Performance evaluation of rice bran biodiesel in small size agricultural diesel engines

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Abstract: India is the second largest rice producing country in the world. The estimated yield of crude Rice Bran Oil (RBO) is about 400,000 tons of which only 50% is of edible grade, 50% of the total available rice bran oil is left unutilized due to the presence of active lipase in bran and lack of economic stabilization methods most of the bran is used as animal feed or for industrial application. One of the best ways for the potential utilization of RBO is the production of biodiesel. This study targets at finding the effects of the engine parameters to compare the performance of diesel and rice bran biodiesel blends. Rice Bran (RB) blends were found to be substitute for diesel fuel. Brake Thermal Efficiency (BTHE) was maximum for RB05 blend and minimum for RB20 blend. RB05 blend can be considered as a substitute for diesel with lower Brake Specific Fuel Consumption (BSFC) and Brake Specific Energy Consumption (BSEC), RB15 was found to have minimum smoke opacity.

Keywords: Rice bran oil, Blend, Brake parameters and opacity

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1 Introduction

Energy is an essential requirement for economic and social development for any country but, with advent of industrial revolution and sky rocketing of petroleum fuel costs in present day has led to growing interest in alternative fuels which can be produced from locally available resources within the country such as alcohol, biodiesel, vegetable oils etc in order to provide a suitable substitute to diesel for a compression ignition (CI) engine [(Anonymous, 2007, Gupta et.al 2007)]. Currently the vegetable oils are the promising alternative fuel to diesel oil since they are renewable, biodegradable and clean burning fuel having similar properties as that of diesel. The most commonly used method to make vegetable oil suitable for use in CI engines is to convert it into biodiesel. The estimated yield of crude rice bran oil (RBO) in India is about 4, 00,000 tons of which only 50% is of edible grade, 50% of the total available rice bran oil is left unutilized due to presence of active lipase in bran, which hydrolyses the triglyceride to fatty acids and glycerol, as a result the Free Fatty Acid (FFA) content increases making it difficult to refine, due to the presence of tightly associated wax [(Kusum et.al, 2011)]. Due to lack of economic stabilization, most of the bran is used as animal feed or for industrial application. One of the best ways for the potential utilization of RBO is to extract biodiesel from it; very little research has been done to utilize this oil as a replacement for mineral diesel. Keeping the point in view, this study was conducted on performance evaluation of rice bran biodiesel in small size agricultural diesel engines.

2 Materials and methods

In the study, experiments were designed to optimize the engine operating parameters for biodiesel as fuel in CI engine commonly used for agricultural applications in our country. Initially the crude rice bran oil was tested for free fatty acid content and accordingly esterified or trans-esterified to prepare biodiesel meeting the

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acceptable quality standards and then used as fuel for the test engine. Different properties were evaluated during the study. The results were compared with diesel and different blends of rice bran methyl ester (RB00), (RB05), (RB10), (RB15), (RB20) at different loads viz. (5%, 25%, 50%, 75%, and 100%).

2.1 Rice bran methyl ester

The sourced crude oil was filtered to remove the contaminants of oil. A mesh was used to catch the larger contaminants followed by course filter cloth of 5 micron to obtain clear oil for the experiment. Standard procedure was adopted for transesterification of the oil was in the laboratory. In order to determine the percent of FFA content in the oil, chemical titration method was adopted as per manual of methods of analysis of foods, oils, and fats, Directorate General of Health Services, Ministry of Health and Family, GOI.1 mL of rice bran oil in 10 mL of methanol was titrated with 0.1% NaOH solution (1 gram of NaOH in 1,000 mL of water) using four to five drops of phenolphthalein as the end point indicator until the color changed to light pink. The observations were recorded and compared with standard values.

