

A review on thermal barrier coating for diesel engine and its characteristics studies

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Abstract. Thermal Barrier Coating (TBC) on diesel engine performance was studied with a purpose of improving the thermal efficiency by decreasing Specific fuel consumption (SFC) and reducing exhaust emissions. This review paper gives a comparison of a standard diesel engine over a Low heat rejection engine. The experimental results from the various researchers show a gradual improvement in efficiency and specific fuel consumption rate. Higher operating temperature in combustion chamber gives higher efficiency which by using temperature resistant materials. Ytria-stabilized zirconia (YSZ) ceramic, ZrO_2 , Al_2O_3 , Aluminium titanium are the coatings used on piston crown, cylinder liners, valves by adopting plasma spray technique. The results of LHR engine shows that, NO_x emission is increased, whereas the efficiency and SFC are closer to standard engines at Low loads and noticeable improvements are seen at higher loads.

1. Introduction

More researchers in automotive industries are concerned in decreasing the fuel consumption and pollution. Temperature is the key factor which affects the efficiency in diesel engines. Temperature has a direct impact on thermal efficiency of a diesel engine, as the temperature is increased in combustion chamber, the thermal efficiency increases.

In the period of 1978-1989, kamo and bryzik were the first persons to introduce thermal barrier coatings for engines [1]. They used thermally insulating materials such as silicon nitride on different surfaces of combustion chamber. Generally, 19-30% energy of the fuel is rejected to coolant fluid. By using TBC, we can reduce this heat loss and increase the thermal efficiency, improved combustion, components life can be increased, lower the pollution rate. The heat rejected to the coolant and utilizing this energy for useful work can be achieved by using low heat rejection (LHR) engines [2].

Some researchers work is experimental and some are theoretical studies. There is an improved performance and fuel consumption in LHR engines and every experiment shows comparable results and graphs with varying composition of TBC materials for different thickness.

The diesel engine is generally 20% more efficient than an equivalent petrol engine as the air is so compressed the engine gets greater efficiency from the fuel distinction to petrol engine. Diesel produces more carbon dioxide per litre of fuel burned about 17 % more than petrol and it rejects about $2/3^{rd}$ of the heat energy of the fuel, $1/3^{rd}$ to the coolant, and $1/3^{rd}$ to the exhaust, leaving only about $1/3^{rd}$ as useful power output. Theoretically, if the heat rejected could be reduced, then the thermal efficiency would be improved, at least up to the limit set by the second law of thermodynamics. LHR engines aim to do this by reducing the heat lost to the coolant [3].



The literatures review of TBC for diesel engines is performed to investigate all effects of TBC on engine performance. As a result, by considering the application of this kind of ceramic coating, Aluminium Titanium, Mullite, which is Coated on combustion chambers, piston crown, cylinder liners, depend on the diesel engine Fuel consumption is reduced, combustion efficiency is increased, and emission particulates is decreased.

2. General Review

Research is carried out on use of coatings on diesel engines using different coating materials. Mullite coated engines showed a better improvement in fuel efficiency. Tests were carried out for 500hours long. Mullite also shows an increased resistance to micro cracking. [4] Similarly Ceria-yttria stabilized zirconia (CYZ) coatings was developed with low thermal conductivities, it has excellent thermal shock resistance and erosion resistance compared to yttria stabilized zirconia (YSZ) coatings dense zirconia-titania-yttria (ZTY) and chromia-titania-silica (CTS) coatings have reduced erosion resistance properties. [5] A SI Daihatsu engine was coated with ceramic on its piston crown by using YSZ. Performance of the engine and the specific fuel consumption comparison with a standard diesel engine was made, and it gave better results. [6]

