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Effect of Injection Opening Pressure on the Engine Performance with Free Fatty Acid of Rice Bran Oil as Bio Diesel

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Abstract— **The objective of this study was to evaluate the various properties of biodiesel and optimize the biodiesel blend with conventional diesel fuel. Biodiesel fuel is a clean burning fuel made from natural renewable sources such as free fatty acid of rice bran vegetable oil. Biodiesel operates in compression ignition engines similar to diesel fuel. It can be burnt in any standard unmodified diesel engine blended with 0% to 100% biodiesel with diesel. Free fatty acid of rice bran oil can be converted into biodiesel fuel as methyl ester by transestirification. Experimental investigations have been carried out using biodiesel as an alternative fuel in single cylinder, compression ignition engine under varying operating conditions. Various parameters such as brake power, specific fuel consumption, exhaust temperature and emissions during combustion process under varying operating conditions with diesel, biodiesel, blends of biodiesel were studied. Various properties of the biodiesel thus developed were evaluated according to ASTM and compared in relation to that of conventional diesel. These tests for biodiesel and diesel oil include density, viscosity, flash point, aniline point/cetane number and calorific value, etc. The prepared biodiesel from free fatty acid of rice bran oil was used for short-term engine performance test with different blends with diesel. It was found that 20 percent blend of biodiesel gave the best performance amongst all blends. There was a net advantage of 3 percent in peak thermal efficiency, substantial reduction in smoke opacity values and 3 to 4 percent increase in NOx. This blend was chosen for long term test on the CI engine. The engine operating on optimum biodiesel blend showed substantial improved behavior. A series of engine test provide adequate and relevant information that the biodiesel can be used as an alternative, environmental friendly fuel in existing diesel engines without modification in the engine hardware.**

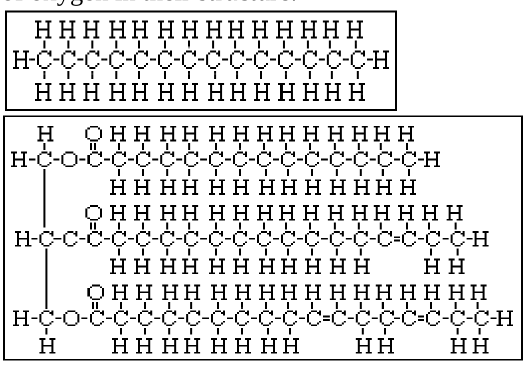
Keywords— Biodiesel, Biodiesel blend, Free fatty acid of rice bran oil, Methyl ester & Emissions

I. Introduction

The world is presently confronted with the twin crisis of fossil fuel depletion and environmental degradation. Indiscriminate and lavish consumption of fossil fuels have led to reduction in underground carbon-based resources. The need to exploit bio-origin-based alternative fuels to quench the world's energy thirst has long been realized. The inventor of diesel engine, Dr Rudolf diesel, in 1885, used peanut oil as a fuel for demonstration at the 1900 world exhibition in Paris. Speaking to the engineering society of St. Louis Missouri, in 1992, Diesel said, "The use of vegetable oil for engine fuels may seem insignificant today but such oil may become in course of time as important as petroleum and the coal tar products of present times." The same petroleum based fuel used in Diesel's day is still the fuel of choice in modern motorized society [1]. It is only in recent years that systematic efforts have been made to utilize vegetable oils as fuels in engines. A review of literature shows that European counties and U.S.A have mainly concentrated on saffola, sunflower, peanut oils, etc., as alternate fuels for diesel engines, which are essentially edible in nature. In Indian context, only non edible vegetable oils can be seriously considered as a fuel for IC engines as the edible oils are in great demand and are far too expensive at present. Kaltschmitt et.al [2], conducted a study which shows that bio-energy carriers offers some clear ecological advantages over fossil fuels such as conserving fossil energy resources or reducing the green house effect, therefore the process of utilizing biodiesel in the IC engines for transport as well as other applications, is gaining momentum. The international energy agency has recognized biodiesel as an alternative fuel for the transportation sector. The European commission proposed a 12 percent market share for biodiesel by the year 2020 [3]. Rapeseed oil methyl ester [RME] is compared with regard to the exhaust gas emissions and effects of these emissions on the environment were analyzed [4]. However, even the combustion of green fuels leads to the emission of gaseous hazardous compounds and particulate matter that may affect human health. Environmental and health effects by the use of biodiesel [5] were observed and recorded considerable reduction of NOx from the exhaust. The total exhaust from the engine run using methyl ester and rape seed oil was studied [6] and the effects on the environment is recorded.

