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ASSESSMENT OF COMBUSTION, PERFORMANCE AND EMISSION FEATURES OF BIODIESEL IN A THERMAL BARRIER COATED DIESEL ENGINE

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ABSTRACT

Thermal Barrier Coating technique was used to coat the piston crown with Alumina. The test was conducted in a single cylinder DI diesel engine. In common, the coating acts as a thermal barrier which improves the efficiency by dipping energy losses. In the first phase of the investigation, baseline reading of diesel was taken. The second part of the investigation, engine components was coated. And the third phase of investigation has carried the performance, combustion and emission of biodiesel in thermal barrier coated diesel engine. Thus the coating and testing were done successfully. As per our aim of improving the burning, performance and pollutant features of CI engine by Coating the Piston head with a Ceramic Coating of Alumina (Al_2O_3) Up to 250 microns have improved the burning characteristics like cylinder pressure and heat release rate considerably, As well as the performance characteristics like Brake Thermal Efficiency is enlarged up to 15.69 %, Mechanical Efficiency is increased up to 67.9% for TBC coated piston with Biodiesel when compared to others and Other Performance Characteristics were also increased. Notably, the Exhaust Emission like CO, Hydrocarbons ,and Oxygen were also reduced. Thus the project conducted by implementing the Thermal Barrier Coating in the Piston Head had given a good improvement in all burning, performance and pollutant features of the tested CI Engine.

KEYWORDS: Engine, Biodiesel, Coating, Performance, Emission & Combustion

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Original Article

INTRODUCTION

In a standard engine, a big proportion of energy is washed out through the cooling/ exhaust arrangement. By thermally insulate the engine's piston top, valves and cylinder head, which progress the burning process and reduces the heat energy loss through exhaust gas, by this the performance enlarged and emission diminished. Subsequently, it can raise the power output, thus by raising the BTE and decreasing SFC. Diesel engine plays a dominant role in the agriculture, transport and industrial sector of all the countries due to its higher efficiency than that of a petrol engine (Ahmet et al.). Even though its efficiency is higher, the maximum possible efficiency falls between 30 to 40%. Apart from the various losses, heat taken away by cooling water, through combustion chamber walls contributes a significant percentage of the total heat losses. As per the second law of thermodynamics, by minimizing the heat rejection rate, the efficiency of the engine can be improved. Low heat rejection, which is called, as semi- adiabatic engine is one such concept developed to reduce the heat lost through the combustion chamber walls. In this method heat developed during combustion was restricted to flow through the combustion chamber wall. By this method, the heat available in the combustion chamber to convert it into mechanical work gets increased which may increase the power output of the engine (Husnawan et al.). Earlier investigations have reported that the thermal efficiency of an LHR engine was lesser or superior to a standard engine depends upon the test conditions and the method used. From Dickey's investigation, the thermal efficiency of LHR engine is lesser than that of the standard engine, because of lower compression ratio and degraded combustion. Researchers (Jindal et al.) conducted an experiment with a thin layer thermal barrier coated (TBC) engine to improve its performance and found that TBC engine had a higher thermal efficiency by 5-6%, 1-8% reduced specific fuel consumption and NOx emissions were reduced by 11-18% when compared to the standard engines. Earlier investigations on the LHR engine were conducted with diesel fuel and less attempt was made to test the LHR engine with biofuels. Alumina with its excellent properties likes high insulation, toughness, and high expansion coefficient factor, it is used in this investigation and it acts as a base coating material.

THERMAL BARRIER COATING

Thermal barrier coatings (TBC) are extremely superior materials systems usually constructive with metallic surfaces of aero-engine parts, operating at elevated temperatures, as a form of exhaust heat management. This 100µm to 2mm coatings serve to insulate parts from big and extended heat loads by using thermally insulating material which can maintain a noticeable temperature dissimilarity among the load-bearing alloys and the coatings face (Metin et al.). These coatings can permit elevated working temperatures while preventing the thermal contact of structural parts, extending part life by dipping oxidation and thermal fatigue. In conjunction with action film cooling, TBCs permit working fluid temperatures higher than the melting point of the metal airfoil in some turbine applications. Due to increasing demand for higher engine operation (efficiency increases at higher temperatures), better durability/lifetime, and thinner coatings reduce parasitic weight for rotating/moving components, there is great motivation to develop new and advanced TBCs.

