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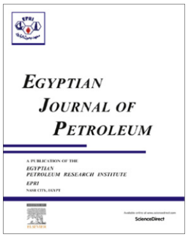

FULL LENGTH ARTICLE

Performance evaluation of diesel engine using rice bran biodiesel

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KEYWORDS

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Transesterification;
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Rice bran oil;
Diesel;
Engine

Abstract The consumption of fuels in the world is increasing rapidly and it affects the global economy of all the countries so this factor forced all the countries to find the alternative fuel to reduce and even replace the usage of petroleum. Thus use of biodiesel from non-edible oil sources serves as an alternative to this problem. The present study focuses on impact assessment of rice bran and crude rice bran biodiesel and its blends with diesel on diesel engine performance. The experimental investigation provides in depth detail of the biodiesel production process, evaluation of fuel properties and impact on engine performance. The study also investigates the optimization of the Compression ratio (CR) of a compression ignition engine fueled with blends of biodiesel. In order to find out the optimum CR of the engine, experiments were conducted at different CRs ranging from 12 to 18. Then the experiments were conducted using B_{10}, B_{20} and B_{40} blends of crude rice bran bio-diesel and diesel at CR of 12 and 14 and these results were compared with the results obtained when the same engine was tested on conventional diesel fuel. Similarly the experimental results of B_{10}, B_{20} and B_{40} blends of rice bran bio-diesel at CR 14 were investigated and analyzed. Based on the experimental investigation the blends of crude rice bran bio-diesel can be used as fuel in diesel engine without making any modification to the diesel engine.

1. Introduction

Bio-diesel is an alternative to petroleum-based fuels derived from vegetable oils, animal fats, and used waste cooking oil including triglycerides. Increasing environmental concern, diminishing petroleum reserves and agriculture based economy of our country are the driving forces to promote bio-diesel as an alternate fuel [1,2]. Biodiesel can be produced from a great variety of feedstock's which includes most common vegetable oils (e.g., soybean, cottonseed, palm, peanut, rapeseed/canola, sunflower, coconut) and animal fats (usually tallow) as well as waste oils (e.g., used frying oils). The choice of feedstock depends largely on availability. Biodiesel has a higher cetane number than diesel fuel, no aromatics, no sulfur, and contains 10–11% oxygen by weight [3,4]. The lower sulfur in the blend helps in the reduction in the sulfur dioxide emissions which generates sulfuric acid in our atmosphere and this results in the formation of acid rain. The absence of toxic and carcinogenic aromatics (benzene and xylene) in bio-diesel

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means the gases produced due to combustion will have reduced impact on human health and the environment. The high cetane rating of bio-diesel (ranges from 49 to 62) is another measure of the additive's ability to improve combustion efficiency. Due to environmental concern about pollution coming from automobile emission, biodiesel is emerging as a developing area of high concern [5–9].Generally the direct use of vegetable oils in the diesel engine is not recommended due to their high viscosity, which affects combustion. So in order to reduce its viscosity so that it can be used in common diesel engines without making any modification in the engine the transesterification method is used to reduce the high viscosity of oil [10–13].

Rice bran oil ranks first among the non-conventional, inexpensive, low-grade vegetable oils. Furthermore, crude rice bran oil is a rich source of high value-added byproduct. Therefore, use of rice bran oil as raw material for the production of biodiesel not only makes the process economical but also generates value added bio-active compounds. Isolation and purification of these byproducts make the process attractive and remunerative. Thus, if the by-products are derived from crude rice bran oil and the resultant oil is used as feedstock for biodiesel, the resulting biodiesel could be quite economical and affordable. In the present study, crude rice bran oil and refined rice bran oil are chosen as potential alternatives for producing biodiesel and use as fuel in four stroke compression ignition engines.

The kinematic viscosity of crude rice bran oil and refined rice bran oil is however several times higher than that of diesel oil [8] and this leads to problems in pumping and atomization in the injection system of a diesel engine so their viscosity must be lowered. The combined effect of high viscosity and low volatility causes poor cold engine start up, misfire and ignition delay. Hence, it is necessary to bring their combustion related properties closer to those of diesel oil [4]. The free fatty acid (FFA) content of crude rice bran oil is high depending on the quality of rice bran from which the oil has been extracted. Because of the high FFA content for crude rice bran oil a 2-stage transesterification process is carried out which includes an acid catalyzed transesterification followed by a base catalyzed transesterification. For refined rice bran oil a single stage base catalyzed transesterification was carried out. The present study focuses on production and performance evaluation of rice bran biodiesel as an alternative source of fuel.

