

Review of Emission Characteristics of Low Heat Rejection Internal Combustion Engines

Debasish Das¹, K.R. Sharma² and Gautam Majumdar³

^{1,2}*Mechanical Engineering Department, National Institute of Technology Hamirpur,
Himachal Pradesh, India.*

³*Department of Mechanical Engineering, Jadavpur University,
Kolkata, West Bengal, India.*

Abstract

Air pollution is a major problem for us all and emissions out of automobiles have an important role in this. The automobiles produce harmful gases like CO, CO₂ and NO_x. With increase in vehicles there is a need to work in the field of controlling emissions of automobiles. Thermal Barrier coating has evolved as a technology in which the cylinder walls, valves and top surface of the piston of an internal combustion engine are coated with a suitable ceramic material having a very less thermal conductivity using thermal spray methods, such type of insulated engines are low heat rejection internal combustion engines. The low heat rejection internal combustion engines have attractive emission characteristics due to the more complete combustion in the insulated configurations.. The present paper is a review of the effects of thermal barrier coating on the emission characteristics in low heat rejection internal combustion engines. In this article, few ceramic materials which are being used for thermal barrier coating and effects of thermal barrier coatings on pollution content of the engine are investigated based on presented articles.

Keywords: Thermal barrier coating (TBC); plasma spray technique; lower heat rejection (LHR); partially stabilized zirconia (PSZ); Emission characteristics.

1. Introduction

Historically, the automobiles have been a noxious polluter all around. The incomplete combustion of the hydrocarbon fuels that provide power for the automobiles are primarily responsible for this exhaust spewed into the air. In the emission of an internal combustion engines carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), sulfides and particulate are present. In an internal combustion engine heat is transferred from combustion chamber to piston head, cylinder walls and then to the cooling water circulated through water jackets around the cylinder. Generally, in diesel engines about 19-22 percent of heat energy from fuel combustion is rejected to coolant fluid. Heat transfer affects emission characteristics of internal combustion engine. For a given mass of fuel burnt within the cylinder, higher heat transfer to cylinder walls lowers the average combustion gas temperature and reduces the indicated power. Due to lower average combustion temperature some fuel remains unburned after combustion thus results in poor emissions. To reduce heat loss to the cooling water thermal barrier coating (TBC) is used. The ceramic coating on metallic materials have shown appreciable improvements since 1970. First of all the thermal barrier ceramic coating were used for gas turbine wings then from 1980 the thermal barrier ceramic coating was introduced in adiabatic engines. The first breakthrough in diesel engine technology was brought by the pioneering work by Kamo and Bryzik since 1978 to 1989 in introducing TBC system for engines (Kamo R and Bryzik W, 1978; Kamo R and Bryzik W, 1979; Kamo R and Bryzik W, 1981; Kamo R and Bryzik W, 1983; Kamo R and Bryzik W, 1984 a, b; Kamo et al., 1989). Many researchers have done large number of studies on design of internal combustion engines with lower heat rejection (LHR) by using TBC. An engine with its combustion chamber walls insulated by ceramics is referred to as LHR engine. LHR engines aim to improve thermal efficiency and improved emissions by reducing the heat loss to the coolant. The TBC coating using ceramic materials is also done on the piston crown surface, valves and cylinder liners.

Thermal spray coating technique used to obtain the TBC on the substrate metal or super alloy are flame spray and plasma spray techniques. Plasma spraying technique is more commonly used for thermal barrier coating by ceramic material in powder form though it is expensive because it makes possible to coat with high melting point materials also the plasma-sprayed ceramic coatings have higher bonding strength than flame-sprayed coatings (Berndt CC, 1985). In accordance with many researchers the bonding strength of a ceramic coating with bonding coating is higher than without a bonding coating. The adhesion strength between the substrate and the ceramic coating could be improved by a NiAl bonding coating (Under R H, 1987; Gates W D et al., 1993).

