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Combined effect of YTTRIA stabilized zirconia coating and swirl in a diesel engine: an experimental study

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ABSTRACT

Improving the performance of an internal combustion engine, while maintaining lower emission levels and better fuel efficiency is a big challenge for the engine researchers. In this research work, an attempt is made to study the combined effect of thermal barrier coating and enhanced air swirl on the performance and emission characteristics of a naturally aspirated diesel engine. A 100 micron layer of Yttria Stabilized Zirconia has been coated on the piston crown surface to reduce the heat loss to the coolant. A swirler device has been fabricated and installed at the inlet side of the engine manifold to improve the swirl and hence the mixing characteristics of the incoming air with the fuel. As the increase in cylinder temperature and improved turbulence of incoming air reduces the ignition delay, the combustion of fuel inside the cylinder is improved and it reflects in the performance metrics such as brake power, torque, brake thermal efficiency and brake specific fuel consumption. Because of the improved swirl and reduction of heat loss, the modified engine build performs better in comparison with the baseline engine characteristics. The benefits included improvement in the brake thermal efficiency by 1.55%, reduction of BSFC by o.44%, increase in rated power by 1.41%, brake torque by 1.18%. However hydrocarbon and carbon dioxide emission levels are found to increase by 17.30% and 11.13% respectively. Carbon monoxide emissions are decreased by 32.20%. The findings of the experimental study are discussed in detail and are presented in this paper.

KEY WORDS: TBC, YSZ, Swirl, Engine Performance, Emission.

1. INTRODUCTION

Thermal barrier coatings (TBCs) and various swirl enhancement methods are used extensively by researchers to improve the performance and emission characteristics of internal combustion engines (Bharathi 2013; Buyukkaya, 2006; Chan & Khor 2000; Sivakumar & Senthil Kumar 2014; Taymaz 2007). Thermal barrier coating of the combustion chamber helps in reducing the heat loss to the coolant, thereby increases the in-cylinder temperature (Sivakumar & Senthil Kumar, 2014) and the fuel burns in a better environment. Enhancement of the incoming air swirl helps in better atomization and better mixing of air and fuel mixture (Sivakumar & Senthilkumar, 2014), thereby improves the chances of better combustion of fuel. Both these effects ultimately reduces the ignition delay period of the combustion and increases the probability of conversion of heat energy into mechanical work or in other words increases the duration of combustion. Hence the combined effect of increasing in-cylinder temperature by using thermal barrier coating and increasing the incoming air turbulence by using induction swirl technique could positively improve the performance of the engine with better fuel economy and lesser emission. However there is a possibility that it could also detoriate the combustion process as the ignition timing become inappropriate under improved chamber conditions (Chan & Khor 2000). Hence in this present work an attempt is made to investigate the combined effect of thermal barrier coating and enhanced air swirl by coating the piston crown surfaces with Yittria Stabilized Zirconia (YSZ) and by placing a swirler device at the inlet side of the engine manifold. YSZ is chosen as the candidate material for coating the piston crown because of its desirable physical properties such as high coefficient of thermal expansion, low thermal conductivity and high Poisson's ratio, stable phase structure at higher temperature conditions (Clarke & Phillpot, 2005). A 100 micron layer of YSZ coating has been applied on the piston crown surface by plasma spray method, which is known to be the best method to apply thin layers of YSZ (Clarke & Phillpot, 2005). The YSZ coated piston crown surface acts as a thermal insulation and reduces the heat loss to the coolant and through piston surfaces and piston rings (Taymaz, 2007). Hence some additional heat energy is retained with in the cylinder, which can be converted into useful work. This effect would contribute to the increase in power and efficiency of the engine. Better combustion of fuel and reducing the heat transfer could increase the exhaust gas temperature, providing greater potential for energy recovery by other means.

2. EXPERIMENTAL TEST PROCEDURE

A four stroke, direct injected, water-cooled, three cylinder, naturally aspirated diesel engine is used for the investigation. The line diagram of the test setup is shown in figure.1 and photographs of the eddy current dynamometer facility are shown in figure.2. The specifications of the test engine are presented in Table.1. The experiments were conducted at full load conditions for the measurement of performance parameters at 6 different speeds viz. 1000, 1200, 1400, 1600, 1800, 2000 and 2150rpm. Emission levels of Carbon monoxide (CO), Hydro carbon (HC), Carbon dioxide (CO_2) and Nitrogen Oxide (NO_x) were measured by using AVL Di-gas 444 Gas analyser as per ISO 8178-4 'C1' 8 Mode testing cycle procedure (ARAI 2016). The mass flow rate of air is measured using a manometer setup by Air Box method. Fuel flow rate is measured by a gravimetric type Fuel consumption meter. Pressure and temperature sensors are mounted at appropriate locations in engine exhaust, water inlet, water outlet, air intake, lube oil for online recording of pressure and temperature values using a Digital Dyno Controller unit and Data Acquisition System.

