Research Paper

STUDY OF ENGINE PERFORMANCE AND EXHAUST EMISSION CHARACTERISTICS OF A 4-STROKE CI ENGINE OPERATED WITH VARIOUS BLENDS OF BIODIESEL AND RICE BRAN OIL

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Biodiesel is receiving increased attention as an alternative, non-toxic, biodegradable, and renewable diesel fuel. It is derived from oils and fats by transesterification with alcohols. The main hurdle to the commercialization of biodiesel is the cost of raw materials. Non edible, inexpensive, low-grade high free fatty acid rice bran oil as raw material, continuous transesterification process and recovery and purification of bioactive compounds from biodiesel by-product are primary options to be considered to lower the cost of biodiesel. An improved engine design can lead to lesser fuel consumption along with better engine performance. This thesis is focused on biodiesel production from crude rice bran oil and rice bran oil, comparative study of engine performance and exhaust emission characteristics between the prepared biodiesel with diesel and optimization of the compression ratio of a compression ignition engine fuelled with blends of biodiesel. Firstly, the methyl esters of rice bran oil were prepared. In the second part experiments were carried out at different compression ratios ranging from 12 to 18 to figure out the optimum compression ratio of a compression ignition engine. A B20 blend of rice bran methyl ester was used as fuel for conducting the experiments. After that comparative analysis based on engine performance and exhaust emission results of B10, B20 and B40 blends of crude rice bran methyl ester with diesel at compression ratio 12 and 14 was investigated. In the last part comparative analysis based on engine performance and exhaust emission results of B10, B20 and B40 blends of crude rice bran methyl ester and rice bran methyl ester at compression ratio 14 was investigated.

Keywords: Diesel engine, Dual fuel, Rice bran oil, Compression ratio, Performance, Emissions

INTRODUCTION

The predicted shortage of fossil fuel has encouraged the search for substitutes for petroleum derivatives. This search has resulted...
in an alternative fuel called "biodiesel". Bio-diesel is an alternative to petroleum-based fuels derived from vegetable oils, animal fats, and used waste cooking oil including triglycerides. Since the petroleum crises in 1970s, the rapidly increasing prices and uncertainties concerning petroleum availability, a growing concern of the environment and the effect of greenhouse gases during the last decades, has revived more and more interests in the use of biodiesel as a substitute of fossil fuels. Bio-diesel production is a very modern and technological area for researchers due to the relevance that it is winning everyday because of the increase in the petroleum prices and the environmental advantages biodiesel offers over diesel. Accordingly, many researchers around the world have dealt with these issues and in many cases devised unique solutions.