Raghu experiments of TBC coating on the piston top show the increased unburned charge oxidation and decrease in the thermal conductivity. There is an increase in mechanical efficiency and brake thermal efficiency by 7.5% to 20%. specific fuel consumption is reduced by 5% with coated piston. Some studies show the coating systems has an increased fatigue life of engine components [7] Tadeusz Hejwowski [8] carried out tests on double layered TBC by plasma spray technique. Plasma sprayed coatings showed good results compared to flame sprayed coatings. Axial plasma spraying is also an advanced thermal spraying technique for depositing TBC [9]. It is seen that using tbc gave better results with emissions. Most of the researches were interested in doing the analysis on exhaust gases as it was the most important source of available energy. Energy recovery had to be done by using secondary heat recovery devices [10]. Uzun [11] work mainly concentrated on emissions as well. The results showed that ceramic coatings tested for their ability to control particulate emissions. Hydraulic engine dynamometer was used to test the ceramic coating. Comparison of the emissions from standard engine shows that particulate matter emissions were highest at low load and low speed conditions. In TBC coated engines it decreases the particulate mass. [12]

3. Fuel Consumption

As the surface temperature of LHR engine is very high, the BSFC values will be lesser than conventional engine. The decrease in fuel consumption of LHR engine, can give higher premixed combustion, reduced combustion rate, reduced heat transfer losses and increase in heat release rate during combustion. From the figure 1, it is observed that 1.76% of BSFC value is decreased in LHR engine compared to conventional engine at different loads [13].

Table 1: Gives the experimental data for fuel consumption and speed [14].

Modified Engine	Fuel consumption	Speed
1	4.2%	1100 rpm
2	11.7%	4000 rpm
3	20.7%	2500 rpm

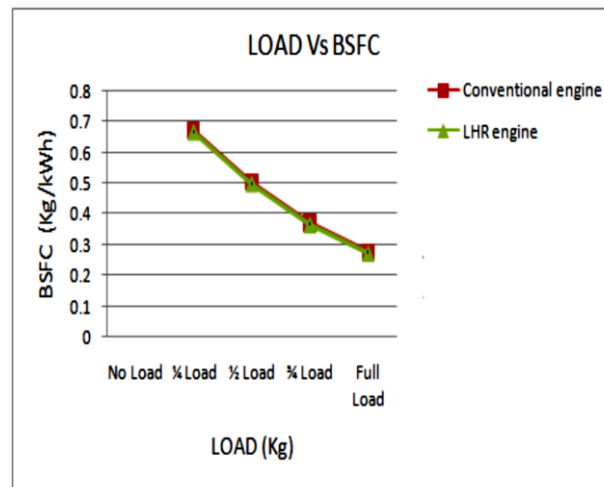


Figure 1: Engine Load Vs. BSFC

There is a gradual decrease in specific fuel consumption in modified engine at highest speed range and came approximately to 8% higher as shown in figure 2.

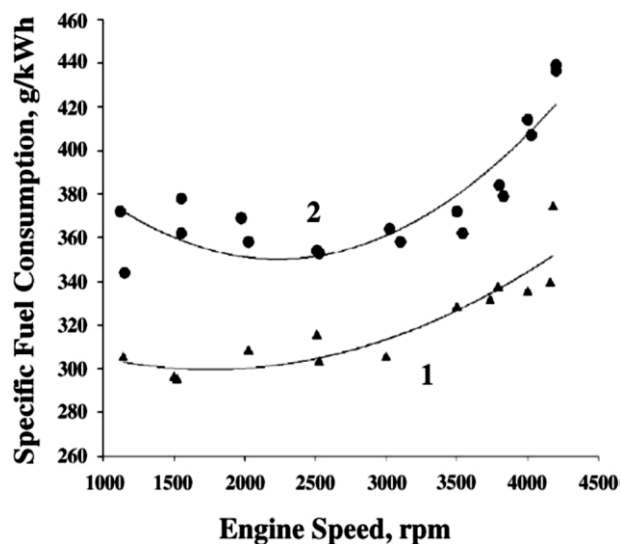


Figure 2: Specific fuel consumption for a conventional (1) and modified engine (2)

