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EXPERIMENTAL INVESTIGATION OF DIESEL ENGINE COMBUSTION CHAMBER COATED WITH CERAMIC MATERIALS

S.SRINIVASAN[1], K.MURUGAN[2]*, T.GANESAN[3],R.PRAKASH

[1]Assistant Professor (Senior Scale), Faculty of Mechanical Engineering, Indian Naval Academy, Ezhimala - 670310, Kerala, India.

[2]Associate Professor, Department of Mechanical Engineering, Mahendra Institute of Technology, Namakkal - 637503, Tamil Nadu, India.

[3]Associate Professor, Department of Automobile Engineering, Mahendra Institute of Technology, Namakkal - 637503, Tamil Nadu, India.

[3]Assistant Professor, Department of Mechanical Engineering, AVS College of Technology, Salem - 636106, Tamil Nadu, India.

ABSTRACT - This work focuses on thermal barrier coating (TBC) for a thickness of 300µm insulated in combustion chamber for single cylinder four stroke diesel engine. The piston crown and inlet and exhaust value head are coated by using Air plasma spray coating technique. The ceramic powder material is molybdenum (Mo) and Aluminum Oxide Titanium Dioxide (Al_2O_3-TiO_2). The coating on single cylinder four stroke diesel engine aims at reducing the emission behaviors to attain a greener and cleaner system. The engine performance test with the coating on the combustion chamber was carried out to investigate brake power, brake thermal efficiency, volumetric efficiency, brake specific fuel consumption and air fuel ratio. Also emission characteristic test are carried out to investigate unburned hydrocarbon (HC), carbon monoxide (CO), oxide of nitrogen (NO, NO_2, NO_3 etc..) NOx and engine emitted smoke opacity. The effect of (Al_2O_3-TiO_2) coated engine combustion chamber and also (Mo) coated engine combustion chamber is analyzed and concluded that the brake thermal efficiency, brake specific fuel consumption shows a significantly increases because of this coating materials. The effect of (Al_2O_3-TiO_2) coating reduces the engine emissions producing HC, CO significantly. This work appreciates the usage of coating materials in the engine combustion chambers to increase the performance characteristics and emission characteristics of the engine.

Keywords: Thermal barrier coating, Air plasma spray coating technique, Aluminum Oxide Titanium Dioxide, Molybdenum, Ceramic powder material, Engine performance, Engine exhaust emission.

NOMENCLATURE

IC engine – Internal Combustion Engine
BP – Brake power
BTE – Brake thermal efficiency
BSFC – Brake specific fuel consumption
BSEC - brake specific energy consumption
VE – Volumetric efficiency
A / F ratio
HC – Hydrocarbon
CO – Carbon monoxide
NOx – Oxide of nitrogen
SO – Smoke opacity

1. INTRODUCTION

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 $CaZrO_3$ and $MgZrO_3$ 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). Injection delay and EGR rate in a diesel engine was investigated in the optimum EGR rate range from 15-20% for given engine tested at 550cc and 1100cc capacities (Im et al. 2009), 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 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 gas-turbine engine applications, structure of coating, properties and failure mechanism of thermal barrier coated engine. It is focused on various type of coating used to different structural engineering materials, like thermal insulation, corrosion, erosion, wear and lubrication examined (Padture et al. 2002). Efficiency and ecological characteristics of a VCR diesel engine, the evidence of compression ration change the combustion chamber diameter. In conventional engine is different speed and load at ambient condition (Pesic et al. 2013). 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). The experimental to found crack number density theory on air-plasma-sprayed thermal barrier coating. The paper focused on crank number density model, quasi-isothermal-cyclic oxidation test conduct on crank number density to assess air plasma sprayed coating. This CND model can be describe thermal barrier coating failure provide (Wu et al, 2019).Thermal barrier coatings with Al_2O_3–Pt composite bond-coat and $La_2Zr_2O_7$–Pt top-coat prepared by cathode plasma electrolytic deposition. 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 Al_2O_3 composite and top coating thickness of 120 μm $La_2Zr_2O_7$ present (Deng et al, 2016). 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). 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). Engine performance parameters using thumba biodiesel-diesel blends by applying the taguchi method and gray relational analysis. The result concluded that the maximum performance and minimum emission. The CR of 14 nozzle pressure 250 bar injection timing is 20^o evidence (Karnwal et al. 2011). 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 TBC MATERIALS AND METHOD

