Investigation Behavior of Diesel Engine Performance and Emission Analysis Using Al_2O_3 - TiO_2 Material Coated Engine

Murugan K[1], Thirumalai R[2], Kumar M[3]

[1] Assistant Professor, Department of Automobile Engineering, Mahendra Institute of Technology, Namakkal, Tamil Nadu, India.
[2]Professor, Department of Mechanical Engineering, Dr.N.G.P. Institute of Technology, Coimbatore, Tamil Nadu, India.

3Final Year, M.E.Thermal Engineering, Salem College of Engineering and Technology, Salem Tamil Nadu, India.

[1]muruganauto@gmail.com, [2]vkrthirumalai@gmail.com, [3]mmkumar771@gmail.com

ABSTRACT

A World Health Organization (WHO) report by state that of the 20 most polluted cities in the world, 13 are in India at the top in Delhi. Central Pollution Control Board (CPCB) currently monitors air quality in 8 locations at Delhi. CPCB was announced at five key pollutant level SO_2, NO_2, CO, $PM_{2.5}$ and O_3. Mostly this pollutant formed at automobile emission. In this study to reduce amount of automobile pollution with promise on my research on thermal barrier coated single cylinder direct injection diesel engine coated with Aluminum Oxide Titanium Dioxide (Al_2O_3 – TiO_2) and air plasma spray technique. The coating has been used to piston crown and valve heads for the coating thickness is 300 microns. The test was carried out in single cylinder four stroke direct injection diesel engine the result is noted. The effect of TBC is analyzed to improve the brake thermal efficiency, brake specific fuel consumption and slightly increase the thermal efficiency. The effect of (Al_2O_3 – TiO_2) coating is reduce the engine emission HC, CO and slightly increase the NOx emission.

KEY WORDS: *Aluminum Oxide Titanium Dioxide, Air Plasma Spray Technique, Thermal Barrier Coating, Performance, Emission.*

1. Introduction

The (TBC) coated engine and without coated engine to reduce 6% heat losses through the piston and cylinder wall coating. To assess the aluminum alloy piston have 100µm thickness cast iron and 200µm oxide based coating material (Prasad et al. 1990). Implement the effects of ceramic coatings on diesel engine much better thermal efficiency, lower level of CO, unburned HC, NOx concentration and also reduced smoke emission in to the coated engine. It focuses on performance and engine emission was coated engine relieved (Assanis et al. 1991). The engine piston to improved engine efficiency that increase thickness of yttria-stabilized zirconia coating with decreased temperature and heat flux using of finite element analysis of the redesign piston crown and therefore mechanical efficiency of diesel engine (Kamanna et al. 2017). The effect of thermal barrier coatings reduced in fuel consumption to improve the engine efficiency effectively. The engine combustion chamber surface, piston crown, head of the cylinder, inlet and exhaust valves were coated with base coating of NiCrAl and top coating of $CaZrO3$ and $MgZrO3$ with prepared plasma spray coated engine (Hejwowski et al. 2002). The coated engine was evaluated to reduce particulate emission, different emission in engine emission lower at CO, HC. Thermal barrier coating is able to eliminate visible smoke, reduced NOx emission (Uzun et al. 1999). Thermal fatigue resistance of two layers TBC was investigated in the result found to be degradation mechanism improved spallation of diesel and petrol coated engine test present (Hejwowski et al. 2010). The study examined on wear characteristics for air plasma spraying deposited on CoNiCrAlY inner metallic coating on aluminum alloy substrate. Literature concentrating on wear characteristics and microstructure properties of air plasma spray technique used CoNiCrAlY coating, to increasing the sliding distance; it will be reduce the wear rate of CoNiCrAlY coating (Kumara and Pandey 2016). Thermal barrier coating can prevent low oxygen diffusion rate, low thermal conductivity and better mechanical property, prepared by the cathode plasma electrolytic deposition. The coating were prepared with bond coat thickness 6-8 μm Al2O3 composite and top coating thickness of 120 μm La2Zr2O7 present (Deng et al, 2016). In the TBC on diesel engine rich mixture region leads to performance with thermal barrier coating in engine due to increase of higher temperature to surface volume ratio. Improvement of thermal efficiency, heat transfer losses effectively of thermal barrier coating engine emission and combustion presented (Yao et al. 2018). The electrolytic jet plasma oxidation (EJPO) coatings thermal behavior analyzed in finite element analysis model was improved thermal behavior of electronic jet plasma oxidation coated IC engine, concluded that thermal conductivity, coating thickness and improved wear resistance evaluated (Shen et al. 2019). The emission reduction in thermal barrier coated engine using single blend ratio of various non-edible oils, cashew nut shell, orange, neem oil via transesterification process can change of biodiesel, the engine coated with partially stabilized zirconia material used thermal barrier coating. The result focused on alternative fuel batter BTE, BSFC, engine emission HC, CO, NOx compare to conventional diesel explained (Karthickeyan et al. 2017). In this study investigated in nozzle geometry and cavitation characteristics of diesel and biodiesel in the result biodiesel rate of flow velocity is constant and diesel fuel is increase in flow rate (Suh et al. 2008). Use biodiesel/diesel blended fuel on common rail DI diesel engine, that the higher biodiesel content cause to low engine power output. Due to the effect of biodiesel blend is up to B50 (Jaroonjitsathian et al. 2016). The result predict the fuel injection pressure and fuel injection timing using of waste cocking palm oil converted biodiesel using artificial neural network (Kannan et al. 2013). The benefits of thermal barrier coating greater are level of thermal fatigue, heat release rate within the Yattria – stabilized zirconia insulated engine component with diesel and biodiesel. The piston was insulated with help of plasma spray coating (Selvam et al. 2018).