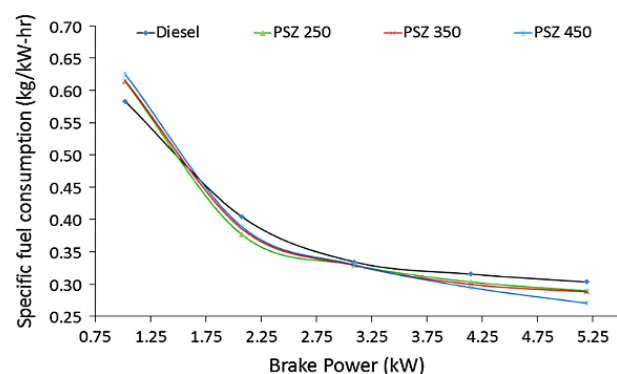
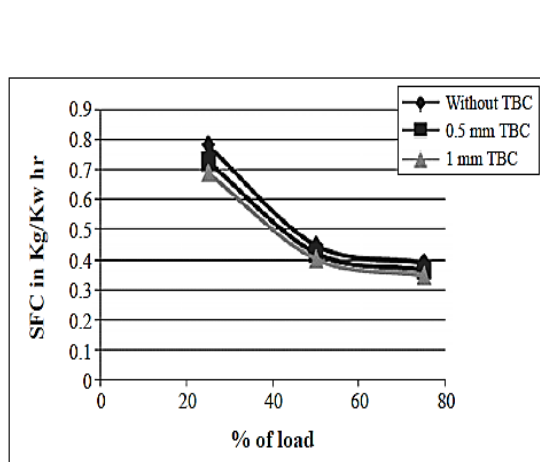
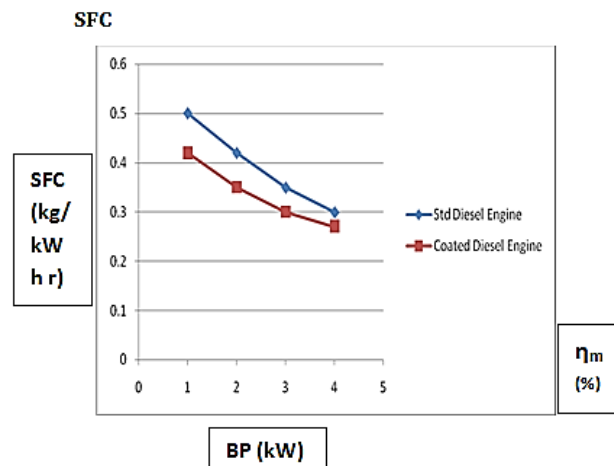


Figure 3: Specific fuel consumption against brake power

As shown in figure 3, The diesel engine piston coated with the TBC, shows at low load specific fuel consumption is high, when compared to a conventional diesel engine. For medium load the SFC is same in both the engines. As the load is increased to maximum as 250, 350 and 450 the coated LHR engine works on 4.41, 4.98 and 10.78% less fuel. The temperature of the combustion chamber increases by increasing the wall temperature, the fuel temperature and the viscosity of the fuel reduces which leads to heavy leakage of fluid inside the nozzle. Fuel injection duration also increase thereby reducing the specific fuel consumption [15]

**Figure 4:** % of Load Vs SFC**Figure 5:** Specific Fuel Consumption v/s Brake power

The specific fuel consumption of the engine is reduced after the application of thermal barrier coating. For different thickness of TBC coating specific fuel consumption decreases as the load increases. We can see a better result for diesel engine with coating compared to an uncoated diesel engine for different thickness [16].

Figure 5 shows on the basis of tests conducted to the diesel engine by using ceramic coating and diesel engine without coating tells us there is a reduction in SFC nearly 16% compared to diesel engine [17].