In this study, the literature review is performed to investigate TBC materials and their effects on LHR internal combustion engine emission characteristics. As a result, after considering the application TBC kind of ceramic coating which is made on combustion chambers, piston crown and valves etc, depending on the type of the engine, the pollution contents decreases.

2. Experimental Section

2.1 Coating materials

Where conventional metals and alloys fail to perform at elevated temperatures, advanced ceramic materials like nitrides and carbides of silicon (Si_2N_4 and SiC), oxides of chromium, aluminum, and iron ore (Cr_2O_3 , Al_2O_3 and FeO_2) and partially stabilized oxide of zirconium (ZrO_2 or PSZ). (Clarke D R, 2008) indicated that few rare-earth zirconates such as $\text{Gd}_2\text{Zr}_2\text{O}_7$ and $\text{Sm}_2\text{Zr}_2\text{O}_7$ have lower thermal conductivity than 8 w/o yttria-stabilized zirconia (YSZ) which is most preferred coating material for many years because of its thermodynamic stability in contact with alumina, the oxide formed at high temperatures on all present bond-coat alloys.

2.2 Emission characteristics

1.2.1 Hydrocarbon (HC) emissions

In LHR engines the higher temperatures both in the gases and at the combustion chamber walls assist in permitting the oxidation reactions to occur close to completion thus emission of unburned hydrocarbons (HC) is more likely to be reduced most of the researchers show reduction in HC levels in LHR engines (Jaichandar S and Tamilporai P, 2003). The figure 1 shows the variations of HC emissions depending on the load of a turbo charged diesel engine and comparing it with that of a standard engine (SE), shown in the work of shrirao et al. (Shrirao P N and Pawar A N, 2011). This clearly indicates that the ceramic coating improves local conditions specifying temperature, pressure, mixture ratio, and amount of oxygen affects combustion, and makes combustion continuous in diesel engines. The emission of unburned hydrocarbons from LHR engine with turbocharger is more likely to be reduced because of the decreased quenching distance and the increased lean flammability limit.

1.2.2 Carbon monoxide (CO) emissions

Also many investigations have reported lower level of carbon monoxide (CO) emissions with TBC insulated engines. This is because of the reduced level of pre-mixed combustion in the insulated engine decreases the initial production of CO and the higher temperatures during diffusion combustion increases the oxidation of CO (Jaichandar S and Tamilporai P, 2003). Figure 2 shows CO variations depending on the load of the engine. CO emission from the diesel engine is related to the fuel properties as well as combustion characteristics. It is well known that better fuel consumption usually resulted in lower CO emission. This is due to the fact that application of turbocharger provides increased air in the engine and enables mixing of fuel-air easily in the combustion chamber, thereby causing better combustion and lower CO emission values.

1.2.3 Nitrogen oxide (NO_x) emission

In conventional engines due to less mean temperature of gases nitrogen does not take part in the combustion so emission of nitrogen oxides (NO_x) is less but in LHR engines due to increased combustion efficiency NO_x emission increases since NO_x emissions

are mainly the function of gas temperatures and resident time. All factors facilitating and accelerating the reaction between oxygen and nitrogen increase NO_x formation. The main factor in the NO_x formation is temperature. However, engine speed, combustion chamber content, combustion chamber homogeneity, and mixture density in the combustion chamber are also factors. The increase of NO_x for the LHR engine may be a result of an increase in after-combustion temperature due to the ceramic coating. Most of the earlier investigations showed that NO_x emission from LHR engines is generally higher than in water cooled engines. A noticeable increase in the NO_x emission was observed in the LHR engine with the turbocharger operation. This is due to the fact that application of turbocharger provides more air to the engine and causes a higher combustion temperature which yields an increase in the formation of NO_x emission.

