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RESEARCH ARTICLE

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EXPERIMENTAL INVESTIGATIONS IN TO PERFORMANCE AND EMISSION CHARACTERISTICS OF THERMAL BARRIER COATED LOW HEAT REJECTION DIESEL ENGINE USING BIODIESEL AS FUEL

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ABSTRACT

The importance of energy and energy security is paramount. With alarming rate of depleting fossil fuels, rising crude oil prices, depreciating domestic currency and increasing oil imports, India stares at an acute prospect of having to incur huge foreign exchange outgo to buy expensive energy in the name of oil. Technology commands enormous power to effect major transformation. In conventional diesel engine approximately one-third of the fuel energy input is converted into useful work and the other major is rejected as heat via cooling system and exhaust gases. Moreover, this engine poses a major cause for automobile pollution.

The Thermal Barrier Coating (TBC) has been recognized as showing considerable promise for IC engines. TBCs are basically ceramic coatings with ultra low thermal conductivity deposited on engine components thereby making an insulated engine. This minimizes the heat transfer to the cooling system due to which it gets the name Low Heat Rejection (LHR) engine. Likewise, Bio-diesel too has a potential as a promising alternative fuel to their diesel counterparts while being renewable, sustainable, and environmental friendly.

The experimental work is carried out on 4-stroke, single cylinder, naturally aspirated, water cooled DI diesel engine. The results showed improved efficiency, fuel consumption and exhaust emissions except for No_x.

Key words— thermal barrier coatings,LHR diesel engine,bio fuel,diesel.

I. INTRODUCTION

Thermal barrier coatings (TBC) are advanced material systems generally applied to metallic surfaces that operate at high temperatures. The ceramic coatings insulate the base material and protect it from high heat sources. They have been extensively used in the aerospace and gas turbine industries to protect components from the extreme operating temperatures present in those devices. They have also been used in automotive applications as a way to insulate exhaust components with the goal of reducing ambient temperatures in the engine bay and decreasing catalytic converter light-off time.

The insulation strategy by the use of TBCs was augmented to diesel engines by Kamo and Bryzik. They used thermally insulating materials such as silicon nitride for insulating different components of combustion chamber and reported an improvement of 7% in performance [11].

Thermodynamics of LHR engine: The key behind the LHR engine is to recover the in-cylinder heat transfer to the cooling medium instead on the crankshaft as useful work, which results in substantial fuel economy and efficiency. This is satisfied by first law of thermodynamics. Second law of thermodynamics mandates no engine is 100% efficient, that is, the input energy cannot equalize the useful work output and some heat has to be rejected by the system, preferably at the lowest possible limit to gain the highest possible efficiency. This reduction of in-cylinder heat transfer to the cooling medium satisfies second law, moreover according to first law has the potential to do more work [12-13]. As heat transfer to the cooling system is reduced due to insulating effect by TBC, the modified engine thus gets the name Low Heat Rejection (LHR) engine.

TBC and LHR engines have significant effect on critical engine performance parameters including thermal efficiency, and brake specific fuel consumption (BSFC) and exhaust gas temperature (EGT). Thermal efficiency measures the energy conversion efficiency of the engine, and has been the primary reason for the investigation into TBC use in diesel engines. Reducing the heat rejected to the engine coolant theoretically provides an increase in the thermal efficiency. This has been demonstrated by simulation studies and by some experimental researchers. Other researchers report a decrease in the thermal efficiency of the engine; this is attributed to increases in the convective heat transfer coefficient which causes greater heat flux. Also non-optimized combustion conditions in the LHR engine can cause deterioration of the thermal efficiency. Greater cylinder temperatures reduce ignition delay and therefore require modification of engine timing to perform at peak efficiency. Majority of the researchers who studied the LHR engines for performances also investigated its effect on engine emissions owing to environmental considerations and stringent emission standards stipulated by governments. The researchers also investigated the potential of bio-diesels under same working conditions to its diesel counterparts. Increased in-cylinder temperatures from TBC lead to reduced hydrocarbon, particulate matter, and carbon monoxide emissions. Unburned hydrocarbon emissions are reduced as the high temperatures decrease the quenching distance of the fuel spray from the injectors, resulting in more complete vaporization which allows oxidation reactions to proceed to completion. HC emissions could increase in the case of inefficient combustion or the increased vaporization of lubrication oil due to higher wall temperatures. CO emissions, while already low for diesel engines, are expected to decrease for similar reasons to HC emissions.

