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EXPERIMENTAL STUDY ON PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINE USING RICE BRAN OIL AS FUEL

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Abstract

Diesel engine is a prime mover which is widely used where the electric power is not available and for transportation. Due to depletion of fossil fuels, it is necessary to look after the alternate fuels. The use of Biofuels can partially fulfill the problem of fuel crises and environmental issues. Biofuels are classified into bio-ethanol and biodiesel. Biodiesel is a monoalkyl ester of long chain fatty acids synthesized from vegetable oils (Edible and Non-edible oils).Bio-fuel is a clean burning fuel made from natural renewable energy resource; it operates on IC engine similar to the petroleum diesel. The rising cost of diesel and the danger caused to the environment has led to an intensive and desperate search for alternative fuels. Among them, the rice bran oil has proven to be a promising substitute to diesel. In this experimental study, A 4-stroke, single cylinder, constant speed, direct injection diesel engine was operated on rice bran oil-biodiesel of different blends. Four different blends of 20, 40, 60 and 80 % by volume were used for this study. Various engine performance, combustion and emission parameters such as Brake Thermal Efficiency, Brake Specific Fuel Consumption, Heat Release Rate, Peak Pressure, Exhaust Gas Temperature, etc. were recorded from the acquired data. The recorded parameters were studied for varying loads and their corresponding graphs have been plotted for comparison purposes. Petroleum Diesel has been used as the reference. From the properties and engine test results it has been established that rice bran oil biodiesel is a better replacement for diesel without any engine modification.

Key words*:* Rice bran oil, biodiesel, diesel, diesel engine

1. Introduction

India is one of the fastest growing economies in the world. The Development Objectives focus on economic growth, equity and human wellbeing. Energy is a critical input for socio-economic development. The energy strategy of a country aims at efficiency and security and to provide access which being environment friendly and achievement of an optimum mix of primary resources for energy generation. Fossil fuels will continue to play a dominant role in the energy scenario in our country in the next few decades. However, conventional or fossil fuel resources are limited, non-renewable, polluting and, therefore, need to be used prudently. On the other hand, renewable energy resources are indigenous, non-polluting and virtually inexhaustible. India is endowed with abundant renewable energy resources. Therefore, their use should be encouraged in every possible way. The crude oil price has been fluctuating in the world market and has increased significantly in the recent past, reaching a level of more than $ 140 per barrel. Such unforeseen escalation of crude oil prices is severely straining various economies the world over, particularly those of the developing countries. Petro-based oil meets about 95% of the requirement for transportation fuels, and the demand has been steadily rising. Provisional estimates have indicated crude oil consumption in 2007-08 at about 156 million tons. The domestic crude oil is able to meet only about 23% of the demand, while the rest is met from imported crude. India's energy security would remain vulnerable until alternative fuels to substitute/supplement petro-based fuels are developed based on indigenously produced renewable feedstocks. In bio fuels, the country has a ray of hope in providing energy security. Bio fuels are environment friendly fuels and their utilization would address global concerns about containment of carbon emissions. The transportation sector has been identified as a major polluting sector. Use of bio fuels has become compelling in view of the tightening automotive vehicle emission standards to curb air pollution. Bio fuels are derived from renewable bio-mass resources and, therefore, provide a strategic advantage to promote sustainable development and to supplement conventional energy sources in meeting the rapidly increasing requirements for transportation fuels associated with high economic growth, as well as in meeting the energy needs of India's vast rural population. Bio fuels can increasingly satisfy these energy needs in an environmentally benign and cost- effective manner while reducing dependence on import of fossil fuels and thereby providing a higher degree of National Energy Security. Liquid fuel meets most of the energy requirement of the transport sector with a continuous rise in the demand over the past decades across the country. The growth of the demand for the liquid fuel is increasing almost 30% over every 4-5 years. The crude oil supply from the domestic sources, hardly reach 30% of the demand, while the rest met out of the imports. In this project Bio-fuels provide a ray of hope to offset a reasonable margin of the imports serving as a good substitute for the fossil fuels. The present bio-fuels that are bio-diesel, methanol and ethanol which are gaining immense importance and awareness across the globe. This is particularly because of the wider acceptance due to its environment friendly, providing energy security at grass root level providing employment to rural community and improved income generation.