2. Selection of Thermal Barrier Material

Selection of the TBC material is restricted by some requirement, such as low thermal conductivity, chemical inertness, thermal expansion co efficient, low sintering rate, high melting point, and no phase transfer from room temperature to operating condition this requirement can fulfill the TBC materials. The ceramic material has been used as thermal barrier coating (TBC) materials to increase temperature turbine, with engine efficiency increase metal surface temperature reduce. The first application of TBC in exhaust nozzle of the X-15 manned rocket plane was ceramic coating developed by National Advisory Committee for Aeronautics (NACA) and the National Bureau of Standards (NBS). With further development of ceramic material such as Al_2O_3, TiO_2, yttria stabilized zirconium (ZrO_2 / Y_2O_3), Mullite, $SrZrO_3$, CaO / MgO + ZrO_2, Zircon, CeO_2, CeO_2 + YSZ, Y_2O_3 +HfO_2, $LaMgAl_{11O19}$, etc. have been evaluated as TBC materials.

Plasma sprayed ceramic coatings are used in various industrial applications, where high wear resistance and corrosion resistance with thermal insulation are necessary, various types of Al_2O_3–TiO_2 plasma sprayed coatings in compositions were prepared for (Al_2O_3–3 wt.% TiO_2, Al_2O_3–13 wt.% TiO_2, Al_2O_3–40 wt.% TiO_2 and Al_2O_3–50 wt.% TiO_2) an AISI 304L austenitic stainless steel substrate. Plasma spray coating prepared for ceramic coating Al_2O_3-13TiO_2, The properties of the coatings depend up on the spraying powder and TiO_2 content. Effects of both plasma spraying powder and TiO_2 content on hardness and wear resistance as well as corrosion resistance of the as-sprayed coatings were apparent. In The engineering materials which have the possible capability to be able to use the automobile, aerospace, nozzles, tubes, thermocouples, master moulds in the glass industry, plasma and flame spraying, coatings (thermal, corrosion and wear protection) and in the biomedical sectors, especially to their features such as lightness, specific strength that they have and biocompatibility.

