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PERFORMANCE AND EMISSION CHARACTERISTICS OF THERMAL BARRIER COATING ON PISTON CROWN IN DIESEL ENGINE

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Abstract: In this paper, it is aimed to investigate the study of thermal barrier coating on piston crown in a single cylinder four stroke diesel engine. This research is intended to emphasis on performance and emission characteristic for with and without thermal barrier coated piston on single cylinder diesel engine. Research is carried out at different engine load conditions for standard and thermal barrier coated engine. Three different thermal barrier coatings (TBC) are coated in piston crown with different material and different composition such as 1. MO +Al_2O_3, 2. Al_2O_3 + TiO_2, 3.Zr_2O_3 + Y_2O_3, by atmospheric plasma spray method. Tests were performed on a single cylinder, four stroke, direct injection, diesel engine whose piston crown was coated with 300μm thickness of three different thermal barrier coating materials in different composition ratio such as 1. MO +Al_2O_3 (60%+40%), 2 Al_2O_3 + TiO_2 (60%+40%), 3. .Zr_2O_3 + Y_2O_3 (92%+8%), over a 150μm thickness of NiCrAlY bond coat. The results showed was decreasing on Brake specific fuel consumption (BSFC) and increasing brake thermal efficiency (BTE). There was a increasing on exhaust gas temperature, increasing NOx emission and decreasing the CO and HC emission on exhaust gas, on TBC engine when compared to without coated piston at different engine load conditions.

Keywords: TBC Engine, Piston crown coating, Performance and Emission.

1. INTRODUCTION

The rapid increase in fuel expenses, the decreasing supply of high-grade fuels on the market and environmental concerns stimulated research on more efficient engines with acceptable emission characteristics. The state-of-art thermal barrier coatings (TBC) provide the potential for higher thermal efficiencies of the engine, improved combustion and reduced emissions. In addition, ceramics show better wear characteristics than conventional materials. Lower heat rejection from the combustion chamber through thermally insulated components causes an increase in available energy that would increase the in-cylinder work and the amount of energy transported by the exhaust gases, which could be also utilized.

The diesel engine rejects about two thirds of the heat energy of the fuel as a waste, (one-third to the coolant and one-third to the exhaust) remaining one-third as a useful power output. In order to save energy, it is an advantage to protect the hot parts by a thermally insulating layer. This will reduce the heat transfer through the engine walls, and a greater part of the produced energy can be utilized, involving an increased efficiency. With this aim, coating combustion chamber components with low thermal conductivity materials becomes a more important subject at these days. For this reason, combustion chamber components of the internal combustion engines are coated with ceramic materials using various methods.

The major promises of thermal barrier coated engines were increased thermal efficiency and elimination of the cooling system. A simple first law of thermodynamics analysis of the energy conversion process within a diesel engine would indicate that if heat rejection to the coolant was eliminated, the thermal efficiency of the engine could be increased. Thermal barrier coatings were used to not only for reduced in-cylinder heat rejection and thermal fatigue protection of underlying metallic surfaces, but also for possible reduction of engine emissions.

A major breakthrough in diesel engine technology has been achieved by the pioneering work done by Kamo and Bryzik [7-8]. Sekar and Kemo [9] developed an adiabatic engine for passenger cars and reported an improvement in performance to the maximum extent of 12%. Woschni et al. [10] state that 5% of the input fuel energy cannot be accounted for which is of the order of the expected improvements. Havstad et al. [11] developed a semi-adiabatic diesel engine and reported an improvement ranging from 5 to 9% in ISFC, about 30% reduction in the in-cylinder heat rejection. Prasad et al. [13] used thermally insulating material, namely partially stabilized zirconia (PSZ), on the piston crown face and reported a 19% reduction in heat loss through the piston. Among possible alternative materials, one of the most promising is 1. MO +Al_2O_3(60%+40%), 2. Al_2O_3 + TiO_2 (60%+40%), 3.Zr2O3 + Y2O3 (YPSZ) (92%+8%), with different composition ratio. This is an important ceramic material because of its low density, high thermal stability, stability in severe chemical environments, low thermal conductivity and favorable strength and creep behavior.