2. Biodiesel production methodology

Due to high FFA (15%) for crude rice bran oil transesterification was carried out in two stages. First stage is called acid catalyzed transesterification in which transesterification reaction was carried out in a water bath shaker and some quantity of crude rice bran oil was taken in a conical flask and it was preheated to the temperature of 60 °C for 30 min. Then a mixture of known quantity of sulfuric acid (H_2SO_4) as acid catalyst and methanol was then mixed with the preheated crude oil. The preheated oil mixture was then subjected to 1 h constant stirring at a constant temperature of 60 °C inside a water bath shaker. After 1 h of constant stirring the mixture was poured into a separating funnel for impurities to settle down. After 4–5 h the settled down impurities are separated from the remaining oil. After this second stage of transesterification (base catalyzed) starts in which remaining oil quantity was measured and again heated up to 60 °C. Potassium hydroxide (KOH) as base catalyst and methanol was then mixed with the remaining preheated oil. The preheated oil mixture was then again subjected to 1 h constant stirring at a constant temperature of 60 °C inside a water bath shaker. After 1 h of constant stirring the mixture was poured into a separating funnel for glycerol to settle down. After 2–3 h settled down glycerol is separated and removed. The remaining portion is methyl ester (biodiesel) of crude rice bran oil (yield 82%) which is further purified through washing and drying for removal of excess KOH, methanol and water. The biodiesel yield of 90% is obtained using same procedure for rice bran oil.

3. Measurement of fuel properties

The properties of crude rice bran oil biodiesel and refined rice bran oil biodiesel were evaluated using the standard test methods given in Table 1. Table 1 shows the apparatus and standards used for evaluating the fuel properties.

4. Impact on engine performance

The specification of the engine used for experimentation is given in Table 2. The set-up enables the study of engine brake power, fuel consumption, air consumption, heat balance, thermal efficiency, volumetric efficiency etc. The performance tests were carried out on the variable CR single cylinder four stroke

Table 1 Different apparatus and standards used for fuel characterization.

Fuel property	Test method/standard	Crude rice bran biodiesel	Rice bran biodiesel
Density, g/cc	Hydrometer, IS: 1448 [P: 32]: 1992	0.897	0.876
Viscosity at 40 °C, mm^2/s	Redwood viscometer, IS: 1448 [P: 25]	3.59	3.24
Flash point, °C	Closed cup flash and fire point apparatus, IS: 1448 [P: 32]: 1992	205	152
Fire point, °C	Closed cup flash and fire point apparatus, IS: 1448 [P: 32]: 1992	210	159
Cloud point, °C	Cloud and pour point apparatus, IS: 1448 [P:10] 1970	−1	3
Pour point, °C	Cloud and pour point apparatus, IS: 1448 [P:10] 1970	−3	−1
Calorific value, kJ	Bomb calorimeter, IS: 1448 [P: 6] 1984	9814	9920
FFA content, %	Titration with 0.1 N NaOH	0.28	0.07
Carbon residue, % by mass	Carbon residue apparatus, ASTM D189-IP 13 of IIP	0.251	1.15
Ash content, % by mass	Electric muffle furnace, ASTM D482-IP 4 of IIP	0.27	0.22

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Table 2 Engine specification.

Make type	Kirloskar
Engine type	Single cylinder 4-stroke, water cooled
CR	Variable ranging from 12 to 18
Rated power	3.75 kW@1500 R.P.M
Stroke	110 mm
Bore	87.5 mm
Loading device	Eddy current dynamometer
Load indicator	Digital, range 0–50 kg, supply 230 V AC
Load sensor	Load cell, type strain gauge, range 0–50 kg
Speed indicator	Digital with non contact type speed sensor
Temperature sensor	Thermocouple
Rotameter	Engine cooling 40–400 LPH; calorimeter 25–250 LPH

diesel engine using various blends of crude rice bran oil biodiesel and refined rice bran oil biodiesel and diesel as fuels. The tests were conducted at various loads. The experimental data generated were documented and presented here using the biodiesel–diesel mixture for the engine test operation. In each experiment, engine performance parameters such as brake specific fuel consumption (BSFC), brake thermal efficiency (BTE) and variation of cylinder pressure with crank angle were measured. Fig. 1 shows variable CR compression ignition engine test Rig.

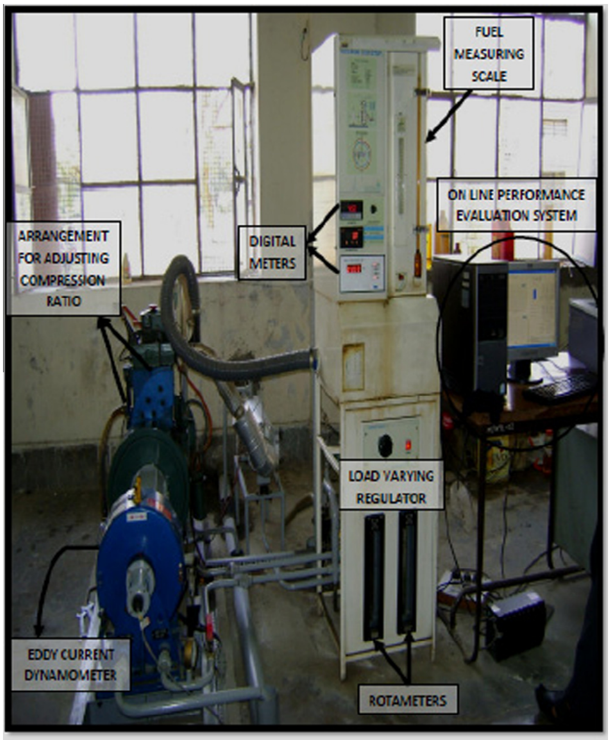

Figure 1 Variable CR compression ignition engine test Rig.

