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Influence of thermal barrier coating on combustion characteristics in a biodiesel fuelled Di diesel engine

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ABSTRACT

There are so many methods are used to improve the efficiency of a diesel engine, reduced fuel consumption. For this purpose, one of the technologies is used that is ceramically coated IC engine. It is also known as Thermal barrier coating (TBC). In the present work, YSZ has used as thermal barrier coating on combustion chamber to increase the thermal efficiency and reduce the fuel consumption. In this experimentation, YSZ – TBC is done by plasma spray coating technique which is the simplest method. Production of biodiesel from algae is a promising option. The present work aims to focus on the performance of a diesel engine with algae oil as fuel. In order to use the oil in an engine, its blends with the petroleum diesel were prepared. It is found that the properties of neat algae oil and its blends are very close to the properties of neat diesel. The investigation was carried out in the single cylinder water cooled, constant speed DI diesel engine with Yttria Stabilized Zirconia as Thermal Barrier Coating with the Diesel fuel and various blends of biodiesel like B20, B40, B60, B80, and B100. Here, the investigation carried out at idle load, part load and full load conditions. The combustion characteristics were analyzed at various load conditions for baseline without coating and YSZ –TBC coated engine. Here, YSZ – TBC coated engine have better combustion characteristics compared with the uncoated engine because of the thermal barrier coating on combustion chamber which gives the high heat release rate due to its high coefficient and low thermal conductivity. The blend of B20 has higher heat release rate characteristics. The addition of fuel additives is one of the possible approaches for increases the combustion characteristics. The present work, DEE is used as additives to improve the combustion characteristics of YSZ – TBC coated engine. Among the various blends tested, B20 + 5% DEE has better combustion characteristics.

Keywords: *Thermal Barrier Coating (TBC), Yttria Stabilized Zirconia (YSZ), Diethyl (DEE), Emission, Biodiesels*

1. INTRODUCTION

Thermal spraying techniques are coating processes in which melted materials are sprayed onto a surface. Thermal spraying can provide thick coatings, thickness range is 20 micrometers to several mm, depending on the process and feedstock, over a large area at high deposition rate as compared to other coating processes such as electroplating, physical and chemical vapor deposition. Coating materials available for thermal spraying include metals, alloys, ceramics, plastics, and composites. They are fed in powder or wire form, heated to a molten or semi-molten state and accelerated towards substrates in the form of micrometer-size particles. Combustion or electrical arc discharge is usually used as the source of energy for thermal spraying. Resulting coatings are made by the accumulation of numerous sprayed particles. The surface may not heat up significantly, allowing the coating of flammable substances. Coating quality is usually assessed by measuring its porosity, oxide content, macro and micro-hardness, bond strength and surface roughness. Generally, the coating quality increases with increasing particle velocities.

1.1. Biodiesel

Biodiesel is an attractive renewable fuel for diesel engines that is made from new vegetable oils, animal fats or waste cooking oils. In addition to being biodegradable and non-toxic, is also essentially free of sulfur and aromatics, producing lower exhaust emissions than conventional diesel fuels. Chemically, biodiesel is defined as mono-alkyl esters of long chain fatty acids derived from renewable bio-lipids. Biodiesel is typically produced through the reaction of a fat or oil which contains triglycerides, with an alcohol, in presence of a catalyst to yield methyl esters (biodiesel) and glycerine. The resulting biodiesel, after its purification, is quite similar to conventional diesel fuels in its main features, and it also can be blended with conventional diesel fuel. For example, B20 means 20% of biodiesel and 80% of petrodiesel. The advantages of biodiesel as a diesel fuel are its portability, ready availability, renewable energy resource, higher combustion efficiency, higher lubricate, lower sulfur and aromatic content, higher cetane number, and its potential for reducing petroleum dependency. Biodiesel degrades about four times faster than petrodiesel. Biodiesel is also safe to transport because it has a high ignition temperature. The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum diesel fuel.

