Research Paper

EFFECT OF THERMAL BARRIER COATING ON PERFORMANCE AND EMISSION CHARACTERISTICS OF A DIESEL ENGINE

L. Anantha Raman[1], S. Rajakumar[2], Lokesh Paradeshi[3]

Address for Correspondence

[1]Department of Aeronautical Engineering, Satyam College of Engineering and Technology, Aralvaimozhi, India
[2]Department of Mechanical Engineering, Regional Office of Anna University, Tirunelveli, India
[3]Department of Mechanical Engineering, National Institute of Technology Calicut, Kozhikode, India.

ABSTRACT

The main objective of this present study is to evaluate the performance characteristics of thermal barrier coating in direct injection diesel engine. Combustion chamber of the engine (piston crown, cylinder head and valves) were coated with partially stabilized zirconia of 0.5 mm thickness. Plasma spray coating technique has been used to coat the engine components. Experiments were carried out in a single cylinder, four stroke direct injection diesel engine. The results showed that, the brake thermal efficiency of diesel engine is increased marginally after ceramic coating. Also, the specific energy consumption decreased with engine coating. Carbon monoxide and hydrocarbon emission levels are decreased but in contrast, the oxide of nitrogen emission level was increased due to the higher peak temperature.

KEYWORDS: Diesel engine, Ceramic coating, Partially stabilized zirconia.

INTRODUCTION

Energy conservation and efficiency have always been the quest of engineers concerned with internal combustion engines. The diesel engine generally offers better fuel economy than petrol engine. Diesel engine normally rejects about two third of its heat energy produced, one-third to the coolant, and one third to the exhaust, leaving only about one-third as useful power output [1, 2]. If we reduce the heat rejected to the coolant, the thermal efficiency of the engine can be improved, at least up to the limit set by the second law of thermodynamics. Low Heat Rejection engines aim to do this by reducing the heat lost to the coolant and recovering the energy in the form of useful work [3]. This can be achieved by means of thermal barrier coatings to the engine components [4, 5]. The use of thermal barrier coatings to increase the temperature in diesel engines has been pursued for over 20 years. Converting an ordinary engine into low heat rejection engine through thermal barrier coatings have many advantages including higher power density, fuel efficiency, and multi fuel capacity due to higher combustion chamber temperature (900°Cvs.650 °C) [6,7]. Jaichandar et al [1] have investigated theoretical and experimental work on low heat rejection engine and also overview about previous research efforts. They used different materials used for coating such as silicon carbide (SiC), silicon nitride (Si_3N_4), Zirconia (ZrO_2), aluminium titante (Al_2O3 TiO_2), Chromium oxide (Cr_2O_3) and reported that the inner cylinder temperature greater than 600˚C will enable the use of less volatile fuels to auto ignite. Lawrence at al [8] have investigated the effect of thermal barrier coating in a diesel engine using ethanol as a fuel and reported that the brake thermal efficiency and power output of the engine increased after coating due to the reduction of heat loss in the surroundings. Ken Voss et al [9] have studied the zirconia coated two stroke engine for the durability of coating and emissions characteristics and found that the ceramic coated cylinders helped in reducing the particulate matter to a large extent. They concluded that the ceramic coated engine showed 50% reduction in NOx emissions. Santhanakrishnan and Ramani [10] studied the effect of ceramic coating on performance and emission characteristics of a diesel engine using alternate fuels. They reported that the diesel engine after coating offers higher brake thermal efficiency, lower specific fuel consumption and lower emission levels compared to uncoated engine. The aim of the present work is to increase the engine performance and to make the engine parts more resistance to wear. For this purpose, thermal barrier coatings are applied on cylinder head, piston and valves through plasma spray method. In this study the cylinder head, valve, and piston of the test engine were coated with a partially stabilized zirconia of 0.5 mm thick by the plasma spray coating method.

MATERIALS AND METHOD

Increased combustion temperature can increase the efficiency of the engine; decrease the CO and NOx emission rate. The most common thermal barrier coating system is partially stabilized zirconia (PSZ) which has shown good performance in turbine blade coatings where temperatures approach 1100°C [11]. Partially stabilized zirconia is a mixture of zirconia polymorphs. A smaller addition of stabilizer to the pure zirconia will bring its structure into a tetragonal phase at a temperature higher than 1,000˚C [12]. In this study, Yttrium Partially Stabilized Zirconia (Y-PSZ) was used as a coating material. This material was coated on the engine components for a thickness of 0.5mm through plasma coating method. The properties of partially stabilized zirconia used are given in Table 1.

