Effect of Thermal-Barrier Coating plus Fuel Additive for Reducing Emission from Di Diesel Engine

A.P. Sathiyagnanam, C.G. Saravanan and S. Dhandapani

***Abstract*—In internal combustion engines, approximately one third of the total fuel input energy was converted into useful work and two-third has been lost through exhaust gas and cooling system. Recently research has been focused on the reduction of diesel engine pollutants due to strict emission regulations. The objective of this study is to evaluate performance, combustion and emission characteristics of thermal barrier coated DI diesel engine plus fuel additives. Plasma spray coating (PSC) technique has been used to coat the cylinder head, valves and piston crown with ZrO_2 /Al_2 O_3 about 150/150 microns. The test was carried out in a single cylinder, four stroke, water cooled DI diesel engine. In general, the ceramic coating acts as a thermal barrier which improves the efficiency by reducing energy losses.**

In the first phase of the investigation, engine components were coated with ZrO_2 /Al_2 O_3 by using PSC technique and thickness of 150 microns each. Second part of the investigation was carried out by blending of fuel additive (di iso propyl ether) with neat diesel fuel in thermal barrier coated diesel engine. The additives are in the ratio between 0.5% to 2.0% with the intervals of 0.5%. They were added to neat diesel fuel, by volume respectively. The fuel additive reduces the smoke density of the engine exhaust. The experiments were carried out for various loads via. 25%, 50%, 75% and maximum loads, then the results were compared. The results indicate that the reduction in fuel consumption, NOx emission and slightly increases the thermal efficiency of the engine. The combined effect of coating and fuel additive has further reduced the NOx emission.

***Key words*—ZrO_2/Al_2O_3, Di iso propyl ether, Plasma Spray Coating (PSC), Thermal Barrier Coating (TBC)**

I. Introduction

In a standard engine, a large percentage of energy is wasted through the cooling and exhaust system. By thermally insulating the engine's piston crown, valves and cylinder head which improve the combustion process and reduces the heat energy loss through the exhaust gases, by this the performance increases and emission reduces. Then it can be harnessed to increase the power output of the system, thus by raising the thermal efficiency and decreasing specific fuel consumption.

A. P. Sathiyagnanam, Assistant Professor, Department of Mechanical Engineering, Annamalai University, Annamalainagar – 608 002. Tamilnadu, India. (Corresponding author phone: +91 4144 239733; fax: +91 4144 238275; e-mail: apsgnanam@yahoo.co.in).
C.G. Saravanan, Professor, Department of Mechanical Engineering, Annamalai University, Annamalainagar – 608 002. Tamilnadu, India. (e-mail: rsdk66@yahoo.com)
S. Dhandapani, Principal, Dr. N.G.P Institute of Technology, Coimbatore - 641035. (e-mail: dmgpit@kmch.ac.in)

Fleisch *et al.* [1], Kapus *et al.* [2] and Sorenson *et al.* [3] has studied the use of dimethyl ether (DME) in the modified diesel engine. Their results show that the engine can achieve ultra low emission without fundamental change to the combustion system. Huang *et al* [4] and Wang *et al* [5] investigated the combustion and emission characteristics in a compression ignition engine with DME and found that the DME engine has high thermal efficiency, short premixed combustion and fast diffusion combustion, making it possible to achieve smoke-free combustion. Gong *et al* [6] found that diesel engine fuelled with 2-methoxyethyl acetate (MEA) reduced smoke, HC, and CO emissions. However, there was slight increase in the NOx emission.

The state of art thermal barrier coating (TBC) provides the potential for higher thermal efficiency of the engine, improved combustion and reduced emissions. Taymaz *et al*.[7] 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. The experimental results of Morel *et al*. [8] indicate that the higher combustion temperature generated by adiabatic engine and reduce the heat rejection rate it is due to thermal barrier coating. Kamo and *et al*. [9] used thermally insulating materials such as silicon nitride for insulating different surfaces of the combustion chamber.