From the Table-2, it is clearly observed that at all low, medium and high loads the engine speed, show a (2%–7%) decrease in bsfc for ceramic-coated engine in comparison to standard engine (without coating). At higher speed the BSFC value is more for coated engines compared to standard engines.

Table 2: Gives the experimental data for BSFC values for varying loads at different speeds [18]

Load applied	Type of Engine	SPEED(rpm)		
		1000	1600	2400
Low	SE 20°C A	218	213	235
	CCE 20°C A	222	218	235
	CCE 18°C A	236	226	237
Medium	SE 20°C A	248	222	263
	CCE 20°C A	252	230	248
	CCE 18°C A	263	262	278
High	SE 20°C A	308	293	320
	CCE 20°C A	310	295	324
	CCE 18°C A	318	305	340

4. Emissions

4.1 Exhaust Gas Temperature (EGT)

Exhaust gas temperature is a method of analysing the progress of combustion taking place in engines. Thermal barrier coating (TBC) engines have lower exhaust gas temperature compared to standard engines. EGT of the TBC engine reduces to 3 and 18°C for Fig. 6 EGT against break power

250 and 350 μm coated piston as compared to standard engines it was reduced 450 μm in coated piston at 23°C [15].

4.2 Smoke Density

Ceramic coated engine shows an 18% reduction in smoke emission. Hydrogen molecules in fuel reacts quickly, the rest of carbon leaves as smoke. For different loads, the amount of smoke released was reduced in TBC engine. The values were recorded at 20% it of the engine load, 250, 350 and 450 μm coated diesel engine emits 49.59, 15.10 and 44.2 75% less smoke. Similarly, at 100% engine load, the smoke emission was 21.59, 47.88 and 48.95% less as diesel engine. [15]