5. Results and discussion

5.1. Optimizing CR

In order to investigate experimentally the performance characteristics of all the blends such as CB_{10}, CB_{20}, CB_{40}, RB_{10}, RB_{20}, RB_{40} an optimum CR has to be figured out. For this experiments were carried out using a CB_{20} blend of rice bran biodiesel at different load conditions. Based on the performance characteristics of the engine the results obtained are as follows. The change in BTE with brake power at various CRs was reported in Fig. 2.

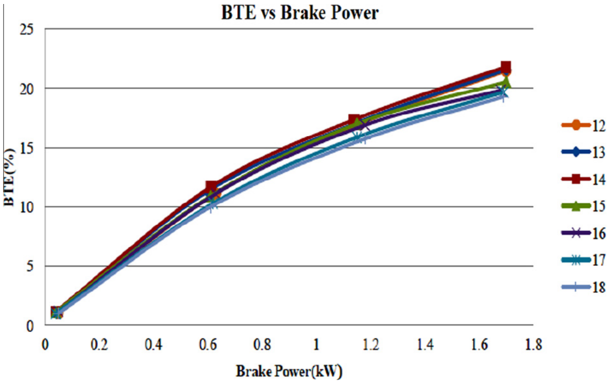

Figure 2 Variation of BTE with brake power at various CRs.

The above figure shows that break thermal efficiency (BTE) increases with the increase in break power for all CRs. Maximum thermal efficiency achieved is about 21.86% at a CR of 14. Minimum thermal efficiency achieved is about 19.34% at a CR of 18. It is observed that up to a CR of 14 the BTE shows an increasing trend, but reverses its trend and starts decreasing with further increase in the CR. Reason can be due to the better intermixing of fuel and air along with better combustion at CR of 14. Fig. 3 shows BSFC as a function of engine load (brake mean effective pressure).

The above figure shows that the BSFC decreases when the brake power was increased. This reduction could be due to higher percentage of increase in brake power with load as compared to increase in fuel consumption. Also as load increases the cylinder wall temperature also increases as shown in Fig. 4, which reduces the ignition delay. Thus shortening of ignition delay improves combustion and reduces fuel consumption. At full load conditions the lowest BSFC obtained is about 380 g/KWh at a CR of 14. Highest obtained is 445 g/KWh at CRs of 16, 17 and 18. This can be contributed to charge dilution. Also BSFC is almost the same at CR of 12 and 13 due to incomplete combustion of the fuel at these CRs. It is observed that with increase in engine load and CR exhaust gas temperature increases as shown in Fig. 4. The highest exhaust gas temperature obtained is about 242 °C at a CR of 18 and lowest of about 212 °C at a CR of 12 under full load conditions as shown in Fig. 4.

The variation of cylinder pressure with crank angle at different CRs under no load and full load conditions is shown in Fig. 5. In both the loading conditions, the maximum pressure is attained at a CR of 12 and minimum at a CR of 18. It is observed that the maximum change in cylinder pressure is at a CR of 14 while moving from no load to full load conditions. It is due to better mixing ability and burning of the fuel with air during the initial stage of combustion at this CR.

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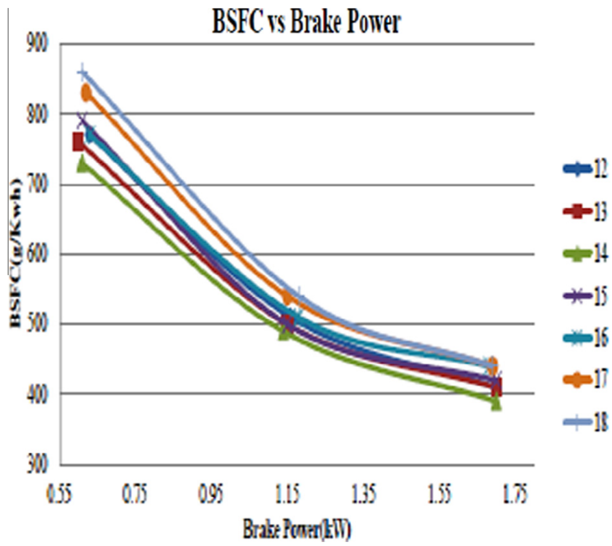

Figure 3 Variation of BSFC with brake power at various CRs.