3. Thermal Barrier Coating (TBC)

Figure 1. Plasma Spray Coating

The physical and chemical properties of Aluminum oxide titanium dioxide ceramic material (Al_2O_3-TiO_2), has the potential to withstand wear and tear, high hardness, low coefficient of friction, higher ionic conductivity, high melting point and low thermal conductivity which make superior engineering materials. Shown in the figure 1. Illustrate the air plasma spray coating used to coat piston head and inlet and exhaust valve head by using of Aluminum Oxide Titanium Dioxide ceramic material (Al_2O_3-TiO_2), modified TVI kirloskar engine. Before the engine component was machined the head of the piston crown and valve heads the thickness of the component 300 µm using of CNC horizontal milling machine. After that the machining component was coated with the use of Air plasma spray coating (APS) same machined thickness 300 µm engine components were coated at TBCs (Al_2O_3-TiO_2) material the thickness 300 µm with different piston and inlet and `exhaust valves. The use of air plasma spray coatings to increase the combustion temperature can increase the efficiency of the engine, decrease the engine emission rate.

4. The Physical Property of TBC on Al_2o_3 – TiO_2

A highly reactive ceramic powder with low thermal expansion, low thermal conductivity, and high thermal shock resistance, higher toughness, Al_2O_3 – TiO_2, chemical properties for Al_2O_3= 87%, TiO_2= 9.5 – 13.5%, SiO_2=0.5% and MgO = 3%. Table 1 Show in the physical and chemical properties of Al_2O_3 – TiO_2.

Table – 1. Property of Aluminum Oxide Titanium Dioxide

Aluminum Titanium	Properties
Molecular weight (g/mol)	181.86
Density (g/cc):	3.5
Melting point (°C)	2000°C (3632 °F)
Thermal conductivity (cal/s-cm-°C)	2 – 4
Nominal particle size (µm)	-45+5
Coating Weight (lb/ft2/.001″):	.018
Service temperature °C	540°C (1000°F)
Refractive index	1.7

5. Experiment Details

Shown in the figure 2. Highlight the kirloskar manufacturer TV1 engine schematic diagram of the engine experimental setup. The engine used in this experiment was a single cylinder DI diesel engine with a bore 87.5mm, a stroke of 110mm and a compression ratio of 17.5:1. The rated power was 5.2 kw @ 1500 rpm. Tests were carried out at 1500 rpm at full load. The diesel engine connected to eddy current dynamometer for loading. AVL DiGas 444 is used to measure the emission parameters like CO, HC, CO2, O2, NOx while AVL 437C smoke meter is used to measure the exhaust smoke opacity. AVL DiGas 444 is used to measure the emission parameters like CO, HC, CO2, O2, NOx while AVL 437C smoke meter is used to measure the exhaust smoke opacity.

Figure 2. Schematic layout of experimental setup

6. Results and Discussion

The results obtained from the experimental investigation using Aluminum Oxide Titanium Dioxide (Al_2O_3 – TiO_2) and neat diesel at full load condition on single cylinder four stroke direct injection diesel engine are presented and discussed in this section, and also compared with diesel fuel operation.

6.1 Performance Analysis

6.1.1 Brake Thermal Efficiency

Illustrate the figure 3. the variation of brake power with brake thermal efficiency for Al_2O_3 – TiO_2 insulated engine, the highest brake thermal efficiency compare to Al_2O_3 – TiO_2 coated piston 28.3% normal piston 29.7% at full load condition. The variation of brake thermal efficiency is batter due to compare of conventional engine and insulated engine. The heat withstand rate of piston is high for insulated engine.