1.2. Engine

Stationary diesel engines are being widely used in agricultural and marine applications because of their higher thermal efficiency and reduced engine emissions. In the wake of petroleum fuel demand, researchers have shown increasing interest in the use of biodiesel, a vegetable oil-based fuel, in the stationary diesel engine. Thus far, researchers have conceived the variety of oil-yielding crops and among these, production of biodiesel from non-edible food crops have been widely acknowledged as it reduces the production cost of biodiesel. Further, waste products such as discarded engine lubricating oil, waste cooking oil and waste plastic oil have been reckoned as a potential feedstock for producing biodiesel. Since a diesel engine is standardized for the use of diesel fuel alone, the use of biodiesel requires either fuel or engine modifications. Categorically, to improve the engine performance and emission when using biodiesel, researchers have proposed engine design modification strategies like increasing the engine compression ratio, varying the combustion chamber geometry and TBC (thermal barrier coating) of the engine components. Among these engine design modification strategies, TBC of engine components, an attempt to minimize the heat losses and improve the thermal efficiency, has conquered the interest of many researchers. Noticeably, an improvement in efficiency has been accomplished in the past studies by applying a ceramic coating on the engine components using various methods. Regardless of the wide range of methods available for insulating the engine components, plasma spray coating is the common method employed to apply suitable coating for diesel engine application. There are several factors which govern the application of the coating on the engine components and in the past few years, many researchers have investigated and studied the effect of TBC on engine performance. In this connection showed that the heat transfer was ably prevented by applying TBC and pointed out the prevalence of high in-cylinder temperature, supporting better combustion so as to improve the thermal efficiency.

The demand for fossil fuel increases rapidly because of the increase in the vehicle population. The decrease in the availability of crude oil supplies and greater environmental stringent norms on pollution had created enormous interest in researchers in formulating and testing biofuels in recent times. The most promising method for deriving biodiesel from the renewable energy source is transesterification process. The natural biodiesel resources such as oil crops and waste cooking oil are not sufficient to cover the global transportation fuel demand. Therefore, exploring other potential sources of alternative fuels is a necessity. Microalgae are regarded as a promising alternative fuel for IC engines. Many researchers have reported on the possibility for production of biodiesel from algae. The growth of algae by nature itself it has the photosynthesis by using sunlight along with nutrients. Algae have a capability of fixing atmospheric carbon dioxide and can be grown in intensive culture on a non-arable land. In India, algae biodiesel research is being pursued by few research institutes develop technologies for alternative renewable energy using algae. The higher viscosity of the algae oil is a major disadvantage of using it as biodiesel; transesterification, thermal reduction and many more in which transesterification is the most suited. The emissions from diesel engines also seriously threaten the environment and are considered one of the major sources of air pollution. Many countries are evaluating a variety of alternative fuels for use in motor vehicles in an attempt to reduce greenhouse gas emissions and to improve the energy security of the country. Biodiesel and other biofuels are substitute fuels capable of replacing fossil fuels on large scale in the transportation sector. Biodiesels have good ignition characteristics due to their long chain hydrocarbon structure. On the other hand, their disadvantages include higher viscosity, higher pour point, lower calorific value, and poor volatility. The addition of fuel additives is one of the possible approaches for reducing this problem because of the obvious fuel oil constituent influences on engine performance and emission characteristics. The present work, DEE is used as an additive to improve the combustion and emission characteristics of YSZ – TBC coated engine.

2. MATERIALS AND METHODS

2.1. Materials

In this paper, we are used in the microalgae oil, yttria stabilized zirconia, and diethyl ether is used to improve the performance of the engine and to reduce the emission characteristics. Microalgae supplied by. Microalgae sequester CO2 from flue gasses emitted from fossil fuel power plants and other sources, reducing emissions of a major greenhouse gas. Producing biodiesel from microalgae provides the highest net energy because converting algae oil to biodiesel is much less energy intensive than methods for conversion to other fuels (such as Ethanol). Microalgae are highly biodegradable, environmentally sustainable while reducing emissions of particulate matter, CO, hydrocarbons, and SOx.