There is some Thermal Barrier Coating which exists on earth as follows:

- YSZ
- Mullet
- Alumina
- CeO2 + YSZ
- Rare – earth zircons
- Rare – earth Oxides
- Metal – Glass Composites

TBC coatings are fetching more general in automotive application. They are distinctively designed to diminish heat loss from exhaust system parts, including tailpipes, exhaust manifolds, downpipes, turbocharger casings and exhaust headers. This process is also known as "exhaust heat management". When used under-bonnet, these have the positive effect of reducing engine bay temperatures, therefore reducing the intake air temperature. Although most ceramic coatings are applied to metal parts directly related to the engine exhaust system, technological advances now allow thermal barrier coatings to be applied via plasma spray onto composite materials (Sajith et al.). It is now commonplace to find ceramic-coated components in modern engines and of high-performance components in race series such as Formula 1. As well as providing thermal protection, these coatings are also used to prevent physical degradation of the composite material due to friction. This is possible because the ceramic material bonds with the composite (instead of merely sticking to the surface with paint), thereby forming a tough coating that doesn't chip or flake easily. Although TBC has been applied to the insides of exhaust system components, problems have been encountered because of the difficulty in preparing the internal surface prior to coating.

BIODIESEL

Biodiesel may be efficiently used in both when blended with diesel and impure form. Tests conceded by the motor manufacturer in the European Union on blend with diesel up to 5-10%, or at 25-30% and 100% pure have the better result for each type of use. Minor modifications (seals, piping) are requisite for utilize at 100% purity, unless specifically guaranteed by car manufacturers. The biodiesel as a transportation fuel does not necessitate any change in the distribution system, as a result avoiding costly changes. Algae - based biofuels have been hyped in the media as a potential panacea to our Crude Oil based Transportation problems. Algae-based fuels are being successfully tested by the U.S. Navy Algae based plastics show potential to reduce waste and the cost per pound of algae plastic is expected to be cheaper than traditional plastic prices. Methanol and Ethanol fuel is typically primary sources of energy; they are convenient fuels for storing and transporting energy. These alcohols can be used in "internal combustion engines as alternative fuels", with butanol also having known advantages, such as being the only alcohol- based motor fuel that can be transported readily by existing petroleum-product pipeline networks, instead of only by tanker trucks and railroad cars. Biodiesel has been established to have noteworthy ecological benefits in terms of reduced global warming impact, reduced pollutants, energy independence and in agriculture. Various studies have estimated that the use of 1 kg of biodiesel leads to the reduction of some 3 kg of CO2. Hence, the use of biodiesel results in a significant reduction in CO2 emission (65%-90% less than conventional diesel), particulate emissions and other harmful emissions. Biodiesel is particularly low in sulfur, and have a high lubricity and fast biodegradability (Karikalan et al). Additionally, reducing pollutant emissions alleviates various human health problems. The fuel properties are listed in table.1

Table 1: Fuel Properties

Property	Diesel	Jatropha Oil	Jatropha Methyl Ester
Density @20^0 C, kg/m	840	900	880
Viscosity @ 40° C Cst	3	35.6	4.58
Flash Point ° C	75	240	165
Fire Point ° C	-	260	170
FFA Content (%)	-	9.10	-
Moisture Content (%)	-	0.5	-
Specific gravity @ 20ºC	0.84	0.9	0.88

Figure 1: Coated Piston

Figure 2: Engine Setup

Table 2: Engine Specification

Engine Make	Kirloskar
Engine type	4 stroke, Single Cylinder Diesel Engine
Stroke x Bore	110mm x 87.5mm
Method of cooling	Water cooled
Horsepower	10HP
Compression ratio	17.5:1
Rated RPM	1800
Load type	Electric load bank

EXPERIMENTAL SET UP

The engine for the experiment is a single cylinder diesel engine having 4.4 kW @ 1500 rpm. The engine was attached to an electric dynamometer to evaluate the output.The fuel flow rate is measured with a burette. The exhaust gas analyzer to measure exhaust gas and the pressure crank angle graph is obtained with a piezo-electric pressure transducer. The Coated Piston and trial arrangement are shown in Fig.1 and Fig.2. The smoke opacity was calculated by AVL smoke meter. NOx release was calculated by AVL Di-Gas Analyzer. An AVL combustion analyzer was utilized to compute the burning distinctiveness of the engine. The engine speed was 1500 rpm and the piston was coated with ZrO2 /Al2 O3 and coating thickness of 150/150 microns. The injection pressure of 200bar was maintained.The first engine without coating was connected to eddy current dynamometer. The tests were performed at dissimilar loads at constant speed.