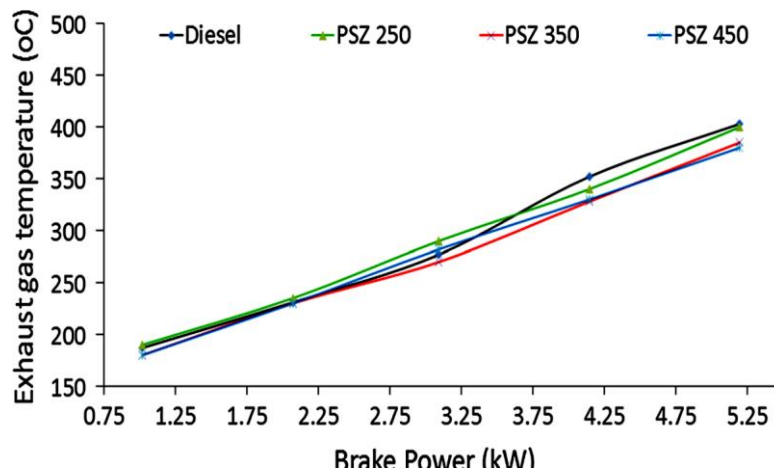


Figure 6: Exhaust gas temperature vs. BP

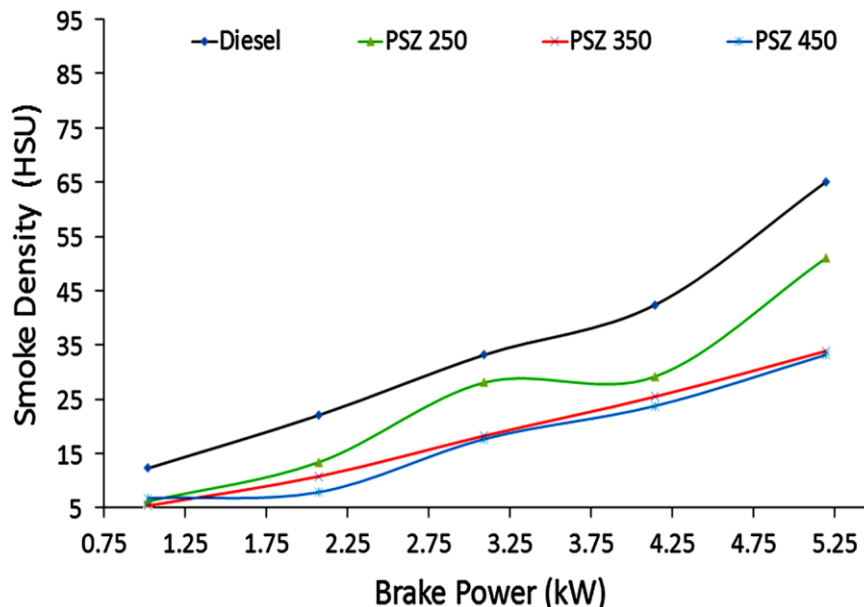


Figure 7: Smoke density Vs Brake power

4.3 CO Emission

CO Emission at low load is nearer to standard engine as compared to LHR engine, but as the thickness of coating is increased, the CO emission falls and there is increase in BP. experimental results shows

250, 350 and 450 μm coated piston diesel engines emit 13.51, 10.81 and 43.24 % less CO compared to standard engine. [15]

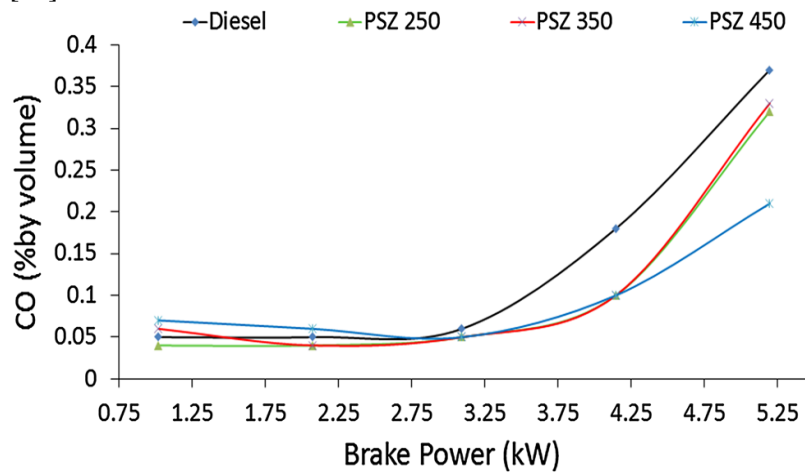


Figure 8: CO Vs Brake power

The incomplete combustion of the fuel and excess of fuel, causes increase in CO. as the fuel has mix percentage of carbon as compared to oxygen then it's a rich mixture. There was not enough oxygen for complete combustion of carbon as carbon monoxide is an odourless gas and poisonous. [16]