2.2. Experimental methods

First, compare the diesel and algae along with their properties and then divide the algae and diesel oil based upon the requirement condition. Divide the blend such as B20 (algae 20% + diesel 80%). Compare their result (combustion and emission). Select the suitable blends.

2.3. Plasma Spray coating

The plasma spray process uses a dc electric arc to generate a steam of high-temperature ionized plasma gas. The coating material in powder form is carried in an inert gas stream into the plasma jet where it is heated and propelled towards the substrate. Because of the high temperature (15000deg) and high thermal energy of the plasma jet, materials with high melting points can be sprayed. The plasma spray gun comprises a copper anode and tungsten cathode which are water cooled. Plasma gas flows around the cathode and through the anode which is shaped as a constricting nozzle. The resistance heating from the arc causes the gas to reach extreme temperature dissociate and ionize to form a plasma.

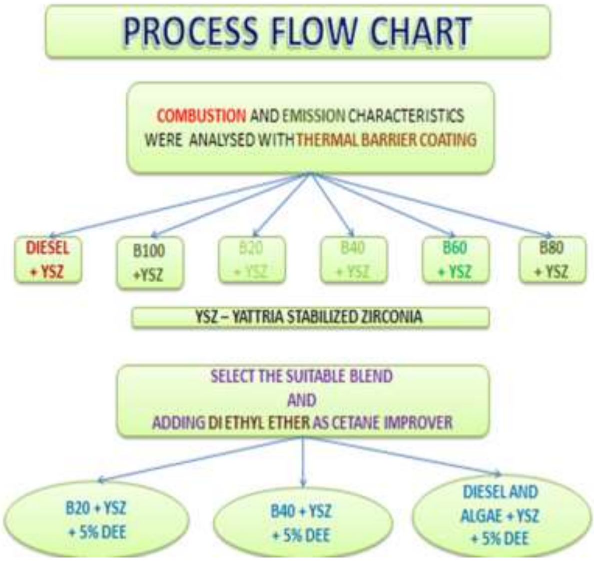

Fig.1.1: Process flow chart

Plasma spraying produces a high-quality coating by a combination of a high temperature, high energy heat source, a relatively inert spraying medium, and quite high particle velocities, typically 200-300m/s. Plasma spraying has the advantage that it can spray very high melting point materials such as refractory melts like tungsten and ceramics like zirconium. Plasma spray coating accounts for the widest range of thermal spray coatings and applications and makes this process the most versatile.

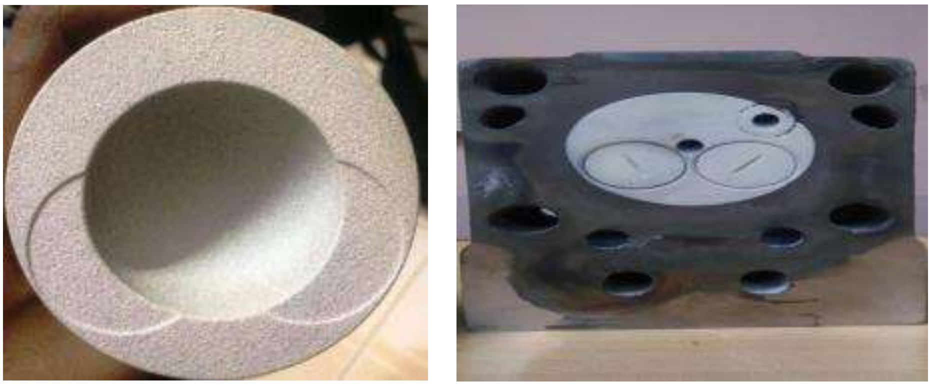

Fig. 1.2: Thermal Barrier coating

2.4. Engine setup

The engine chosen to carry out experimentation is a single cylinder, constant speed, four strokes, water-cooled direct injection kirloskar diesel engine. The kirloskar engine is used extensively in agriculture, pump sets, farm machinery and industrial sectors. The engine can withstand high pressure encountered during tests because of its rugged Construction. The injection timing recommended by the manufacturer was 23º BTDC. The governor used to maintain constant speed under varying load conditions which control the fuel flow as load changes. The engine has an open combustion chamber with overhead valves operated through pushrods. A provision was made in the cylinder head surface to mount a piezoelectric pressure transducer for measuring the cylinder pressure.