Exhaust gas emissions from diesel engines are more smoke, oxide of nitrogen and HC. This emission is difficult to reduce simultaneously for ultra low emission diesel engine. The simulations reduction of smoke and NOx is the one of the major challenges in diesel engines. The experimental results of Hasimoglu et al.[10] indicate that use of ethanol-diesel fuel blend may be an alternative way to reduce smoke and nitrogen oxide emissions, at the same time without modification of any engine operating parameters. In practice adding some oxygenated fuel additive to diesel in order to reduce engine emission without engine modification seems to be more attractive. Oxygenates are those compounds, which have more content of oxygen per, molecule of the compound. The extra oxygen content helps in better combustion of the fuel. Bertoli *et al*. [11] and Miyamoto *et al*. [12] also conducted research on diesel combustion improvement and emission reduction by the use of oxygenated fuels. The blend of fuel additives have to improve cetane number and calorific values. Hence they can increase the local oxygen concentration in the fuel mixture during the combustion. Based on the literature, the present study is to evaluate the performance and emission characteristics of the coated, uncoated and fuel additive plus coated on diesel engine, at different loads and at constant speed. The coating of insulation materials used in the Low heat rejection (LHR) engine should have a high temperature strength, high expansion co-efficient, low friction characteristics, good thermal shock resistance, lightweight and durability. ZrO_2 with its excellent properties like toughness, high expansion coefficient and high insulation factor. . So it is used in this investigation and it acts as a base coating material. In addition, $Al_2O_3$was coated on the ZrO_2 coated engine components for absorbing oxygen during combustion.

Based on the previous study the objectives of the paper are:

- To study the combustion and emission characteristics of engine with thermal barrier coating.
- To study the combustion and emission characteristics of engine with fuel additive plus thermal barrier coating.

II. Preparation of Coatings

As the substrate material an Aluminium piston, cylinder liner, valves etc. were used. Commercially available ZrO_2 and Al_2O_3 ceramic feedstock powders (Sulzer Metco ZrO_2, Sulzer Metco Al_2O_3) with particle sizes ranging from 38.5 to 63 µm and Ni-20Cr-6Al-Y metal powder (Sulzer Metco NiCrALY-9) with particle sizes ranging from 10 to 100 µm were used. The surfaces were grit blasted using 400 mesh Al_2O_3 powder. The substrates were grit blasted until a surface roughness of alumina (Ra ~ 4) was achieved. The grit blasted substrates were ultrasonically cleaned using anhydrous ethylene alcohol and dried in cold air prior to coating deposition. NiCrALY bond coat of about 150 µm in thickness was air plasma sprayed onto the substrate. ZrO_2 coating o 150 µm was deposited over the bond coat and Al_2O_3 with thickness of 150 µm was sprayed over ZrO_2 coating. Air plasma spray system (Ion Arc 40kW) was used to deposit the coating. No air-cooling on the backside of the substrates was applied during the spraying process.

III. Test Rig

Figure 1. Shows the water cooled single cylinder, four strokes, direct injection diesel engine that was used for the study. The engine was coupled to an eddy current dynamometer for load measurement and the smoke density was measured using a AVL smoke meter. NOx emission was measured using AVL di-gas analyser. An AVL combustion analyzer was used to measure the combustion characteristics of the engine.

The engine was maintained at 1500 rpm and the piston, valves and cylinder head were coated by using ZrO_2 /Al_2O_3 and coating thickness of 150/150 microns. The fixed injection pressure of 200 bar was maintained. First standard engine (with out coating) was fully instrument connected to eddy current dynamometer. The first stage testes were performed at different loads at constant speed.