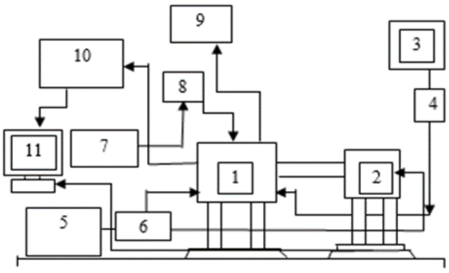

Figure.1. Line diagram of the laboratory setup

1. Engine, 2. Dynamometer, 3. Fuel tank, 4. Fuel filter, 5.Water tank, 6. Water Filter, 7. Manometer setup, 8. Air filter, 9. AVL Di-Gas 444 gas analyser, 10. Sensor junction box, 11. EDACS.


DYNAMOMETER LOADED WITH ENGINE
VIEW FROM CONTROL ROOM

Figure.2. Eddy Current Dynamometer Facility and the E-DAC System

Table.1. Test Engine Specifications

Bore	108mm
Stroke	120mm
Rated Power	50HP @ 2150rpm
Maximum Torque	180Nm @ 1200 rpm
Compression ratio	18.5:1
Capacity	3.3 L

3. RESULTS AND DISCUSSION

In this study, performance characteristics such as Power, Torque, Brake Specific Fuel Consumption, Brake Thermal Efficiency, and Volumetric Efficiency are considered and compared. Similarly the emission characteristics such as emission levels of Hydrocarbon, Carbon Monoxide, Carbon di-oxide and Nitrogen Oxides are measured and compared. The findings from the experimental results are discussed in this section. As already mentioned the performance characteristics are measured and compared only at full load conditions whereas the emission characteristics are measured as per ISO-8178-4 C1 8 mode testing cycle procedure and the weighted averages are compared to understand the combined effect of TBC and swirl on engine characteristics.

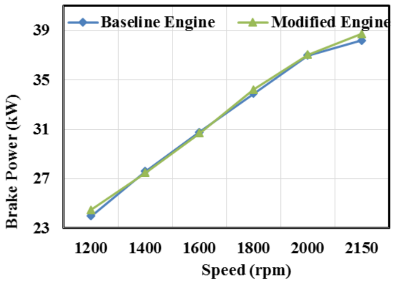

Figure.3. Brake power vs Speed at full load condition

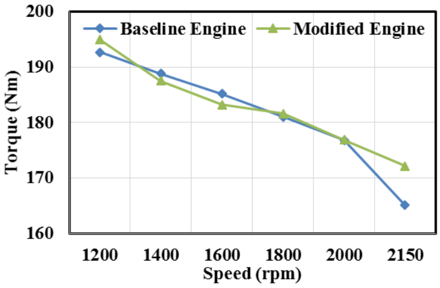

Figure.4. Torque vs Speed at full load condition

From figures.3 and 4, it is found that the Brake Power and the maximum torque are improved by 1.41% and 1.18% respectively in the modified Engine. The reason for the improvement may be attributed to the following;

- The swirl induced in the incoming air flow helps in better mixing of the air fuel Mixture and hence better combustion of the fuel take place (Bharathi, 2013).
- The YSZ coating on the piston Crown prevents the heat loss to the coolant and through the piston surfaces. This increases the in–cylinder temperature and hence better evaporation of fuel takes place (Sivakumar & Senthil Kumar, 2014).

Combustion characteristics depends largely upon ignition delay (Buyukkaya, 2006).The better vaporization of Fuel and its better mixing with air helps in reducing the Physical delay period of ignition (Jaichandar, 2003) and hence the better combustion takes place. Due to the reduction of ignition delay the effective time available for combustion increases (Jaichandar, 2003), leading to better conversation of energy into Mechanical work, which is evident from increase in the rated power and increase in the maximum torque.