The engine was allowed to run with diesel, algae oil and its blends at various loads for nearly ten minutes to attain the steady state and constant speed conditions. Then the following observations were made. The water flow was maintained constant throughout the experiment. The load, speed, and temperature indicators were switched on. The engine was started by cranking after ensuring that there is no load. The engine was allowed to run at the rated speed of 1500 rpm for a period of15 minutes to reach the steady state.

Fig. 1.3: Engine setup

The fuel consumption was measured by a stopwatch. The amount of NOx, HC and CO were measured using exhaust gas analyzer. The exhaust temperature was measured by using a temperature sensor. Then the load was gradually applied by 0%, 50%, and 100 % respectively. Each load readings were noted. The properties of standard diesel and algae oil were analyzed. To prepare the blends of biodiesel as per requirements such as B20, B40, B60, and B80. The experiment was carried out without thermal barrier coating and their results were analyzed. Then select the suitable blends. The experiment was carried out with YSZ –TBC on the combustion chamber and their results were analyzed. Then select the suitable blends. Here, 5% of DEE as additives is added with standard diesel, algae and selected blends that investigation carried out on YSZ – TBC coated diesel engine. Finally, compare the results and select the suitable fuel depends upon the combustion and emission characteristics.

3. RESULTS AND DISCUSSION

a) Pressure vs. crank angle

It is observed that the peak pressures of 40.39, 39.06, 37.79, 37.84, 37.04 and 38.05 bars were recorded for standard diesel, algae, B20, B40, B60, and B80, respectively. Therefore the viscosity and volatility of the fuel have a very important role to increase atomization rate and improve air-fuel mixing formation. The cylinder peak pressure is slightly higher for standard diesel fuel due to its high volatility and low viscosity compared with algae and its blends. It is observed that the peak pressures of 50.86, 50.05, 49.29, 49.62, 49.11 and 49.24 bars were recorded for standard diesel, algae, B20, B40, B60, and B80, respectively. Standard diesel fuel has high peak cylinder pressure compared with algae and its blends due to high volatility and low viscosity of the diesel fuel.