Alkidas (Alkidas A C, 1989) indicates an increase in the LHR engine NO_x emissions and concluded that diffusion burning is the controlling factor for the production of NO_x . Ramu et al. (Ramu P and Saravanan C G, 2009) reported that the combined effect of TBC plus fuel additive shows better performance and simultaneously reduces the smoke and NO_x emission (Fig. 3). Lawrence et al. (Lawrence P et al., 2011) reported that increased reduction of NO_x was observed due to coating of zirconia because nitrogen was absorbed by zirconia.

Figures

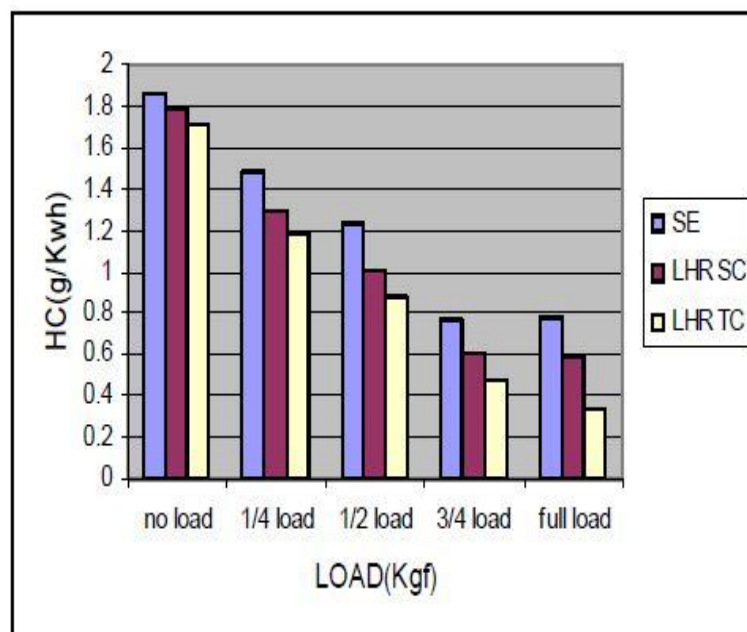


Fig. 1: Load Vs HC emission (Shrirao P N and Pawar A N, 2011).

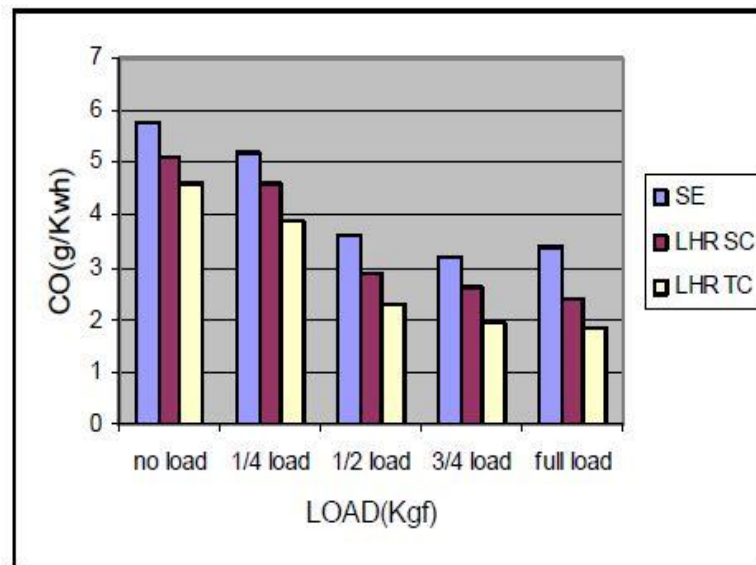


Fig. 2: Load Vs CO emission (Shrirao P N and Pawar A N, 2011).

