Performance and Exhaust Emission Analysis of Thermal Barrier Coated Diesel Engine Using Rice Bran Oil Biodiesel

Sunil I. Patel, Dipak C. Gosai, Vandana Y. Gajjar

Abstract— ***Increasing the performance of an internal combustion engine requires the transformation of total fuel energy to useful energy at the highest as possible. Increase of inner cylinder heat plays important role in the increase of engine performance and decrease of exhaust emissions. It is understood that coating combustion chamber elements with thermal barriers contributes a lot to the increase of inner cylinder heat. This study includes an evaluation of experimental studies and its results carried out upon the methods applied on coating with thermal barrier in diesel engines, the effects of coating on the performance of engine using rice bran oil biodiesel blends of B10, B20, B40, B100 with the diesel fuel. By using rice bran biodiesel blends with diesel fuel, the result showed that brake thermal efficiency and mechanical efficiency of different blends with diesel fuel were less as compared to conventional diesel. Fuel consumption was increased with blending percentage in the engine. Emission level of HC decreased (40-50 %) with blending percentage increased with all type of fuel modes. NO_x, CO also decreased with blending percentage increased with diesel fuel.***

Index Terms—**Rice bran** ***biodiesel, TBC engine, Brake thermal efficiency, Mechanical efficiency, Heat balance sheet, Exhaust emission.***

I. INTRODUCTION

Fuels derived from renewable biological resources for use in diesel engines are known as biodiesel. Biodiesel is environmentally friendly liquid fuel similar to petrol-diesel in combustion properties. Increasing environmental concern, diminishing petroleum reserves and agriculture based economy of our country are the driving forces to promote biodiesel as an alternate fuel.

While search for alternate fuels is continuing, researchers are also attempting to find different techniques of efficient fuel utilization in diesel engines. These fuels are fossil in nature, leads to the depletion of fuel. Pollution levels are increasing with the fossil fuels. And also there is burden on Govt. of India in importing crude oils. In the context of depletion of fossil fuels, the search for alternate and renewable fuels has become pertinent. It has been found that the vegetable oil is a promising fuel, because of its properties are similar to those of diesel fuel and it is a renewable and can be easily produced [1].

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It is well known fact that about 30% of the energy supplied is lost through the coolant and the 30% is wasted through friction and other losses, thus leaving only 30% of energy utilization for useful purposes.

The concept of LHR engine is to provide thermal insulation in the path of heat flow to the coolant and increase thermal efficiency of the engine. LHR engines are classified into low grade, medium grade and high grade engines depending on degree of insulation. Low grade engines consist of thermal coatings on piston, liner, cylinder head and other engine components, medium grade engines provide an air gap in the piston and other components with low-thermal conductivity materials like cast iron and mild steel etc and high grade engines are combination of low and medium grade engines[2].

Thermal barrier coatings are duplex systems, consisting of a ceramic topcoat and a metallic intermediate bond coat. The topcoat consists of ceramic material whose function is to reduce the temperature of the underlying, less heat resistant metal part. The bond coat is designed to protect the metallic substrate from oxidation and corrosion and promote the ceramic topcoat adherence. A thermal barrier application is shown in figure 1.

Ceramic coatings are widely used in industry for providing valuable improvements against wear, corrosion, erosion, and heat in designs. The bottle neck is that coatings must maintain intended performance during their life cycles. Although coatings exhibit excessive variability and unpredictability in nature, thermal barrier coating in internal combustion engine is a subject of research for many investigations especially reducing in-cylinder heat rejection of adiabatic engines because ceramic coatings demonstrates good thermal barrier properties. Therefore, thermal barrier coating (TBC) technology is successfully applied to the internal combustion engines, in particular to the combustion chamber. Insulation of the combustion chamber components of low heat rejection (LHR) engines can reduce the heat transfer between the gases in the cylinder and the cylinder wall and thus increase the combustion temperature. The LHR engine concept is based on suppressing this heat rejection to the coolant and recovering the energy in the form of useful work. Thermal barrier coatings on the elements of combustion chamber of internal combustion engine offer advantages including fuel efficiency, multi fuel capacity and high power density. Insulation of the combustion chamber may provide not only reduced heat rejection but also thermal fatigue protection of the underlying metallic surfaces in engines as well as possible reduction of engine emissions. However, the insulation of the combustion chamber influences the combustion process and the exhaust emission characteristics.