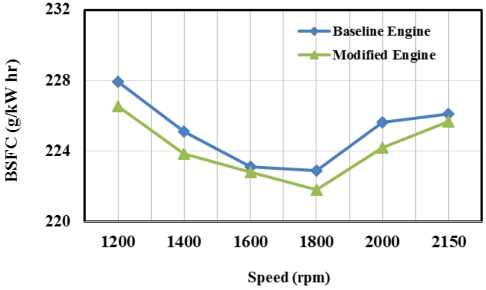

Figure.5. BSFC vs Speed at full load condition

From figure.5, it is found that the average BSFC decreased very marginally by 0.44% in the modified Engine. The reason for the decrease may be attributed to the following

- The increase in the brake power leads to a proportionate decrease in BSFC as BSFC and brake power are inversely proportional to each other. Another reason could be better mixing of air and fuel and faster vaporization of fuel achieved using swirl and thermal barrier coating respectively (Bharathi, 2013). Hence due to swirl and TBC, more energy is converted into mechanical work for the given speed and load conditions of the engine and hence the engine consumes less fuel leading to decrease in BSFC. The maximum decrease in the BSFC is absorbed at 2000rpm, which is found to be 224.18 g/kW-hr in the modified engine as against 225.61g/kW-hr in the baseline Engine

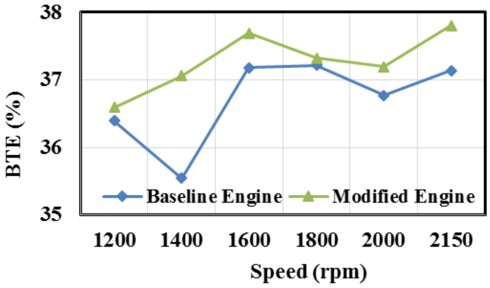

Figure.6. BTE vs Speed at full load condition

From Figure.6, it is found that the average BTE increased by 1.55% in the modified Engine. The reason for the improvement may be attributed to the reasons explained for the decrease in BSFC. As BSFC and BTE are inversely proportional to each other, decrease in BSFC leads to a proportionate increase in BTE by 1.55% at full load conditions.

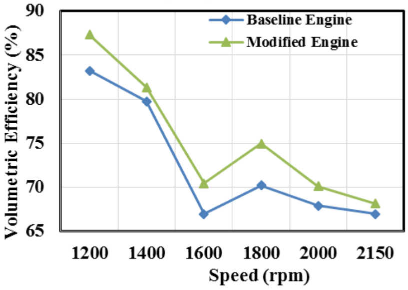

Figure.7. Volumetric efficiency vs Speed at full load condition

Volumetric efficiency is the breathing ability of the engine. Higher the volumetric ratio, better will be the performance of the engine. Comparing the baseline and modified engine, the average volumetric efficciency is found to increase by 3.98% in the modified engine. The reason for the increase in volumetric efficiency is due to the vacuum created by the incoming air swirl, which adds on to the suction effect generated by the downward movement of the piston (Paul & Ganesan 2010). Eventhough the increase in in-cylinder temperature due to TBC could decrease the density of air and can tend to reduce the quantity of air flowing into the cylinder, the effect of swirl overcomes the effect of TBC with a net increase of 3.98% in the volumetric efficciency, which is evident with the increase in the brake power and torque developed by the engine.

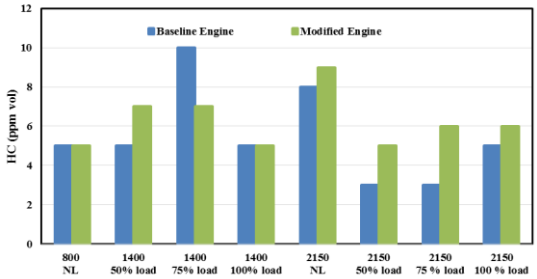

Figure.8. HC emission as per ISO 8178-4 ''C1'' 8 Mode testing cycle

From figure.8, it is found that the weighted average of unburned hydrocarbon emission incresaed by 17.30% in the modified Engine. From the exprimental results it is also found that the HC emission increases drastically at higher speed Indicating that the time avaliable for combustion of fuel is insuficient. This further infers that the standard ignition timing of 15^0 bTDC is not appropriate for the engine runing with TBC and swirl and hence combustion may detoriate (Chan & Khor, 2000). Other probable reasons for the increase in HC emission are burning of lubrication oil near hot combustion chamber walls and higher oil consumption (Jaichandar, 2003), rich fuel/air ratio or quenching of the combustion process in the proximity of the cold combustion chamber walls.