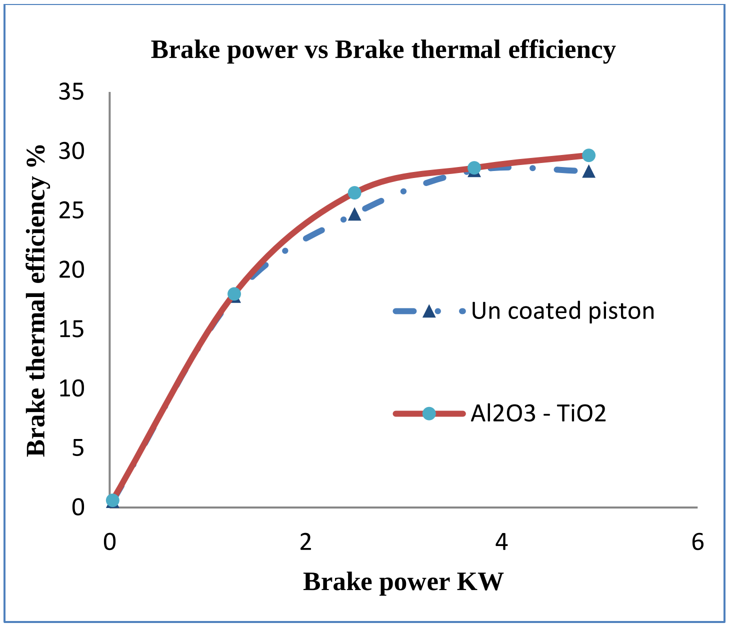

Figure 3. Brake power vs Brake thermal efficiency

6.1.2 Brake Specific Fuel Consumption

Figure 4 show in the variation of brake power with brake specific fuel consumption (BSFC) for $Al_2O_3 - TiO_2$ insulated engine, the BSFC decrease compare to $Al_2O_3 - TiO_2$ insulated engine and conventional engine at all load condition. The reduction of BSFC was observed to $Al_2O_3 - TiO_2$ coated piston 0.32 kg/kWh and normal piston 0.36 at 2.5 kW brake power.

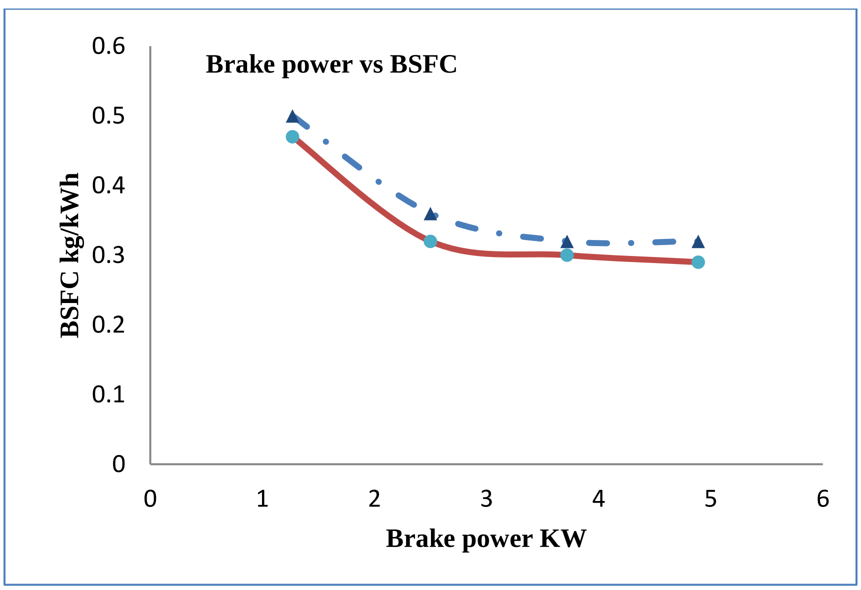

Figure 4. Brake power vs BSFC

6.1.3 Volumetric Efficiency

Figure 5. mentioned in the variation of brake power with volumetric efficiency for Al_2O_3 – TiO_2 coated engine, the volumetric efficiency is less for during starting brake power, it gradually increase at maximum compare to conventional engine. The variation of volumetric efficiency is batter due to heat withstand rate of piston is high for coated piston and inside combustion temperature is sufficient.