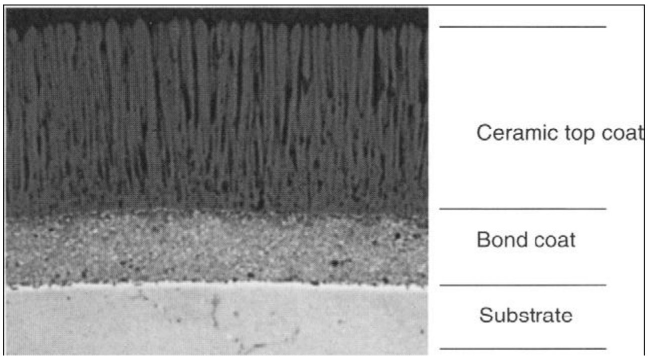

Fig. 1 Thermal barrier coating consisting of metallic bond coat on the substrate and ceramic top coat on the bond coat

To increase the thermal efficiency or to reduce the fuel consumption of engines leads to the adoption of higher compression ratios in order to reduce in-cylinder heat rejection. Both of these factors cause increases in mechanical and thermal stresses of materials used in the combustion chamber. In particular, durability concerns for the materials and components in the engine cylinders, which include pistons, rings, liners and the cylinder heads, limit the maximum in-cylinder temperatures. The application of TBC on the surfaces of such components enhances high temperature durability by reducing the heat transfer and lowering the temperature of the underlying metal.

Advantages of biodiesel versus diesel

Biodiesel is an alternative for normal diesel, which is comparatively more efficient, pollution-free and cost-effective in the form of biodiesel. It reduces the dependence on oil as it can be inexhaustibly synthesized from locally available raw material, thus, providing energy security. Listed below are some of the advantages of Bio-diesel over normal diesel:

Ignition rate- Biodiesel has a high cetane rating, thus, ensuring easy ignition and better combustion.

Lubricity- Biodiesel offers more lubricity as compared to normal diesel, a factor that is essential for effective fuel injection system.

Effect on Environment- It is a renewable source of energy and serves as a clean burning fuel, which reduces emissions of greenhouse gases like unburned hydrocarbons and carbon monoxide.

Economic Factor- It helps in enhancing the rural economy as this fuel is developed using locally available raw material like seeds and other decomposed biological material.

Reduction of Import- Bio-diesel serves as a potential substitute for normal diesel and effectively reduces the import rate of normal diesel from other nation, thus, eliminating the problem of dependence on limited gas reserves and depleting global oil reserves. Therefore, it helps in saving crores of money spent annually on imported diesel. Production of Organic Fertilizer- The by-product obtained after the processing of Bio-diesel serves as effective organic fertilizer. Biodiesel fuel burns up to 75% cleaner than conventional diesel from fossil fuels. Biodiesel substantially reduces unburned hydrocarbons, carbon monoxide and particulate matter in exhaust fumes. Sulphur dioxide emissions are eliminated (biodiesel contains no sulphur) Biodiesel is plant-based and adds no CO2 to the atmosphere. The ozone-forming potential of biodiesel emissions is nearly 50% less than conventional diesel fuel.

Nitrous oxide (NOx) emissions may increase or decrease but can be reduced to well below.

Biodiesel exhaust is not offensive and doesn't cause eye irritation.

Biodiesel is environmentally friendly: it is a renewable energy.

Biodiesel can be used in any diesel engine, fuel economy is the same as conventional diesel fuel.

Biodiesel is a much better lubricant than conventional diesel fuel and extends engine life.

Biodiesel can be mixed with ordinary diesel fuel in any proportion -- even a small amount of biodiesel means cleaner emissions and better engine lubrication: 1% biodiesel will increase lubricity by 65%.