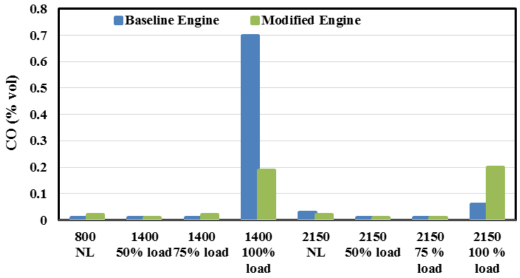

Figure.9. CO emission as per ISO 8178-4 ''C1'' 8 Mode testing cycle

From figure.9, it is found that the weighted average of CO decreased by 32.20% in the modified Engine. The exprimental data also revealed that the CO emission increased drastically at higher speed and full load condition. How ever CO emissions decreased drastically at inter mediate speeds and more or less same at low speeds and partload conditions. The abnormal variation and drastic increase at high speed and full load condition indicates inappropiate injection of fuel that is 15^0bTDC, when the engine is running with TBC and enhansed air swirl. However looking at the weighted average, the reduction in CO emission may be atributed to the better combution of fuel achieved through enhancement of the air swirl and in-cylinder temperature (Sivakumar & Senthil Kumar, 2014)

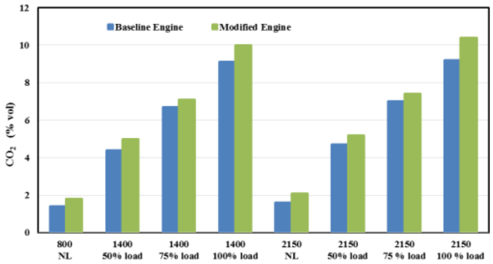

Figure.10. CO_2 emission as per ISO 8178-4 ''C1'' 8 mode testing cycle

Figure.10, shows CO_2 variations with respect to various load and speed conditions. It was experimentally determined that the modified engine causes an increase in CO_2 emission at all loads and speed conditions. Experimental results revealed that the weighted average of CO_2 emission increased by 11.13%, indicating that better combustion of fuel is taking place in the modified than the baseline engine (Sivakumar & Senthil Kumar, 2014).

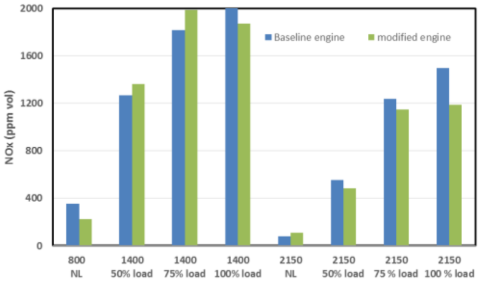

Figure.11. NOx emission as per ISO 8178-4 ''C1'' 8 mode testing cycle

Figure.11, shows the variation of nitrogen oxide emission with respect to various speed and load condition as per ISO-8178-C4 8 mode testing cycle. Decrease in NOx emission is observed almost at all the speeds except 1400rpm. As per the weighted average calculations, the NO_x emissions are found to decrease by 8.30% in the modified engine. Normally NO_x production vary with parameters such as in-cylinder temperature, exhaust temperature and oxygen concentration. However in the modified engine, the increased air turbulence assists in better mixture formation and makes it homogeneous and the chances of increasing the localized chamber temperature reduces. Hence there is a decrease in the NO_x level.

4. CONCLUSION

The test engine was successfully run with TBC on its piston crown and placing a swirler device at inlet side of the engine manifold for investigating the combined effect of increase in in-cylinder temperature and air swirl on the performance and emission characteristics. Based on the experimental results it is concluded that the TBC and air swirl helps the engine to run with better performance and lesser emissions. However the comparison of results and the trend observed in the experimental data indicate that fuel injection is not appropriate for the test engine under improved condition of in-cylinder temperature and air turbulence. Experimental results also indicated that the modified engine runs better than the base line engine with the following improvements:

- The brake power and maximum torque improved by 1.5% and 2% respectively
- The BSFC is decreased by 0.44%
- The brake thermal efficiency is increased by 1.79%
- The CO emission is decreased by 32.20%

The HC and CO_2 emissions are increased by 18.44% and 11.12% respectively. The increase in CO_2 emission is actually indication of better combustion of fuel. The increase in HC emission indicates that there is further scope for improving the emission characteristics of the test engine by appropriately adjusting the fuel injection timing.

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