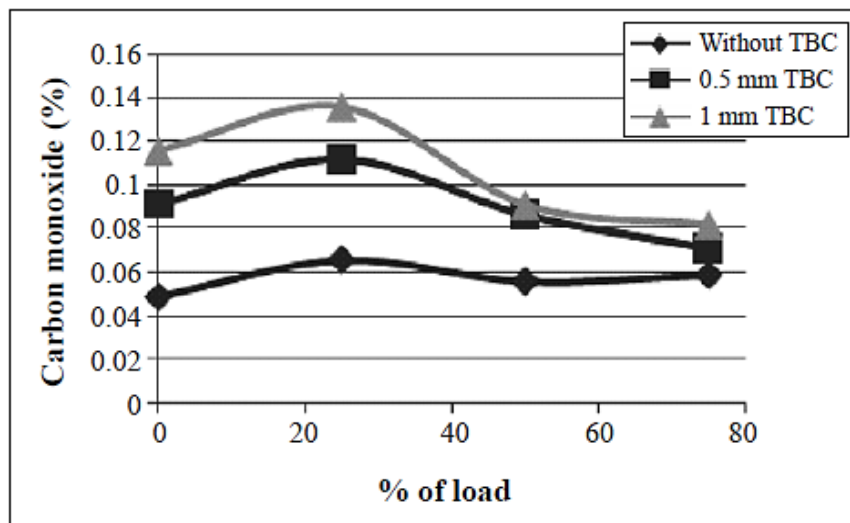


Figure 9: % of Load Vs carbon monoxide

From graph it is clearly seen that TBC, engines has a considerable drop in CO emissions of 3-6 % between 1100 to 2000/min, and 7.5-10% between 2200 and 2800/minute compared with standard diesel engine. As we change the properties of standard diesel engine keeping load condition and engine speed, Carbon monoxide is completely burnt to carbon dioxide. If enough O_2 is available, Carbon monoxide oxidation is very less at low load and as the load increases, the temperature increases there by Carbon monoxide burns completely and its emission decreases. As time required is inadequate for reaction then again CO will increase. [19]

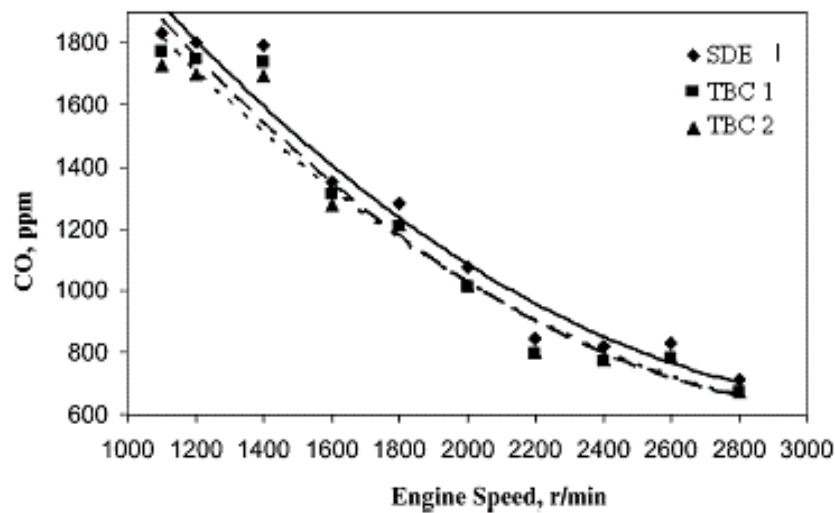


Figure 10: Change in CO emissions as a function of engine speed at full load

4.4 HC Emission

TBC coated Piston shows A reduction in hydrocarbon emission at maximum load when compared with diesel engine, 250, 350 and 450 μm engine emits 37.84, 43.24 and 37.84 % less. As heat loss to atmosphere is reduced due to decrease in heat rejected to coolant for engine cooling, at maximum load HC emission in LHR engine is less, whereas low load there is not much difference between a LHR and standard engine.

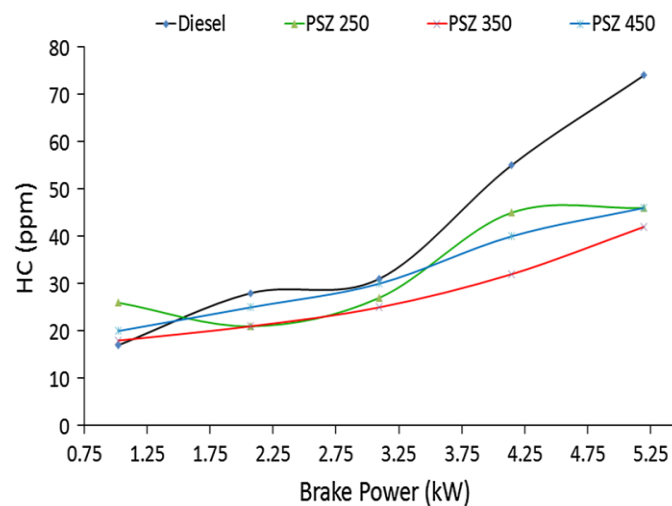


Figure 11: HC against Brake power

Due to incomplete combustion unburned fuel exits through the exhaust. It is required to keep it low. The relationship between unburned fuel and the PPM of HC is about 1/200. [16]