In 1984 Pryde *et al*. showed that the methanolysis of soybean oil, in the presence of 1 mol% of H2SO4, with an alcohol/oil molar ratio of 30:1 at 65°C, takes 50 h to reach complete conversion of the vegetable oil (> 99%), while the butanolysis (at 117 °C) and ethanolysis (at 78 °C), using the same quantities of catalyst and alcohol, take 3 and 18 h, respectively. **Freedman *et al in 1986*.** found that a 30:1 ratio of methanol to soyabean oil with 1% sulphuric acid gave higher conversion after 44 h of heating at 60°C. they emphasized that if vegetable oils have more than 1% free fatty acids, the acid catalysis become more effective than alkali catalyst. **Sukumar *et al*.***in2005* conducted an experiment on a direct injection 4 stroke diesel engine using methyl esters of MAHUA OIL and found that, engine performance with Mahua oil ester does not differ greatly from that of diesel fuel. Vegetable oil was used as an alternative fuel for diesel engine. **Lang *et al*.**in**2006** have synthesized canola methyl ester (CME), rapeseed methyl ester (RME), linseed methyl ester (LME) and sunflower methyl ester (SME) in a batch type reactor using both potassium hydroxide and sodium hydroxide as catalysts and maintaining molar ratio of 6:1. It has been reported that in a commonly used single stage process, a period of 1 hr is required to achieve 98% conversion of rapeseed oil to rapeseed methyl ester **Balusamy *et al*.***in 2007* have investigated methyl ester of thevetiaperuviana seed oil (TPSO) and blended with diesel fuel, has been tested in naturally aspirated single cylinder diesel engine a trated speed of 1500 rpm. **Kandasamy *et al*.***in 2009* have discussed the performance characteristics of a single cylinder diesel engine using rice bran and pungam oil blended with diesel fuel.From the above review of literature the following important conclusions are made. The past work reveals that they used esters of edible and non-edible oil like soybean, honge, jatropha, yellow grease, and mahua oil in place of diesel in a single cylinder and heavy duty diesel engines. So far a very few kinds of vegetable oil have been tested on CI engines. India has the one of the great potential for production of bio-fuels from rice bran oil. Hence there is a need to identify new kinds of biodiesel such as rice bran oil biodiesel and examining their suitability as an alternate fuel in single cylinder 4-stroke diesel engines.

2. Methodlogy

Extraction Of Biodiesel From Rice Bran Oil By Transesterification Process

The transesterification is an equilibrium reaction and the transformation occurs essentially by mixing the reactants. However, the presence of a catalyst (typically a strong acid or base) accelerates considerably the adjustment of the equilibrium. In order to achieve a high yield of the ester, the alcohol has to be used in excess.

Mild Acid Catalyzed Transesterification

This is a type of reaction that takes place in the presence of methanol (30%) and orthophosphoric (0.6%) acid at 60˚c with constant stirring, helps in the separation of impurities which were dissolved in the methanol as an upper layer and oil in the lower layer.

Strong Acid Catalyzed Transesterification

The first stage product is reacted with the sulphuric (0.6%) acid and methanol (20%) for 2 hours at 60˚c with constant stirring. The reaction product is allowed to settle. The FFA and the other impurities were removed in this stage as an upper layer and oil in the lower layer. The product of earlier stages i.e. pure triglycerides is made to react with methanol (30%) and catalyst, KOH (3gms) for 2 hours at 60˚C with constant stirring rate. The reacted product of this third stage is made to settle down under gravity. The lower contains which contain glycerol and other impurities are removed and further excess of alcohol and other impurities present are removed by water wash process after the pH neutralization. The water wash product then heated above 100˚C in order to remove the moisture content.