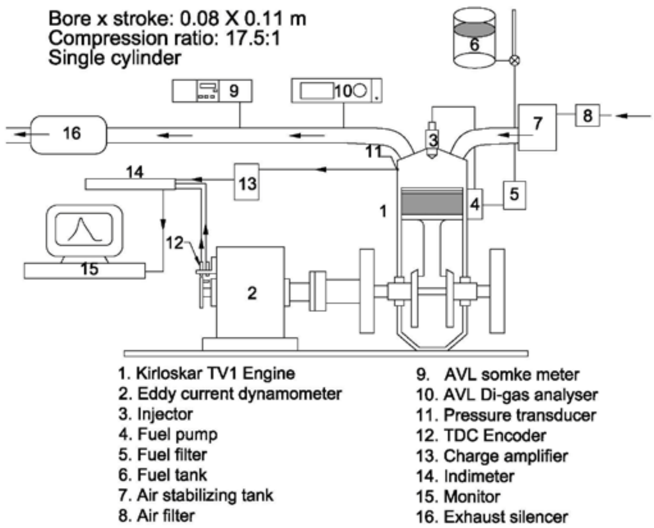

Figure – 1 Experimental Setup

IV. Experimental Procedure

The experiments were conducted at four loads level via. 25%, 50%, 75% and maximum load. The required engine load percentages were adjusted by using the eddy current dynamometer. The second part of the investigation was carried out by using various blends of fuel additives (di iso propyl ether). The concentration of 0.5%, 1.0%, 1.5% and 2.0% by volume were blend with the neat diesel fuel and the same experimental procedure was repeated.

The engine was allowed to run with neat diesel fuel at a constant speed for nearly 10 minutes to attain the steady state condition at the lowest possible load. The following observations were made twice for averaging or concordance. During the test trial parameters were obtained such as fuel consumption, smoke density and NOx. The table-1 shows the properties of neat diesel fuel.

The experiments were repeated for the following combinations:

- Neat diesel fuel,
- Neat diesel fuel with thermal-barrier coating,
- Fuel additive blends with neat diesel fuel at various ratios plus thermal barrier coating.

Table – 1 Properties of Neat Diesel Fuel

Density (kg/m^3)	820 - 860
Calorific value (kJ/kg)	42490
Cetane number	45 - 55
Flash point °C	50
Specific gravity	0.82
Viscosity @ 40°C (cSt)	2.0 – 5.0

After completing the experimental investigation for various concentrations of fuel additives the best concentration was determined on the basis of brake thermal efficiency, smoke density and NOx emission

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V. RESULTS AND DISCUSSION

The calibration of AVL5 gas analyzer was regularly checked. The NOx emission, smoke and cylinder pressure was recorded manually after allowing sufficient time for the engine to stabilize. The uncertainties in the measured parameters are shown in table – 2.

Table – 2 Error Analyses.

Parameter	Error
NOx	0.6 ppm
Smoke	1.8 HSU
Cylinder pressure	0.5 bar

The experimental results of brake thermal efficiency, heat release rate, smoke and NOx emissions were obtained from standard engine, thermal barrier coated engine and fuel additive plus thermal barrier coated engine are compared.

The variation of brake thermal efficiency with brake power for standard engine, thermal barrier coated engine and different ratios of fuel additive plus thermal barrier coated engine are shown in figure 2. It can be observed that there is a marginal difference in brake thermal efficiency between standard engine and thermal barrier coated engine. The brake thermal efficiency is increased by 3% from coated engine at maximum load when compared to standard engine.

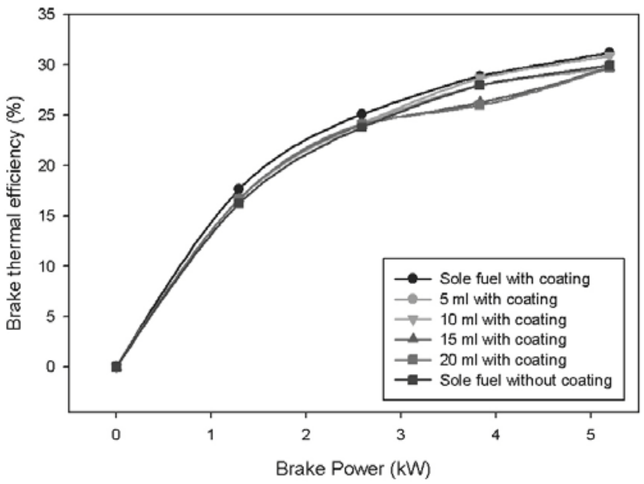

Figure 2. Brake thermal efficiency against Brake power

There is marginal improvement in brake thermal efficiency among the various concentration of fuel additive with thermal barrier coated engine. Due to the effect of thermal barrier coating, lower heat rejection from the combustion chamber through thermally insulated components increases available energy. Hence thermal efficiency is slightly higher when compared to the conventional engine.