The IC engine combust the fuel produce high temperature inside the combustion chamber. The increasing temperature with atmosphere oxygen and nitrogen react to produce oxide of nitrogen (NO, NO_2, NO_3,…) Name is NOx polluted at atmosphere. This is due to the engine temperature maintained at a level with help of insulated combustion chamber. The aluminum alloy piston head and valve stem head was insulated with Thermal barrier coating (TBC). This study is carried out to assess thermal barrier coating (TBC) is completed that can withstand the combustion chamber temperature by using of molybdenum (Mo) ceramic powder material and Aluminum Oxide Titanium Dioxide (Al_2O_3-TiO_2) ceramic powder material. This molybdenum (Mo) and Aluminum Oxide Titanium Dioxide (Al_2O_3-TiO_2) material coated with different piston crown, inlet valve and exhaust valve heads using of Air plasma spray coating (APS) technique. 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. Two various engine components were coated at TBCs (Mo) and (Al_2O_3-TiO_2) material the thickness 300 µm with different piston and inlet and exhaust valves. The experimental setup was tested at the brake thermal efficiency, brake specific fuel consumption, volumetric efficiency were reported at computerized eddy current dynamometer. The engine emissions producing HC, CO NOx reading reported at AVL Five gas analyzer and engine smoke opacity tested at AVL smoke meter significantly. The engine component combustion chamber replace at (Mo) insulated piston crown, inlet valve and exhaust valve. The same test carried out and reported. In addition will be used for the current and (Al_2O_3-TiO_2) insulated with piston crown, inlet valve and exhaust valve. The same test carried out and reported. This work appreciates the usage of coating materials in the engine combustion chambers to increase the performance characteristics and emission characteristics of the engine.

Table-1 *Property of* Al_2O_3-TiO_2 and Mo

Properties	**Values for Al_2O_3-TiO_2**	**Values for Mo**
Molecular weight (g/mol)	181.86	95.94
Density (g/cm^3)	3.5	10.2
Melting point Tm (°C)	2000 °C	2620 °C
Thermal conductivity λ W/(m·K) at 20°C	2 – 4	142
Co efficient of thermal expansion k^{-1} @ 20°C	$2x10^{-6}$	$5.2x10^{-6}$
Poisson's ratio v @ 20°C	0.21	0.31
Hardness	-	160-180
Young's modules E Gpa	20	320
Nominal particle size (µm)	-45+5	-
Coating Weight (lb/ft^2/.001″):	0.18	-
Service temperature °C	540	700
Refractive index	1.7	3.7362

The physical and chemical properties of (Al_2O_3-TiO_2) imprudent ceramic powder combined with a property that can withstand wear and tear, low coefficient of friction, higher ionic conductivity, high hardness, low thermal conductivity can create better engineering materials. Al_2O_3 – TiO_2, where as chemical properties at Al_2O_3= 87%, TiO_2= 9.5 – 13.5%, SiO_2=0.5% and MgO = 3%. Molybdenum consists of high melting point, higher thermal conductivity and low coefficient of thermal expansion used in many industrial applications. Physical and chemical properties of Aluminum Oxide Titanium Dioxide (Al_2O_3-TiO_2) and Molybdenum respectively are neatly presented in the table 1.

3. EXPERIMENTAL SETUP

From the Figure 1. provide the experimental setup of the current study TVI kirlosker single cylinder four stroke direct injection diesel engine, power 5.2 kw @1500 rpm water cooled engine connected with eddy current dynamometer link PV angle encoder sensors and engine exhaust manifold with attached AVL DiGas analyzer and AVL 437C smoke meter. The experimental setup was prepared to reduce the thickness of piston crown, inlet and exhaust valve heat surface machined for 300µm thickness removed from CNC Horizontal milling machine. After that the machined component was insulated with (Al_2O_3-TiO_2) used to coat a piston crown, inlet and exhaust valve head surface area thickness of 300µm prepared with plasma spray coating technique.