In this experiment two different types of bio fuels are used, one is palm stearin methyl ester and the second one is animal tallow methyl ester

II. EXPERIMENTAL DETAILS AND SETUP

The Kirloskar engine is one of the widely used engines in agriculture pump sets, farm machinery and medium scale commercial purposes. The setup consists of a single cylinder, four strokes, naturally aspirated, water cooled Diesel engine connected to eddy current dynamometer. This eddy current dynamometer is used for loading the engine. The engine is interfaced with Engine Soft Software for the measurement of combustion parameters. It is provided with necessary instruments for combustion chamber pressure and crank-angle measurements. For the measurement of cylinder pressure, a pressure transducer is fitted on the engine cylinder head and a crank angle encoder is used for the measurement of crank angle and TDC position. The pressure and crank angle signals are fed to a data acquisition card fitted with Pentium 4 personal computer. The engine speed is sensed and indicated by an inductive pick up sensor in conjunction with a digital rpm indicator, which is a part of eddy current dynamometer. The liquid fuel flow rate is measured on the volumetric basis using electronic transmitter. Provision is also made for interfacing airflow, temperatures and load measurement. The airflow is measured using an

Orifice meter and the exhaust gas temperatures are recorded with chromelalumel thermocouples. The set up has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rota meters are provided for cooling water and calorimeter water flow measurement. A computerized Diesel injection pressure measurement can be conducted through sensor transmitters.

The various components of experimental set up are described below. Fig.2.1 shows line diagram & Fig.2.2 shows the photograph of the experimental set up. The Instruments of the Experimental Setup are

- The engine
- Dynamometer
- Exhaust Gas Analyzer

The Engine

The Engine chosen to carry out experimentation is a single cylinder, four stroke, vertical, water cooled, direct injection computerized Kirloskar make CI Engine. This engine can withstand higher pressures encountered and also is used extensively in agriculture and industrial sectors. Therefore this Engine is selected for carrying experiments. Fig.3.3 shows the actual photos of the C.I. Engine and its attachments.

Dynamometer:

The engine has a DC electrical dynamometer to measure its output. The dynamometer is calibrated statistically before use. The dynamometer is reversible i.e., it works as monitoring as well as an absorbing device. Load is controlled by changing the field current. Eddy-Current Dynamometer's theory is based on Eddy-Current (Fleming's right hand law). The construction of eddy-current dynamometer has a notched disc (rotor) which is driven by a prime mover (such as engine, etc.) and magnetic poles (stators) are located outside with a gap. The coil which excites the magnetic pole is wound in circumferential direction. When current runs through exciting coil, a magnetic flux loop is formed around the exciting coil through stators and a rotor. The rotation of rotor produces density difference, then eddy-current goes to stator. The electromagnetic force is applied opposite to the rotational direction by the product of this eddy-current.

Exhaust Gas Analyzer

All emissions like Carbon monoxide, Carbon dioxide, Un-Burnt Hydrocarbons, Nitrogen oxide and Unused oxygen are found in 5 gas emission analyzer of model “MULTI GAS ANALYZER MN-05” is used. In this cable one end is connected to the inlet of the analyzer and the other end is connected at the end of the exhaust gas outlet. Continuous charging of the analyzer is essential to work in an effective way.Fig.3 show the actual photo of Exhaust Gas Analyzer. The measuring method is based on the principle of light absorption in the infrared region, known as "non-dispersive infrared absorption". The broadband infrared radiation produced by the light source passes through a chamber filled with gas, generally methane or carbon dioxide. This gas absorbs radiation of a known wavelength and this absorption is a measure of the concentration of the gas. There is a narrow bandwidth optical filter at the end of the chamber to remove all other wavelengths before it is measured with a pyro-electric detector