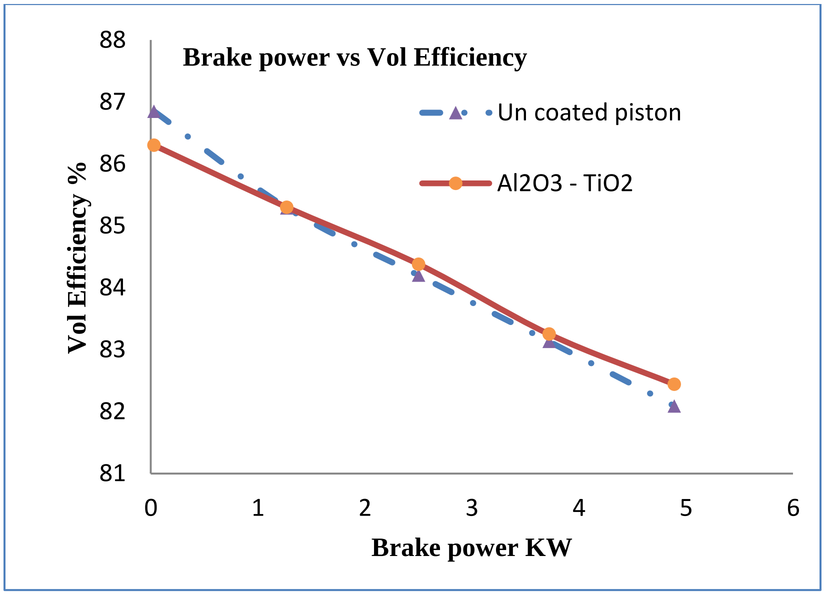

Figure 5. Brake power vs Vol efficiency

6.1.4 Air / Fuel Ratio

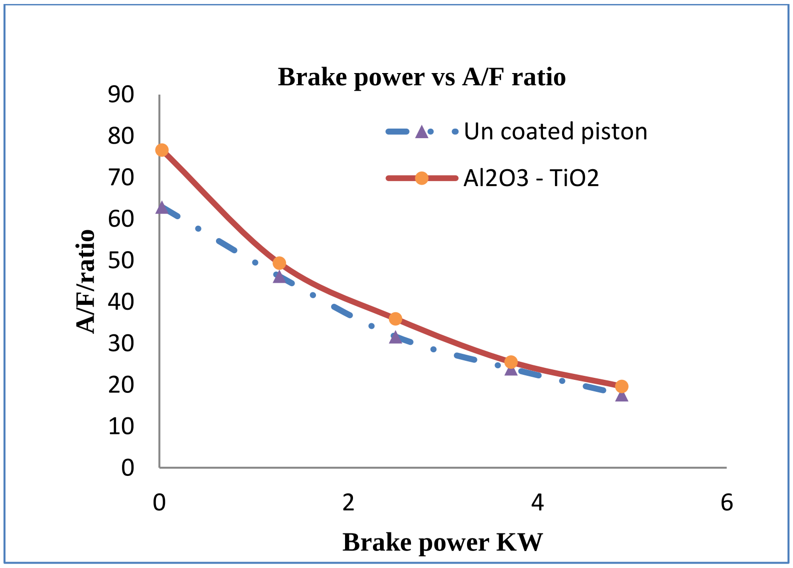

Figure 6. Brake power vs A/F ratio

In the Figure 6. Presented in the variation of brake power with air fuel ratio for Al_2O_3 – TiO_2 coated engine, the higher than the normal piston. The amount of intake air fuel ratio is needful to supply the combustion chamber for the Al_2O_3 – TiO_2 coated engine combustion chamber is sufficient air intake.

6.2 Emission Analysis

6.2.1 Carbon Monoxide (Co)

Illustrate the Figure 7. the variation of brake power with carbon monoxide emission for Al_2O_3 – TiO_2 insulated engine and conventional engine, the percentage of CO is minimum compare to Al_2O_3 – TiO_2 coated engine 0.212 % normal piston 0.49%. The variation of CO is decreased due to the absence of carbon in coated piston, the oxygen concentration increase due to sufficient air intake.