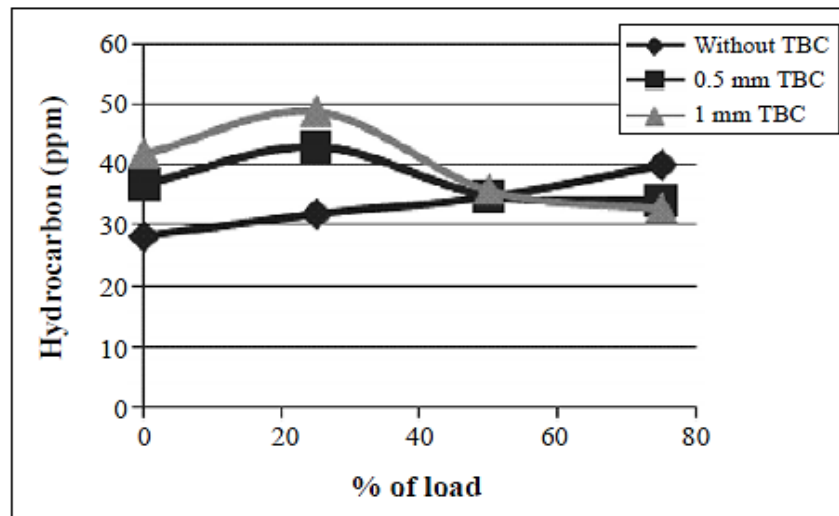


Figure 12: % of load Vs hydrocarbon

4.5 Oxides of nitrogen

NOX emission is almost same at primary load in both LHR and standard engines it starts increases between 262 and 473 ppm at medium load and gradually increases between 152 and 250 ppm to maximum load, nearly to full load as compared with diesel engines This NOX emission can be reduced in LHR engine by increasing the combustion duration. [15]

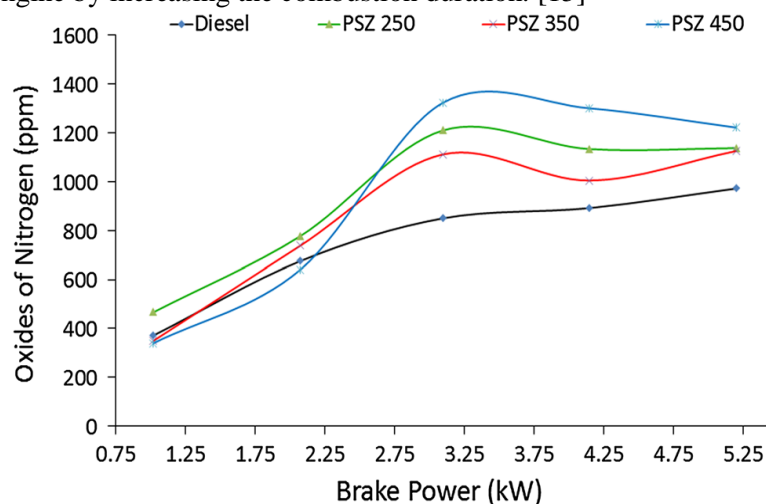


Figure 13: NO_x vs BP

A Gas analyser working and different loads is used to see the NOX emission percentage. At Higher temperature and pressure in the combustion chamber there will be excess O₂ molecules, that combine with nitrogen to form NO_x. Ignition timing is directly affected as the NOX percentage increases. NOX its starts getting collected in the engine, it become very harmful. [16]