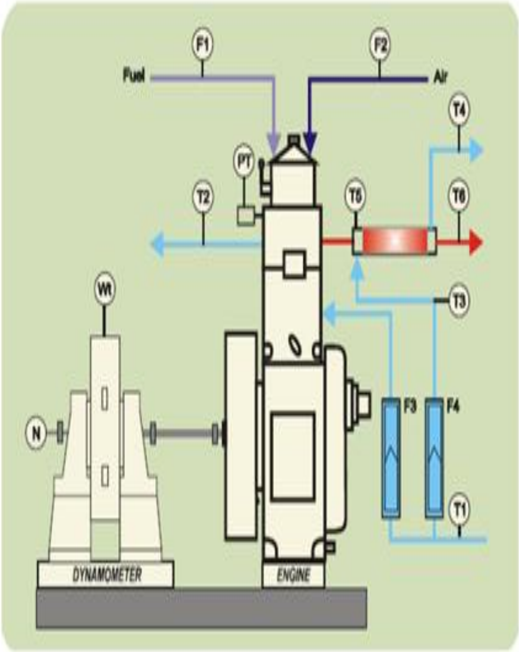

Fig 1: Experimental setup with Instrumentation

Figure 2: Experimental Setup of Computerize CI Engine

Figure 3: Five Gas Emission Analyzer

- *Engine Specification*

Engine Make and Model	Kirloskar TV 1
Intake charge	Naturally aspirated
Number of cylinders	01
Number of Strokes	04
Fuel	Diesel
Rated Power & Speed	5.2 KW/7 hp @ 1500 RPM
Cylinder bore × Stroke	87.5 × 110
Compression Ratio	17.5:1
Injection timing	23° b TDC
Dynamometer arm length	185 mm
Dynamometer Type	Eddy current
Type of cooling	Water cooled

Table 1 Engine specification

Figure 4: Uncoated and Coated Piston Crowns

III. EXPERIMENTAL PROCEDURE

In this work, the engine is maintained at 1500 rpm throughout the experimentation and fixed injection pressure of 180 bar. The standard engine (STD) without coating is experimented at nine different loads in increasing order. For this, eddy current dynamometer is used. Emissions are recorded by Multi Gas Analyzer MN-05. To attain the steady state, engine is put to idling for 15min before every set of experimentation at minimum possible load. Then the STD engine's piston is uninstalled and replaced by PSZ and MSZ coated piston turn by turn. Then the same procedure is carried out. The modified engine (LHR) is compared for performance and emission characteristics with base line engine (STD) using Diesel, PSME and ATME fuels. Performance characteristics are recorded by GUI software-Engine soft by Apex technologies Ltd. In each set of test readings, fuel consumption, cylinder pressures at different crank angles, exhaust gas temperatures and concentrations of CO, CO_2, HC, and Nox emissions are taken at nine different loads

IV. FORMULAS

1. Brake Specific fuel consumption= (Total fuel consumption)/ (Brake Power)
2. Indicated specific fuel consumption = (Total fuel Consumption)/ (Indicated Power)
3. Indicated Power (IP)= BP+FP kw
4. Total Fuel Consumption (TFC) = (Fuel consumption/time) x specific
   Gravity Of fuel x (3600/1000) kg/hr
   Indicated Mean Effective Pressure
   P_{im} = (60000Xip) / (LAnK) bar
5. Brake Thermal Efficiency, η_{bth} = (BPX3600) / ((TFC) X (Calorific value Of Fuel))
6. Indicated Thermal Efficiency,
   η_{ith} = (IPX3600) / ((TFC) X (Calorific Value Of fuel))
7. Mechanical Efficiency, η_m = BP/IP
8. Volumetric Efficiency, $\eta_{vol} = V_s/V_a$
9. Brake Specific fuel consumption= (Total fuel consumption)/(Brake Power) kg/kw-hr
10. Indicated specific fuel Consumption = (Total fuel Consumption)/ (Indicated Power) kg/kw-hr
11. Brake Mean Effective PressureP_{bm} = (60000Xbp)/ (LAnK) bar

V. RESULTS AND DISCUSSION ON ENGINE PERFORMANCE

Brake Thermal Efficiency (BTHE), Brake Specific Fuel Consumption (BSFC) and Exhaust Gas Temperature (EGT) are compared with Brake Power (BP) at nine different loads. These are visualized with the help of graphs

- **STD-DIESEL**

Experimentation of standard engine (baseline engine or uncoated engine) fueled with diesel