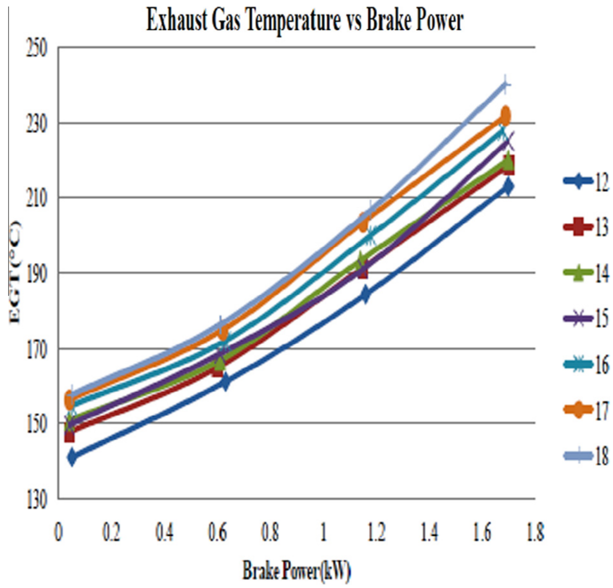

Figure 4 Variation of exhaust gas temperature with brake power at various CRs.

5.2. Blends of crude rice bran bio-diesel vs diesel

Comparative results of engine performance characteristics of the blends such as CB10, CB20 and CB40 of crude rice bran methyl ester with that of diesel at CR of 12 and 14 are discussed.

5.3. Results of performance characteristics of engine at CR 12 and 14

5.3.1. Brake thermal efficiency

The BTE for different blends of fuel and that of conventional diesel at different brake power is reported in Fig. 6(a). The test was conducted for pure diesel fuel which is base line fuel and then for different blends such as CB10, CB20 and CB40 samples. It was observed that BTE increases when the break power was increased for all operations of diesel and bio-diesel blends.

This was due to reduction in heat loss and increase in power with increase in brake power. The BTE of CB10 and CB20 blend was almost similar to conventional diesel fuel. The reason for comparable efficiency up to CB20 may be because of better combustion due to inherent oxygen and higher cetane number. But beyond CB20, the BTE was slightly lower to that of diesel which may be due to lower calorific value and higher viscosity which was more dominant over inherent oxygen and higher cetane number. Because of higher viscosity of blends beyond CB20, the atomization of fuel will not be as good as it will be for lower viscosity at the same level of pressure developed by injector pump. Only CB40 showed value on the lower side. Maximum thermal efficiency achieved is about 21.94% for diesel. Minimum thermal efficiency achieved is about 19.81% for CB40. Results from Fig. 6(b) show that CB10 has the maximum thermal efficiency whereas CB40 has minimum thermal efficiency at full load conditions.

5.3.2. Brake specific fuel consumption

The BSFC for different blends of fuel and that of conventional diesel at different brake power is reported in Fig. 7(a). The test was conducted for pure diesel fuel which is base line fuel and then for different blends such as CB10, CB20 and CB40 samples. It was observed experimentally that the BSFC decreases when the break power was increased for all operations of diesel and bio-diesel blends. This reduction could be due to higher percentage of increase in brake power with load as compared to increase in fuel consumption.

Also as break power increases the cylinder wall temperature also increases, which reduces the ignition delay. Thus shortening of ignition delay improves combustion and reduces fuel consumption. However the rate of decrease in BSFC was more during lower loads than that of higher loads. Also for CB40 blend, the increase in BSFC was more than that of other blends and diesel operations at higher load conditions. This was due to the higher viscosity and lower calorific value of CB40 as compared to other blends and conventional diesel fuel. At full load conditions the lowest BSFC obtained is about 390 g/kWh for diesel and highest obtained is 430 g/kWh for CB40. Also BSFC is the same as that of CB10 and CB20 i.e. 400 g/kWh. Fig. 7(b) shows a variation in BSFC with brake power. At full load conditions the lowest BSFC obtained is about 390 g/kWh for CB10 and highest obtained is 440 g/kWh for CB40. Also BSFC is nearly the same for CB10 and diesel.

5.3.3. Cylinder pressure

The variation of cylinder pressure with crank angle at different CRs under no load and full load conditions is shown in Fig. 8. Maximum cylinder pressure attained was for CB10 at both no load and full load conditions. Lowest cylinder pressure attained was for CB40 at both no load and full load conditions. Longer ignition delay observed was for CB40 whereas CB10 had the shortest ignition.

The variation of cylinder pressure with crank angle at different CRs under no load and full load conditions is shown in Fig. 9. Maximum cylinder pressure attained was for CB10

