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AN EXPERIMENTAL STUDY ON THE EFFECT OF THERMAL BARRIER COATING ON DIESEL ENGINE PERFORMANCE

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Abstract: In a conventional internal combustion engine, approximately 60 % of total heat energy is lost with exhaust gases and cooling systems. In this study, the effect of insulated heat transfer surfaces inside the combustion chamber of a diesel engine was investigated. Thermal barrier Zirconium coatings are used in diesel engine piston, valves and heads. An experimental investigation into the effect of coatings on the performance of a Diesel engine was conducted. Tests were performed on a single cylinder diesel engine with eddy current dynamometer whose piston and head were coated with 0.35 mm thickness $CaZrO_3$. The coating is evaluated for its ability to improve the combustion characteristics. The coated engine was tested at the same operating condition as that of standard engine (without coating). The results indicate an improvement in the Brake thermal efficiency with a consequent reduction in the brake specific fuel consumption.

Keywords: Thermal barrier, Engine performance, Brake thermal efficiency, Brake, Specific fuel consumption.

I. INTRODUCTION

The quest for developing energy efficient internal combustion engines has been going on from past several decades. In recent times, research is focused on reducing the energy lost to exhaust gases, cooling systems, all and head of combustion chamber. One of the trends is to improve performance of the heat engines by engine adiabatization. The method to adibatize an engine is to cover the surfaces of the combustion chamber with a thermal barrier coating. The thermal insulation provided by coating leads to energy efficient engines. Kamo and Bryzik [1] used thermal barrier coating such as silicon nitride for insulating different surfaces of the combustion chamber and found an improvement of 7 % in engine performance. Imdat Taymaz [2] coated the head, combustion chamber surfaces, valves and piston crown faces with CaZrO3 and MgZrO3, Observed that at medium load effective efficiency improved by 2 %. However the authors have not clearly demarcated the influence of speed and the effect of thermal barrier coatings on enhancing of thermal efficiency of the engine. Abdulla Uzun and Ismet cevik [3] showed that with thermal barrier coatings on diesel engine, the thermal efficiency increases by 10 % and fuel consumption showed a 2 % decrease. I.Taymaz and K.Cakir [4] have shown that the thermal barrier coatings on the combustion chamber of a diesel engine prevent the excessive heat loss during the combustion. Imdat Taymaz [5] has shown in a LHR engine, High temperature on the combustion chamber wall surface due to insulation cause a drop in volumetric efficiency. Ekrem Buyukkaya, Tahsin Engin and Muhammet cerit [6] have developed a low heat rejection engine and showed that 1-8 % reduction in brake specific fuel consumption can be achieved. The main purpose of this study is to evaluate the performance of a Diesel Engine with and without Thermal barrier coating. Experiments were conducted on single cylinder water cooled Diesel engine with Eddy current dynamometer for loading. The results showed an improvement in Brake thermal efficiency and a reduction in Brake specific fuel consumption with a reduction in heat losses.

Nomenclature

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LHR: Low heat rejection engine.
SE: Standard Diesel engine
CCE: CaZrO3 coated Diesel engine.
BSFC: Brake Specific fuel consumption.
HE: Heat engines.

II EXPERIMENTAL DETAILS

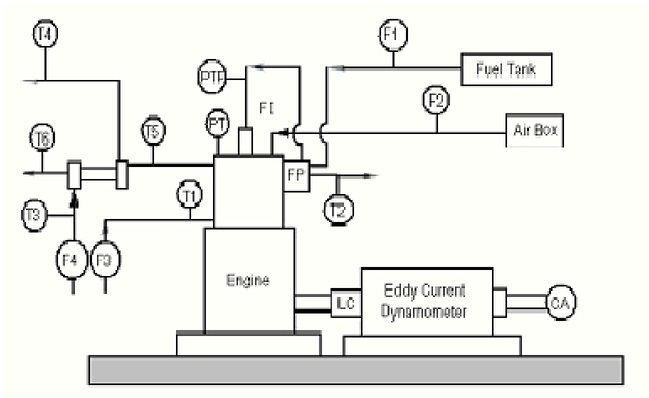

Fig. 1: Schematic Diagram of the Experimental Set-up.