- **STD-PSME**

Experimentation of standard engine fueled with PSME

- **STD-ATME**

Experimentation of standard engine fueled with ATME

- **YSZ-DIESEL**

Experimentation of coated engine with YSZ (lhr engine) fueled with DIESEL

- **YSZ-PSME**

Experimentation of YSZ coated engine fueled with PSME

- **YSZ-ATME**

Experimentation of YSZ coated engine fueled with ATME

- **MSZ-DIESEL**

Experimentation of MSZ coated engine fueled with DIESEL

- **MSZ-PSME**

Experimentation of MSZ coated engine fueled with PSME

- **MSZ-ATME**

Experimentation of MSZ coated engine fueled with ATME

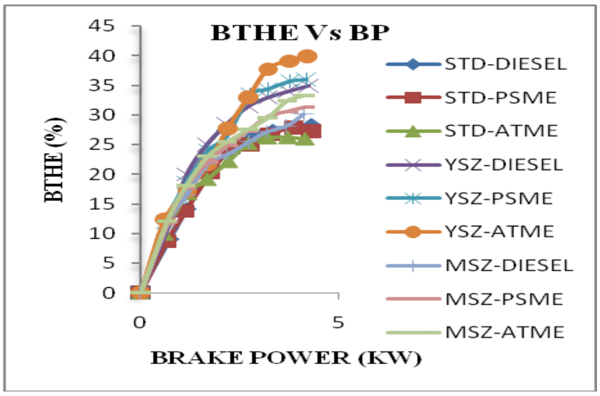

Fig 5: Variation of Brake Thermal Efficiency with Brake Power

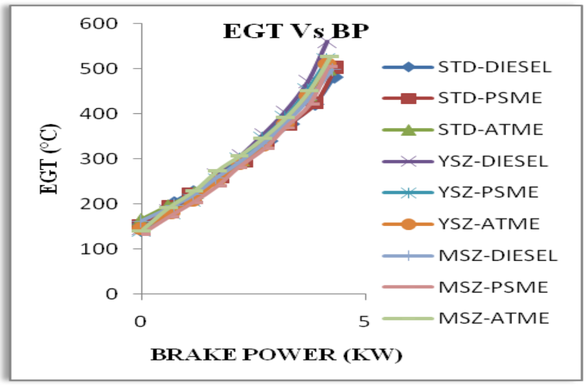

Fig 6: Variation of Exhaust Gas Temperature with Brake Power

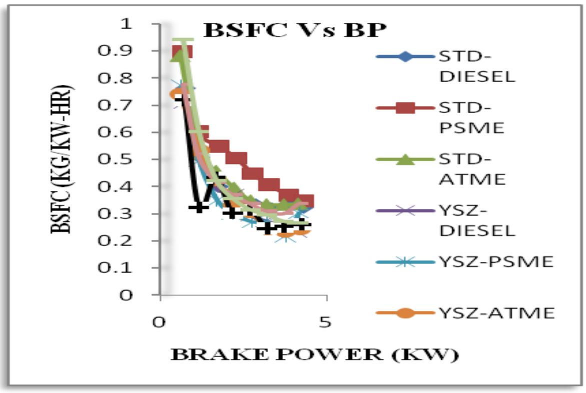

Fig 7: Variation of Brake Specific Fuel Consumption with Brake Power

- *Brake Thermal Efficiency*

Fig 5 shows the variation of Brake Thermal Efficiency with Brake Power. There is an improvement of about 11% for coated engine fueled with ATME when compared to base line engine. This is attributed to high in-cylinder temperatures and pressures in coated engines which decrease viscosity, improve vaporization and atomization of biodiesel. Further, higher oxygen content and cetane number help in better combustion resulting in more expansion work. In standard engine, to compensate the lower heating value of bio-diesels increased fuel consumption is observed.

- *Brake Specific Fuel Consumption*

Fig 6 shows the variation of BSFC with BP. It is inferred that coated engine powered with diesel has the lowest fuel consumption. This is due to higher temperature of combustion chamber walls which atomize fuel issuing from the injector completely and reduce quenching distance yielding lower fuel consumption. LHR-ATME has lower BSFC than the baseline engine. At top loads, STD-Diesel has 0.323 kg/kw-hr, YSZ-Diesel has 0.235 kg/kw-hr and YSZ-ATME has 0.245 kg/kw-hr. Shrirao et al [18] report improved BSFC by a turbocharged LHR engine. The effect of injection pressure and injection timing are crucial for Bio-diesels for improving BSFC which needs further investigations. Compounding of EGT has potential to improve BSFC significantly.

- *Exhaust Gas Temperature*

Fig 7 shows the variation of EGT with BP. Due to insulation strategy by LHR engine much of the heat transfer which is reduced to cooling system is recovered as exhaust energy. This is credited for increased EGT in LHR engines compared to standard engines. There is an improvement by 80°C for YSZ-Diesel compared to baseline engine. Thus, coated engines increase the enthalpy of the exhaust gases, and the same can be compounded to run power turbines, turbo-chargers etc to improve the overall efficiency, economy and emissions.