Molecular Structure of The Vegetable Oil

The ideal diesel fuel molecule is a saturated, non-branched hydrocarbon molecule with carbon number of 12 to 18 whereas vegetable oil molecules are triglycerides generally with non branched chains of different lengths and different degrees of saturation. The typical molecular structure of a vegetable oil is shown in Fig. 1 in comparison with diesel oil and methyl alcohol [7]. It may be seen that vegetable oils contain substantial amount of oxygen in their structure.



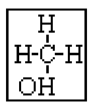


Fig.1 Typical structure of diesel oil ethanol and rice bran oil molecules

Diesel Oil Methanol Vegetable Oil

The characteristics of a wide variety of the available vegetable oils fall within a fairly narrow band and are close to those of diesel oil. Free fatty acid of rice bran oils have about 10 percent less heating value than diesel oil due to the oxygen content in their molecules. The kinematic viscosity is, however, several times higher than that of diesel oil. The high viscosity, 35-45 mm^2/s, as against 5.0 mm^2/s for diesel oil is likely to lead to some problems in pumping and atomization in the injection system of a diesel engine. The high carbon residue indicated by the conradson value and high viscosity is due to the large molecular mass and chemical structure. The high carbon residue is likely to lead to heavy smoke emission from an engine. Rice bran oils have poor volatility characteristics precluding their use in spark ignition engines. By their properties, free fatty acid of rice bran and other vegetable oils are suitable as fuels only for compression ignition engines. The cetane number of free fatty acid of rice bran oil is in the range 40 to 45, which meet cetane requirement for a diesel engine but it can not be used with out transestirification.

Since the free fatty acid of rice bran oil is not suited as fuel for a diesel engine, they have to be modified to bring them closer to diesel oil in their properties. This modification is mainly aimed at reducing the viscosity, which would eliminate flow problems. The methods employed include the heating of the free fatty acid of rice bran oil, thermal cracking or the highly complex free fatty acid of rice bran oil molecule into lighter ones and transestirification with methanol.

II. Material and Methodology

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Transestirification

Transestirification is a chemical reaction that aims at substituting the glycerol of the glycerides with three molecules of monoalcohols such as methanol.

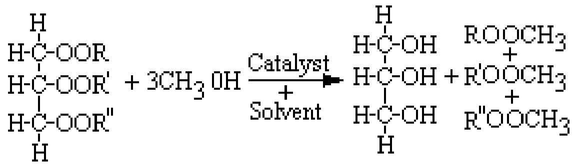

Fig. 2 Process of methyl esterification of rice bran oil.There by obtaining three molecules of methyl ester of the vegetable oil. The chemical reaction is shown in Fig.2. A mixture of anhydrous alcohol and reagent [NaOH] in proper proportions is combined with moisture-free free fatty acid of rice bran oil. The materials are maintained at 40 to 45^{o}C and allowed to settle by gravity for 24 hours.

III. Results and Tables

A series of experiments were conducted on compression ignition engine using biodiesel to find optimum blend of biodiesel by varying the concentration of blends from 0 to 100 percent. The experimental data were presented through appropriate graphs to find the optimum biodiesel blend. A typical engine system widely used in the agriculture sector in India has been selected for the present experimental investigation. A single cylinder, direct injection, water cooled engine system having a bore of 87.5mm diameter and a stroke of 110mm and capacity of 661cc with a compression ratio of 17.5 is used for the experiment. The engine can be started by hand cranking using decompression lever. The engine is provided with a centrifugal governor. The inlet valve opens 4.5 deg before TDC and closes 35.5 deg ABDC. The exhaust valve opens 35.5 degree BBDC and closes 4.5 deg ATDC. The test engine is directly coupled to D.C generator, which absorbs the maximum power produced by the engine. The engine provided with suitable arrangements permitting wide variation of controlling parameters. The unit manufactured by M/s Kirloskar, India is shown in Fig.3. This system monitors engine speed, cylinder pressure, exhaust gas temperature, inlet and out let engine jacket water temperature.