Table 1. Properties of partially stabilized zirconia

Property	PSZ
Density ($g.cm^{-3}$)	5.7 - 0.75
Modulus of Rupture (MPa)	700
Hardness – Knoop (GPa)	10 - 11
Young's Modulus (GPa)	205
Specific Heat (J/kgK)	400
Thermal Conductivity (W/mK)	1.8 - 2.2
Poisson ratio	0.23

Experiments were carried out in a vertical, single cylinder, naturally aspirated, four stroke, constant speed, water cooled, direct injection diesel engine. The specification of the engine is shown in Table 2. The engine was operated at a constant speed of 1500 rpm. The series of tests were carried out in the engine with and without coating.

Table 2. Specification of the engine

Make	Kirloskar
Type	Four stroke, direct injection
No. of cylinder	One
Rated output (kW)	5.95
Bore (mm)	95
Stroke (mm)	115
Rate speed (rpm)	1500
Cooling type	Water cooling

RESULTS AND DISCUSSIONS

Figure 1 shows the variation of brake thermal efficiency with respect to brake power. It can be observed that at maximum load (5.81kw), the brake thermal efficiency of the engine was increased by 7.05% in low heat rejection engine. Zirconia is a low thermal conductivity material. It will act as barrier for the heat transfer to the surroundings from the engine and reduces the heat loss from the engine. The reduction in heat loss ultimately increased the power output and thermal efficiency of the engine.

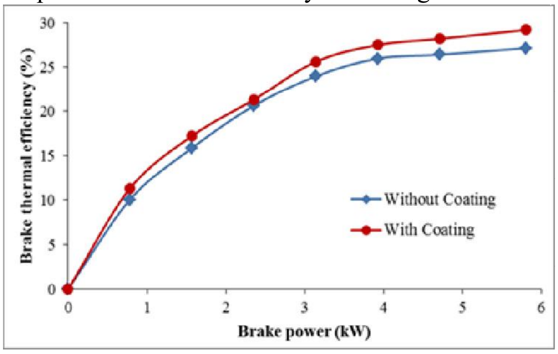

Figure 1. Variation of brake thermal efficiency

Figure 2 shows the variation of brake specific energy consumption with respect to brake power. The brake specific energy consumption is an important parameter to measure fuel efficiency of an engine. The BSEC was very high with low load operation and low for higher loads. It can be observed that at maximum load condition, the brake specific energy consumption of the low heat rejection engine was decreased by 15.8% compared with normal uncoated engine. This is because of the higher surface temperatures of its combustion chamber, the BSFC values of the low heat rejection engine were lower than those of the standard engine. Similar type of result was obtained by Buyukkaya et al [13] who investigated the effect of thermal barrier coating on diesel engine.

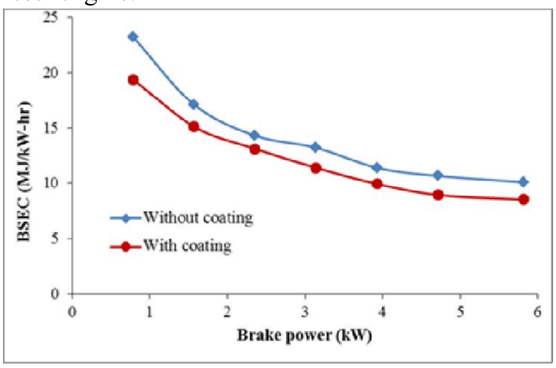

Figure 2. Variation of brake specific energy consumption

Figure 3 shows the variation of exhaust gas temperature at various loads for both the conventional and low heat rejection engine. Diesel fuel operation in LHR modes indicates a higher exhaust temperature than the baseline diesel due to the insulation in the combustion chamber [14]. At low loads there was very slight difference in the exhaust temperature for the engine before and after ceramic coating.

Figure 4 shows the variation of carbon monoxide emission with respect to brake power for both the conventional and low heat rejection engine. The high operating temperature in LHR engine makes the combustion nearly complete than the limited operating temperature condition as in the case of diesel engine. At all the load conditions, the carbon monoxide emission levels decreases for low heat rejection engine. It can be observed that at maximum load condition, the carbon monoxide of the ceramic coated engine was decreased by 18.6% compared with normal uncoated engine.