3. Governing Equations

1. **Brake Power**

$$BP = \frac{2\pi NT}{60 \times 1000}$$

2. **Specific Fuel Consumption**

$$BSFC = \frac{X1 \times 3600}{t \times 1000 \times BP}$$

3. **Specific Energy Consumption**

$$BSEC = \frac{X2 \times 3600}{t \times 1000 \times BP}$$

4. **Brake Thermal Efficiency (%)**

$$\eta_{bth} = \frac{BP \times t \times 1000}{X2} \times 100$$

Note:

1. $X1 = (\text{Volume} \times \text{Specific gravity})^{BD} + (\text{Volume} \times \text{Specific gravity})^{D}$

2. $X2 = (\text{Volume} \times \text{Specific gravity} \times CV)^{BD} + (\text{Volume} \times \text{Specific gravity } CV)^{D}$

Blending Of Fuel

The produced bio diesel is blended with the regular Diesel in different percentages. Below are the notations for different fuel samples which are blended.

Sl. No.	Bio diesel percentage	Diesel percentage	Notation
1	20%	80%	B20
2	40%	60%	B40
3	60%	40%	B60
4	80%	20%	B 80
5	100%	0%	B100

The blending process was carried out with the help of a measuring jar and beaker. The appropriate percentages of diesel and biodiesel were added to the beaker and then transferred to bottle. The bottles were shaking well and were allowed to stay upside down to ensure proper mixing of fuels. The bottles were stored in dry place and kept still for the next 24 hour. Blends were checked for every 6 hrs time intervals for any layer formation. All the blends were stable and passed the 24 hrs stability test and were ready to be used on engine.

4. Properties of Rice Bran Biodiesel

The blended fuel samples and biodiesel were tested for different chemical and physical properties. The results have been furnished below

CALORIFIC VALUE (KJ/Kg)	40164
DENSITY (Kg/m^3)	909
KINEMATIC VISCOSITY CST at 40^{o}C	30
FLASH POINT ^{o}C	126
FIRE POINT ^{o}C	152

5. Experimental Setup for Engine Performance Test

A four stroke, single cylinder water cooled diesel engine is employed for the present study. The detail specification of the engine used are given in table. Five gas analyzer was used to measure the concentration of gaseous emissions such as Oxides of nitrogen, unburned hydrocarbon, carbon monoxide, carbon dioxide and oxygen level. The performance and emission tests are carried out on the C.I. engine using various blends of diesel-biodiesel blends as fuels. The tests are conducted at the constant speed of 1500rpm at various torque.

SLNO	PARAMETERS	SPECIFICATION
1	Type	TV 1 (kirloskar made)
2	Nozzle opening pressure	200 bar
3	Governor type	Mechanical centrifugal type
4	Number of cylinders	Single cylinder
5	Number of strokes	Four stroke
6	Fuel	Diesel
7	Compression ratio	16.5:1
8	Cylinder diameter(Bore)	80mm
9	Stroke length	110mm
Electrical dynamometer		
10	Type	Foot mounted, continuous rating
11	Alternator rating	3KVA
12	Speed	2800-3000RPM
13	Voltage	220 V AC

6. Experimentation Methodology

First the experimentation is performed with diesel (for getting the base line data of the engine) and then blends of different percent volumes of Biodiesel B20, B40, B60, B80 were carried out. The performance of the engine is evaluated in terms of brake thermal efficiency, brake specific energy consumption, exhaust gas temperature, and emission of the engine is analyzed (HC, CO, CO2, O2 and NOx).

7. Results and Discussion

The studies were, conducted on blends of different present volumes of Biodiesel B20, B40, B60 and B 80 were carried out.

Engine Performance And Exhaust Emission Analysis

Performance Characteristics

The performance characteristics of the engine are the very important criterion for selection and suitability of alternate fuels. This study evaluates BSFC, BTE and EGT of diesel blends.