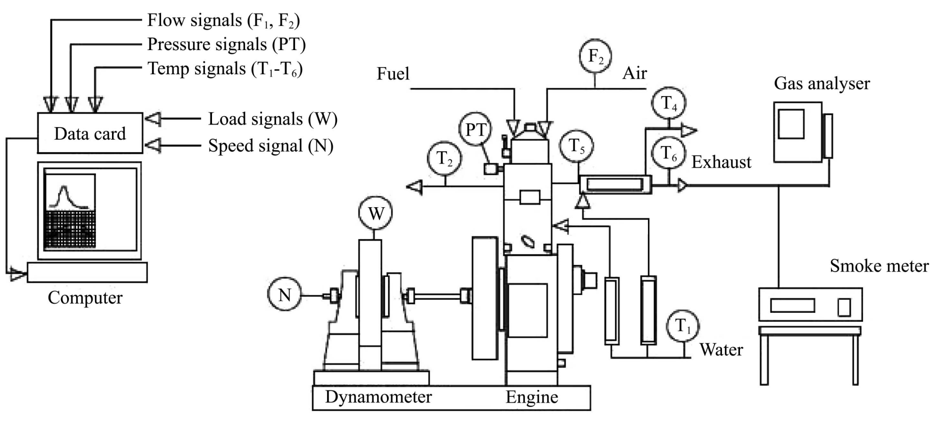
After obtaining the FFA content in the oil from the above process, the sample was trans esterified as per standard rules i.e. if the oil contained more than 2% FFA, the FFA was reduced first by acid catalyst esterification method (using methanol in presence of sulphuric acid) and then alkali catalysed method (using methanol in presence KOH) esterification was done [(Maa, and Hanna, 1999)]. After separation of glycerol, the ester was washed to remove unreacted methoxide. It was then heated to remove the water traces to obtain clear biodiesel. The rice bran methyl ester (biodiesel) thus obtained by this process was totally miscible with mineral diesel in any proportion. The properties of so prepared bio-diesel were tested in the laboratory using standard test procedures as per ASTM and are listed in Table 1 [(Sanford et.al, 2009, Mohanty 2013)].

Table 1 Properties of selected fuel compared with ASTM standards

Serial. No.	Properties	ASTM Methods	Rice Bran Biodiesel	Diesel
1	Calorific Value, MJ/Kg	D4809	43.1	45
2	Relative density g/cm^3 at room temperature	D-1298	0.88	0.831
3	Kinematic viscosity @ 40^0C cSt	D445	4.6	3.21
4	Flash Point (^{o}c)	D93	190	76
5	Copper strip corrosion test @ 50^0c	D130	1A (slight tarnish)	1A

2.2 Experimental set-up

The study was carried out in the laboratory on a fully advanced computerized experimental engine test rig comprising of single cylinder, water cooled, four stroke, VCR (Variable compression ratio) diesel engine connected to an eddy current type dynamometer for precise loading, normally used in agricultural operations (i.e. 3.5 kW at 150 revolution per minute, kirloskar made). The schematic diagram of the setup is shown in (Figure 1); the engine has a provision for varying compression ratio in the range of 12 to 18, without disturbing the main



Where, F_1 and F_2 – are flow sensors for fuel and air; W- load sensor; T_1 – T_6- are temperature sensors; P&T – are cylinder pressure and injection pressure sensor; N – is engine speed.

Figure 1 Experimental set-up

chamber. Peizo sensors were mounted for measurement of pressure inside the cylinder. The crank angle signal was picked up with the help of digital encoder mounted on the shaft extension. The signals from the peizo sensors (pressure) and encoder (crank angle) were interfaced to computer through engine indicator for obtaining PV diagrams dynamically. Water flow rates were measured with the help of rotameters. The engine performance analysis was done by the software package " Engine soft LV" which displays pressure-angle (p-Θ) plots and enables study of BMEP, IMEP, BTHE, ITHE, mechanical efficiency, volumetric efficiency, SFC, air-fuel ratio and heat balance. The specifications of the engine and sensors used for study are given in Table 2.

Table 2 Test engine specifications

Engine specification	Test engine and instrument details
Make	Kirloskar
Model	TV1
Details	Single Cylinder, DI, Four Stroke
Cooling	Water
Bore and stroke	87.5 mm × 110 mm
Cubic capacity	0.661 litres
Compression ratio	17.5:1
Rated power	3.5 kW at 1500 rpm
Load at rated power	12 kg
Injector opening pressure	210 bar
Peak pressure	77.5 kg/cm^2
Injection timing	23° BTDC static (diesel)
Modified compression ratio range	12 to 18
Eddy-current dynamometer	Model AG10 of Saj Test Plant Pvt. Ltd.
Cylinder pressure sensor	Piezo sensor of PCB Piezotronics Inc, Model-M111A22: Resolution-0.1 psi; Sensitivity-1 mV/psi
Fuel pressure sensor	Piezo sensor of PCB Piezotronics Inc, Model-M108A02: Resolution-0.4 psi; Sensitivity-0.5 mV/psi
Load cell	Sensortronics Make, Model 60001
Fuel flow measurement	Differential Pressure Transmitter, Make-Yokogawa; Model-EJA110A-DMS5A-92NN
Air flow transmitter	Make- Wika; Model- SL1