Application of biodiesel

In the current scenario, where conservation of fuel is a burning issue, we are offering an ideal substitute for diesel. Biodiesel is produced using locally available raw material like decomposed biologically material. It is processed in accordance to the industrial standards and using the latest technology. Owing to their economical prices, high efficiency and eco-friendly nature, our products serve as an ideal substitute for diesel various applications in automobile, railways, and aircrafts**.** It is also used as heating oil in domestic and commercial boilers

II. MATHODOLOGY

A. Technical specifications:

ENGINE : Water cooled 4- stroke direct injection diesel engine Test rig made by GANGADHAR RAJKOT.
Cylinder : Vertical twin cylinders with individual cylinder head.
Engine power : 10 HP
Engine speed : 1560
Bore : 80
Stroke : 110
Compression ratio: 16:1
Lubricating oil : 20x40, quantity required 7 litres.
Cooling type : Water cooling.
Electrical dynamometer: 6 KVA capacity alternator coupled to the engine with load bank. (with ammeter and volt meter).
Measurement:
Calibrated burette for fuel intake measurement.

Orifice meter fitted to the air inlet tank with water manometer for air intake measurement.

Multichannel digital temperature indicator for measurement of temperature at various points.

Exhaust gas calorimeter to measure heat carried away by exhaust gas.

Measure the water flow rate of engine jacket and calorimeter.


Fig. 2 Experimental setup

Table 1 Properties of diesel and rice bran biodiesel blends.

Test Parameter	100 % Diesel	B10	B20	B40	B100
Calorific Value, Kcal/Kg	9957	9885	9606	9368	8430
Kinematic Viscosity @ 27 °C, mm^2/s	3.6	3.6	4.0	5.7	15.0
Density @ 25 °C, gm/cm^3	0.820	0.811	0.814	0.821	0.832
Ash Content, %w/w	0.002	0.003	0.009	0.01	0.02
Carbon Residue, %w/w	0.20	0.70	1.5	2.6	9.9
Sulfur Content, ppm	30	3	7	12	30
Flash Point, °C	55	68	69	76	111
Water Content, %w/v	0.01	0.08	0.09	0.19	0.45

III. RESULT AND DISCUSSION

The result obtained pertaining to the performance of the engine are demonstrated with the help of graphs.

B. Comparison of Brake Power and Fuel Consumption (FC)

The variation of fuel consumption with brake power for diesel fuel and different biodiesel blends is shown in Fig. 3. Fuel consumption of the fuel increased with load for all fuel modes. The fuel consumption of rice bran biodiesel blends (B10, B20, B40, B100) are higher than that of the conventional diesel fuel over the entire range of the brake power. The maximum fuel consumption increase (10-20 %) was at the full load of B10, B20, B40, B100 than the diesel fuel.

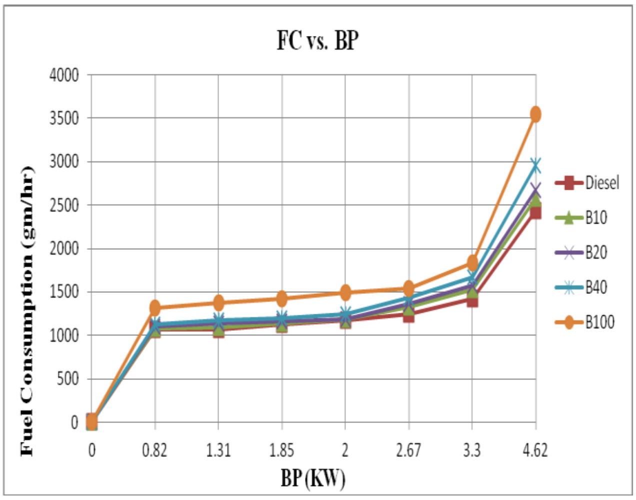

Fig. 3 FC vs. BP

C. Comparison of Brake Power (BP) and Specific Fuel Consumption (SFC)

The variation of specific fuel consumption (SFC) with brake power for diesel fuel and different biodiesel blends is shown in Fig.4. The specific fuel consumption (SFC) reduced with brake power for all fuel modes. The SFC of diesel, rice bran biodiesel and its various blends at different load were estimated. In comparison of diesel a slightly increased (10-15 %) of SFC was found for rice bran biodiesel blends B10, B20, B40, B100 through all loads. SFC of B100 was found higher in comparison to the other blends in all loads.