PT: Combustion Chamber Pressure Sensor F
Fig1. Engine set up
PTF: Fuel Injection Pressure Sensor
FI: Fuel Injector
FP: Fuel Pump
T1: Jacket Water Inlet Temperature
T2: Jacket Water Outlet Temperature
T3: Inlet Water Temperature at Calorimeter
T4: Outlet Water Temperature at Calorimeter
T5: Exhaust Gas Temperature before Calorimeter
T6: Exhaust Gas Temperature after Calorimeter
F1: Liquid fuel flow rate
F2: Air Flow Rate
F3: Jacket water flow rate
F4: Calorimeter water flow rate
LC: Load Cell
CA: Crank Angle Encoder
EGC: Exhaust Gas Calorimeter

The engine used for performance evaluation of the $CaZrO_3$ coating was a four stroke, water cooled single cylinder diesel engine. This engine is equipped with eddy current dynamometer for loading and Piezo pressure sensors for obtaining pressure crank angle diagrams. Thermo couples are introduced at a distance of 2 mm from the surface of head (One thermocouple at centre), liner and cylinder wall for temperature measurements. The cylinder head, valves and piston were coated with $CaZrO_3$. The thickness of coating was 0.35 mm. The coating process was performed using plasma spray technique. Finally the $CaZrO_3$ coated test engine was tested with same operating conditions as that of standard engine. Fig 1 shows the line diagram of the engine setup used for the experiments and Table 1 gives the specification of the engine. The results obtained were analyzed for the performance of the engine.

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Table 1. Specification of Engine

Sl.No	Engine parameter	Specification
1	Number of Cylinders	Single cylinder 4 S
2	Engine type	TV1 Kirloskar
3	Rated Power	5.2kW
4	Bore	87.5mm
5	Stroke	110mm
6	Cubic Capacity	661CC
7	Compression Ratio	17.5
8	Rated Speed (constant)	1500rpm
9	Dynamometer	Eddy current
10	Cooling	Water cooling
11	Fuel Injection Pressure	190-210 bar
12	Load Measurement	Load cell
13	Speed Measurement	Rotary encoder
14	Temperature Indicator	Digital K type

III RESULTS AND DISCUSSIONS

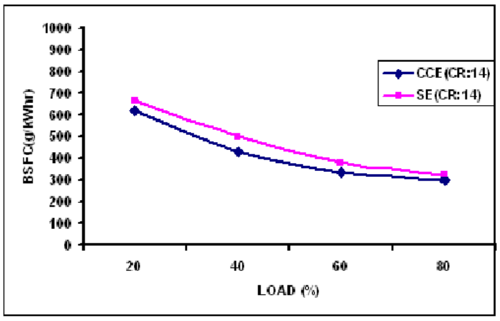

Fig. 2: Variation of BSFC with Load

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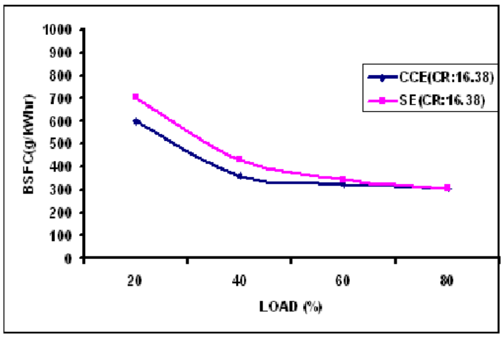

Fig. 3: Variation of BSFC with Load

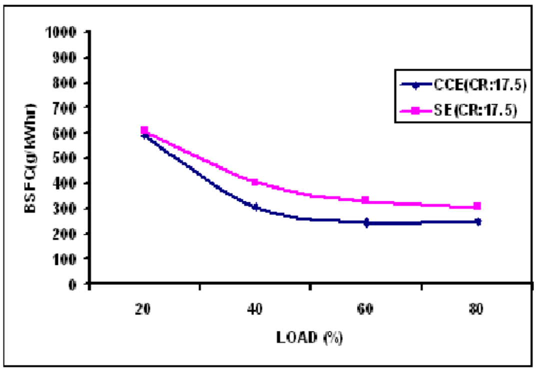

Fig. 4: Variation of BSFC with Load

Figures 2, 3 and 4 represent the variation of the brake specific fuel consumption with load for different compression ratios. The results are shown for standard engine and ceramic coated engine. The results show 3 to 7 % decrease in brake specific fuel consumption for coated engine at loads lower than 50 % at low compression ratios. At higher compression ratio the brake specific fuel consumption decreases from 3 to 14 % for loads above 30 %. This is mainly due to the higher temperature reached in the combustion chamber, however the decrease in brake specific fuel consumption is marginal at low compression ratios, Therefore it appears that the thermal barrier coatings have considerable influence at higher compression ratios and tends to a higher reduction in Brake specific fuel consumption.