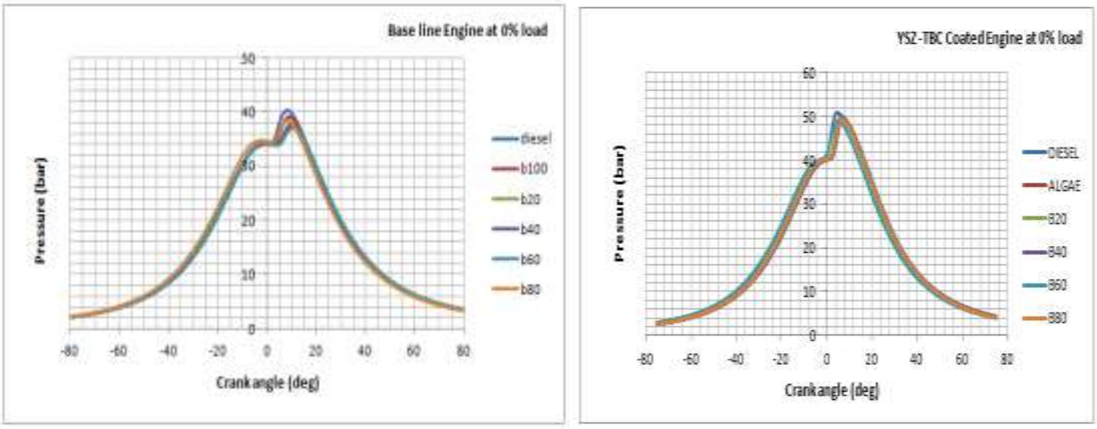

Fig. 1.4: Baseline engine and YSZ – TBC coated engine at 0% loads

In baseline engine, the variation of cylinder pressure with a crank angle for diesel, algae and its blends at part load conditions. It is observed that the peak pressures of 49.09, 48.82, 48.87, 48.35, 48.25 and 49.32 bars were recorded for standard diesel, algae, B20, B40, B60, and B80, respectively. Although algae and its blends have competitive cylinder pressure than diesel due to load increased. It is observed that the peak pressures of 58.79, 58.56, 59.01, 59.37, 58.45 and 58.58 bars were recorded for standard diesel, algae, B20, B40, B60, and B80, respectively. Blends of biodiesel B20 and B40 have higher cylinder peak pressure compared with other fuels. Because of load increases that results increase the charge temperature at injection that reduces the viscosity of the biodiesel blends and increases the volatility properties of biodiesel blends for increasing atomization rate, vaporization rate and mixer of fuel vapor with air.

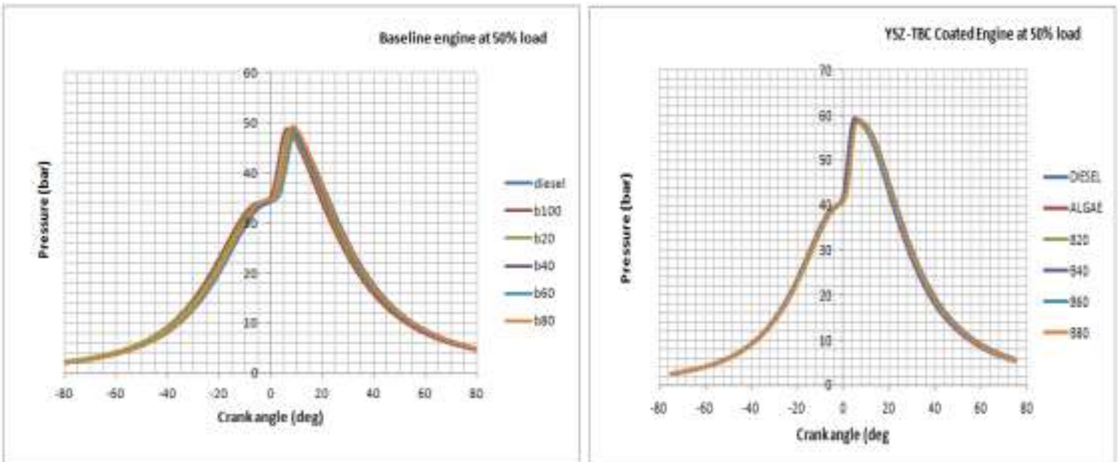

Fig. 1.5: Baseline engine and YSZ – TBC coated engine at 50% loads

It is observed that the peak pressures of 54.21, 55.24, 55.14, 55.20, 55.35 and 55.80 bars were recorded for standard diesel, algae, B20, B40, B60, and B80, respectively. From this figure, algae and its blends have high peak pressure during increases of the load. At full load condition, the rate of fuel vaporization and mixing with air is very high due to high cylinder charge temperature and pressure that reduce the ignition delay period. When the load is increased, the fuel is injected too more that increases the ignition delay period due to the accumulation of fuel. In Yttria Stabilized Zirconia TBC coated engine, the variation of cylinder pressure with a crank angle for diesel, algae and its blends at full load conditions. It is observed that the peak pressures of 65.31, 66.76, 66.48, 66.73, 66.42 and 66.14 bars were recorded for standard diesel, algae, B20, B40, B60, and B80, respectively.