The experiment was conducted at 4 different load level via. 25%, 50%, 75% and 100% load. The requisite engine load was tuned by the eddy current dynamometer. The next part of the test was carried out by using Biodiesel [Jatropha]. The engine was permitted to run on diesel at a constant speed for almost 10 minutes to reach the stable condition at the less load. The following were made twice for averaging. During the test, test parameters were obtained, such as SFC, Smoke Opacity ,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 with TBC,
- Neat Bio-diesel with TBC.

Subsequent to the untried study for a variety of concentrations of Bio-diesel the finest concentration was found on the basis of the BTE, mechanical efficiency, smoke density, hydrocarbon, and carbon dioxide pollution.

RESULTS AND DISCUSSIONS

The performance, burning and pollutant features of a highspeed single cylinder diesel engine at different loads from no load to full load are discussed below as per the results obtained. Thus the result and discussion were classified into three categories they are as follows,

Combustion Characteristics

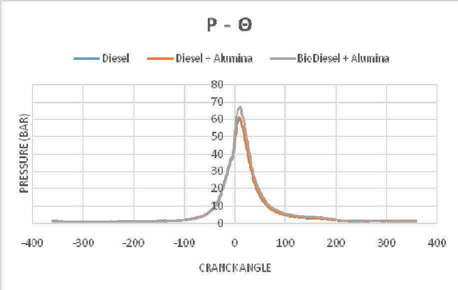

Figure 3: Cylinder Pressure vs. Crank Angle

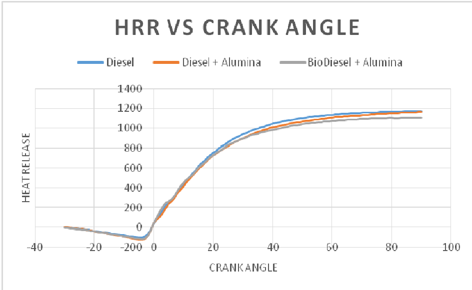

Figure 4: Heat Release Rate vs. Crank Angle

The cylinder pressure depends on the burning rate in the burning stage. The higher cylinder pressures ensure the improved burning and heat release. Figure.3 shows the distinctive cylinder pressure disparity with respect to crank angle at 75% of the load. It is prominent that the highest pressure obtained for biodiesel is higher than the baseline and diesel readings, which is a significant improvement in combustion. Figure.4 show the variation of the rate of heat release with crank angle at 75% of load. It is noticed that the heat release rate for Biodiesel and thermal barrier coated piston with diesel is low as compared to standard diesel. This is due to maximum pressure obtained for both the Biodiesel and thermal barrier coated piston with diesel.

Performance Characteristics

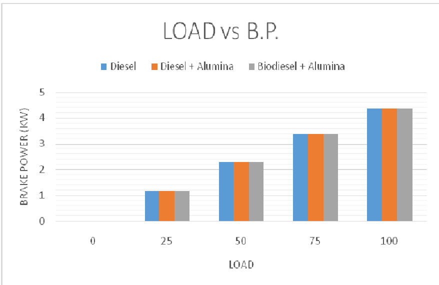

Figure 5: Brake power vs. Load

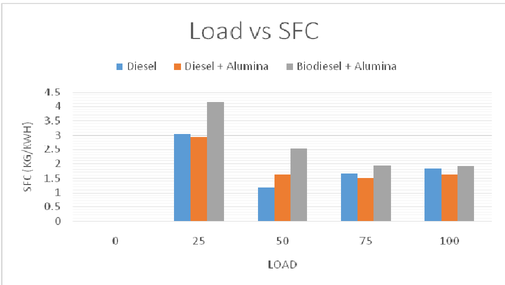

Figure 6: SFC vs. Load

The above figure.5 shows the graph of load vs. brake power. It shows that the brake for the entire load is equal as the voltage and the current supply is same for all the cases. It is clearly observed that indicated power is increased with increase with load. The indicated power of the diesel is more than the others, i.e. TBC coated piston with diesel and Biodiesel. This happens due to the speed of the engine is more in diesel as compare to others. It is obvious that SFC is higher for lower loads and it is declining when the load increase (figure.6). Furthermore, similar for coated and uncoated pistons, but at the upper load a considerable change in SFC occurs in coated pistons. The decrease of SFC is almost equal in both at 75% load and at the maximum load condition for coated piston and biodiesel. It is owing to that the TFC increase for upper load conditions.