Figure 3 shows the smoke density with brake power of the standard engine, thermal barrier coated engine and fuel additives plus thermal barrier coated engine. The results show that smoke density increases for the thermal barrier coating plus fuel additive engine. In thermal barrier coated diesel engine the combustion wall temperature increase more significantly. It increases compression air temperature which changes the ignition delay. So that change combustion behavior increases smoke density in the coated engine.

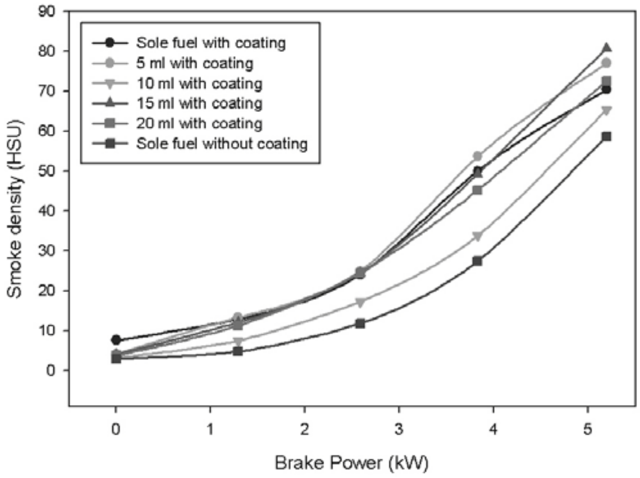

Figure 3 Smoke density against brake power

It is found that 1.0% blend of fuel additive plus thermal barrier coating reduces smoke density to 15 HSU when compared to standard engine. It is observed that up to part load, smoke density is lower for various concentrations of the fuel additive when compared to ceramic coated engine. Beyond part load 0.5%, 1.5% and 2.0% concentrations of the fuel additive, smoke density was slightly increased.

Figure 4. Shows the variation of NOx emission with brake power for standard engine, thermal barrier coated engine and fuel additive plus thermal barrier coated engine. The results indicate a lower NOx level for the thermal barrier coated piston when compared to conventional engine. The main cause in lowering NOx is due to the fact that the late combustion occurs. In the heat release diagram centroid is to be shifted away from top dead center, which results drop in a peak pressure rise. Since the peak pressure rise is lower due to the above reason, assuming the same value of mass, the peak gas temperature may also be lower near TDC, resulting in reduced NOx formation. The same trend was observed by Assanis *et al.* [13] during their experiments.

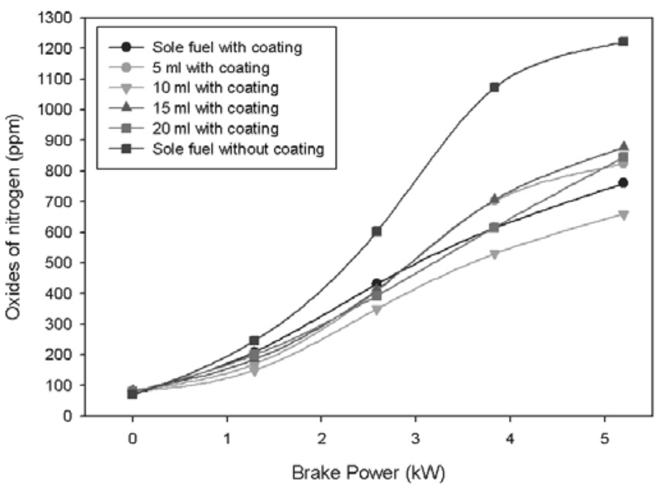

Figure 4 Oxides of nitrogen against brake power

Bryzik *et al.* [14] also found lower NOx level for a low heat rejection (LHR) engine than the standard engine. From the graph, it is observed that the thermal barrier coated engine reduces NOx emission approximately 500 ppm when compared to conventional engine. Further it is found that effect of 1.0% of fuel additive with thermal barrier coating, NOx emission reduces to about 600 ppm at the maximum brake power of the engine due to premixed combustion by fuel additives.