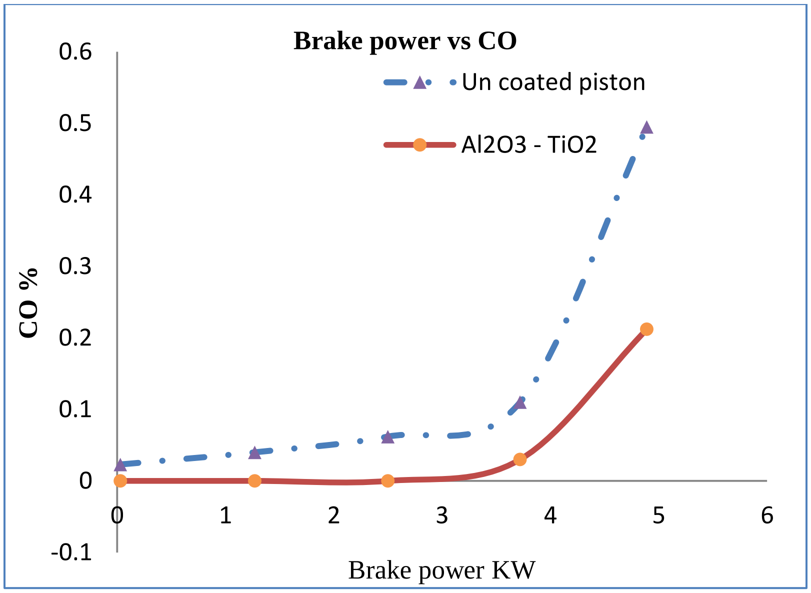

Figure 7. Brake power vs CO

6.2.2 Hydrocarbon (HC)

Figure 8. presented the variation of brake power with hydrocarbon emission (HC) for Al_2O_3 – TiO_2 insulated engine and conventional engine, the HC is minimum compare to Al_2O_3 – TiO_2 insulated engine 84 PPM normal piston 121 PPM. The lowest HC obtained for all load condition.