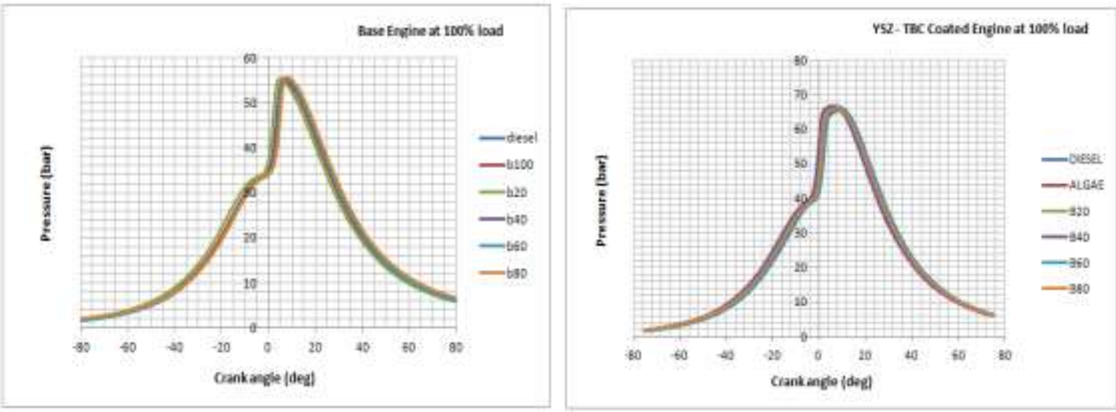

Fig. 1.6: Baseline engine and YSZ – TBC coated engine at 100% loads

b) Heat release rate vs. crank angle

In baseline engine, the variation of heat release rate with a crank angle for diesel, algae and its blends at no load conditions. The maximum heat release rate of standard diesel, algae, B20, B40, B60, and B80 is 31.57, 30.99, 28.28, 28.59, 26.45 and 24.45, respectively. Heat release rate indicating that the ignition delay for algae and its blends was longer than diesel. In Yttria-stabilized zirconia, TBC coated engine, the variation of heat release rate with a crank angle for diesel, algae and its blends at no load conditions. The maximum heat release rate of standard diesel, algae, B20, B40, B60, and B80 is 49.7, 53.3, 46.8, 54.8, 32.4 and 49.01, respectively.

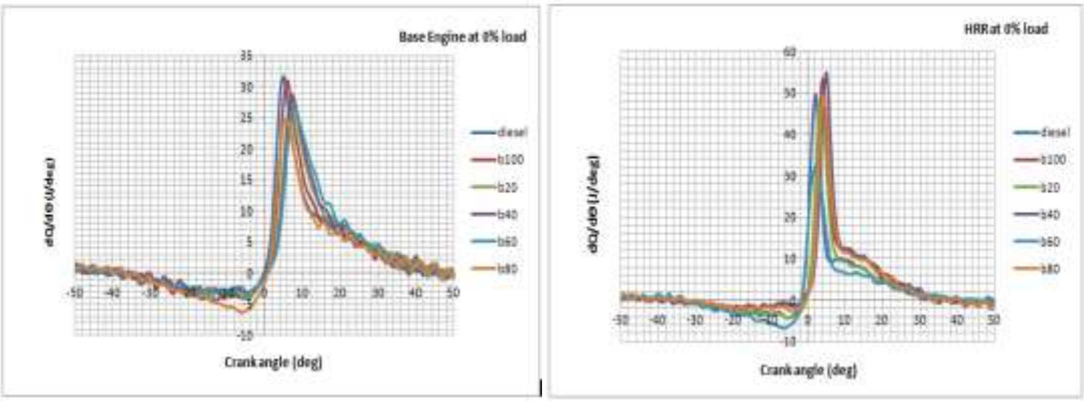

Fig. 1.7: Baseline engine and HRR at 0% loads

The maximum heat release rate of standard diesel, algae, B20, B40, B60, and B80 is 60.11, 49.59, 58.13, 57.43, 57.81 and 58.95, respectively. From this figure, when the load is increased the heat release rate is increased for all the fuels. In premixed combustion phase, the heat release rate is highly obtained by ignition delay. The maximum heat release rate of standard diesel, algae, B20, B40, B60, and B80 is 71.39, 69.74, 78.62, 73.19, 69.60 and 69.31, respectively. From this figure, blends of B20 and B40 have higher heat release rate compared with other fuels. The diesel engine combustion process is heterogeneous, its spontaneous ignition process is even more complex. Though ignition occurs in vaporization phase regions, the oxidation reaction can proceed in the liquid phase as well as between the fuel molecules and oxygen dissolved in the fuel droplets.