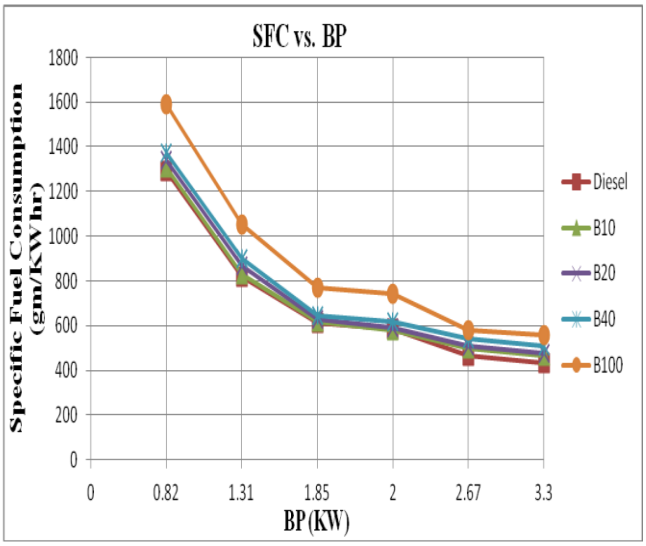

Fig. 4 SFC vs. BP

D. Comparison of Brake Power (BP) and Mechanical Efficiency ($\eta_{mech.}$)

The variation of mechanical efficiency ($\eta_{mech.}$) with brake power for diesel fuel and different biodiesel blends is shown in Fig. 5. The mechanical efficiency increased with load for all fuel modes. Mechanical efficiency of the different blends B10, B20, B40, B100 were lower than that of the diesel fuel. The maximum increased efficiency was found (10-15 %) at 100 % diesel fuel than the biodiesel blends B10, B20, B40, B100.

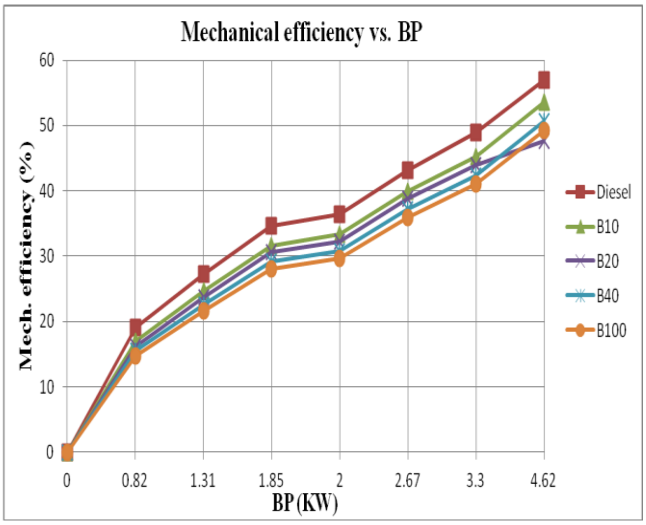

Fig. 5 Mechanical efficiency vs. BP

E. Comparison of Brake Power (BP) and Brake Thermal Efficiency ($\eta_{bth.}$)

The variation of brake thermal efficiency ($\eta_{bth.}$) with brake power for diesel fuel and different biodiesel blends is shown in Fig. 6. The brake thermal efficiency increased with brake power for all fuel modes. The brake thermal efficiency of rice bran biodiesel blends B10, B20, B40, B100 are (5%) lower than that of the diesel fuel with respect to all loads. The reason may be the extended ignition delay and the leaner combustion of diesel fuel, resulting in large amount of fuel burned in the mode of diesel fuel. It may be due to the reduction in the density and viscosity of the diesel fuel than the rice bran biodiesel.