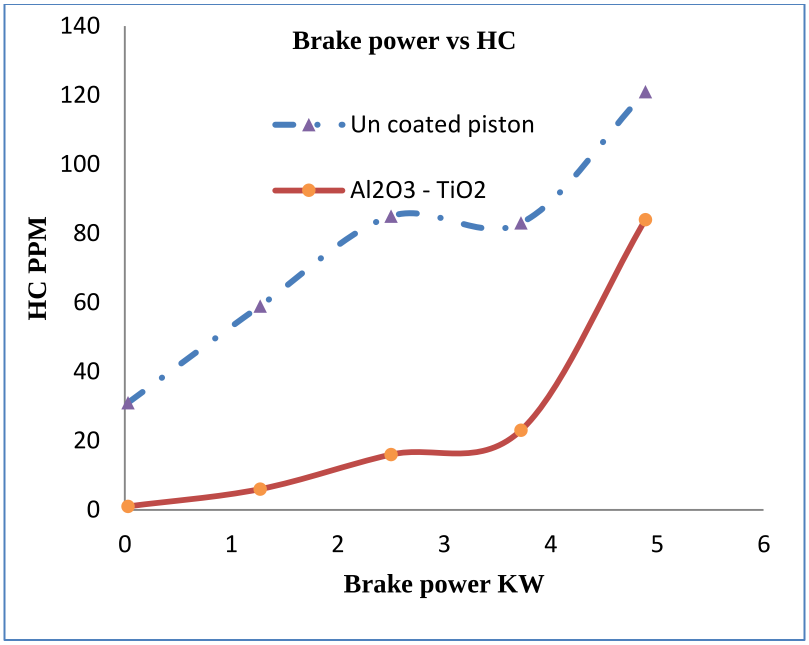

Figure 8. Brake power vs HC

6.2.3 Nitrogen Oxide (NOx)

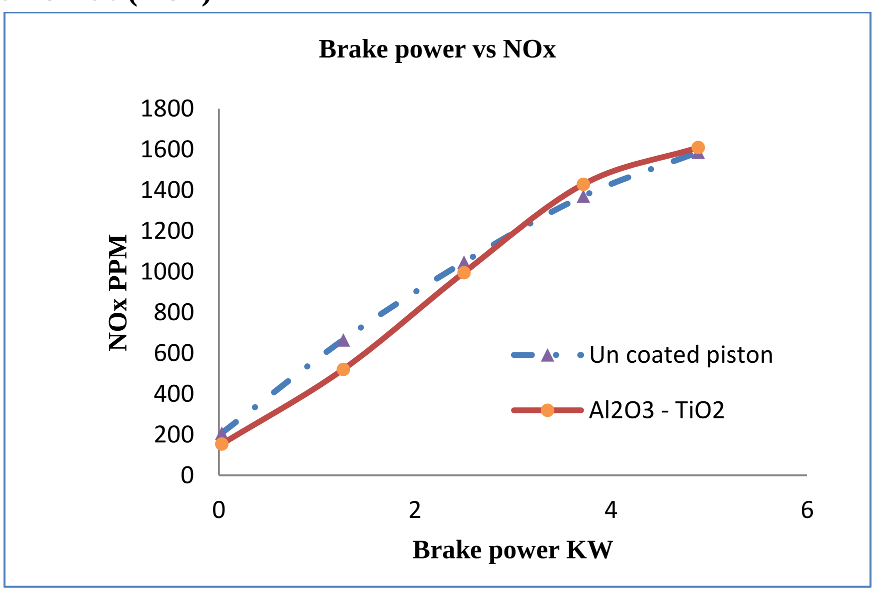

Figure 9. Brake power vs NOx

In the Figure 9. shown in the variation of brake power with nitrogen oxides emission the name of (NOx) for Al_2O_3 – TiO_2 coated engine, the (NOx) emission is minimum compare to normal piston at idling the engine, on the time NOx emission gradually increased for engine maximum speed.

6.2.4 Smoke Opacity

For the Figure 10. Illustrate the variation of brake power with smoke opacity for Al_2O_3 – TiO_2 coated engine, the smoke opacity is minimum compare to conventional engine and gradually increased for top load condition.