Mustafa Balat and Havva Balat (2008) described that the problems with substituting triglycerides for diesel fuels were mostly associated with their high viscosities, low volatilities and polyunsaturated character. The viscosity of vegetable oils, when used as diesel fuel, can be reduced in at least four different ways: (1) dilution with hydrocarbons (blending), (2) emulsification, (3) pyrolysis (thermal cracking), and (4) transesterification (alcoholysis). Gerhard Knothe (2005) in their book described the technical concept of using vegetable oils or animal fats or even used oils as a renewable diesel fuel. Biodiesel is the form in which these oils and fats are being used as neat diesel fuel or in blends with petroleum-based diesel fuels. The concept itself may appear simple, but that appearance is deceiving since the use of biodiesel is fraught with numerous technical issues. Fangrui Maa et al. (1999) described the four primary ways to make biodiesel, direct use and blending, microemulsions, thermal cracking (pyrolysis) and transesterification. Of the several methods available for producing biodiesel, transesterification of natural oils and fats was the method of choice. The purpose of the process is to lower the viscosity of the oil or fat. Although blending of oils and other solvents and microemulsions of vegetable oils lowers the viscosity, engine performance problems, such as carbon deposit and lubricating oil contamination, still exist. Pyrolysis produces more biogasoline than biodiesel fuel. Ulf Schuchardta (1998) reviewed the transesterification of vegetable oils with methanol as well as the main uses of the fatty acid methyl esters. The general aspects of this process and the applicability of different types of catalysts (acids, alkaline metal hydroxides, alkoxides and carbonates, enzymes and non-ionic bases, such as amines, amidines, guanidines and triamino(imino)phosphoranes) were described. Mathiyazhagan (2011) researched on the non-edible oils as feed stocks for biodiesel production to reduce the cost of biodiesel. Normally alkali catalyzed method was followed for biodiesel production process. However the non-edible oils having high FFA content which is not suitable for normal transesterification process. Hence a two-step catalyzed method was used to prepare the biodiesel. High FFA content of non-edible oils were efficiently converted into biodiesel fuel. Gupta (2007) discussed the effect of various parameters on yield and conversion of oil to bio-diesel prepared from rice-bran oil. Percent conversion as well as yield was good at molar ratio of 6:1, reaction time of 4 hour and oil temperature of 60ºC. Yield showed an increasing trend with increase in oil temperature or reaction temperature. Increase in FFA content resulted in decreased
yield but conversion remained unaffected. Novy Srihartati Kasim (Canakci, 2011) carried out the study of reaction between supercritical methanol and rice bran or DDRBO (dewaxed degummed rice bran oil) with CO₂ as the co-solvent. The production of FAMEs (fatty acid methyl esters) by in situ transesterification of rice bran and supercritical methanol was not a promising way. It was found that the yield of biodiesel was low (51.28%) and rice bran cannot be recovered for reuse. Yi-Hsu Ju, Shaik Ramjan Vali (Gupta, 2007) discussed that the main concern with biodiesel fuel is its high price. One of the future aims in biodiesel research is on the selection of inexpensive feedstock with high value-added by-products. Young-Cheol Bak (Gupta, 2007) investigated the transesterification of rice bran oil to produce the bio-diesel oil. Experimental condition included molar ratio of rice bran oil to alcohol (1:3, 1:5, 1:7), concentration of catalyst used (0.5, 1.0 and 1.5 wt%), types of catalysts (sodium methoxide, NaOH and KOH), reaction temperatures (30, 45 and 60°C) and types of alcohols (methanol, ethanol and butanol). Venkata Subbaiah (Orchidea et al., 2007) investigated the performance and emission characteristics of conventional diesel, rice bran oil biodiesel, diesel and biodiesel blend and diesel-biodiesel-ethanol blends on a single cylinder diesel engine. The conclusions of the investigation were, the maximum brake thermal efficiency of 28.2% was observed with the blend B10E15. The BSFC of the biodiesel and all the other fuel blends was higher than that of the diesel fuel. The exhaust gas temperature of the blend B10E15 was slightly lower than that of diesel fuel throughout the range of the load on the engine. The CO emissions of the biodiesel and all the other fuel blends were lower than that of the diesel fuel. The minimum CO emissions were observed with the blend B10E15 well below the diesel fuel and the biodiesel. The HC emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends, but lower than those of the diesel at higher loads on the engine. The NOx emissions of the biodiesel and all the other fuel blends were low at lower loads and high at higher loads compared with the diesel fuel. The CO₂ emissions of the biodiesel and all the other fuel blends were higher than that of the diesel fuel.

**EXPERIMENTAL METHODOLOGY**

Here a brief description of the apparatus and its method of operation is given. Along with it different performance and exhaust emission parameters are also discussed. Figure 1 shows the schematic diagram of the complete experimental setup.

![Figure 1: Pictorial View of the Variable Compression Ratio Compression Ignition Engine](image)

The specifications of the diesel engine are given in Table 1.

A tilting cylinder block arrangement is used for varying the compression ratio without stopping the engine. Setup is provided with necessary...
instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for P-V diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. 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.

Experimental Results: Optimizing Compression Ratio

An optimum compression ratio was to be figured out to carry out the performance and emission characteristics of the all the blends mentioned. Experiments were carried out using a B20 blend of rice bran methyl ester at different load conditions. Based on the performance characteristics of the engine the results obtained are as follows:

Variation in brake thermal efficiency with brake power is shown in Figure 2. Graph shows a similar increasing trend in brake thermal efficiency w.r.t brake power for all compression ratios. Maximum thermal efficiency achieved is about 21.84% at a compression ratio of 14. Minimum thermal efficiency achieved is about 19.31% at a compression ratio of 18. It is noticed that up to a compression ratio of 14 the brake thermal efficiency shows an increasing trend, but reverses its trend and starts decreasing with further increase in the compression ratio. Reason can be due to the better intermixing of fuel and air along with better combustion at compression ratio of 14 maximum thermal efficiency is achieved.