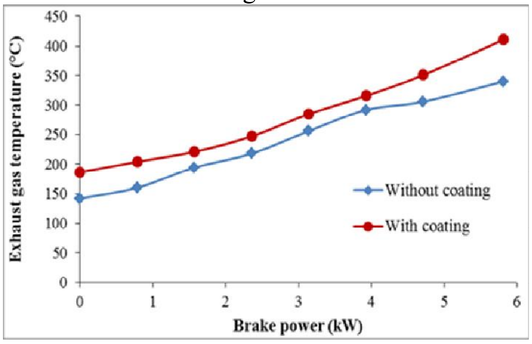

Figure 3. Variation of exhaust gas temperature

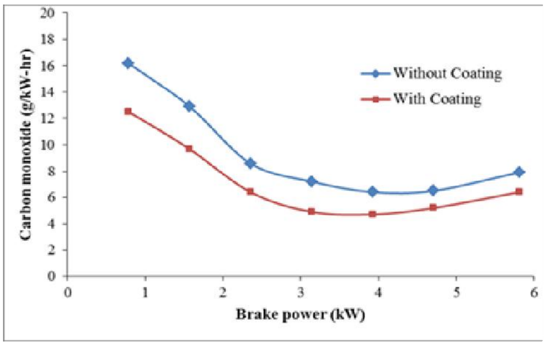

Figure 4. Variation of carbon monoxide emission

Figure 5 shows the variation of unburned hydrocarbon emission with respect to brake power. The results of the hydrocarbon emission show a similar trend as that of the carbon monoxide emission. From the figure, it is understood that, the low heat rejection engine achieved lower hydrocarbon emission than the conventional engine. At maximum load condition, the unburned hydro carbon emission of the ceramic coated engine was decreased by 22.8% compared with normal uncoated engine.

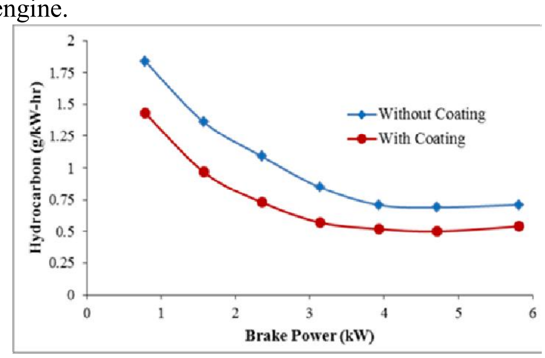

Figure 5. Variation of unburned hydrocarbon emission

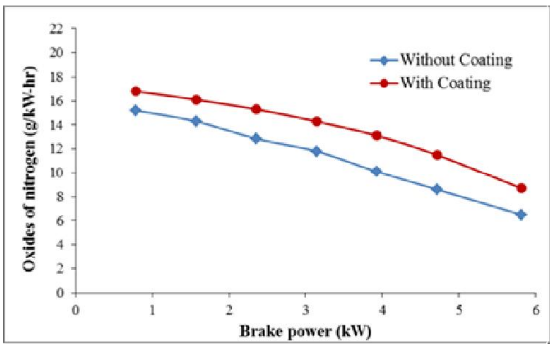

Figure 6. Variation of oxides of nitrogen emission

Figure 7 shows the variation of carbon monoxide emission with respect to brake power for both the conventional and low heat rejection engine. Form the figure, it has been observed that the smoke emission of the low heat rejection diesel engine are lower than the conventional engine. At maximum load condition, the smoke emission of the thermal barrier coated engine was decreased by 11.7% compared with conventional uncoated engine.

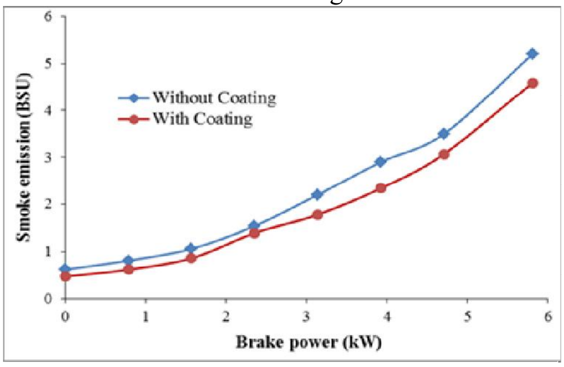

Figure 6. Variation of smoke emission

CONCLUSION

The following conclusions were drawn from the experimental study of direct injection compression ignition engine with coated with partially stabilized zirconia.