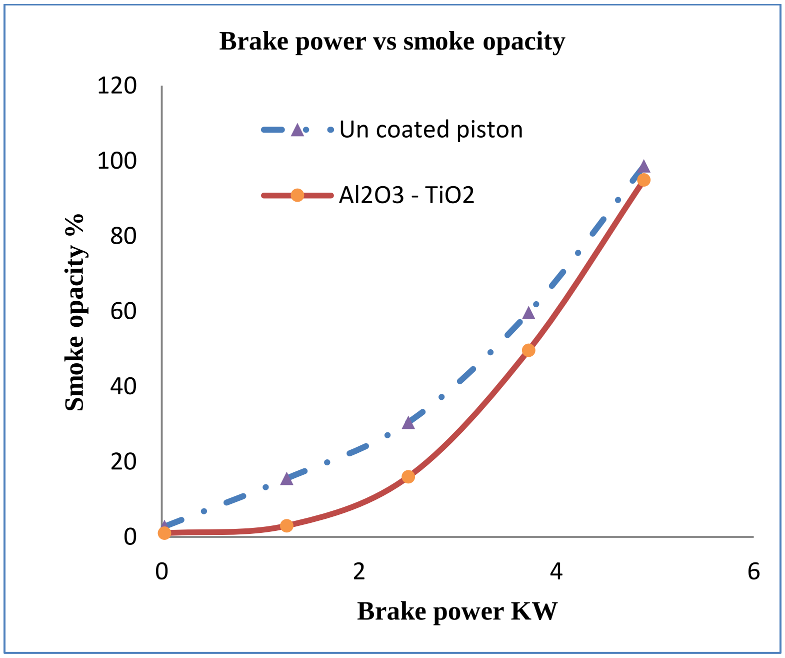

Figure 10. Brake power vs Smoke opacity

7. CONCLUSIONS

The test conducted on a Aluminum Oxide Titanium Dioxide (Al_2O_3 – TiO_2) insulated engine and conventional engine the result are brake thermal efficiency of the coated piston was quite higher than the normal piston. The BSFC for coated piston is decreases with normal piston at all load condition. The volumetric efficiency is batter due to heat withstand rate of piston is high for coated engine. The CO is decreased due to the absence of carbon in coated engine, the HC is minimum compare to coated piston at all load condition. The NOx is gradually increased for top load condition. The smoke opacity is minimum compare to normal piston and gradually increased for top load condition. Hence Al_2O_3 – TiO_2 coated piston modified engine can be regarded as an eco – friendly engine.

ACKNOWLEDGEMENT

The authors are thankful to Department of Automobile Engineering, Mahendra Institute of Technology, Namakkal for support, co-operation and logistical support and encouragement. Authors wish to thank Aum Surface Technology Bangalore for coating requirements. Authors are also grateful to VMKV Engineering college, Salem. The authors would like to thank the reviewers.

REFERENCES

[1] *Prasad, R. and Samria, N.K. (1990). Transient heat transfer analysis in an internal combustion engine piston. Computers & structures, 34(5), 787-793.*

[2] *Assanis, D.N et al. (1991). The effects of ceramic coatings on diesel engine performance and exhaust emissions. SAE Technical Paper. (No. 910460).*

[3] *Kamanna, B et al. (2017). Thermal Barrier Coating on IC Engine Piston to Improve Engine Efficiency. Global Journal of Enterprise Information System, 9(1),47-50.*

[4] *Hejwowski, T. and Weroński, A. (2002). The effect of thermal barrier coatings on diesel engine performance. Vacuum, 65(3-4), 427-432.*

[5] *Uzun, A. and Akçil, M. (1999). Effects of thermal barrier coating on a turbocharged diesel engine performance. Surface and coatings technology, 116, 505-507.*

[6] *Hejwowski, T. (2010). Comparative study of thermal barrier coatings for internal combustion engine. Vacuum, 85(5), 610-616.*

[7] *Kumara, D. and Pandey, K.N. (2016). Study on dry sliding wear characteristics of air plasma spraying deposited CoNiCrAlY inter metallic coatings on aluminum alloy substrate. International Journal of surface science and Engineering, 10(3), 303-316.*

[8] *Deng, S et al. (2016). Thermal barrier coatings with Al_2O_3–Pt composite bond-coat and La2Zr_2O_7–Pt top-coat prepared by cathode plasma electrolytic deposition. Surface and Coatings Technology, 291, 141-150.*

[9] *Yao, M et al (2018). A theoretical study on the effects of thermal barrier coating on diesel engine combustion and emission characteristics. Energy, 162, 744-752.*

[10] *Shen, X et al. (2019). Effects of electrolytic jet plasma oxidation (EJPO) coatings on thermal behavior of engine cylinders. Heat and Mass Transfer, 1-13.*

[11] *Karthickeyan, V., Balamurugan, P. and Senthil, R., (2017). Comparative studies on emission reduction in thermal barrier coated engine using single blend ratio of various non-edible oils. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 39(5), 1823-1833.*

[12] *Suh, H.K., Park, S.H. and Lee, C.S., (2008). Experimental investigation of nozzle cavitating flow characteristics for diesel and biodiesel fuels. International Journal of Automotive Technology, 9(2), 217-224.*

[13] *Kannan, G.R., Balasubramanian, K.R. and Anand, R., (2013). Artificial neural network approach to study the effect of injection pressure and timing on diesel engine performance fueled with biodiesel. International Journal of Automotive Technology, 14(4),507-519.*

[14] *Selvam, M., Shanmugan, S. and Palani, S., (2018). Performance analysis of IC engine with ceramic-coated piston. Environmental Science and Pollution Research, 25(35), 35210-35220.*