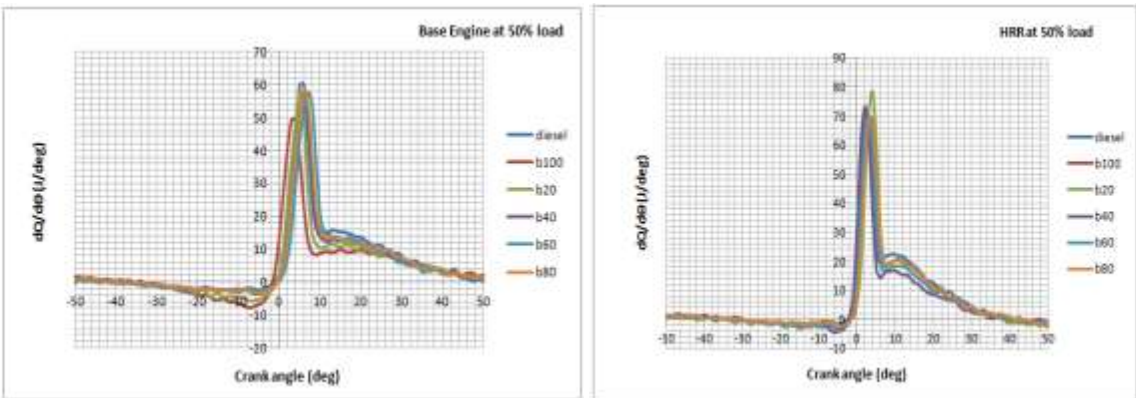

Fig. 1.8: Baseline engine and HRR at 50% loads

The maximum heat release rate of standard diesel, algae, B20, B40, B60, and B80 is 88.53, 97.31, 94.82, 100.93, 99.10 and 101.44, respectively. From this figure, algae and its blends have higher heat release rate compared with standard diesel. When the load is increased, the cylinder wall temperature and residual gas temperature are increased that gives the high heat release rate. Here algae and its blends have higher heat release rate because of its higher cetane number and more oxygen concentration. The maximum heat release rate of standard diesel, algae, B20, B40, B60, and B80 is 78.15, 107.44, 106.46, 104.07, 108.76 and

105.53, respectively. From this figure, algae and its blends have higher heat release rate because of its higher cetane number and more oxygen concentration. Here YSZ–TBC is predominantly used to increases the heat resistance inside the combustion chamber that results reduces the heat transfer through the cooling system and assists the engine for better combustion inside the combustion chamber.