Table 1. Composition ratio of TBC Materials

S.No.	MATERIALS	COMPOSITION RATIOS (%)
1	MO +Al_2O_3	60 + 40
2	Al_2O_3 + TiO_2	60 + 40
3	Zr_2O_3 + Y_2O_3	92 + 8

2. Experimental Setup

A four stroke, direct injected single cylinder diesel engine was used for experimentation. Engine torque was measured by eddy current dynamometer. The engine has a conventional fuel injection system. A piezoelectric pressure transducer was mounted with cylinder head surface to measure the in cylinder pressure. It is also provided with temperature sensors for the measurement of jacket water, calorimeter water, and calorimeter exhaust gas inlet and outlet temperatures. An encoder is fixed for crank angle record. The signals from these sensors are interfaced with a computer to an engine indicator to display P-□ , P-V, mass fraction burnt and heat release versus crank angle plots. The provision is also made for the measurement of volumetric fuel flow. The built in program in the system calculates indicated power, brake power, thermal efficiency, volumetric efficiency and heat balance. The software package is fully configurable and averaged P-□ diagram, P-V plot and other diagram can be obtained for various operating conditions.

Tests were performed on a single cylinder, four stroke, direct injection, diesel engine whose piston crown was coated with 300μm thickness of three different thermal barrier coating materials in different composition ratio such as 1. MO +Al_2O_3 (60%+40%), 2. Al_2O_3 + TiO_2 (60%+40%), 3.Zr2O3 + Y2O3 (92%+8%), in various over a 150μm thickness of NiCrAlY bond coat.

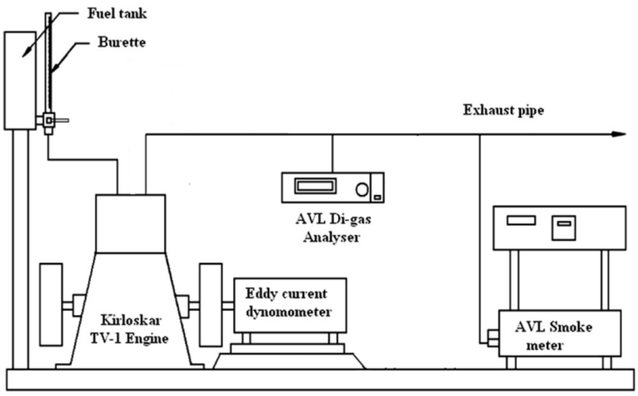


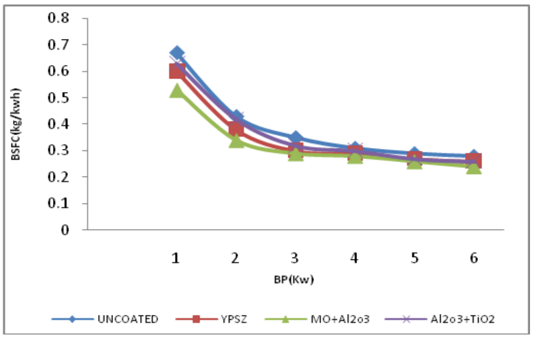
Fig 1: Experimental setup

3. RESULTS AND DISCUSSION

3.1 Performance

3.1.1 Brake specific energy consumption

The variation of brake specific fuel consumption with brake power is shown in fig 3.1 for uncoated and thermal barrier coated engines. It can be observed from the results that Thermal Barrier coated in piston crown decreasing BSFC when compared with uncoated engine. This may be due to increased temperature of the piston crown which increases the temperature of cylinder gas and wall, which results higher temperature in combustion chamber. The combustion conditions become more favourable which results shortening ignition delay time in coated engine affects the both chemical and physical reactions positively. It is believed that, this situation contributes to decrease BSFC when compared to uncoated engine. From the graph BSFC of three different Thermal barrier coated Engine compared to uncoated engine. For MO +Al_2O_3, the BSFC is decreased by 10.34%, For YPSZ the BSFC is decreased by 6.89%. For Al_2O_3 + $TiO_2$the BSFC is decreased by 6.89%.



3.1.2 Brake thermal efficiency (BTE)

The variation of brake thermal efficiency with brake power is shown in fig 3.2 for uncoated and thermal barrier coated engines. It can be observed from the results that Thermal Barrier coating in piston crown improves the thermal efficiency when compared with uncoated engine. The ceramic coating has low thermal conductivity which enhances higher operating temperature of the engine. The thermal efficiency was increased due to the reduction in heat transfer from the gas to the wall (piston crown) during the combustion or expansion. The variation of BTE in TBC engine depends upon the thermal conductivity of the material. From the graph BTE of three different Thermal barriers coated Engine compared to uncoated engine. For MO +Al_2O_3, the BTEis increased by 3.26%, For YPSZ the BTE is increased by 2.09%. For Al_2O_3 + $TiO_2$the BTE is increased by 1.98%.

