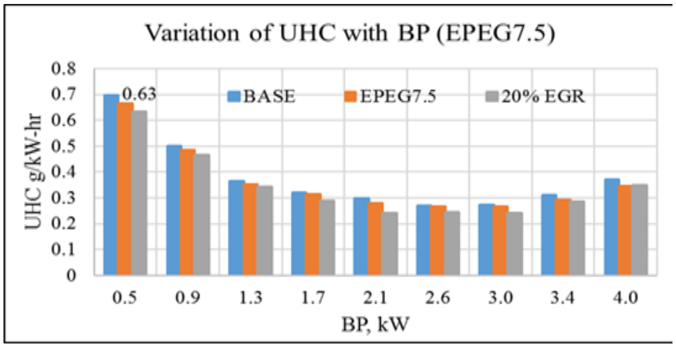

Fig: 16 UBHC Vs Brake Power kW

Figure 16 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 15 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 following performance and emission parameters were obtained from the experimental results: Brake Mean Effective Pressure (BMEP), Indicated Mean Effective Pressure (IMEP), Brake Thermal Efficiency (BTE), Indicated Thermal Efficiency (ITE) and Mechanical Efficiency (ME) and Brake Power (BP), CO, UHC and NOx. CO of base fuel with 0% EGR were and 15% EGR. A sample of experiment results comparing diesel and four ethanol fuels at a load of 3.99 kW shown in Table 1.1. A detailed discussion on the results was presented. 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.

Total fuel Consumption

- TFC of base fuel (diesel) engine with 0% EGR was increased from 0.5kg/h to 1.3 kg/h when load is increased from 0.5 to 3.99 kW.
- TFC of the EPEG0 with 0% EGR fuel engine was increased from 0.84 to 2.18 kg/h when BP increases from 0.5 to 3.99 kW. It was found that TFC was 1.67 times higher compared to the Base fuel engine.
- TFC of EPEG0 with 20% EGR mode experiments was 2.2 % higher compared to EPEG0 with 0%EGR mode experiments.
- TFC of EPEG5.5 with 0% EGR mode was increased from 0.85 to 2.16 kg/h and with 20% EGR mode was 0.05kg/h increased. It was found TFC was that 1.7 times higher compared to the base engine.
- TFC of EPEG6.5 with 0% EGR mode increased from 0.84 to 2. 21 kg/h and TFC of EPEG6.5 with 20% EGR mode was 2.21% higher than without EGR mode. It was 1.73 times higher fuel consumption compared to the base fuel engine. It was found 20% EGR mode was a 0.86% increase compared to 0% EGR.
- TFC of EPEG7.5 with 0% EGR mode was increased from 0.8 to 2.18 kg/h. TFC of EPEG6.5 with 20% EGR mode is slightly higher compared to without EGR mode. It was 1.69 times higher than the base fuel engine. However, 20% EGR mode was a 1.71 % increase compared to 0% EGR.

TFC of four ethanol test fuels, namely EPEG0, EPEG5.5, EPEG6.5 and EPEG7.5 fuel engine, was 1.67 to 1.71 times higher than the Base fuel (Diesel) engine lower heat energy (1.6 times) as compared to diesel fuel.

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

ACKNOWLEDGEMENT

I give my very hearty thanks to my supervisor A.S. Krishnan, Dr G Sureshkannan, associate professor, Dr K Marimuthu, head of mechanical engineering department, Dr V Selladurai, principal, Coimbatore Institute of Technology, Coimbatore, for all encouragement during this research.

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