Brake Thermal Efficiency

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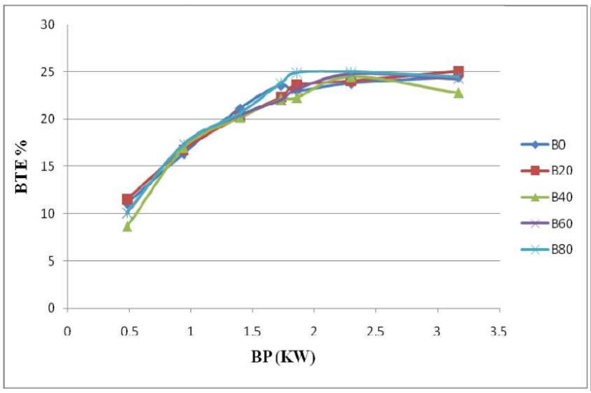

Fig.7.1Variation of BTE with BP

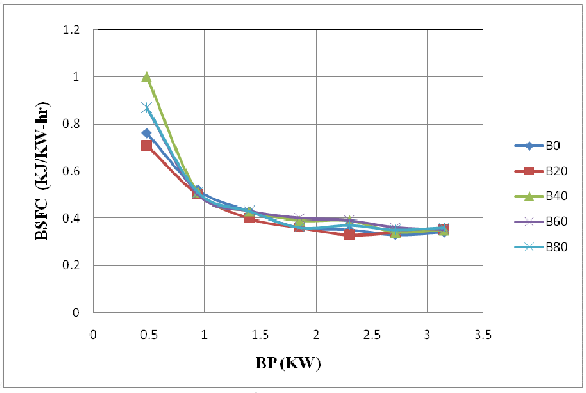

Fig.7.2Variation of BTE with BSFC

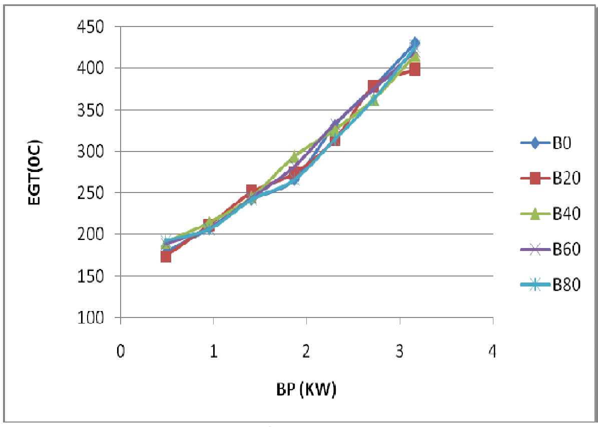

Fig.7.3Variation of BP with EGT