Figure 1. Photograph of experimental setup

This component was replaced for kirloskar TV1 engine dismantled and replaces the engine piston, inlet and exhaust valve then assemble the engine. The engine used in this experiment was kirlosker TV1 single cylinder four stroke diesel engine connected with eddy current dynamometer test rig. Again the test was carried out on the engine using molybdenum (Mo) ceramic material coated with a piston crown, inlet valve and exhaust valve head. The proposed experimental test report relied on single cylinder four stroke diesel engine devoid of any modification with conventional fuel.

4. RESULT AND DISCUSSION

The results depicted below revealed the engine performance and emission levels. The current result is an outcome of comparison of conventional engine with diesel, molybdenum (Mo) insulated engine and (Al_2O_3-TiO_2) material coated engine. In the experimental test, (Mo) and (Al_2O_3 – TiO_2) was plotted at constant engine speed of 1500 rpm, for the no load condition, 25, 50, 75, 100 percentage respectively. The experimental test was carried out to assess the engine performance intended for brake power, brake thermal efficiency, volumetric efficiency, specific fuel consumption and air fuel ratio. In the next stage engine emission intended for unburned hydro carbon (HC), carbon monoxide (CO), oxide of nitrogen (NOx), and engine smoke opacity were tested and also indent the lambda level.

Diesel : Standard engine with diesel
Molybdenum (Mo) – Diesel: Standard diesel with molybdenum (Mo) insulated engine
Aluminum Oxide Titanium Dioxide - Diesel: Al_2O_3 – TiO_2 coated engine with diesel

4.1 Engine Performance

4.1.1 Comparison of Brake Power under varying the Brake Thermal Efficiency

The comparison of conventional and Al_2O_3 – TiO_2 coated engine and (Mo) insulated engine is shown if Figure 2. In case of brake thermal efficiency is compared against conventional diesel and (Mo) insulated piston has more effective then the (Al_2O_3-TiO_2) coated engine. The insulated engine has low thermal conductivity thereby improving high operating temperature, ignition delay caused by physical and chemical reaction in combustion chamber. The increase thermal efficiency of engine full load condition for (Al_2O_3-TiO_2) insulated piston (29.67%), other report lower for (27.95%) and (28.33%) (Mo), uncoated piston respectively. The performance of brake thermal efficiency (Al_2O_3-TiO_2) coated engine performed much better due to reduce concern level of combustion chamber heat.