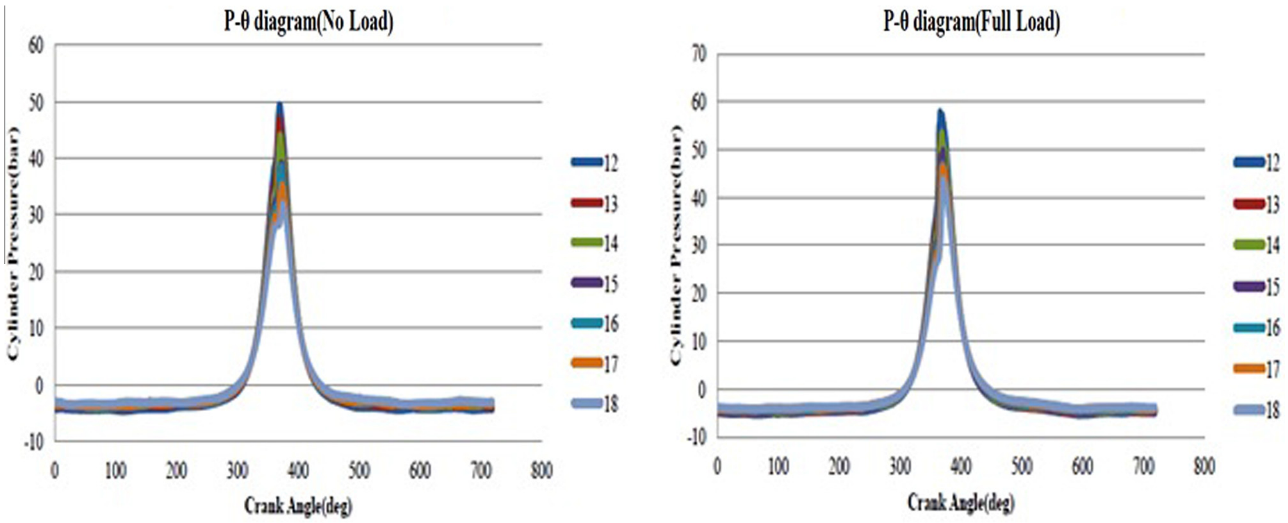

Figure 5 Variation of cylinder pressure with crank angle at different CRs under no load and full load conditions.

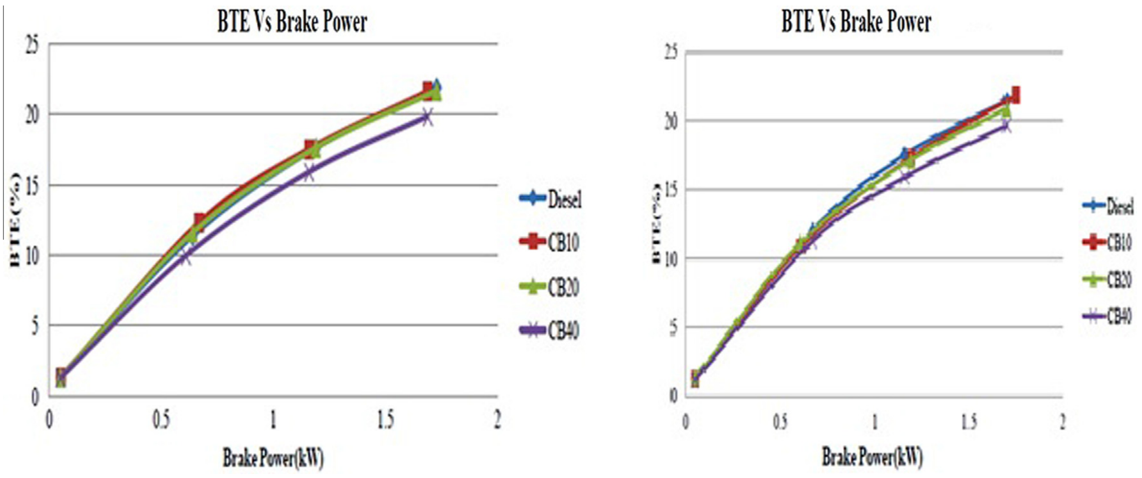

Figure 6 (a) Variation of BTE with respect to break power for CR 12 (b) for CR 14.

at no load condition but with a delay of 2 degree in crank angle as compared to diesel. At full load conditions maximum cylinder pressure attained was for diesel followed by CB10, CB20 and lowest for CB40. Shorter ignition delay was observed at this CR as compared to CR 12.

5.3.4. Variation of hydrocarbon with brake power

Fig. 10(a) shows a variation in hydro carbon (HC) with brake power. Diesel and CB20 showed same hydrocarbon emissions from no load to full load conditions. This is due to their nearly same BSFC. Lowest hydro carbon emission of about 10 ppm was observed for CB10 at part load condition; whereas maximum hydro carbon emission of about 50 ppm was observed for CB40 at full load conditions. Fig. 10(b) shows that higher hydrocarbon emission for CB40 is due to its higher BSFC. Diesel and CB20 showed same hydrocarbon emissions from no load to full load conditions.

5.3.5. Variation of carbon monoxide (CO) with brake power

Fig. 11(a) shows a variation in carbon monoxide (CO) with brake power. At full load conditions lowest carbon monoxide of about 336 ppm was observed for CB10 followed by CB20 (489 ppm), diesel (510 ppm) and highest of about 961 ppm for CB40. This can be due to the longer ignition delay observed for CB40. Longer ignition delay along with increased BSFC decreases the air–fuel ratio inside the cylinder leaving less amount of air for complete combustion which in turn gives rise to higher CO emissions. Fig. 11 (b) shows a variation in carbon monoxide (CO) with brake power. CB10 and CB20 had carbon monoxide emission on the lower side whereas diesel and CB40 had emissions on the higher side.