2.3 Smoke intensity

The smoke intensity of the engine was measured by diesel smoke meter of Manatec Electronics Make (model DSM-200) (Figure 2). It is based on the principle of absorption of light, which is an indicative parameter of the level of smoke present in the exhaust sample from a diesel engine. The smoke level was displayed in terms of percent opacity as well as in terms of light absorption coefficient 'K'. The instrument also displayed the temperature of incoming smoke as well as engine revolution per minute.

Figure 2 Smoke meter

2.4 Engine performance test

The engine performance test was carried out as per IS: 10000[P: 5]: 1980. Initiallythe engine was warmed up first at zero load, long enough to establish correct oil and fuel circulation and checked for any oil, fuel and air leakage. Then the engine was tested for diesel at no load, 25, 50, 75 and 100 percent loads with corresponding changes on dynamometer at 0.8, 3, 6,9,12 Kgf. For each load condition the engine was run for three minutes for which data were logged on the screen. For each load, the emission values of smoke opacity CO, NO, NO_x were measured in PPM. Then the engine was run with different blends of RB biodiesel (RB05, RB10, RB15, and RB20). From the above blends the optimized blend was again run with variable compression ratios (17.5, 17.0, and 16.5), the experimental values obtained were used for the performance evaluation parameters i.e. Brake Power (kW), Brake Specific Fuel Consumption (BSFC) (g/kWh), Brake Specific Energy Consumption (BSEC) (MJ/kW), Brake Thermal Efficiency (BTHE) (%) and compared with the values obtained with "Engine soft LV" software. The BSFC was estimated by the software on the basis of fuel flow and brake power developed by the engine using the expression:

$$BFSC=\frac{\text{Volumetric fuel flow in 1 h}\times\text{Fuel Density}}{\text{Brake Power}}$$

similarly, BTHE was also estimated by software using the expression:

$$\text{BTHE}=(\text{Brake Power}\times 3600\times 100)/(\text{Volumetric fuel flow in 1 h}\times\text{Fuel Density}\times\text{Calorific value of fuel})$$

and,

$$BFSC=\frac{\text{Volumetric fuel flow in 1 h}\times\text{Fuel Density}}{\text{Brake Power}}$$

$$\text{BSEC}=\frac{\text{BSFC}\times\text{CV}}{1000}$$, [Jindal, 2009]

3 Results and discussion

This section presents the analysis and interpretation of experimental results obtained during the course of study; relationships between independent variables (Blend ratio and load) and dependent variables (BSFC, BTHE, BSEC and Smoke Opacity) are shown from Figures 4 to 8. Analysis of variance was done for verifying the significance of relationship and the summary is given in Table 3.

Table 3 Summary of analysis of variance

Source of variation	BTHE	BSFC	BSEC	Brake Power
F test between subject effects				
Blend ratio	20.321**	155.130**	724.394**	1.533
Blend ratio x load	9.819**	152.560**	781.453**	1.622

Note: **Significant at 1 per cent level.

3.1 Brake thermal efficiency

The variation of brake thermal efficiency for different blends is presented in the Figure 3 Brake thermal efficiency was found to increase with the increase in loads for all blends. This may be attributed to the reduction in heat losses and increase in power with increase in load. At lower loads, RB05 showed maximum BTHE (4.57%) as compared to other blends and diesel (4.23%). This might be due to additional lubricity provided by the biodiesel and presence of oxygen in biodiesel resulted improved combustion as compared to diesel. It was also found that the thermal efficiency decreased as the amount of biodiesel increased in the blends beyond 10% at higher loads. It can be seen from the figure that brake thermal efficiency of the engine with biodiesel diesel blends is close to BTHE with diesel. These results are in tune with the findings of the other researchers also. Venkanna et.al, (2009), observed similar results for performance, emission and combustion characteristics of direct injection diesel engine running on rice bran oil / diesel fuel blends.