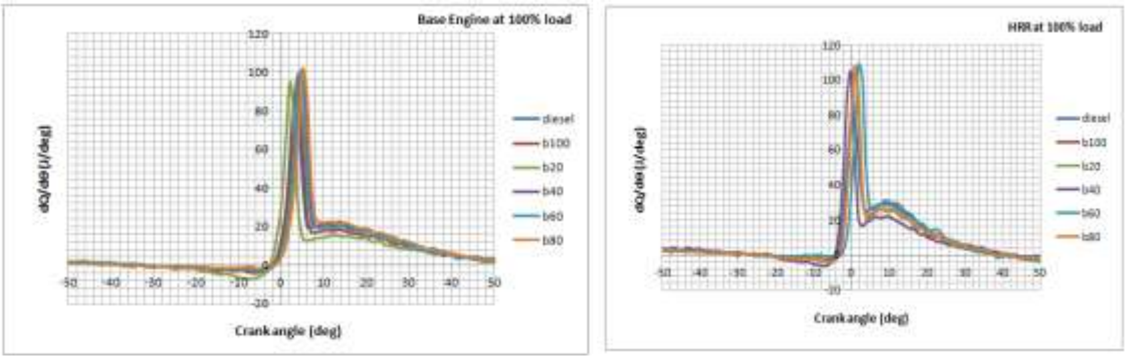

Fig. 1.9: Baseline engine and HRR at 100% loads

c) Effects of dee on combustion characteristics

It is observed that the peak pressures of 68.07, 69.60, 69.31 and 69.57 bars were recorded for standard diesel, algae, B20 and B40, respectively. Here YSZ – TBC is predominantly used to increases the heat resistance inside the combustion chamber that results reduces the heat transfer through the cooling system and assists the engine for better combustion inside the combustion chamber. The maximum heat release rate of standard diesel, algae, B20 and B40 is 81.56, 112.31, 111.28 and 108.78 respectively. From this figure, algae and its blends have higher heat release rate because of its higher cetane number and more oxygen concentration. When the 5% of DEE has added to the fuel which improves the rate of fuel vaporization and mixing with hot air and reduction on ignition that gives the high heat release rate. The DEE has higher cetane number, which has a low boiling temperature that gives the better atomization and fuel vaporization for algae and its blends with help of YSZ – TBC.

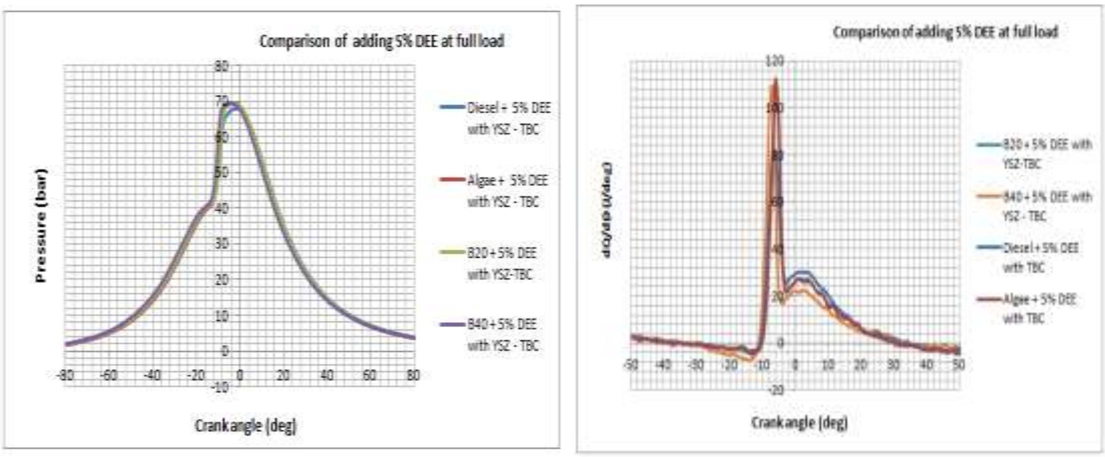

Fig. 1.10: comparison of adding 5% at full loads in with coating and without coating

4. CONCLUSIONS

In this study, algae oil was tested as biodiesel with YSZ – TBC coated and uncoated a single cylinder 4 stroke DI constant speed diesel engine. By using algae and its blends, the engine operated smoothly without any notable problems. The combustion and emissions characteristics of algae and its blends were closer to that of diesel fuel. In YSZ – TBC coated engine, blend of B40 has high peak pressure and high heat release rate which increases up to 30% of peak pressure and 90% of heat release rate compared with baseline uncoated engine at idle load condition. In YSZ – TBC coated engine, blend of B20 and B100 have high peak pressure and high heat release rate which increases up to 20% of peak pressure and 35% of heat release rate compared with baseline uncoated engine at part load condition. In YSZ – TBC coated engine, blend of B20 has high peak pressure and high heat release rate which increases up to 20% of peak pressure and 13% of heat release rate compared with baseline uncoated engine at full load condition. From the above analyze, YSZ – TBC is predominantly used to increase the combustion characteristics at idle and part load conditions. Here, adding of 5% DEE as additives at full load condition, blends of B20 has better combustion characteristics with help of thermal barrier coating, which increases up to 20% of peak pressure and 13% of heat release rate compared with baseline uncoated engine at full load condition.

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