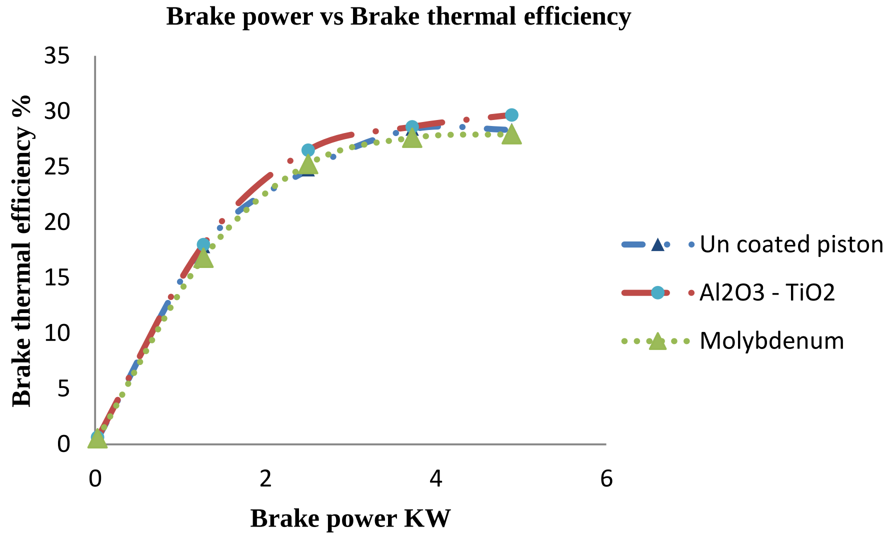

Figure 2. Variation of brake power with brake thermal efficiency

4.1.2 Comparison of Brake Power under varying the Brake Specific Fuel Consumption

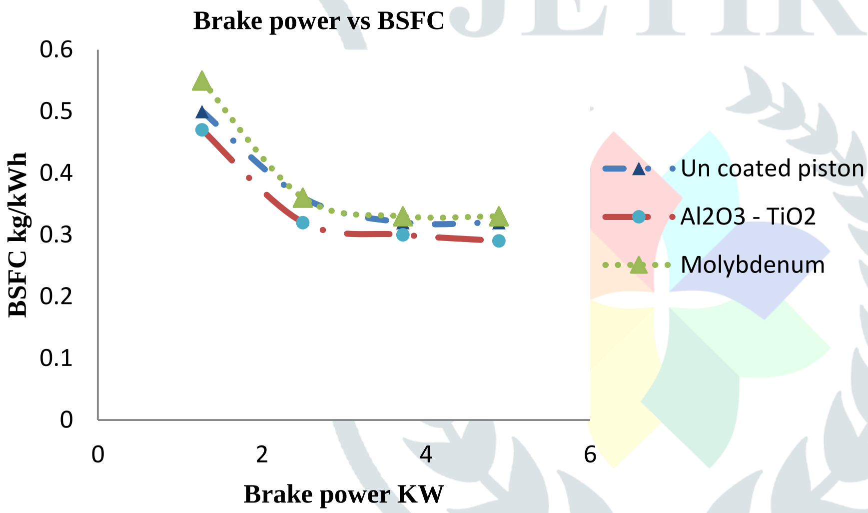

Figure 3. Variation of brake power with BSFC

The BSEC is increase in lower intensive at low load condition same time the BSEC is reduced in higher intensive at full load condition of the engine and improve the reciprocating losses it will be increase the brake specific fuel consumption (BSFC). The BSFC also known as brake specific energy consumption (BSEC) is independent of conventional and coated engine illustrate in the Figure 3. For all the case energy consumption is compared with the ($Al_2O_3 – TiO_2$) coated engine is (0.29 kg/kWh) most economic (BSEC) in case of (Mo) coated engine (0.33 kg/kWh) and conventional diesel (0.32 kg/kWh).

4.1.3 Comparison of Brake Power under varying the Volumetric Efficiency

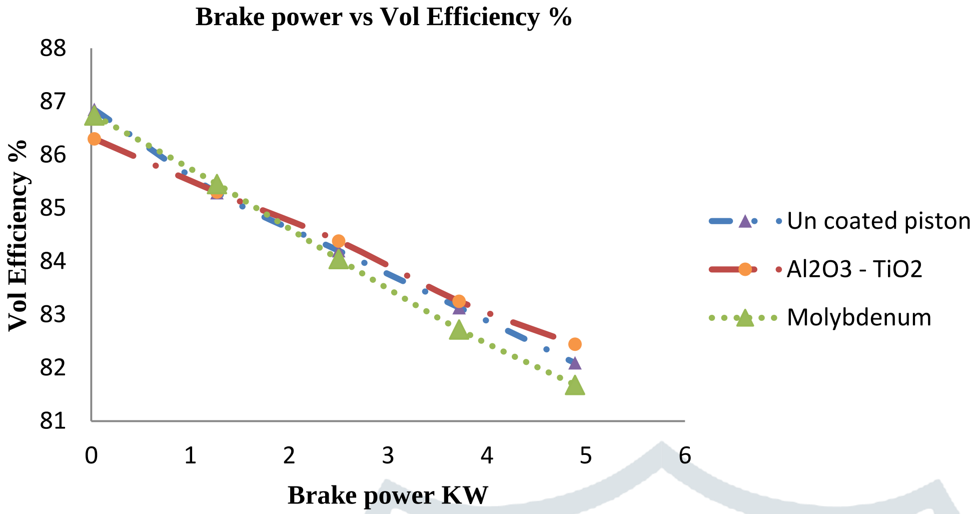

Figure 4. Variation of brake power with vol efficiency

Volumetric efficiency is the breathing capability of engine based on the atmospheric condition, till improve the air breathing inside the cylinder. From the Figure 4. Illustrate the variation of volumetric efficiency is lower than conventional diesel at maximum load, initial condition of the breathing is differ from the low load condition. The (Al_2O_3–TiO_2) insulated engine is batter atomization thereby improving the complete combustion. The result reveled that (Al_2O_3–TiO_2) insulated engine is (83.25), (Mo) insulated engine is (82.72) and uncoated engine is (83.13) percentage of the engine peak load condition.