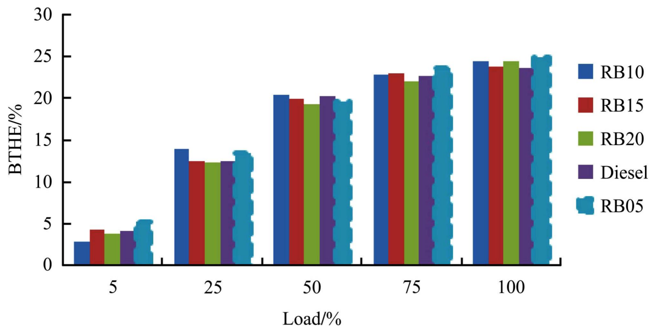


Figure 3 Effect of load on brake thermal efficiency

3.2 Brake specific fuel consumption

Figure 4 shows the BSFC of different RB blends at varying loads. The brake specific fuel consumption decreased with load significantly for all blends. It is clear from the trend line that at lower loads there was significant change in BSFC. RB 10 had shown a higher BSFC with 3 kg/kW-hr whereas RB05 was the lowest with 1.5kg/kW-hr; with higher loads no changes in values were observed. Brake Specific Fuel Consumption (BSFC) was higher for rice bran biodiesel as compared to diesel for higher loads; this may be due to less heating value and higher density of biodiesel. (Kumar, 2007), conducted experiment on high FFA rice bran oil and its application on small engine and found higher BSFC. Higher density leads to more discharge (on weight basis) of fuel thereby increasing fuel consumption rate. Since biodiesel blends have different calorific values, viscosity and density, therefore, BSFC cannot be a reliable tool to compare the fuel consumption per unit power developed. A better approach, brake specific energy consumption (BSEC) was used to compare the RB blends on the basis of energy required to develop unit power output (Wahome,et.al 2013).

3.3 Brake specific energy consumption

Figure 5 represents trend lines for break specific energy consumption at four different loads and blends. The trend line depicts that BSEC of RB10 at lower loads is higher than other blends, while it showed a comparatively lower values at 25% and 50% loads. However with further increase in load a straight line was achieved which illustrates that at higher loads BSEC of diesel and other RB blends are nearly equal. Brake specific energy consumption was found to be higher at lower loads and eventually decreased at full load. RB10 blend showed a higher BSEC as compared to diesel and other blends, which is primarily because of lower calorific value and higher density of fuel. While RB05 showed a comparable results closer to diesel over entire range of varying loads. The brake specific energy consumption was slightly higher in case of RB blends as compared to diesel, which indicated that energy released by biodiesel to develop unit power is more as compared to diesel.