Figure 5 shows the cylinder pressure in different concentration of fuel additives with thermal barrier coating and standard engine at maximum brake power. It is found that for same engine speed and load, the cylinder pressure slightly decreases in coated engine and coated engine plus fuel additives. It is slightly lower than that of the standard engine. This is due to longer duration of diffusion in combustion process.

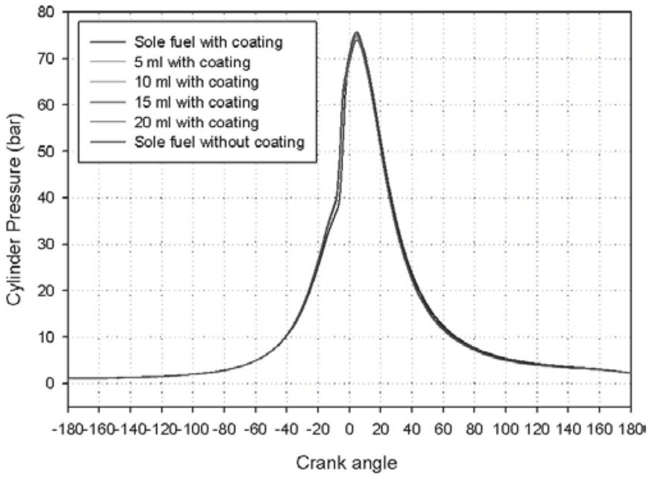

Figure 5. Cylinder pressure for different concentrations of fuel additive

Figure 6. Shows the heat release rate for different concentration of fuel additive plus thermal barrier coating and standard engine with crank angle at maximum brake power. The heat release rate curve for thermal barrier coated engine is slightly shifted from the top dead center due to reduced premixed combustion. The effect of fuel additives shows similar curve pattern.

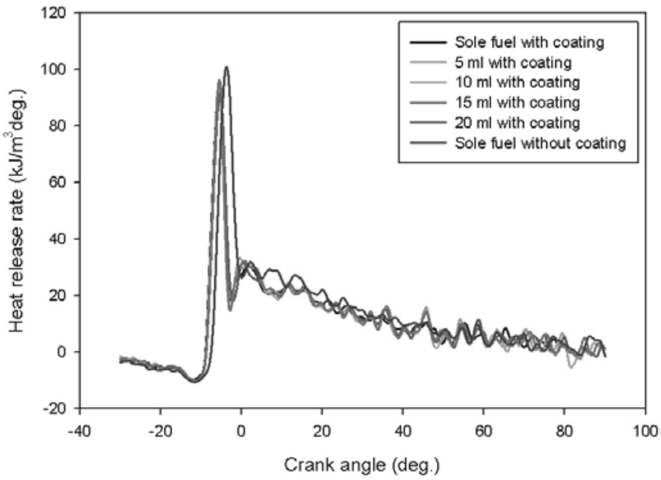

Figure 6. Heat release rate against crank angle

VI. Conclusion

The following conclusions are drawn from the experimental investigation of ceramic coated diesel engine with fuel additive.

1. The thermal efficiency slightly improves due to the effect of thermal barrier coating. The fuel additive with 1.0% shows better performance than other concentration.
2. Smoke level is found higher in thermal barrier coated engine. At the maximum brake power, the smoke level was slightly increased in the fuel additive plus thermal barrier coated engine.
3. Comparing with standard engine the NOx will be reducing about 500 ppm for TBC engine. By introduction of fuel additives to the TBC engine, it was further reduced by 100 ppm of NOx emission.
4. The heat release rate slightly decreases due to the effect of coating and coating plus fuel additives.

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