4.1.4 Comparison of Brake Power under varying the Air Fuel Ratio

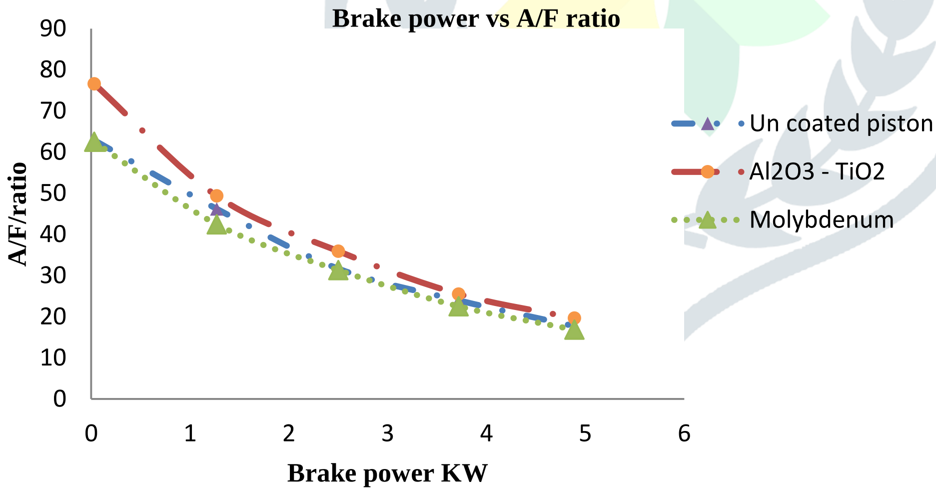

Figure 5. Variation of brake power with A/F ratio

Air fuel ration is mixing of fuel with air important role on the engine to burn completely with the chemically correct fuel with no excess air shown in the Figure 5. The variation of air fuel ratio better as against uncoated engine and (Mo) conventional diesel engine, (Al_2O_3–TiO_2) insulated engine is better at all load condition. The result mention for (19.65%) (Al_2O_3–TiO_2) insulated engine, (Mo) engine is very low (16.85%) and uncoated engine is nearby variation (17.67%) so suitable for that (Al_2O_3–TiO_2) insulated engine.

4.2 Engine Emission

4.2.1 Comparison of Brake Power under varying the Carbon monoxide emission

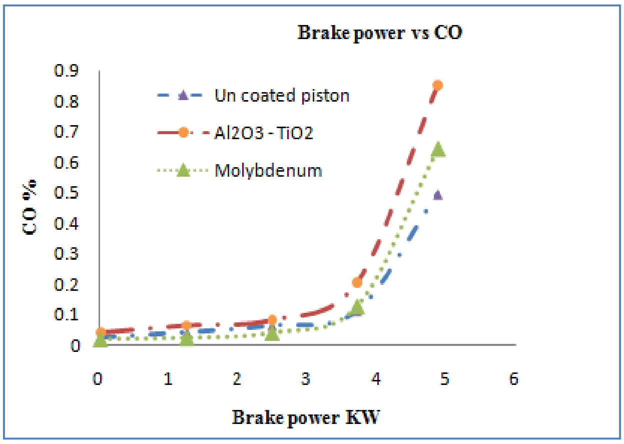

Figure 6. Variation of brake power with CO emission

In the Carbon monoxide emission was assessed, keeping the engine at constant speed 1500 rpm and the no load condition 25, 50, 75, 100 percent, the CO emission for plotted with (Al_2O_3-TiO_2) and (Mo) insulated engine. Higher oxygen content of the engine was eliminating rich fuel it in complete combustion. The CO emission obtained from Figure 6. CO emission is higher than conventional diesel to other coated engine at all load condition. The result of the engine emission is (0.851%) (Al_2O_3–TiO_2) insulated engine, (Mo) engine is low (0.641%) and uncoated engine very lower level (0.495%).