5.3.6. Variation of carbon dioxide (CO_2) with brake power

Fig. 12(a) shows a variation in carbon dioxide (CO2) with brake power at CR 12. From no load condition to full load

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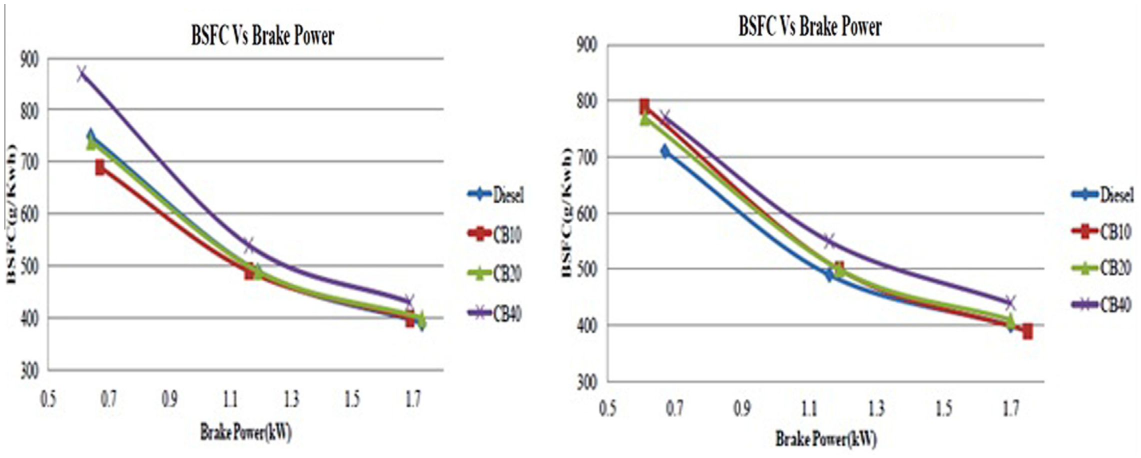

Figure 7 (a) Variation of BSFC with respect to break power for CR 12 (b) for CR 14.

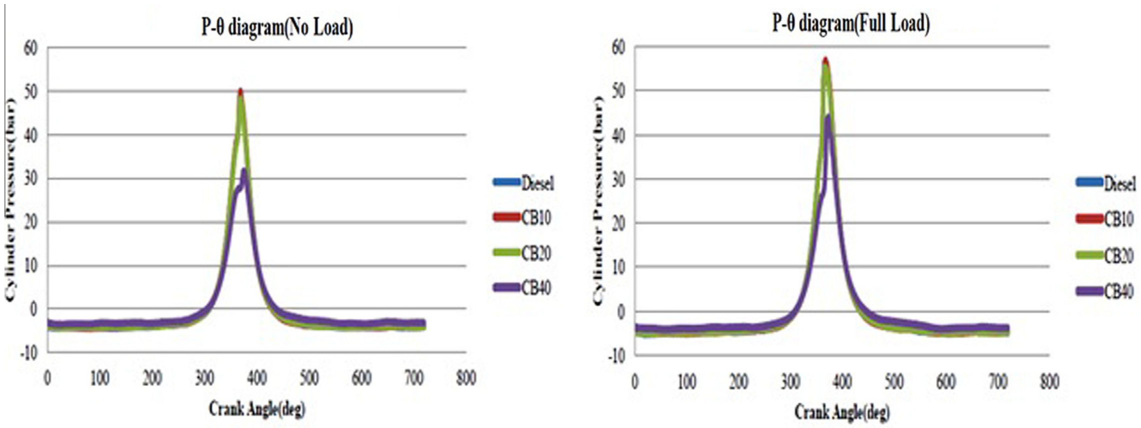

Figure 8 Variation of cylinder pressure with crank angle under no load condition and full load conditions with CR12.

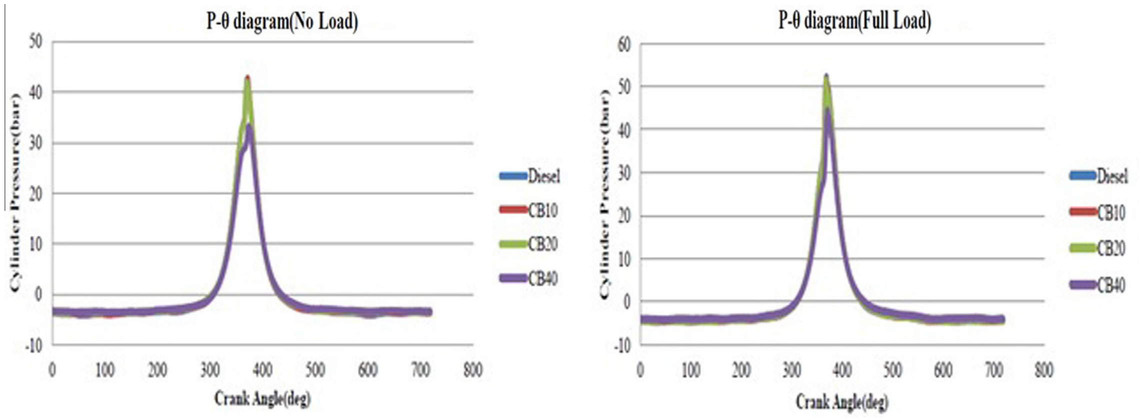

Figure 9 Variation of cylinder pressure with crank angle under no load and full load conditions with CR14.