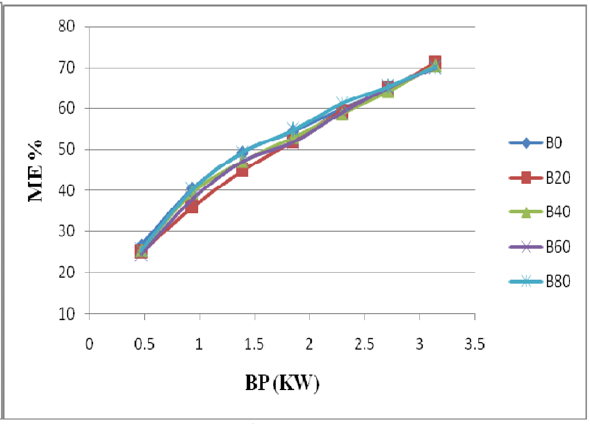

Fig.7.4Variation of BP with ME

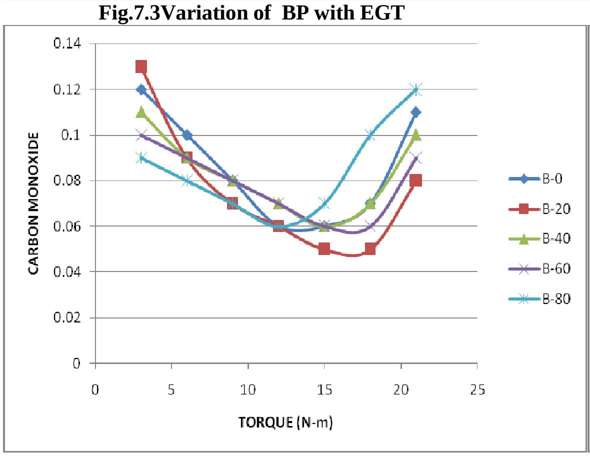

Fig.7.5Variation of Torque with C0

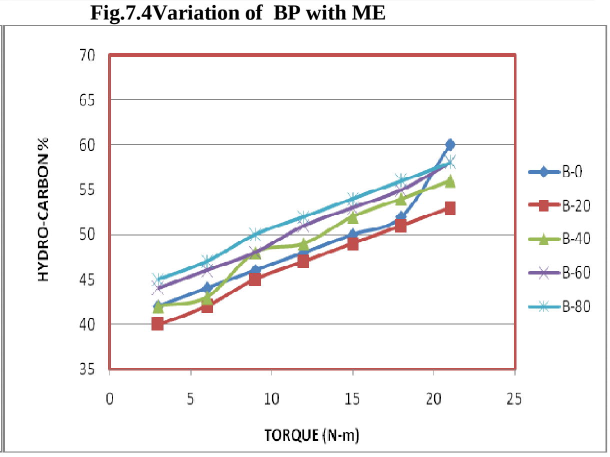

Fig.7.6Variation of Torque with hydrocarbon

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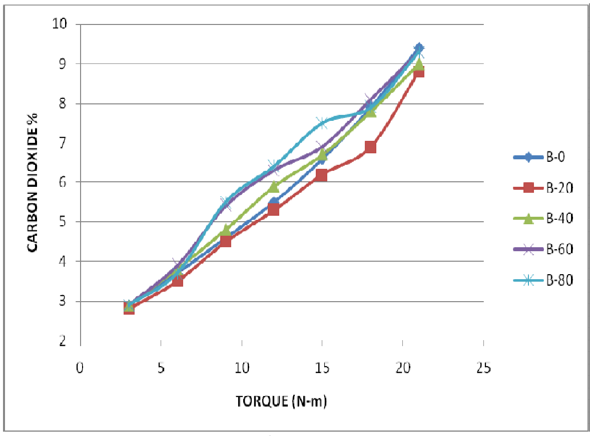