4.2.2 Comparison of Brake Power under varying the Hydrocarbon emission

In the unburned hydrocarbon (HC) emission was assessed, keeping the engine at constant speed 1500 rpm and the no load condition 25, 50, 75, 100 percent brake power, the HC emission for plotted with (Al_2O_3-TiO_2) and molybdenum (Mo) insulated engine. The (Mo) and (Al_2O_3 – TiO_2) has high latent heat of vaporization was reduce the combustion chamber temperature, ignition delay with high flame quenching. It can be formed the Unburned hydrocarbon HC emission, it can be reduce the fuel injection entrancement at lower loading condition. The HC emission obtained from Figure 7. the (Al_2O_3–TiO_2) insulated engine is to lower then (Mo) coated engine and conventional diesel at all load condition.

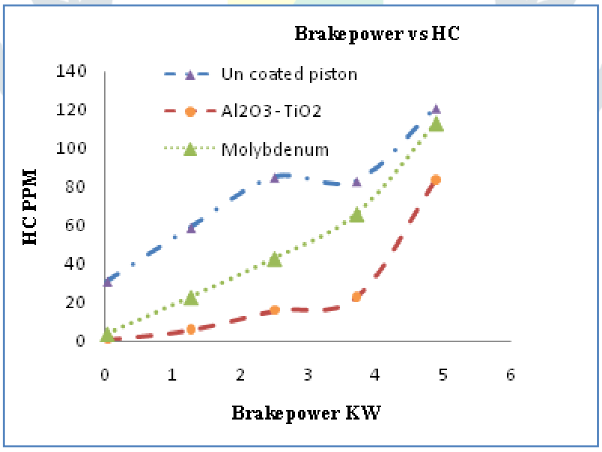

Figure 7. Variation of brake power with hydrocarbon emission

4.2.3 Comparison of Brake Power under varying the NOx emission

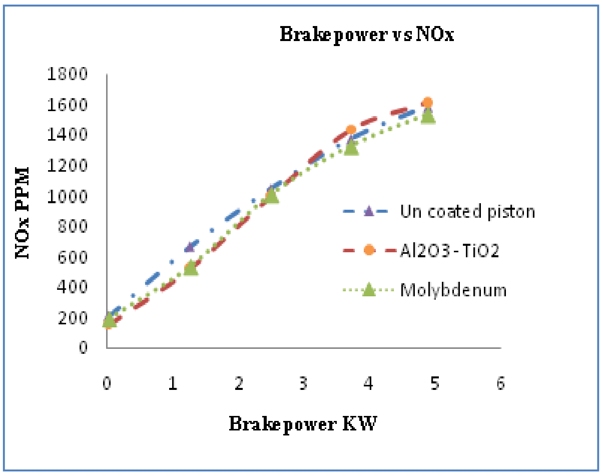

Figure 8. Variation of brake power with NOx emission

The engine running in cursing level on that time engine temperature is higher, on this increased engine temperature to produce the NOx pollution. The cause of NOx formation in IC engine was higher temperature at above 800ºK with high load condition. The test carried out (Al_2O_3-TiO_2) coated engine was good atomization; it was complete combustion to rise the engine temperature minimum the NOx emission is increased. It can be observed Figure 8. Other test revealed reduces NOx level at top speed. The (Al_2O_3 – TiO_2) coated engine (1610 ppm) little higher compare to (Mo) insulated engine (1533 ppm) and then conventional diesel (1587 ppm).