NO_x emission can be seen at Higher temperatures of 1800°C coated engines shows a 150-200° centigrade increase in temperature to as compared to standard engines. this increases NO_x by 7% of the TBC1 and 11% in TBC2 engines. [19]

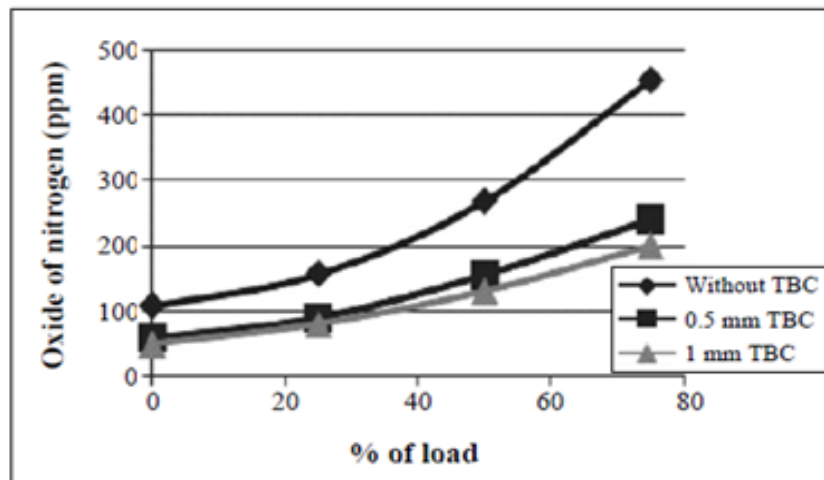


Figure 14: NO_x vs % of load

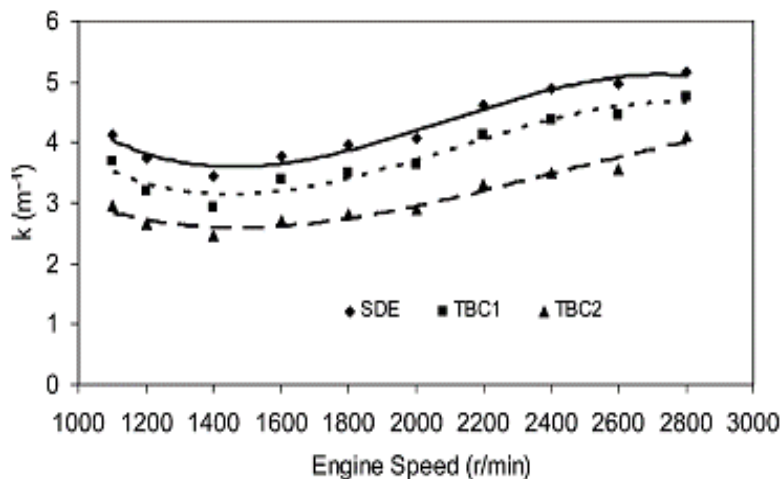


Figure 15: NO_x vs Engine speed

5. Conclusion

Thermal barrier coatings (TBC) are an enabling technology to increase low heat Rejection (LHR) diesel engine performance. This Low Heat Rejection (LHR) engine concept proved as a means for recovering thermal energy from exhaust of a diesel engine [20]. Researches have used different TBC materials to enhance the performance of diesel engine. It has the positive effect on the power, exhaust emission and fuel consumption on the engine. By applying the coating on the combustion chamber components we are trying to make the combustion temperature high.

Tests were conducted on a 4 stroke 4-cylinder diesel engine for SFC, efficiency and emissions. TBC coated engines for various thicknesses were compared with standard diesel engines, the test was conducted from minimum load to maximum load as well as for low speed to high speed. Based on the above results it can be said that replacing the standard diesel engine with TBC engine gave a significant improvement in efficiency and SFC was observed with a drawback of increased NO_x emissions. At low loads the standard engines and LHR coated engines shows similar results and as the load is gradually increased, there is an increase in efficiency and SFC in coated engines were seen.

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