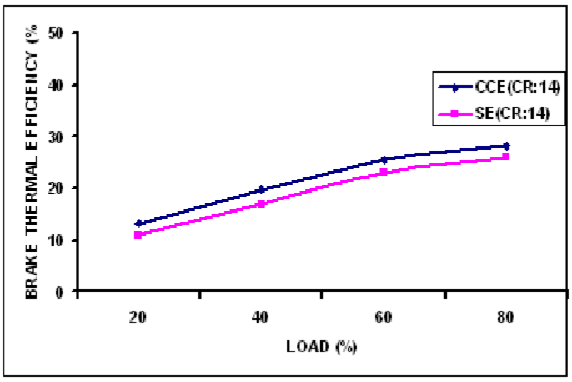

Fig. 5: Variation of Brake thermal Efficiency with Load.

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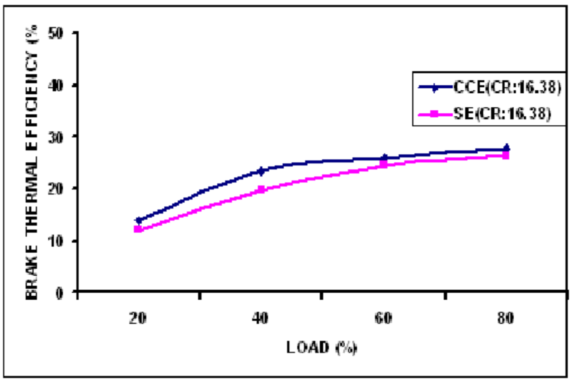

Fig. 6: Variation of Brake thermal Efficiency with Load.

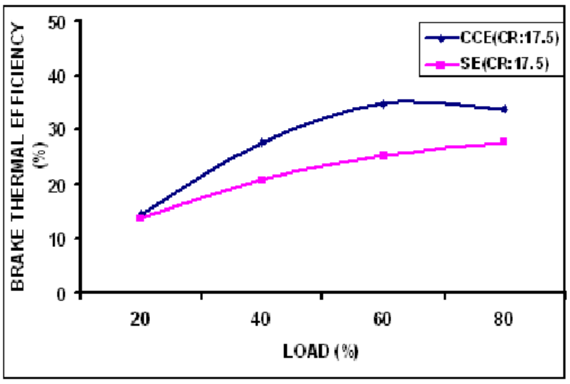

Fig. 7: Variation of Brake thermal Efficiency with Load.

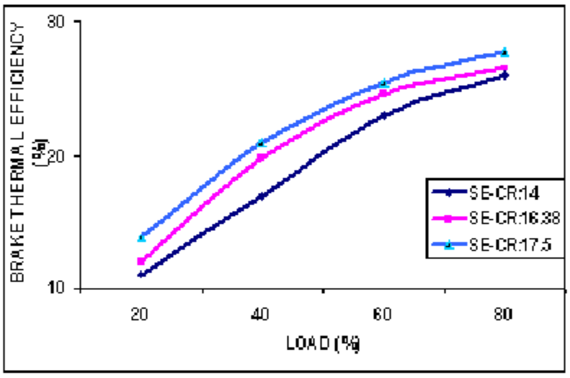

Fig. 8: Variation of Brake thermal Efficiency with Load for Different Compression Ratios.

Figures 5, 6 and 7 represent the variation of Brake thermal efficiency with load for different compression ratios. The Brake thermal efficiency is found to increase by 2 % overall at all loads at low compression ratios for coated engine. With increase in compression ratio the increase in Brake thermal efficiency is around 8 % overall, for coated engine at loads higher than 40 %. It is evident from figure 8, that the Brake thermal efficiency increases by 2-4 % due to increase in compression ratio, and the influence of thermal barrier coating could be attributed to the remaining 2-4%. The influence of thermal barrier coating can be due to the fact that the coating materials have low

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thermal conductivity, there by providing a better insulation allowing a higher operating temperature and reducing cooling requirement which enhances the Brake thermal efficiency.