5.2 Results and Discussion for Engine Emission Characteristics

This experimentation studies the effect of Bio-diesel and TBC individually as well as simultaneously. Bio-diesel when compared to diesel has lower heating value, higher viscosity and higher oxygen content with lower carbon to hydrogen ratio. TBCs increase the in-cylinder temperature by reducing heat transfer to cooling system or surroundings which increase the expansion work. The combined effects are thus worth experimenting.

- *Carbon Monoxide*

Fig 8 interprets the variation of CO with BP and substantiates the potential of LHR engines. It is well known that better combustion leads to lower concentrations of CO at the exhaust. The trend increases with increase in load as air-fuel ratio decreases by increase in load. LHR-ATME has least CO concentration and is startlingly much lower than the baseline engine. An improvement of 37% of CO concentration is observed for YSZ-ATME when compared to baseline engine. This is due to complete combustion in insulated environment of LHR engine and high oxygen content in bio-diesels. Further, ATME has high cetane number which reduces the possibility of formation

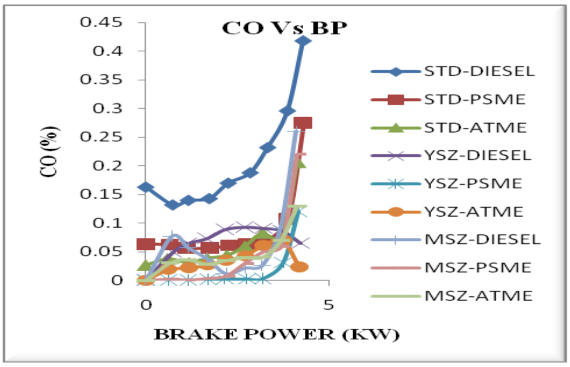

Fig 8: Variation of Carbon Monoxide with Brake Power

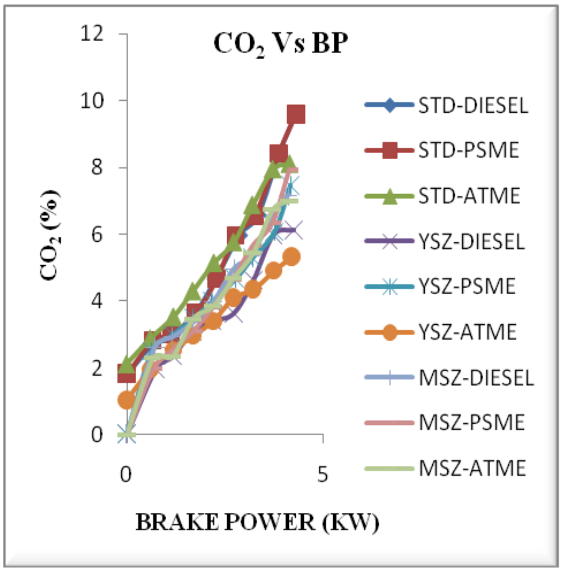

Fig9: Variation of Carbon Dioxide with Brake Power

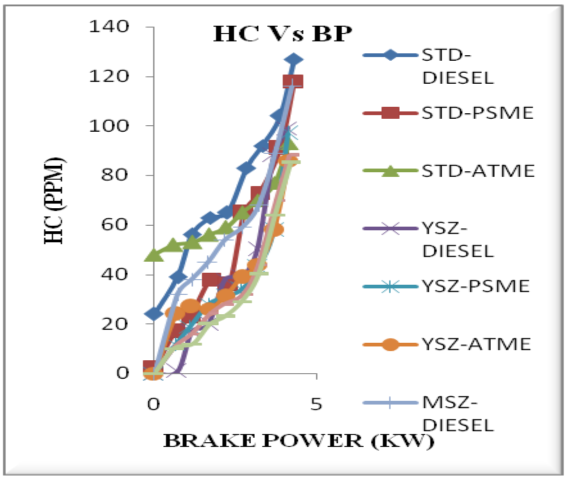

Fig 10: Variation of Un-burned Hydrocarbons with Brake Power

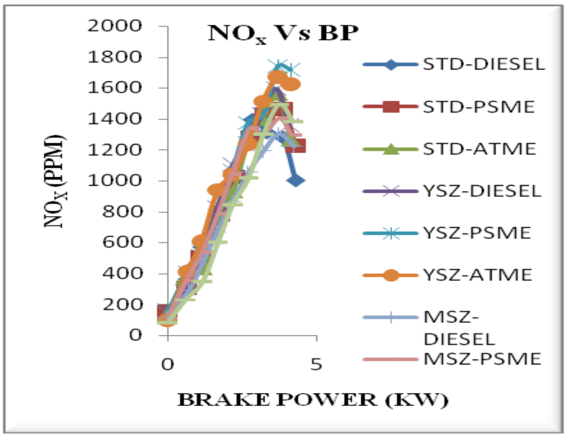

Fig11: Variation of Oxides of Nitrogen with Brake Power

- *Carbon Dioxide*

Fig 9 shows the variation of CO_2 with BP. CO_2 emitted is proportional to fuel consumption. YSZ-ATME has lower CO_2 concentration compared to baseline engine due to lower fuel consumption as is evident from fig 4.2. This may also be attributed to lower carbon content in bio-diesels. Approximately about 4% decrease in CO_2 is observed for LHR-ATME when compared to baseline engine.

- *Hydrocarbons*

Fig 10 shows the variation of HC with BP. HC emission is reduced in LHR-ATME engine due to high after combustion temperatures and stresses which engulf any remaining unburned HC into the combustion process, thereby leaving little possibility of sac volume formation. In bio-diesels this may be due to high cetane number which decreases the quenching distance in high in-cylinder temperature environment of LHR engine.

- *Oxides of Nitrogen*