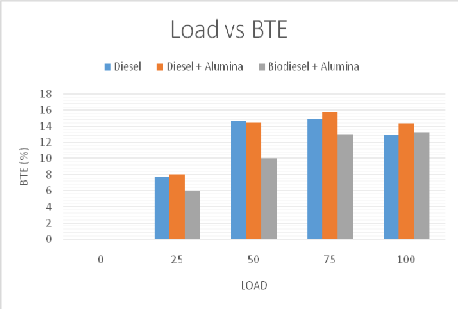

Figure 7: BTE vs. Load

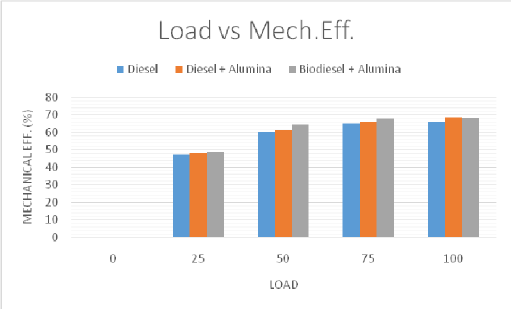

Figure 8: Mech. Eff. vs. Load

Figure.7 shows that BTE is high for the TBC coated piston with diesel when compared with the standard engine and TBC coated piston with Biodiesel, because of the less brake power/ lower loads. Then it has increased owing to the brake power increase. A considerable development is observed at 75% load conditions, the BTE is increased above in the coated piston with diesel. It is owing to the TFC of coated piston is lesser than the uncoated piston at 75% load. From the figure.8, it is noticed that the mechanical efficiency is rising for the coated piston from lesser load conditions to a maximum load conditions. The efficiency is constantly 10% superior in the coated piston from fewer loads to upper load owing to the increase of indicated power in the coated piston. Although the BP is similar for both the cases at all loads, the friction power is 0.6kW superior for uncoated pistons. As a result the mechanical efficiency is constantly superior in the coated piston.

Emission Characteristics

Figure.9 shows the pollutants of CO for different loads. It is noticed that the CO is almost equal for all three conditions at different loads, but the emission of CO is very much lesser in thestandard engines than the TBC coated piston with diesel and biodiesel. Figure.10 shows the pollutants of CO_2 for different loads. It is observed that the emission of CO_2 is less for both the coated and the fuel additives than the normal diesel. This is because the complete combustion of fuel with respect to air fuel mixture.