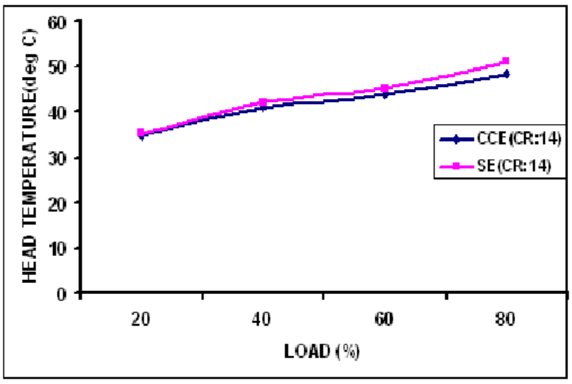

Fig.9: Variation of Head temperature with Load.

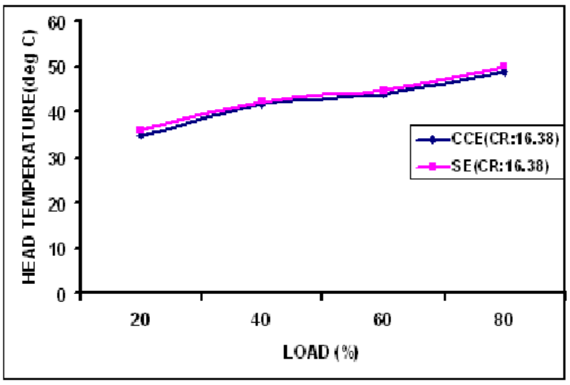

Fig.10: Variation of Head temperature with Load.

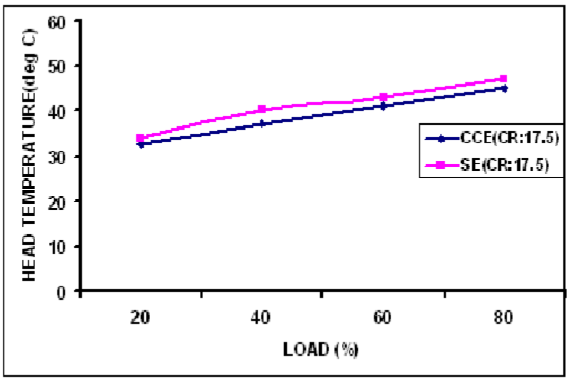

Fig.11: Variation of Head temperature with Load.

Figures 9, 10 and 11 represent the variation of head temperature measured by thermocouple placed at a distance of 2 mm from the head surface, with load for different compression ratios. It can be seen from the figures for coated engine the temperature decreased by 2 to 5 C than compared to standard engine

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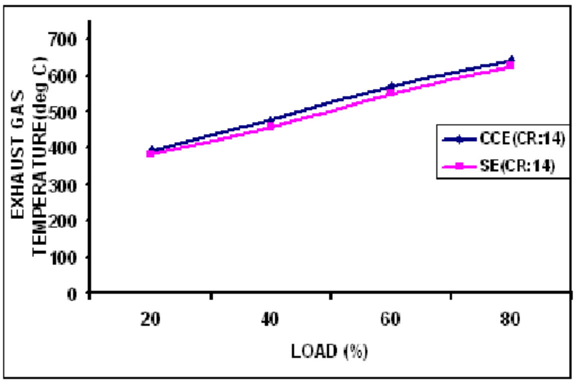

Fig. 12: Variation of Exhaust gas temperature with Load.

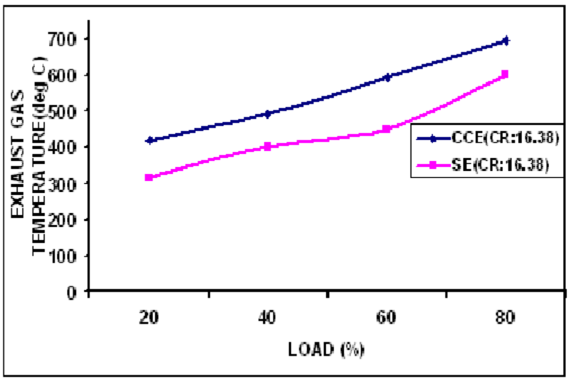

Fig.13: Variation of Exhaust gas temperature with Load.