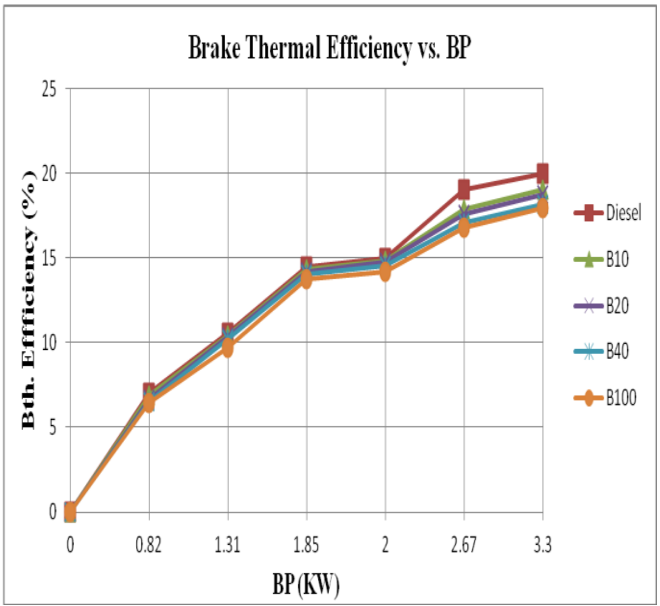

Fig. 6 Brake thermal efficiency vs. BP

F. Comparison of Brake Power (BP) and Indicated Thermal Efficiency ($\eta_{ith.}$)

The variation of indicated thermal efficiency ($\eta_{ith.}$) with brake power for diesel fuel and different biodiesel blends is shown in Fig.7 The indicated thermal efficiency increased with brake power for all fuel modes. The indicated thermal efficiency of diesel fuel is lower than rice bran biodiesel blends B10, B20, B40, B100. The maximum indicated thermal efficiency (44.8 %) was for B100 at 3.3 KW brake power. Reduction was observed at 1.85- 2.0 KW and 2.67-3.3 KW for all fuel modes.

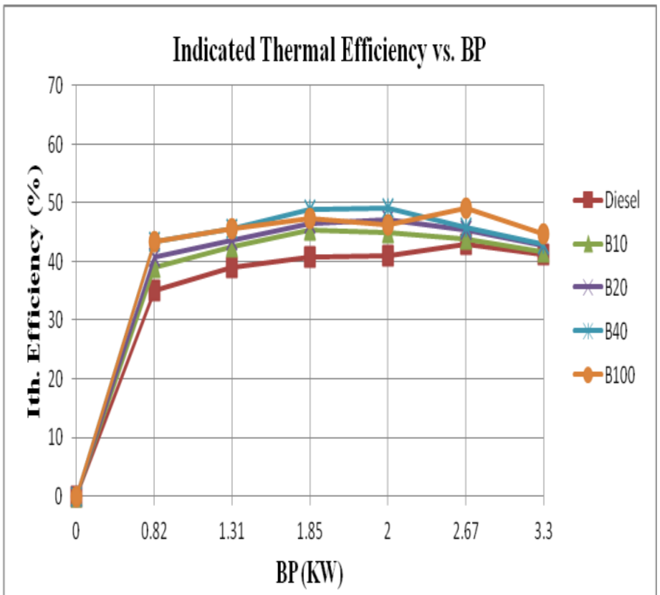

Fig. 7 Indicated thermal efficiency vs. BP

G. Heat Balance Sheet

The heat balance sheet with different blends of rice bran biodiesel with diesel fuel is shown in Fig. 8 The results showed that the heat loss in the Hbp, Hjw and Hu diesel fuel is high as compare to heat loss by exhaust gases because of the thermal barrier coating of the piston top surface. The heat loss by the exhaust gases was only 10.12 % as compare to other losses. The maximum loss was found in the uncoated region 46.24 % as compared to other losses.