Fig 11 shows the variation of No with BP. No is temperature sensitive. The high combustion temperatures, inherent availability of nitrogen and oxygen from fuel and intake charge create favorable conditions in accelerating the reaction to result into oxides of nitrogen. This is the reason for increased No concentrations in LHR engine. In bio-diesels, higher oxygen content increases injection advance thereby increasing chances for No formation. The trend for Kn_{ox} at high loads is decreasing. This may be attributed to reduced residence time at top loads where peak pressures are attained.

5.3 Results and Discussion on Combustion Characteristics

- *Pressure Vs Crank Angle Variation*

Figure 12 visualizes variation of in-cylinder pressures with crank angles. For standard engine the peak pressure is about 81 bars while for its counterparts YSZ-ATME and MSZ-ATME maintained a pressure of 87.5 and 82 bar respectively. This is due to the insulation technique of LHR engines and high O_2 contents of bio-diesel fuels, which increase the in-cylinder working temperatures and help in complete combustion

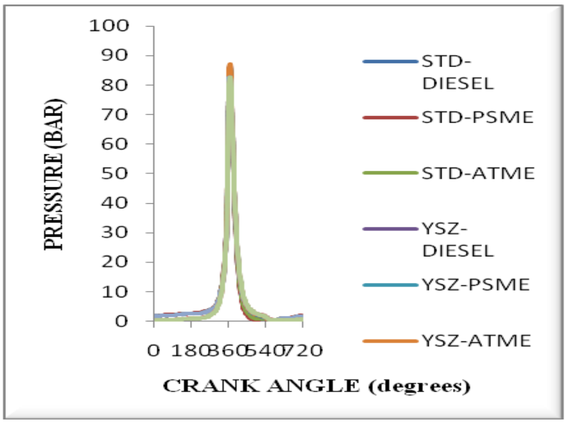

Fig 12: Variation of Pressure with Crank angle

VI. CONCLIUSION

In this work, conventional diesel engine is converted to thin ceramic coated LHR engine. The combined effect of coated engine powered with bio-diesel (ATME & PSME) is studied for performance and emission characteristics. The following conclusion can be drawn:

1. Ceramic coatings make the engine semi-adiabatic. This increases in-cylinder after combustion temperature that lead to more expansion work thus increasing Brake Thermal Efficiency significantly.
2. Due to more oxygen content and high cetane number, bio-diesel under LHR engines enhances complete combustion and thus has the potential to replace diesel fuel
3. . By reducing the heat transfer to cooling medium, exhaust energy is increased. This can be turbo compounded to run power-turbines or turbochargers in the downstream. This can improve BSFC and efficiency significantly.
4. Due to complete combustion at high temperatures, exhaust emission concentrations are diminished drastically. Exhibits eco-friendly system.
5. In LHR engines NO_x concentrations alone are high. Nevertheless, this can be controlled by catalytic converter which needs high temperatures for operation and this is readily available from EGT.

Thus LHR engines and bio-diesels coupled can solve the conflict between economic development and preservation of human health

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