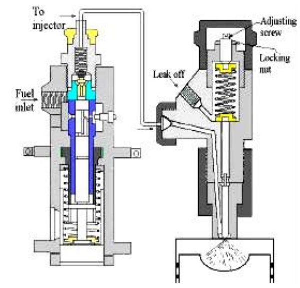

Fig.3 Experimental set up Fig. Bosch fuel pump and fuel Injector

Bosch Fuel Injection System

One of the most important parts of the CI engine is its injection system. Engine performance depends on a proper functioning of injection system that must supply, meter, inject and atomize the fuel. Fig. 4 shows Bosch fuel injection system, which is used to get desirable injection depending on the turbulence in the combustion chamber and engine speed. The rate of injection should be low at the beginning and should increase when the engine piston is approaching the top dead center. In this system the angle of advance remains constant. In order to increase the injection pressure, the spring-loaded screw provided at the top of the atomizer is adjusted.

Engine was successfully developing the rated power under full load for injection pressure of 200-bar under diesel mode operation. The injection pressure was varied from 200 bar to 400 bar in steps of 50 bars for 20 percent blend of bio diesel with diesel and the performance of the engine was analyzed.

Biodiesel Characterization

According to American Society of Testing Methods [ASTM] several tests were conducted [8] to evaluate various physical, chemical and thermal properties such as specific gravity, viscosity [40^{0}C and 100^{0}C], flash point, pour point, cetane number, calorific value of rice bran oil, diesel oil, rice bran methyl ester [biodiesel] and 20% biodiesel blend.

Selection of Optimum Blend

By comparing the thermal efficiencies, brake specific fuel consumption and emissions of various blends the optimum blend concentration was determined. The curves were compared to base-line diesel data in two separate groups in order to optimize blend concentration. In the first group, lower concentrations from 0 to 25 percent were compared with that of diesel oil and in the

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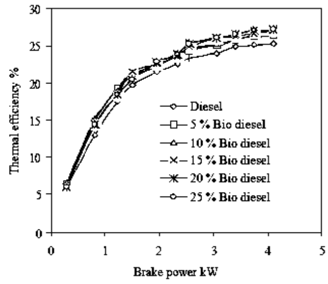
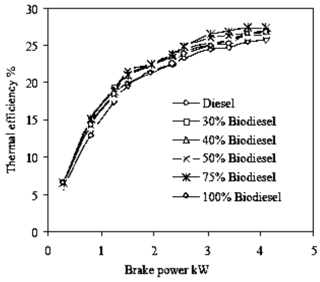
second group, higher concentrations from 30 to 100 percent were compared to that of base-line data. The level of blending for convenience is referred as Bxx. The xx indicates the amount of biodiesel in percentage in the blend [i.e., a B20 blend is 20 percent biodiesel and 80 percent diesel oil].