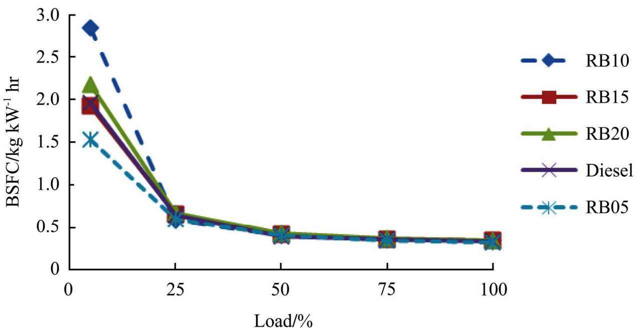


Figure 4 Effect of load on brake specific fuel consumption

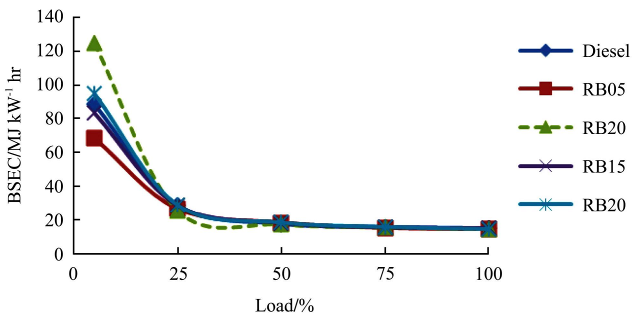


Figure 5 Effect of load on brake specific energy consumption

3.4 Brake power

Relationship between brake power of engine at varying loads for different blends of rice bran methyl ester is shown in Figure 6. Brake power of the engine increased significantly with gradual increase in load for all blends. It is clear from the figure that the power developed by engine at varying loads for diesel is maximum as compared to rice bran methyl ester upper blends viz. (RB10, 15, 20). This is primarily because of less heating value of biodiesel as compared to diesel. It can also be seen that RB 05 blend had a higher brake power as compared to diesel and other RB blends, both at lower and full load. This increase in brake power may be attributed to decrease in friction losses due to increased lubricity of fuel oils [(Velappan, 2007)].

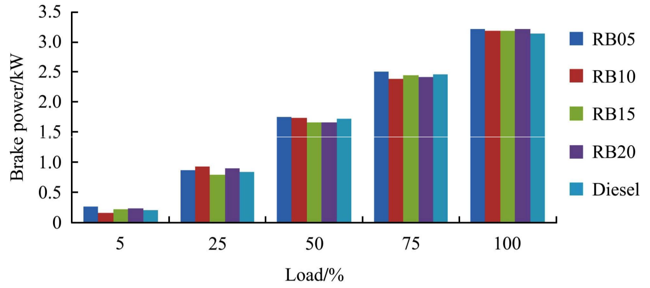


Figure 6 Effect of load on brake power

3.5 Smoke opacity

Smoke opacity with different blends of rice bran methyl ester is shown in Figure 7. The smoke level increased sharply with the increase in load for all blends. It was mainly due to the decreased air – fuel ratio at such higher loads when larger quantities of fuel are injected in to the combustion chamber, much of which goes partially burnt into the exhaust. The smoke opacity of RB blends was found to be higher than diesel. The smoke opacity for RB05 was 38.15% higher than that of diesel fuel at full load of the engine. The smoke opacity was found maximum for RB05 blend and minimum for RB15 blend (Pramanik, 2002, Subbaiah et. al. 2010).

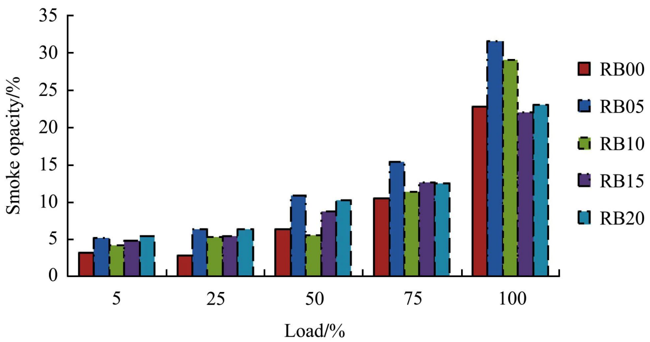


Figure 7 Effect of load on smoke opacity

4 Conclusions

On the basis of less fuel consumption, higher BTHE and brake power, the RB05 was found to be better blend among all blends of rice bran methyl ester; the smoke opacity was minimum for RB15 blend. RB 05 also blend had a higher brake power as compared to diesel and other RB blends, both at lower and full load RB10 blend showed a higher BSEC as compared to diesel and other blends, which is primarily because of lower calorific value and higher density of fuel. The brake thermal efficiency of the engine with biodiesel diesel blends is close to BTHE with diesel. The test of significance showed that the effect of load and blend ratio on optimum blend, found significant at 1 % level. So, we can conclude that rice bran biodiesel and their blends could be used as a substitute for diesel, fuel properties of rice bran methyl ester and diesel were found comparable and within specified limits.

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Nomenclature

RB00 - 100 percent diesel,

RB05 - Blend of 5% RBD and 95% Diesel

RB10 - Blend of 10% RBD and 90% Diesel

RB15 - Blend of 15% RBD and 85% Diesel

RB20 - Blend of 20% RBD and 80% Diesel

RBO - Crude rice bran oil

RB blends - Rice bran biodiesel blends

BSEC - Brake Specific Energy Consumption

BSFC - Brake Specific Fuel Consumption

BTHE - Brake Thermal Efficiency

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