Fig.7.7Variation of Torque with CO_2

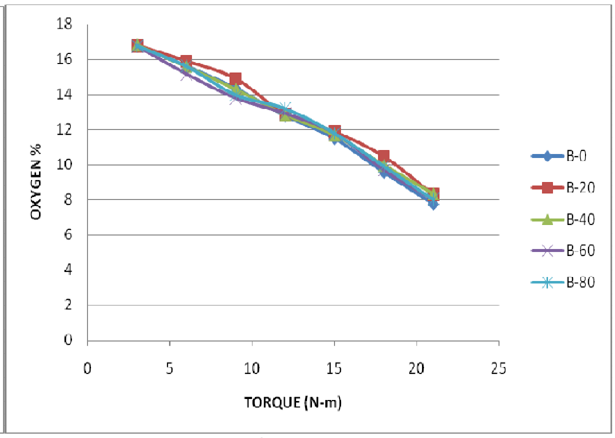

Fig.7.8Variation of Torque with O_2

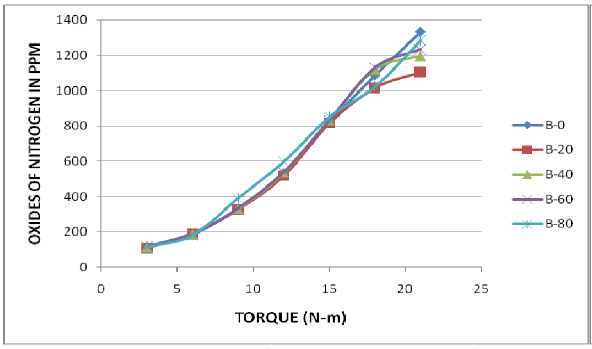

Fig.7.9Variation of Torque with oxides of N_2

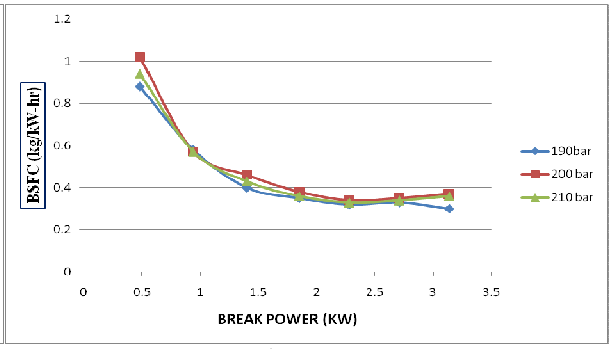

Fig.7.10Variation of BP with BSFC

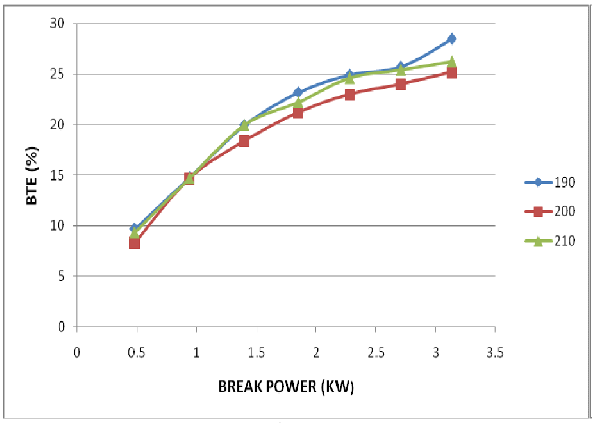

Fig.7.11Variation of BP with BTE

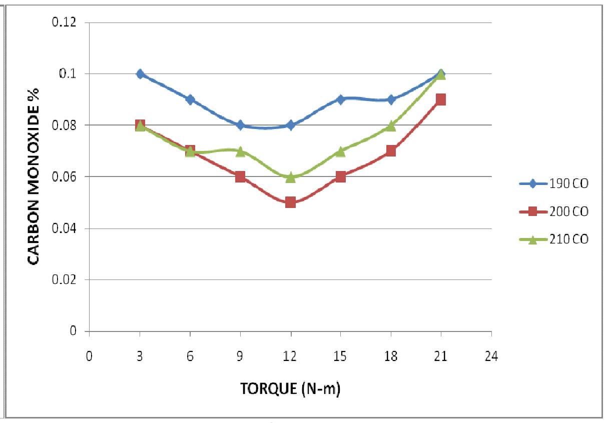

Fig.7.12Variation of Torque with CO

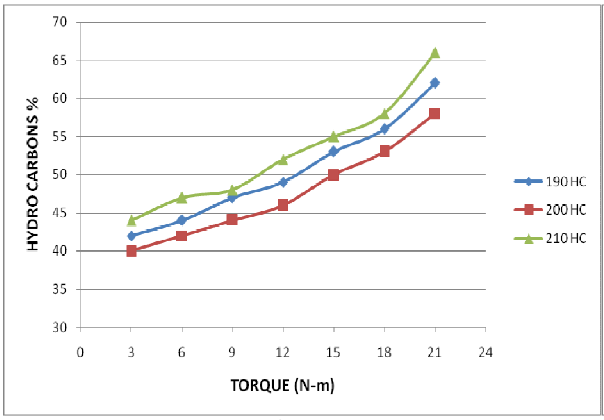

Fig.7.13Variation of Torque with hydrocarbon

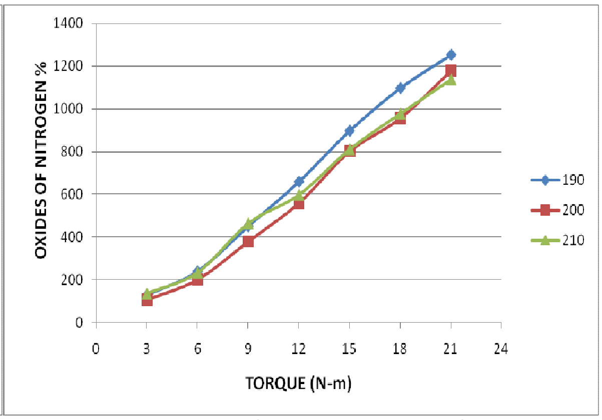

Fig.7.14Variation of Torque with oxides of N_2

The graph 6.1 shows that BTE increases with the increase in the load however for blends B40, B60, B80, it is observed that BTE is less than the diesel, this is due to lower calorific value of blends. However B20 has got higher value of BTE than that of diesel. Hence it is an optimum blend.