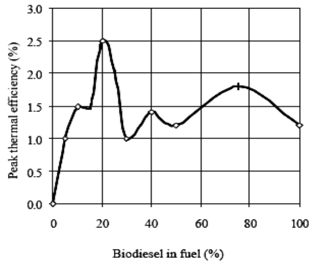


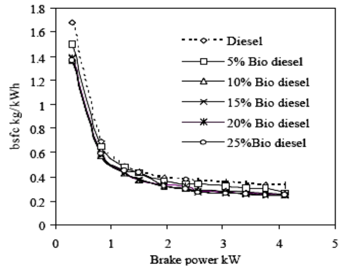


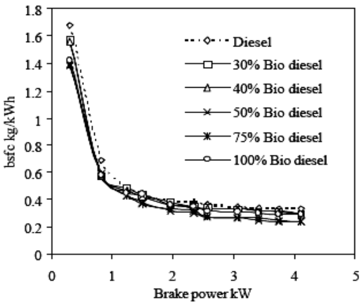
Experiments were conducted initially on diesel alone and the observations were recorded through data logger. The diesel flow rate was found to be 1.25 kg/h when developing 5.2 kW rated power at 1500 rpm. The tests were carried out on the engine, which is already been subjected to preliminary run in. This test is aimed at optimizing the concentration of ester in the biodiesel blends [9]. To achieve this, several blends of varying concentrations were prepared ranging from 0 percent [diesel oil] to 100 percent [biodiesel] through 5 percent, 10 percent, 15 percent, 20 percent, 25 percent, 30 percent, 40 percent, 50 percent, 75 percent and 100 percent. These blends were subjected to performance and emission tests on the engine. The performance data was then analyzed from the graphs recording power output, specific fuel consumption and thermal efficiency etc., for all the blends of biodiesel. An important observation is that the blends have a higher thermal efficiency than the baseline data of diesel fuel for lower concentration of blends [Fig.5]. The thermal efficiencies are very close to one another for higher concentration of blends shown in Fig 6.

The molecules of rice bran oil methyl ester contains some amount of oxygen that takes part in combustion and this may be possible reason for more complete combustion. The oxygen molecule present in biodiesel molecule structure may be readily available for combustion. A graph between the concentration of ester blend and improvement in peak thermal efficiency for various concentrations of biodiesel blend is plotted in Fig. 7. The 20 percent biodiesel was found to be the optimum blend from the graph based on maximum thermal efficiency. The graph reflects that ester blend with concentration of 20 percent gave maximum improvement in peak thermal efficiency. These observations were taken eight times and there was hardly any difference in the values of the performance and emission parameters. However in order to minimize any experimental inaccuracies that might have got in, the average of the eight readings was used for calculating thermal efficiency.

The brake specific fuel consumption is not a very reliable parameter to compare the two fuels The brake specific fuel consumption is not a very reliable parameter to compare the two fuels as the calorific value and the density of the blend follow a slightly different trend. Hence brake specific energy consumption is a more reliable parameter for comparison. However this parameter is also considered in present study to compare volumetric consumption of the two fuels. The trend of the thermal efficiency curves has generally improved by mixing biodiesel in diesel oil. The thermal efficiency of the engine is found to improve by increasing concentration of biodiesel in the blend. The possible reason may be more complete combustion.







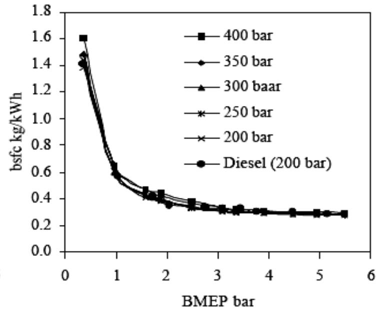
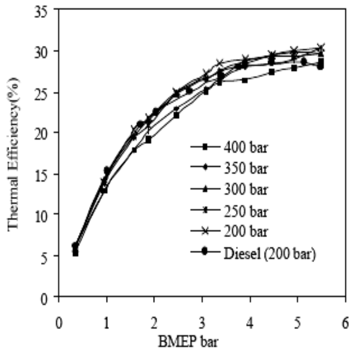
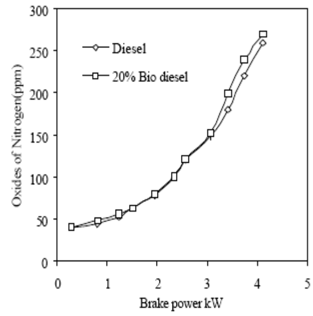
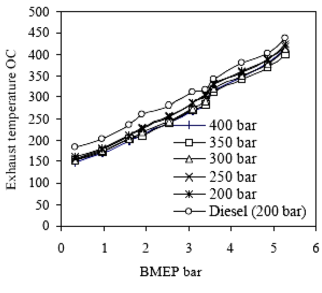


Fig. shows the variation of brake specific fuel consumption at lower concentration of the biodiesel blends. Brake specific fuel consumption of diesel is more when compared with biodiesel blend of 20 percent.