Table 1: xxxxxxxxxxxxxxxxxxx

<table>
<thead>
<tr>
<th>Make</th>
<th>Kirloskar model AV1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling method</td>
<td>Water cooled</td>
</tr>
<tr>
<td>Starting condition</td>
<td>Cold start</td>
</tr>
<tr>
<td>Ignition technique</td>
<td>Compression ignition</td>
</tr>
<tr>
<td>Bore (D)</td>
<td>80 mm</td>
</tr>
<tr>
<td>Stroke (L)</td>
<td>110 mm</td>
</tr>
<tr>
<td>Rated speed</td>
<td>1500 rpm</td>
</tr>
<tr>
<td>Rated power</td>
<td>5 hp (3.72 kW)</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>Variable ranging from 12 to 18</td>
</tr>
</tbody>
</table>

Figure 2 shows brake specific fuel consumption as a function of engine load (brake mean effective pressure). At full load condition the lowest brake specific fuel consumption obtained is about 390 g/Kwh at a compression ratio of 14. Highest obtained is 440 g/Kwh at compression ratios of 16, 17 and 18. This can be contributed to charge dilution. Also brake specific fuel consumption is almost same at compression ratio of 12 and 13 due to incomplete combustion of the fuel at these compression ratios.

A Figure 4 show exhaust gas temperature is depends upon brake power and compression ratio. At maximum compression ratio the exhaust gas temperature is maximum. Exhaust gas temperature is increases with increase in...
respectively. In both the load conditions maximum pressure attained is at a compression ratio of 12 and minimum at a compression ratio of 18. It is noticed that while moving from no load to full load condition the change in the cylinder pressure along with the decrease in the ignition delay period is maximum at a compression ratio of 14.

Variation in brake thermal efficiency with brake power is shown in Figure 7. Graph shows a similar increasing trend in brake thermal efficiency w.r.t brake power for all compression ratios. Maximum thermal efficiency achieved is about 21.84% at a compression ratio of 14. Minimum thermal efficiency achieved is about 19.31% at a compression ratio of 18. It is noticed that up to a compression ratio of 14 the brake thermal efficiency shows an increasing trend, but reverses its trend and starts decreasing with further increase in the compression ratio.
Compression Ratio 12

Engine performance and emission results obtained at compression ratio 12 are as follows:

Variation in brake thermal efficiency with brake power is shown in Figure 8. Results show that CB10 and CB20 have almost similar brake thermal efficiency as that of diesel. Only CB40 showed value on the lower side. Maximum thermal efficiency achieved is about 21.91% for diesel. Minimum thermal efficiency achieved is about 19.84% for CB40.

Figure 9 shows the variation of brake specific fuel consumption with brake power. At full load condition the lowest brake specific fuel consumption obtained is about 390 g/kWh for diesel and highest obtained is 430 g/kWh for CB40. Also brake specific fuel consumption is same for CB10 and CB20, i.e., 400 g/kWh.

Figures 10 and 11 shows variation of cylinder pressure with crank angle under no load and full load condition respectively. Maximum cylinder pressure attained was for CB10 at both no load and full load condition. Lowest cylinder pressure attained was for CB40 at both no load and full load condition. Longer ignition delay observed was for CB40 whereas CB10 had the shortest ignition delay.

Figure 12 shows variation in Hydro Carbon (HC) with brake power. Diesel and CB20 showed same hydrocarbon emissions from no load to full load condition.
load condition. This is due to their nearly same brake specific fuel consumption. 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 condition. Higher hydrocarbon emission for CB40 is due to its higher brake specific fuel consumption.

Figure 13 shows variation in carbon monoxide (CO) with brake power. At full load condition 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 attributed to the longer ignition delay observed for CB40. Longer ignition delay along with increased brake specific fuel consumption 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.

Figure 14 shows variation in carbon dioxide (CO\(_2\)) with brake power. From no load condition to full load condition graphs show that CB10 has lower value of carbon dioxide. Whereas CB40 showed higher value of carbon dioxide emission at all load condition. At full load condition lowest value obtained is about 25% for CB10 and highest of about 37% for both CB20 and CB40.

Figure 15 shows variation in nitrogen oxide as NO with brake power. From no load condition to full load condition graphs show that CB10 has lower value of nitrogen oxide as NO. At full load condition highest value obtained is about 278 ppm for CB20 followed by CB40, diesel and lowest of about 213 ppm for CB10.