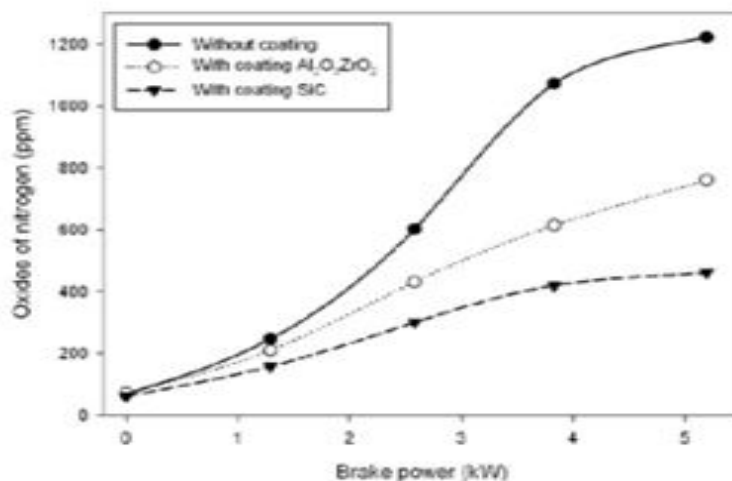


Fig. 3: The amount of nitrogen oxides against the brake power (Ramu P and Saravanan C G, 2009).

3. Conclusion

In this review paper, various types of coating materials have been discussed among them the yttria stabilized zirconia is most widely used for TBC application in LHR engines but few rare-earth zirconates like $Gd_2Zr_2O_7$ and $Sm_2Zr_2O_7$ may give promising results due to their low thermal conductivity than yttria stabilized zirconia. In LHR engines the pollution contents decreases except NO_x but in the case of PSZ coating NO_x also decreases.

References

- [1] Kamo R and Bryzik W (1978), Adiabatic turbo-compound engine performance prediction, SAE International, Paper No.780068.
- [2] Kamo R and Bryzik W (1979), Ceramics in heat engines, SAE International, Paper No.790645.
- [3] Kamo R. and Bryzik W (1981), Cummins-TRADOCOM adiabatic turbo-compounded engine program, SAE International, Paper No.810070.
- [4] Bryzik W and Kamo R (1983), TACOM/Cummins adiabatic engine program, SAE International, Paper No. 830314.
- [5] Kamo R and Bryzik W (1984), Cummins/TACOM advanced adiabatic engine, SAE International, Paper No. 840428.
- [6] Sekar R.R. and Kamo R (1984), Advanced adiabatic diesel engine for passenger cars, SAE International, Paper No. 840434.
- [7] Kamo R, Woods M E and Bryzik W (1989), Thin thermal barrier coating for engines, United States Patent, Patent No. US4852542.
- [8] Berndt CC (1985), Plasma spray coating, Department of Materials Engineering, Clayton, Victoria: Monash University.
- [9] Under R H (1987), In: Proceedings of the national thermal spray conference, Orlando, FL, 365-70.
- [10] Gates W D, Diaz AM Aquilmo SAJ (1993), Prosthetic Dent: 69:12.
- [11] Clarke D R, Material selection guidelines for low thermal conductivity thermal barrier coatings, Materials Department, College of Engineering University of California, Santa Barbara, CA 93106-5050.
- [12] Jaichandar S and Tamilporai P (2003), Low heat rejection engines – an overview, SAE International, Paper No. 2003-01-0405.
- [13] Shrirao P N, Pawar A N (2011), Evaluation of performance and Emission characteristics of Turbocharged Diesel Engine with Mullite as Thermal Barrier Coating, International Journal of Engineering and Technology, ISSN: 0975-4024 Vol.3 (3), 256-262.
- [14] Alkidas A C (1989), Performance and emissions achievements with an un-cooled heavy duty single cylinder diesel engine, SAE International, Paper No. 890144.
- [15] Ramu P and Saravanan C G (2009), Effects of $ZrO_2-Al_2O_3$ and SiC coating on diesel engine to study the combustion and emission characteristics, SAE International, Paper No. 2009-01-1435.
- [16] Lawrence P, Mathews P K and Deepanraj B (2011), Experimental investigation on zirconia coated high compression spark ignition engine with ethanol as fuel, Journal of Scientific & Industrial Research Vol. 70, pp. 789-794.