conditions graphs show that CB10 has lower value of carbon dioxide, whereas CB40 showed a higher value of carbon dioxide emission at all load conditions. At full load conditions lowest value obtained is about 2.5% for CB10 and highest of about 3.7% for both CB20 and CB40. Fig. 12(b) shows a variation in carbon dioxide (CO2) with brake power at CR 14. From no load condition to full load conditions graphs show that CB10 and CB20 have the same type of variation. Only difference is that carbon dioxide emissions for CB10 were on the higher side of the graph whereas CB20 were on the lower side. Carbon dioxide emissions for diesel were found to be higher than both CB20 and CB40.

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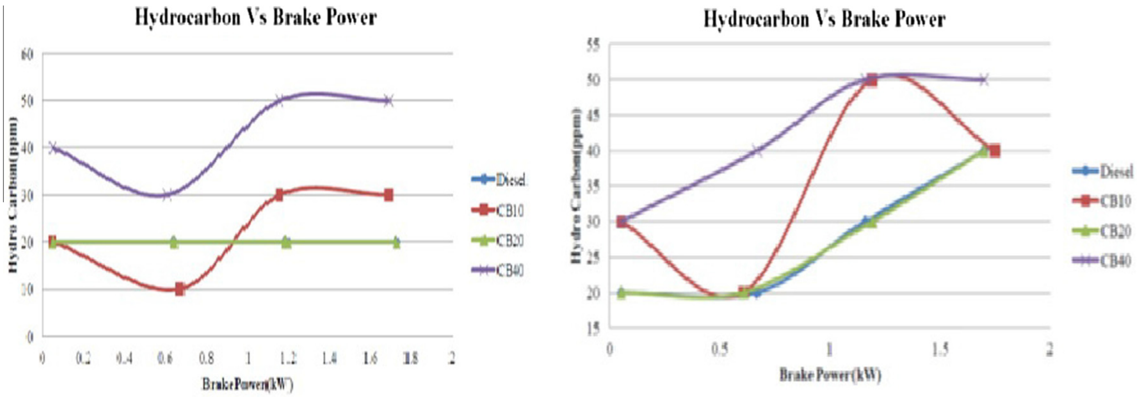

Figure 10 Variation of hydro carbon (HC) with brake power (a) with CR 12 (b) with compression 14.

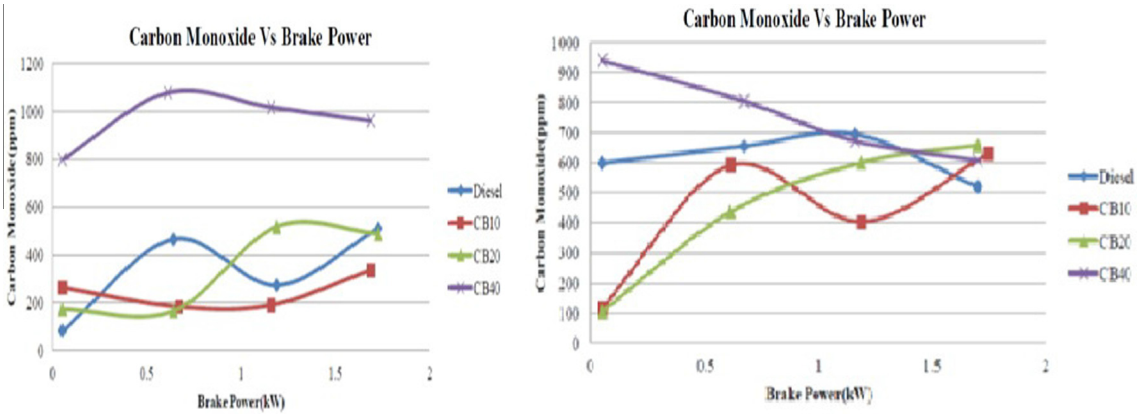

Figure 11 Variation of carbon monoxide (CO) with brake power (a) with CR 12 (b) with CR 14.