4.2.4 Comparison of Brake Power under varying the Smoke opacity

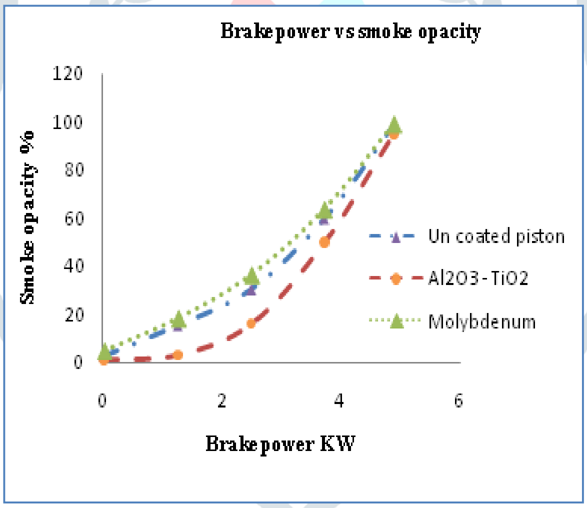

Figure 9. Variation of brake power with smoke opacity

CI engine eliminate the exhaust mixed with smoke opacity, engine starting period much higher to exit. The exiting smoke opacity was better compare (Al_2O_3-TiO_2) and molybdenum (Mo) insulated engine and conventional diesel. The experimental test was conducted at constant speed 1500 rpm and the no load condition 25, 50, 75, 100 percent brake power, the Smoke opacity for plotted with (Al_2O_3-TiO_2) and (Mo) insulated engine. The smoke opacity measured for percentage can be inferred that smoke from (Al_2O_3-TiO_2) insulated engine smoke opacity level is low (95%), (Mo) insulated engine smoke level is (99.1%) and conventional diesel smoke level is (98.7%) at all load condition.

4.2.5 Comparison of Brake Power under varying the Lambda level

In the experimental test carried out engine at constant speed 1500 rpm and the no load condition 25, 50, 75, 100 percent brake power under the varying of exhaust mixing on oxygen or lambda level. The engine initial condition to supply the excess fuel to pick the engine does not supply the sufficient air. So the engine eliminate amount of air escape from the exhaust, the batter result for using of (Al_2O_3-TiO_2) and (Mo) insulated engine. The variation of (Al_2O_3-TiO_2) insulated engine lambda value (7.409) much higher at initial condition, (1.395) lower at full load condition.

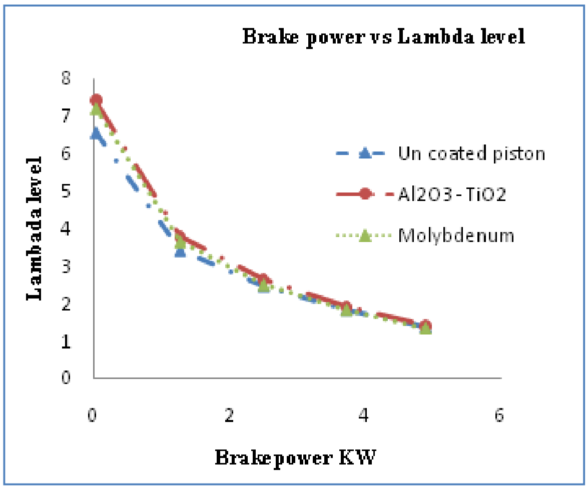

Figure 10 variation of brake power with Lambda Level

5. CONCLUSIONS

In this experimental report was carried out to assess the (Al_2O_3-TiO_2) and (Mo) ceramic powder material coated single cylinder four stroke diesel engine, it's improved the engine emission level. The (Al_2O_3-TiO_2) and (Mo) insulated engine was investigated on exhaust emission scrutiny of the IC engine, the important conclusions were drawn as indicated below.

The test carried out increases theoretical report of thermal efficiency it effect for mechanical efficiency reduced, due to losses of engine power, engine component temperature leads to more expansion work there by increasing the brake thermal efficiency for the suitable engine at maximum load condition. The loss of engine power is increased use of (Al_2O_3-TiO_2) and (Mo) insulated engine against conventional diesel. The (Al_2O_3-TiO_2) coated engine enhances combustion; cooling medium can reduce heat energy improved the brake specific fuel consumption. The result also reveals that breathing atmosphere air is batter for using insulated engine is reacted smoothly operated in engine, it's give the better result for volumetric efficiency and A/F ratio of the given engine.

For the ceramic insulated engine react with high operating temperature and ambient condition the engine eliminate 1.01% more level NOx. But better emission for HC level (Al_2O_3-TiO_2) ceramic insulated engine 84 ppm (Mo) insulated engine 113 ppm and uncoated engine 121ppm. Same time the CO level also giving best compare to ceramic coated and uncoated engine. Thus the (Al_2O_3-TiO_2) coated engine can solve the difference between economic improvement and preservation of human health.

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