Brake Specific Fuel Consumption

The BSFC of an engine for different blends of RBO is shown in above figure 6.2. Generally it is found that with the increase in the concentration of B80 BSFC value increases and sharply decreases with the increase in the BP for all the blends. The main reasons for this could be that the percentage increase in the fuel required to operate the engine is less than the percentage increase in the brake power due to relatively less portion of heat losses at higher loads. BSFC was calculated on weight basis. Thus higher density resulted in higher value of BSFC. As density of biodiesel was higher than that diesel which means the same fuel consumption on volume basis resulted in higher BSFC in case of 100% biodiesel. The higher mass injection will occur for same volume at same injection pressure due to higher density of biodiesel or blends of RBO.

Exhaust Gas Temperature

The variations of EGT with respect to BP are represented in above figure6.3. In general, the EGT increases with increase in engine loading for all the fuel tested. The mean temperature increased linearly from 174^{0}C at no load to 430^{0}C at full load condition. This increase in EGT with load is obvious from the simple fact that more amount of fuel was required to the engine to generate that extra power needed to take up the additional loading. The exhaust gas temperature was found to increase with the increasing concentration of biodiesel in the blends.

Mechanical Efficiency

The variation of mechanical efficiency (η_{mech}.) with brake power for diesel fuel and different biodiesel blends is shown in the above figure6.4. The mechanical efficiency increases with increase in BP for all fuel modes. Mechanical efficiency of the different blends B0, B40, B60 and B80 were found to be lower than that of the B20.The maximum efficiency obtained is 71.25% for B20 at maximum load.

Emission Characteristics

Carbon monoxide Emissions

Variation of CO emissions with engine loading for different fuel is compared in Figure6.5.

The minimum CO produced was found in B80 and it was observed that a reduction of 50%, as compared to diesel. Also it is observed that the CO emissions for biodiesel and its blends are lower than for diesel fuel.

Hydrocarbon Emissions

Above figure6.6 shows the emission characteristics of hydro-carbon v/s load. The reduction in HC was linear with the addition of biodiesel for the blends tested; these reductions indicate a more complete combustion of the fuel. Hydro-carbon emission is more in B0 as compared with the diesel and other blends. Hydro-carbon emission is less in the B20 blend compared with all other blends.

Carbon dioxide Emissions

CO_2 emission increases as the load increases, the maximum CO_2 emission was found in B0. From the above figure6.7 emission of $C0_2$ for different value of blends is near with value of the diesel.

Oxygen Emissions

For methyl ester and its blends, the graph indicated that the O_2 level is comparatively higher in all blends compared to diesel. At all load conditions, B80 shows increasing trend with diesel fuel. Level O_2 of for blends of was slightly in increasing order as blend ratio increased; this may be due to the fact that fuels are oxygenated. The higher O_2 level in fuel blends is always preferred

Nitrogen oxides Emissions

From the above figure6.9 NOx emission for diesel and all the blends increases with increase in loads.
The nitrogen oxides emissions formed in an engine are highly dependent on combustion temperature, along with the concentration of oxygen present in combustion products.
In general, the NOx concentration varies linearly with the load of the engine. As the load increases, the overall fuel- air ratio increases, resulting in an increase in the average gas temperature in the combustion chamber, and hence NOx formation, which is sensitive to temperature increase.

For different injection pressure (IP)

Tests were conducted at three different injection pressures (190, 200 and 210bars) at constant speed of 1500 rpm and at full load condition (3.72 kW) for diesel, B20 blend.