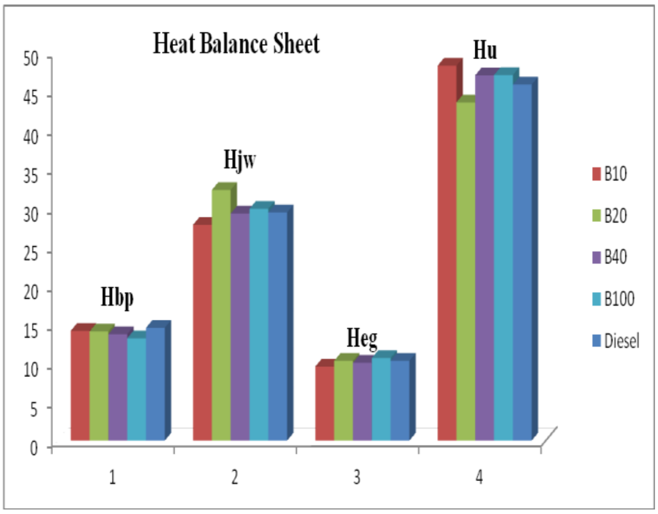

Fig. 8 Heat balance sheet

H. Comparison of Brake Power and Hydrocarbons (HC)

The variation of hydrocarbon (HC) with brake power for diesel fuel and different biodiesel blends is shown in Fig. 9 HC increased with brake power with all fuel modes. Rice bran biodiesel and its different blends B10, B20, B40 showed lower HC (50-60 %) than diesel fuel. HC percentage decreased with blending percentage increased as shown in Fig. B100 produced lowest HC emissions among all fuels and were (50-60 %) lower than diesel fuel.

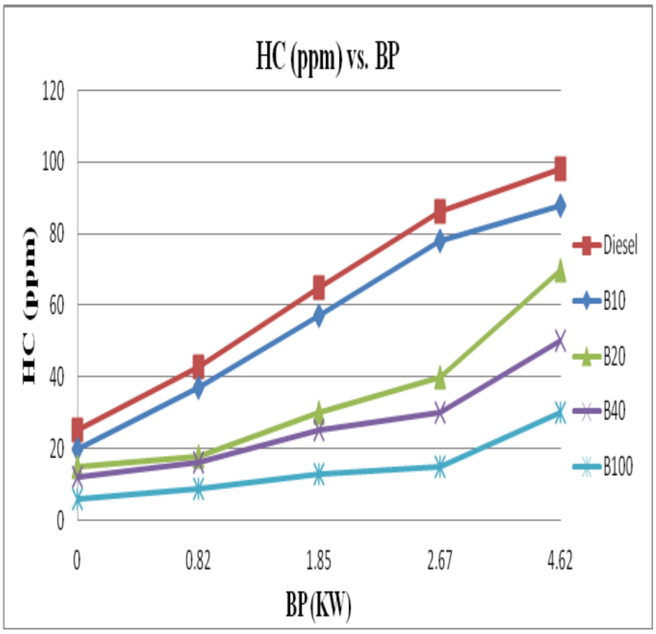

Fig. 9 HC vs. BP

I. Comparison of Brake Power and CO emission

The variation of Carbon Monoxide (CO) with brake power for diesel fuel and different biodiesel blends is shown in Fig. 10 The CO emissions slightly increased at low and medium loads and increased significantly at higher loads with all fuel modes. The results showed that the CO emissions of the different blends B10, B20, B40, B100 were found lower as compared to diesel fuel at full load of the engine. This is due to the higher amount of oxygen in the biodiesel, which will promote the further oxidation of CO during the engine process. The CO emissions reduced by (40-50 %) than the diesel fuel with addition of biodiesel blends.