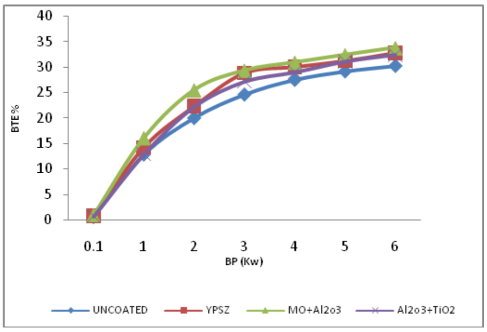


Fig 3.2: Brake power vs Brake Thermal Efficiency

3.1.3 Exhaust gas temperature

The variation of Exhaust gas temperature with brake power is shown in fig 3.3 for uncoated and thermal barrier coated engines. It can be observed from the results that Thermal Barrier coating in piston crown increasing EGT when compared with uncoated engine. In thermal barrier coated engine decrease in heat loss to cooling system which results the more amount of heat generated in the cylinder in which all amount of heat cannot be converted in to useful work and then heat is mixed with the exhaust gas in which results increasing the exhaust gas temperature. From the graph EGT of three different Thermal barriers coated Engine compared to uncoated engine. For MO +Al_2O_3, the EGT is increased by 9.09%, For YPSZ the EGT is increased by 10.1%. For Al_2O_3 + TiO_2 the EGT is increased by 14.14%.

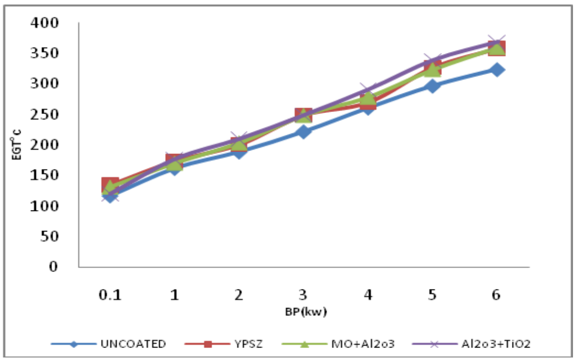


Fig 3.3: Brake Power vs EGT

3.2 Emission Parameters

3.2.1 NOx Emission

The variation of NOX with brake power is shown in fig 3.4 for uncoated and thermal barrier coated engines. It can be observed from the results that Thermal Barrier coating in piston crown increasing NOX emission. For MO +Al_2O_3increased by 5.84%, Al_2O_3 + TiO_2increased by 8.4%, this due to an increase in after-combustion temperature causes an increase in NOx emission. All factors facilitating and accelerating the reaction between oxygen and nitrogen increase NOx formation. The main factor in the NOx formation is temperature. However, engine speed, combustion chamber content, combustion chamber homogeneity, and mixture density in the combustion chamber are also factors. Fig 9.6 shows NOx emission increases with increasing brake power. The increase of NOx for in the thermal barrier coated engine may be a result of an increase in after-combustion temperature due to the ceramic coating but TBC of YPSZ 8% decreasing NOX emission when compared with uncoated engine. This is because of nitrogen has absorbed by zirconia. Even though availability of oxygen high but availability of nitrogen is very less by the presence of impurities. Generally oxygen availability in diesel is high so at high temperatures nitrogen easily combines with oxygen but availability of nitrogen is very less due to coating and forms less NOx.

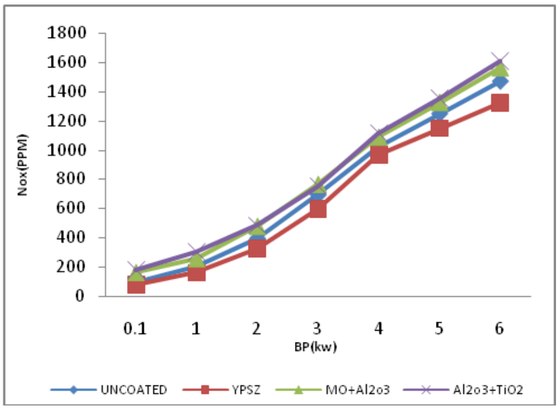


Fig 3.4: Brakepower vs NOx

3.2.2 Carbon Monoxide (CO) Emissions

The variation of CO emissions with brake power is shown in fig 3.5 for uncoated and thermal barrier coated engines. It can be observed from the results that Thermal Barrier coating in piston crown decreasing CO when compared with uncoated engine. CO is decreased after the coating due to the complete combustion. The carbon monoxide, which arises mainly due to incomplete combustion, is a measure of combustion in efficiency .Generally oxygen availability in diesel is high so at high temperatures carbon easily combines with oxygen and reduces the CO emission. . From the graph CO emission of three different Thermal barriers coated Engine compared to uncoated engine. For MO +Al_2O_3, the CO is decreased by 29.09%, For YPSZ the CO is decreased by 28.6%. For Al_2O_3 + TiO_2 the CO is decreased by 28.6%.