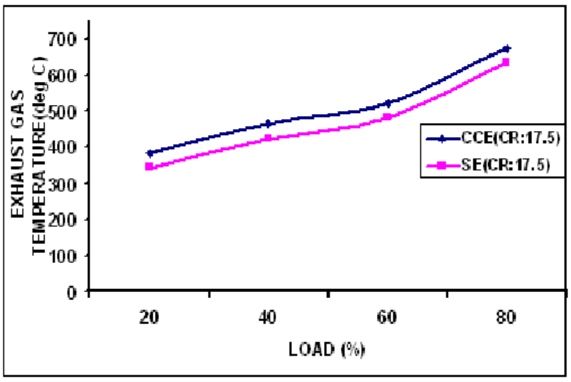

Fig.14: Variation of Exhaust gas temperature with Load.

Figures 12, 13 and 14 represent the variation of exhaust gas temperature with load for different compression ratios. It is evident that the exhaust temperature is higher for coated engine, this might be possibly due to the thermal barrier coating reducing the heat losses to piston and head thereby resulting in higher exhaust temperature /exhaust enthalpy and temperatures are 30-55° C more in case of coated engine than the standard engine for all the loads tested.

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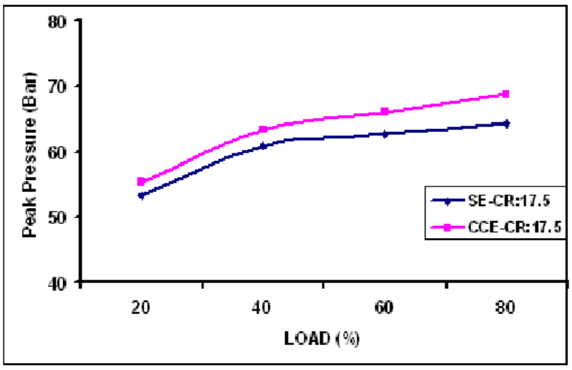

Fig. 15: Variation of Peak pressure with Load.

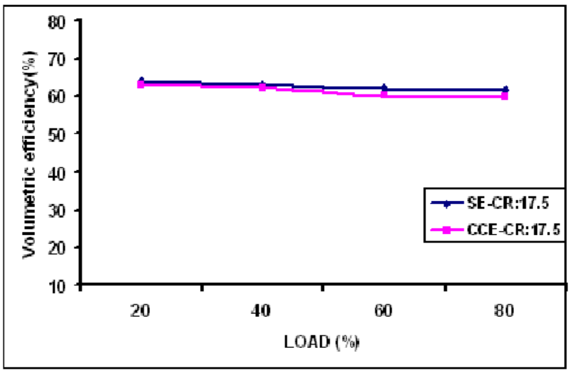

Fig. 16: Variation of Volumetric efficiency with Load

The Figures 15 show clearly that the peak cylinder pressure is more for the coated engine for the same operating conditions and the fuel used. This observation is in line with the fact that the heat transferred to the piston crown surface is less for the coated engine as the thermal barrier coating acts as an insulation barrier. This fact is also reflected in Figure 16 where, because of the enhanced peak cylinder pressure and corresponding combustion temperatures, the volumetric efficiency of the coated engine has shown a marginal decrease owing to the inducted charge coming in contact with piston outer wall which are at higher temperature compared to that of standard engine.

IV CONCLUSIONS

An experimental investigation of the effect of $CaZrO_3$ coating on diesel engine performance was conducted. Tests were carried out for different loads and compression ratios, for standard engine and the engine with its piston, head and valves insulated with ceramic coatings. The following conclusions were drawn from this investigation.

1. Brake thermal efficiency increased by 2-3 % at low compression ratios and 6-8 % for higher compression ratio for coated engine. As the thermal efficiency also increases due to increased compression ratio in general the brake thermal efficiency increases by 2-4 % due to thermal barrier coatings.
2. Brake specific fuel consumption shows a 2-10 % decrease in engines with thermal barrier coatings out of which 4-5% can be attributed to change in compression ratio.
3. Exhaust gas temperature increases between 30-55 ^{0}C for coated engine.
4. There was a nominal drop in volumetric efficiency as hotter gas temperature decreases the density of inducted air due to heat transfer. (At the same time NO_x increase is not discussed in this paper)

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