Figure 16 shows variation in nitrogen oxide as NO\(_2\) with brake power. From no load condition to full load condition graphs show that diesel has...
lower value of nitrogen oxide as NO\textsubscript{2}. CB10 also had values nearly same as that of diesel. At full load condition lowest value obtained is about 29 ppm for both CB40 and diesel. Lowest value of about 75 ppm was obtained for CB20.

Figure 17 shows variation in nitrogen oxide as NO\textsubscript{x} with brake power. At full load condition highest value obtained is about 353 ppm for CB20 followed by CB40, diesel and lowest of about 245 ppm for CB10.

Figure 17: Variation of Nitrogen Oxide as NO\textsubscript{x} with Brake Power

Both CB20 and CB40 showed higher nitrogen oxide emissions than diesel.

Compression Ratio 14

Engine performance and emission characteristics results obtained at compression ratio 14 are as follows:

Variation in brake thermal efficiency with brake power is shown in Figure 18. Results show that CB10 has the maximum thermal efficiency whereas CB40 has minimum thermal efficiency at full load conditions.

Figure 18: Variation of Brake Thermal Efficiency With Brake Power

Figure 19 shows variation in brake specific fuel consumption with brake power. At full load condition the lowest brake specific fuel consumption obtained is about 390 g/kWh for CB10 and highest obtained is 440 g/kWh for CB40. Also brake specific fuel consumption is nearly same for CB10 and diesel.

Figure 19: Variation of Brake Specific Fuel Consumption With Brake Power

Figures 20 and 21 shows variation of cylinder pressure with crank angle under no load and full load condition.

Figure 20: Variation of Cylinder Pressure With Crank Angle Under no Load Condition

Figure 21: Variation of Cylinder Pressure With Crank Angle Under Full Load Condition
load condition respectively. Maximum cylinder pressure attained was for CB10 at no load condition but with a delay of 2 degree in crank angle as compared to diesel. At full load condition maximum cylinder pressure attained was for diesel followed by CB10, CB20 and lowest for CB40. Shorter ignition delay was observed at this compression ratio as compared to compression ratio 12.

Figure 22 shows variation in HC with brake power. Diesel and CB20 showed same hydrocarbon emissions from no load to full load condition. Maximum hydro carbon emission of about 50 ppm was observed for CB40 at full load condition.

Figure 23 shows variation in 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.

Figure 24 shows variation in CO₂ with brake power. From no load condition to full load condition 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 had on the lower side. Carbon dioxide emissions for diesel were found higher than both CB20 and CB40.

Figure 25 shows variation in nitrogen oxide as NO with brake power. From no load condition to full load condition graphs show that CB40 has lower value of nitrogen oxide as NO. At full load condition highest value obtained is about 310 ppm for CB10 followed by CB20, diesel and lowest of about 148 ppm for CB40.

Figure 26 shows variation in nitrogen oxide as NO₂ with brake power. Higher amount of NO₂ emissions were observed for CB10 and diesel. Whereas lowest value of NO₂ emissions were
CONCLUSION

Present work is done to study the production, engine performance and exhaust emission characteristics of rice bran methyl ester. Based on the results of the present work, following conclusion is drawn:

- Brake thermal efficiency was found to have maximum value at compression ratio of 14.
- Fuel consumption and brake specific fuel consumption was found to be lowest at compression ratio of 14.
- Increase in cylinder pressure along with decrease in the ignition delay was found maximum at compression ratio of 14 with increase in load.
- Nearly same brake specific fuel consumption was observed for CB10 and CB20 as that of diesel at compression ratio 12. Maximum brake specific fuel consumption was observed for CB40 for both the compression ratio.
- Maximum cylinder pressure attained was for CB10 at compression ratio 12 and for diesel at compression ratio 14. CB40 attained minimum cylinder pressure with longer ignition delay at both compression ratios.
- Similar hydrocarbon emissions were observed for both CB20 and diesel at both compression ratios. CB40 had highest hydrocarbon emission in both cases.
- CB10 and CB20 showed better carbon monoxide and carbon dioxide emissions than diesel at both compression ratios.
- Higher NOx emissions were observed as compared to diesel.

Comparison of engine performance and exhaust emission results of blends of rice bran methyl ester with the blends of crude rice bran methyl ester resulted in lower brake thermal efficiency, higher brake specific fuel consumption, higher exhaust emissions (CO, CO₂, HC) except nitrogen oxides emissions which were higher in case crude rice bran methyl ester.

REFERENCES

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