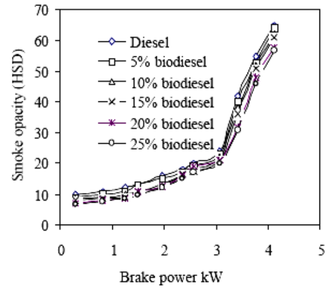
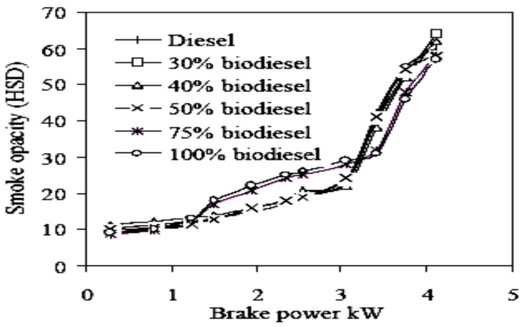


Figure. shows the brake specific fuel consumption versus brake mean effective pressure. For different load conditions the specific fuel consumption is less for diesel and blends of 20 percent bio diesel at 200 bar pressure. It may be observed that specific fuel consumption is more for injection pressures 400, 350, 300 bar. There is no considerable change in the specific fuel consumption at 250 bar pressure.

The molecules of bio diesel i.e., rice bran methyl ester contains some amount of oxygen that takes part in combustion and this may be a possible reason for more complete combustion. The oxygen molecule present in bio diesel molecular structure may be readily available for combustion. However, it was noticed that after a certain limit of bio diesel concentration the thermal efficiency start decreasing. This behavior of bio diesel fuel needs advanced investigation.

It is noticed form the figure.11, that the thermal efficiency diesel at 200 bar is taken as baseline data for comparison with bio diesel with 20 percent blend at 200 bar, 250 bar, 300 bar, and 400 bar respectively. It is observed that there is decrease in thermal efficiency when the injection pressure was increased beyond 250 bar, even though the brake specific fuel consumption is more at 350 bar and 400 bar pressure. This needs further investigation on atomization of 20 percent bio diesel blends under different pressure.

From the NOx curves given in figure.12, two important observations were made. First NOx, emissions are a direct function of engine loading. This is expected because with increasing load, the temperature of the combustion chamber increases and NOx formation is a strongly temperature dependent phenomenon. Second important observation is that the NOx emissions in the case of bio diesel fuel are higher by approximately 2 to 3 percent. These higher NOx emissions may be due to higher temperature of the combustion chamber using bio diesel. A lower emission of NOx for higher injection pressure is due to decrease in the engine exhaust temperature and incomplete combustion as shown in Fig. Smoke opacity for lower concentration of biodiesel blend is shown in the Fig.14 Smoke opacity for base line diesel is higher than the different bio diesel blends. It is also observed that for higher concentration the smoke opacity is more under part load condition for 75 and 100 percent blends of bio diesel



IV. Conclusion

- The diesel engine performed satisfactorily on biodiesel fuel without any engine hardware modifications.
- The 20 percent biodiesel blend was found to be the optimum concentration for biodiesel blend, which improved the thermal efficiency of the engine by 2.5 percent and reduces the brake specific energy consumption.
- NOx emissions in the case of biodiesel fuel are higher by approximately 4 percent. These higher NOx emissions may be due to higher temperature of the combustion chamber.
- Based on the experimental investigation it can be concluded that bio diesel can be adopted as an alternative fuel for the existing conventional diesel engine without any major modification required in the system hardware.
- Lower exhaust temperatures were observed for higher injection pressure with a decrease in thermal efficiency.
- Brake specific fuel consumption is more for injection pressures of 400, 350, 300 bar.
- Improvement in peak thermal efficiency for different injection pressures. The 20 percent blend of fuel gave higher thermal efficiency for 200 bar and 250 bar injection pressure when compared with injection pressures of 300, 350 and 400 bar.
- NOx emissions are lower for injection pressure of 400 and 350 bar when compared to the injection pressures of 250 and 200 bar.

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