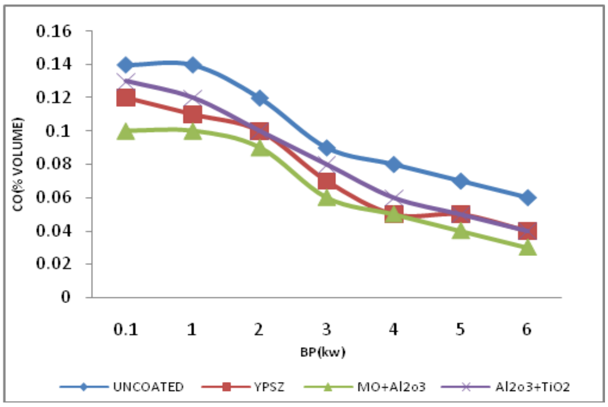


Fig 3.5: Brakepower vs Carbon Monoxide

3.2.4 Unburned Hydrocarbon (UBHC) Emissions

The variation of HC emissions with brake power is shown in fig 3.6 for uncoated and thermal barrier coated engines. coating in piston crown decreasing HC when Compared with uncoated engine. The unburned hydrocarbon emissions are reduced when the engine runs with coating. The unburned HC emissions are slightly higher when the engine runs without the coating. The main reason for this reduction in the unburned HC emissions is that at high temperatures the engine will have sufficient amount of oxygen which mixes with the HC emissions. As a result of this, the HC will split into H and C which mixes with O2, thereby reducing the HC emissions. . From the graph HC emission of three different Thermal barrier coated Engine compared to uncoated engine. For MO +Al_2O_3, the HC is decreased by 31.1%, For YPSZ the CO is decreased by 26.6%. For Al_2O_3 + TiO_2 the HC is decreased by 28.8%.

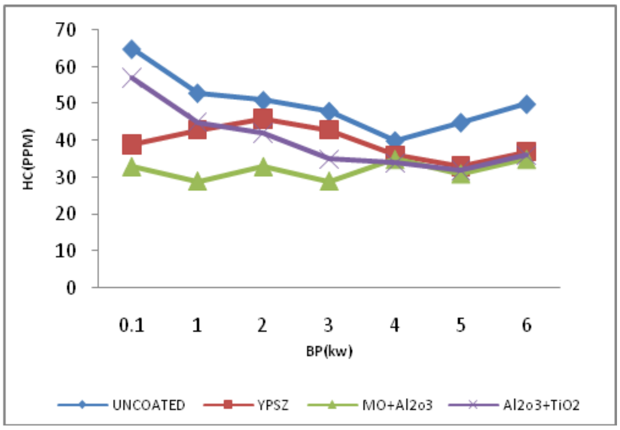


Fig 3.6: Brake Power vs UBHC

4. CONCLUSION

- The brake thermal efficiency was increased in TBC engine mainly depends upon the thermal conductivity of the material. MO +Al_2O_3, the BTE is increased by 3.26%, For YPSZ the BTE is increased by 2.09%. For Al_2O_3 + TiO_2 the BTE is increased by 1.98%.
- The brake specific fuel consumption was decreased in TBC engine. MO +Al_2O_3, the BSFC is decreased by 10.34%, For YPSZ the BSFC is decreased by 6.89%. For Al_2O_3 + $TiO_2$the BTE is decreased by 6.89%.
- The exhaust gas temperature was increased in TBC engine For MO +Al_2O_3, the EGT is increased by 9.09%, For YPSZ the EGT is increased by 10.1%. For Al_2O_3 + $TiO_2$the EGT is increased by 14.14%.
- The carbon monoxide was decreased in TBC engine. For MO +Al_2O_3, the CO is decreased by 29.09%, For YPSZ the CO is decreased by 28.6%. For Al_2O_3 + $TiO_2$the CO is decreased by 28.6%.
- The hydro carbon was decreased in TBC engine. For MO +Al_2O_3, the HC is decreased by 31.1%, For YPSZ the CO is decreased by 26.6%. For Al_2O_3 + $TiO_2$the HC is decreased by 28.8%.
- Thermal Barrier coating in piston crown increasing NOX emission. For . MO +Al_2O_3 increased by 5.84%, Al_2O_3 + TiO_2 increased by 8.4%, The increase of NOx for in the thermal barrier coated engine may be a result of an increase in after-combustion temperature due to the ceramic coating but TBC of YPSZ 8% decreasing NOX emission when compared with uncoated engine. This is because of nitrogen has absorbed by zirconia.

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