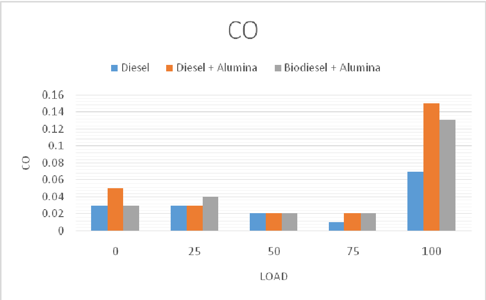

Figure 9: CO vs. Load

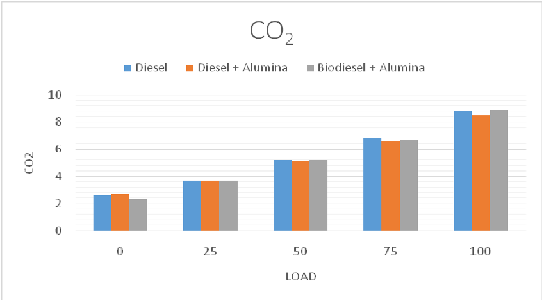

Figure 10: CO_2 vs. Load

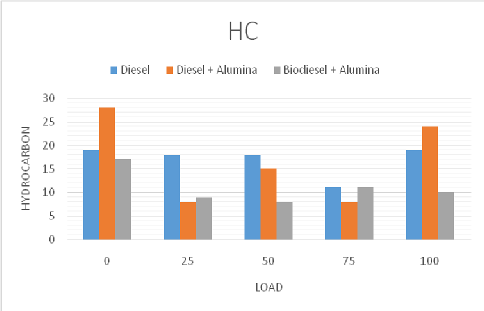

Figure 11: HC vs. Load

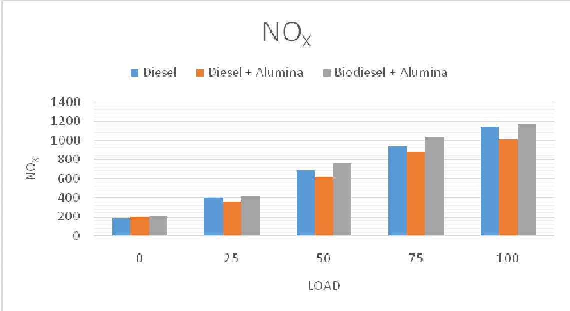

Figure 12: NO_X vs. Load

It is clearly observed that reduction trend in HC for TBC coated piston with diesel and biodiesel (figure.11). Possible causes for HC emission are fuel-rich combustion, misfiring, flame quenching, valve overlaps and desorption of hydrocarbon from oil film in and around the cylinder. Thus the reduction in the emission of hydrocarbon is notably a significant improvement. The mechanism of NOx (figure.12) formation of nitrogen highly depends on temperature, due to the high activation energy needed for the reaction involved. Hence the more significant factor that causes the NOx formation is burning temperature and other factors are combustion quality, injection period and injection timing. By implementing the TBC coated piston with diesel and biodiesel increases the NO_x. But the emission is lesser in TBC coated piston with diesel than the standard engine and TBC coated piston with biodiesel. Figure.13 shows that the emission of smoke in various load conditions for dissimilar fuels. It is noticed that the smoke increases with the rise in the load. The smoke is lesser in the TBC coated piston with biodiesel than the others. Figure.14 shows Exhaust Gas temperature behavior of diesel, TBC coated piston with diesel and biodiesel at different load condition. It observed that the EGT is almost equal in all conditions.

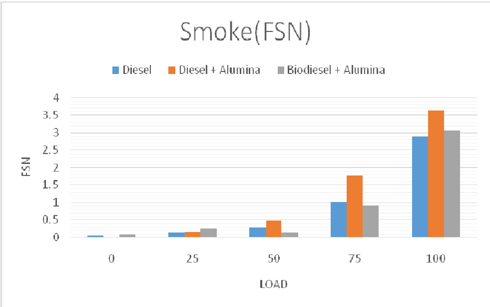

Figure 13: Smoke vs. Load

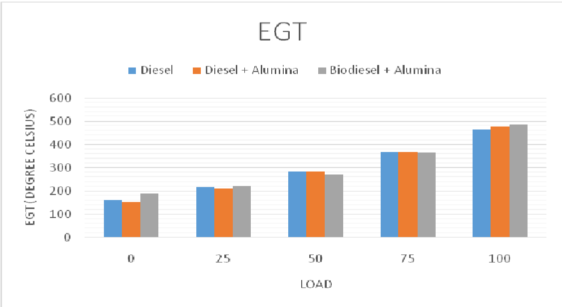

Figure 14: EGT vs. Load

CONCLUSIONS

As per our aim of improving the burning, performance and pollutant Characteristics of CI engine by Coating the Piston head with a Ceramic Coating of Alumina (Al_2O_3) Up to 250 microns. It had improved the burning features like cylinder pressure and HRR for TBC coated piston with diesel and bio-diesel. As well as the performance characteristics like BTE is improved up to 15.69 % for TBC coated piston with diesel when compared to others and Mechanical Efficiency is increased up to 67.9% for TBC coated piston with Biodiesel when compared to others and Other Performance Characteristics were also increased. Notably, the Exhaust Emission like CO, Hydrocarbons, and Oxygen were also reduced. Thus the project conducted by implementing the Thermal Barrier Coating in the Piston Head had given a good improvement in all burning, performance and emission features of the tested Engine.

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