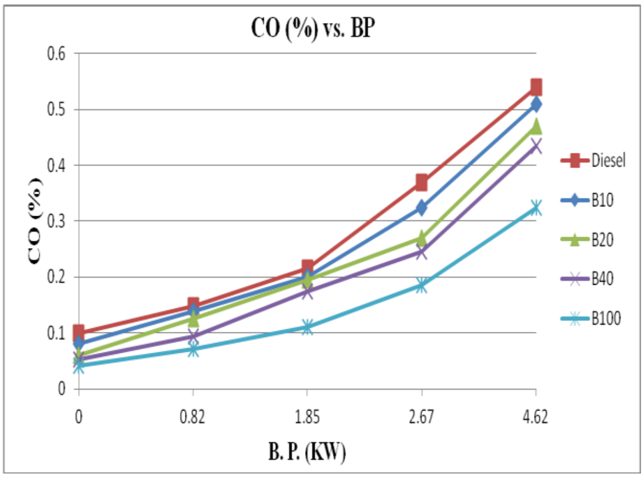

Fig. 10 CO vs. BP

J. Comparison of Brake Power and NO_x emission

The variation of Oxides of Nitrogen (NO_x) with brake power for diesel fuel and different biodiesel blends is shown in Fig. 11. The NO_x emissions of biodiesel blends B10, B20, B40, B100 were less at low loads and more at medium and high loads than those of diesel fuel. It is due to the higher oxygen content and combustion temperature of the biodiesel at medium and high loads. The percentage reduction of NO_x decreased with increased of brake power. NO_x values at maximum load (4.62 KW) were found to be; diesel- 970, B10- 910, B20- 860, B40- 800 and B100- 600 ppm.

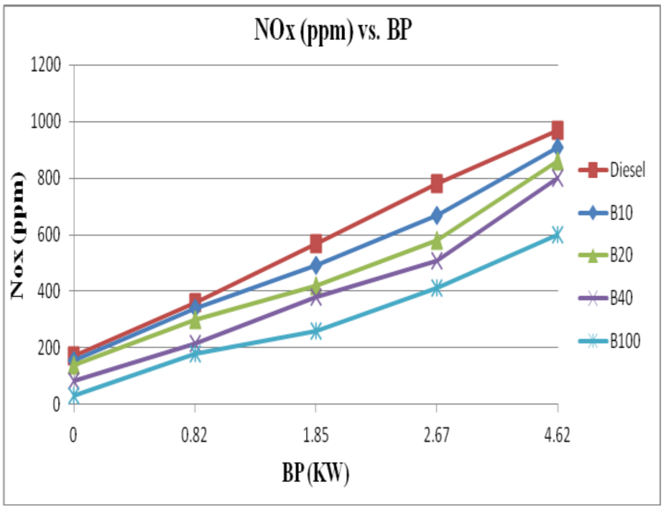

Fig. 11 NO_x vs. BP

IV. CONCLUSION

The performance characteristics of conventional diesel and rice bran oil biodiesel blends were investigated on a single cylinder diesel engine. The conclusions of this investigation are as follows:

The brake thermal efficiency increased with load for all fuel modes. The brake thermal efficiency of rice bran oil biodiesel blend is lower than diesel fuel. The brake thermal efficiency of B10, B20, B40 is near to the diesel fuel. The maximum brake thermal efficiency of 20.0 % was observed with diesel fuel.

Fuel consumption is increased with blending percentage increased in the engine. The fuel consumption of rice bran biodiesel blends (B10, B20, B40, B100) are higher than that of the conventional diesel fuel over the entire range of the brake power. Fuel consumption was increased 10-20 % with blending percentage increased with brake power.

The variation of mechanical efficiency with load for diesel fuel was slightly increased than the biodiesel blends of B10, B20, B40 and B100. The maximum increased efficiency was found 10- 15 % of the diesel fuel to full load.

The variation specific fuel consumption decreased with brake power for biodiesel blends. The maximum SFC was found B100 than the diesel fuel. In comparison of diesel a slightly increased (10-15 %) of SFC was found for rice bran biodiesel blends B10, B20, B40, B100 through all loads.

The indicated thermal efficiency of diesel fuel was less as compared to biodiesel blends. Maximum indicated thermal efficiency was found 44.8 % of B100 at 3.3 KW brake power.

Heat balance sheet with different blends of rice bran biodiesel result showed that heat loss in the Hbp, Hjw and Hu diesel fuel is high as compare to heat loss by exhaust gases. Heat loss by exhaust gases was found 10.12 % and Hbp, Hjw and Hu were 13.89 %, 29.64%, 46.26% respectively.

HC emissions increased with brake power for all fuel modes. HC emissions decreased with rice bran biodiesel percentage increased. HC emissions of B100 blends were lower than all fuel modes.

CO emissions of the rice bran biodiesel blends were lower than that of diesel fuel. The minimum Co emissions were observed with the B100 blend well below the diesel fuel.

The NO_x emissions of the rice bran biodiesel blends were low at lower loads and high at higher loads compared with the diesel fuel. B100 blends were observed less NO_x as compared to all fuel modes.

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