PERFORMANCE CHARACTERISTICS

Brake Specific Fuel Consumption

The above fig 6.10 shows the variation of brake specific fuel consumption with the BP. We observed from the above figure brake specific fuel consumption initially at higher level and with increasing in the load brake specific fuel consumption decreases. In the above three injector pressures 190 bar has higher fuel consumption

Brake Thermal Efficiency

The above figure 6.11 shows the variation of brake thermal efficiency with the BP. We observed from the above figure the brake thermal efficiency gradually increases with the BP. In the above three injector pressures maximum thermal efficiency was obtained at a pressure of 190 bar.

Emission Characteristics

1) Carbon monoxide Emissions

Carbon monoxide emissions from a diesel engine mainly depend upon the physical and chemical properties of the fuel. The bio diesel itself contains 11% of oxygen which helps for complete combustion. From Figure 6.12 it is found that the amount of CO increases at part loads and again greater increase at full load condition for biodiesel. The carbon monoxide emission increases when fuel air-ratio becomes grater. The CO emission for fuels used at full injection pressure is approximately 32% lower than the diesel. The lowest CO emission was observed at 200 bar is 0.32% for biodiesel

Hydrocarbon Emissions

The Hydrocarbon increases with increase in injection pressure for rice bran bio diesel. It is observed from Figure6.13, that the Hydrocarbon emissions for rice bran bio diesel are lower than the diesel fuel, indicating that the heavier hydrocarbon particles that are present in diesel fuel increase Hydrocarbon emissions. The Hydrocarbon emission of rice bran bio diesel the presence of oxygen in the fuel was thought to promote complete combustion that leads to lowering the Hydrocarbon emissions. At 200 bar IP there is minimum Hydrocarbon emissions. An increase in Hydrocarbon which may be due to finer spray, which reduces momentum of the droplets resulting in less complete combustion.

Carbon dioxide Emissions

CO_2 emission increases linearly as the load increases, the maximum CO_2 emission was found at injection pressure of 210bar because of complete combustion of fuel. The CO_2 emissions of all other IP were also higher than the conventional fossil diesel.

NO_X Emissions

Variation of NOx with injection pressure is shown in Figure6.15. The nitrogen oxides results from the oxidation of atmospheric nitrogen at high temperature inside the combustion chamber of an engine rather than resulting from a contaminant present in the fuel. Figures show that the amount of NOx is decreased with increase in injection pressure for bio diesel, this is due to increase in temperature in combustion chamber, as NOx formation is a strong temperature dependent phenomenon. The average NOx emission in case of conditioned bio diesel is 1118 ppm for rice bran bio diesel which is slightly higher than the diesel fuel (1038ppm). NOx emissions were lower at 210 bar injection pressure indicating that effective combustion was taking place during the early part of expansion stroke.

8. Conclusion

Based on the results of this study, the following specific conclusions were drawn:

1. Brake specific fuel consumption for B20 is lower than the diesel fuel and it increases as blend ratio increase.
2. The maximum thermal efficiency for B20 (25.02%) was higher than that of diesel. The brake thermal efficiency obtained for B40, B60, B80 were less than that of diesel.
3. The exhaust temperature increases as a function of the concentration of biodiesel blend i.e. higher the percentage of blend.
4. The fuel properties of rice bran biodiesel except calorific value, all other properties of RBO found to be higher compared to diesel.
5. Viscosity of Biodiesel is higher than that of any other blend & as its concentration increases in the blend, the viscosity of blend increases.

6. From engine performance it is found that the "B20" is optimum blend as it shows higher BTE and lower BSFC & EGT than any other blend.

9. Nomenclature

CV	Calorific value (kj/kg)	NOX	Oxides of nitrogen
CO	Carbon monoxide	BP	Break power (kw)
CO2	Carbon dioxide	FFA	free fatty acid
HC	Hydrocarbon	IP	Indicated power (kw)
O2	Oxygen	BSFC	Break specific fuel consumption (kj/kw-hr)
EGT	Exhaust gas temperature (t 0c)	RBO	Rice bran oil
BTE	Break thermal efficiency (%)	B0	100% diesel
ME	Mechanical efficiency (%)	B20	80% diesel, 20%rbo
BD	Biodiesel	B40	60% diesel, 40%rbo
D	Diesel	B60	40% diesel, 60%rbo
B80	20% diesel, 80%rbo		

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