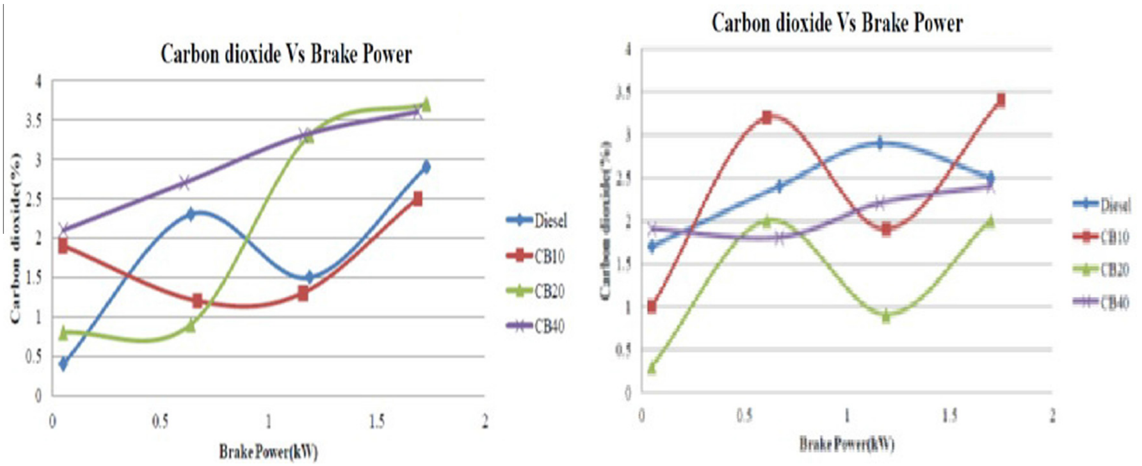

Figure 12 Variation of carbon dioxide (CO_2) with brake power (a) with CR 12 (b) with CR 14.

5.3.7. Variation of nitrogen oxide as NO_X with brake power

Fig. 13(a) shows a variation in nitrogen oxide as NO_X with brake power at CR 12. At full load conditions the highest value obtained is about 353 ppm for CB20 followed by CB40, diesel and lowest of about 245 ppm for CB10. Both CB20 and CB40 showed higher nitrogen oxide emissions than diesel. Fig. 13(b) shows a variation in nitrogen oxide as NO_X with brake power at CR 14. At full load conditions the highest value obtained is about 385 ppm for CB10 followed by CB20, diesel and lowest of about 166 ppm for CB 40.

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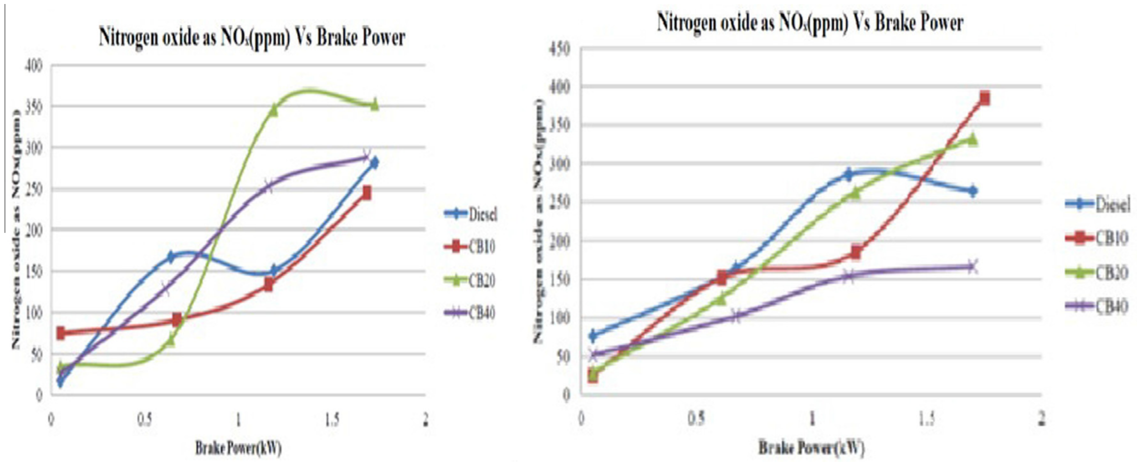

Figure 13 Variation of nitrogen oxide as NO_X with brake power (a) with CR 12 (b) with CR 14.

6. Conclusions

From the experimental investigation it was found that 14 is the most optimum CR; because of the following results obtained experimentally. BTE was found to have maximum value at CR of 14. Fuel consumption and BSFC was found to be lowest at CR of 14. Increase in cylinder pressure along with decrease in the ignition delay was found maximum at CR of 14 with an increase in load. The BTE of CB10 and CB20 blend is almost similar to that of conventional diesel fuel at the CR of 12. At CR 14 maximum BTE was observed for CB10 higher than that at CR 12. A slight decrease in the specific fuel consumption was observed for CB10 at full load conditions for CR 14. Maximum BSFC was observed for CB40 for both the CR. Maximum cylinder pressure attained was for CB10 at CR 12 and for diesel at CR 14. Shorter ignition delay was observed with the increase in CR. CB40 attained minimum cylinder pressure with longer ignition delay at both CR. Performance results observed for CB10 and CB20 blends were closet to that of diesel where as CB40 showed lowest performance results as compared to diesel and other blends. Hydrocarbon emissions were observed for both CB20 and diesel at both CR. CB40 had highest hydrocarbon emission in both cases. CB10 and CB20 showed better carbon monoxide and carbon dioxide emissions than diesel at both CRs. Higher NO_X emissions were observed as compared to diesel. Similar performance results were observed for CB10 and CB20 as that of diesel. Lower emissions as compared to diesel were observed for CB10 and CB20 except the NO_X emissions which were higher in both cases. CB40 showed lowest performance and higher emission results as compared to diesel and other blends. Hence blends of crude rice bran methyl ester can be used as fuel in diesel engine without any modification.

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