- The brake thermal efficiency of the low heat rejection engine marginally increased and the specific energy consumption decreased compared with uncoated engine.
- The carbon monoxide, unburned hydrocarbon and smoke emissions of the low heat rejection engine is lower than the conventional engine.
- The exhaust gas temperature and oxides of nitrogen increased with thermal barrier coating due to higher combustion temperature.

REFERENCES

1. S. Jaichandar, P. Tamilporai, Low heat rejection engines-An overview, SAE paper, 2003-01-0405, 2003.
2. G. Woschni, W. Spindler, Heat transfer with insulated combustion chamber walls and its influence on the performance of diesel engines, Journal of Engineering for Gas Turbines & Power, Vol.110, 1988, pp.482-488.
3. P.R. Srivathsan, P. Terrin babu, V.N. Banugopan, S. Prabhakar , K. Annamalai, Experimental investigation on a low heat rejection engine, International Conference on Frontiers in Automobile and Mechanical Engineering, November 25-27, 2010.
4. C.A. Aman, Promises and challenges of the low-heat-rejection diesel, Journal of Engineering for Gas Turbine and Power, Vol.110, 1988, pp.475–481.
5. M. Prabhahar, K. Rajan, Performance and combustion characteristics of a diesel engine with titanium oxide coated piston using pongamia methyl ester, Journal of Mechanical Science and Technology, Vol.27, 5, 2013, pp.1519-1526.
6. P. Ramaswamy, S. Seetharamu, K.B.R. Varma, N. Raman, K.J. Rao, Thermo-mechanical fatigue characterization of zirconia (8% Y_2O_3-ZrO_2) and mullite thermal barrier coatings on diesel engine components: Effect of coatings on engine performance, Proceedings of Institution of Mechanical Engineers., Vol.214, 2000, pp.729-742.
7. R. Soltani, H. Samadi, E. Garcia, T.W. Coyle, Development of alternative thermal barrier coatings for diesel engines, SAE Paper, 2005-01-0650, 2005.
8. P. Lawrence, P. Koshy Mathews, B. Deepanraj, Experimental investigation on zirconia coated high compression spark ignition engine with ethanol as fuel, Journal of Scientific and Industrial Research, Vol.70, 2011, pp.789-794.
9. Ken Voss, John Cioffi, Alex Gorel, Mike Norris, Tony Rotolico, Art Fabel, Zirconia based ceramic incylinder coatings and after treatment oxidation catalysts for reduction of emissions from heavy duty diesel engines, SAE Paper, 1997-04-69, 1997.
10. S. Santhanakrishnan, B.K.M. Ramani, Performance emission and combustion characteristics of a low heat rejection engine fuelled with diesel-CNSO-EEA blend, Journal of Advanced Engineering Research, Vol.2, 2015, 29-33.
11. C.D. Rakopoulos, G.C. Mavropoulos, Components heat transfer studies in a low heat rejection di diesel engine using a hybrid thermocstructural finite element model, Applied Thermal Engineering, Vol.18, 1998, pp.301-316.
12. Mohd. F. Shair, P.Tamil Porai, B.Rajendra Prasath, Analysis of combustion, performance and emission characteristics of turbocharged LHR extended expansion DI diesel engine, World Academy of Science, Engineering and Technology, Vol.61, 2010.
13. E. Buyukkaya, T. Engin, M. Cerit, Effects of thermal barrier coating on gas emissions and performance of a LHR engine with different injection timings and valve adjustments, Energy Conversion and Management, Vol.47, 2006, pp.1298–1310.
14. I. Taymaz, K. Cakir, M. Gur, A. Mimaroglu, Experimental investigation of heat losses in a ceramic coated diesel engine, Surface and Coating Technology, Vol.169, 2003, pp.168–70.
15. P. Belardini, C. Bertoli, F.E. Corcione, G. Police, Thermal barriers adoption in DI Diesel engines. Effect on smoke gaseous emissions, SAE paper, 840995, 1984.
16. M.M. Musthafa, S.P. Sivapirakasam, M. Udayakumar, A comparative evaluation of Al2O3 coated low heat rejection diesel engine performance and emission characteristics using fuel as rice bran and pongamia methyl ester, Journal of Renewable and Sustainable Energy, Vol.2, 2010, 053105.