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Performance and Emission analysis of Compression Ignition engine in Dual fuel mode using Rice bran biodiesel and LPG

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Abstract: - In the modern world, pollution levels are increasing to a great extent mainly due to vehicular emissions which drives the industries towards finding alternative fuel sources like Hydrogen, CNG, LPG, Vegetable oil and many more. In the present study, Rice bran biodiesel was used along with liquefied petroleum gas in the dual fuel mode in a single cylinder, air cooled compression ignition engine and its performance and emission characteristics were studied. Rice bran ethyl ester was derived using ethanol and sodium hydroxide through Transesterification process. 7.5 mg/cycle of rice bran ethyl ester was injected with liquefied petroleum gas as pilot fuel. The experimental investigation revealed that the brake thermal efficiency was found to be comparatively better than straight diesel. The brake specific energy consumption was noticed to be lower for dual fuel mode than straight diesel mainly at part load operations. The CO and UBHC emissions was found to be reducing with an increase in NO_x at high loading condition due to better combustion.

Keywords: - *Transesterification, Rice bran biodiesel, Compression ignition engine, Performance and Emission.*

I. INTRODUCTION

The need for alternative fuels has been increasing in today's world due to greater depletion of natural petroleum reserves and increasing exhaust emissions from internal combustion engines leading to environmental pollution. Compression ignition engine generally uses diesel as the fuel for combustion which expels more power and better efficiency. But it ultimately leads to environmental hazards like HC, CO and NO_x emission. As an opportunity to reduce the level of pollution, various alternate fuels like producer gas, biogas, alcohols, vegetable oils, microbial oil and many more find its application as a whole or mixed under various proportions along with diesel are used. The properties of diesel fuel closely resembles with esterified vegetable oil which is very suitable for its replacement. Researchers are continuously investigation the use of various vegetable oil like neem, soyabean, jatropha, ricebran, mahua and others in blended and dual fuel mode to obtain a very similar or better performance to petroleum diesel [3,8]. Now-a-days dual fuel technique is most widely adopted with blended fuel and gaseous fuel. In the present study, rice bran biodiesel and LPG are used in compression ignition engine in dual fuel mode to reduce emission and increase the performance characteristics. LPG suits as a better gaseous fuel due to lower carbon content, clean combustion and ease of availability. It also reduces the cylinder wear and improves engine life to a great extent.

Kapilan*et al*. [7] has made extensive study on the combustion and emission parameters of mahua oil and liquefied petroleum gas in dual fuel mode and observed that exhaust emission like smoke, UBHC and CO were lower in conventional fuel. The higher injection pressure and proper pilot fuel quantity also resulted in better atomization, penetration of methyl ester and better combustion of fuel. Sethi *et al*.[10] analyzed the emission and performance characteristics of dual fuel engine which was close to diesel operation but the exhaust emission of CO, HC and NO_x was reduced to a great extent.Poonia *et al*.[9] experimentally investigated the engine performance and exhaust emission in a LPG-Diesel dual fuel engine in which diesel fuel was used as pilot fuel and LPG as main fuel inducted in the intake manifold. The study revealed that poor exhaust emission at lighter loads can be improved by employing longer pilot fuel quantity, using exhaust gas recirculation, increasing intake temperature and injection timing.

In the present study, rice bran oil was used to derive rice bran biodiesel along with ethanol as an esterifying agent. The rice bran biodiesel was analyzed for various compounds using gas chromatography mass spectrometry analysis. The experimental investigation was divided into three phases in which the effect of diesel fuel, biodiesel blended with diesel and biodiesel blended with liquefied petroleum gas were analyzed in detail from low load to full load and the corresponding performance and emission characteristics were studied. In the dual fuel mode, 7.5 mg/cycle rice bran biodiesel was used as combustion initiator and rest with liquefied petroleum gas was used as fuel in various modes of operation.

II. MATERIALS AND METHODS

Rice bran oil was extracted from the germ and inner husk of rice and it contains mono-unsaturated, poly-unsaturated and saturated fat of 47%, 33% and 20% respectively. The various fatty acid composition of raw rice bran oil was found as palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid, arachidic acid and behenic acid at 15%, 1.9%, 42.5%, 39%, 1.1%, 0.5% and 0.2% respectively. The Transesterification process was used to derive biodiesel from rice bran oil using and alcohol and a base. The alcohol replaces the triglycerides into glycerol and three fatty acid esters of rice bran oil in the presence of a catalyst [4]. Due to high free fatty acid content, rice bran oil was converted into ethyl esters using ethanol in a two stage process. In the first stage, neutralization of free fatty acids from 12% to 2% was carried out by adding 2% of dilute hydrochloric acid to 1000 ml of rice bran oil at 60^{o}C for 2 hrs. In the second stage 490 ml of ethanol was mixed with 2.5 gms of sodium hydroxide to form sodium ethoxide. The solution was mixed to 1000 of neutralized rice bran oil for esterification. The entire mixture was transferred to a round bottomed flask and maintained at 75^{o}C for 1.5 hrs. The mixture was allowed to react in a rotating agitator at 150 rpm for 3 hrs and then it was kept for 24 hrs as settling period. The formation of glycerol takes place resulting in the production of rice bran ethyl ester. The glycerol was then carefully removed using a separating funnel and RBEE was washed with 5% distilled water. By this process, 84% of RBEE was obtained [5,11].

The GC/MS spectrum and fatty acid esters of rice bran ethyl ester are shown in figure (1) and table (1). The various properties like flash point, fire point, calorific value, kinematic viscosity, density and cetane number were studied for diesel, RBEE and LPG as shown in table (2). The composition of liquefied petroleum gas was found to be butane, propane & propylene, ethane & ethylene and pentane as 70.4%, 28.6%, 0.5% and 0.5% respectively. The maximum flame temperature in air was found to be 2000^{o}C and the self-ignition temperature for LPG was noted as 525^{o}C [6]. In the dual fuel mode, RBEE blend was used as pilot fuel injection and LPG as the primary fuel and the pilot fuel quantity of 7.5 mg/cycle was considered to study the effect of pilot fuel quantity.

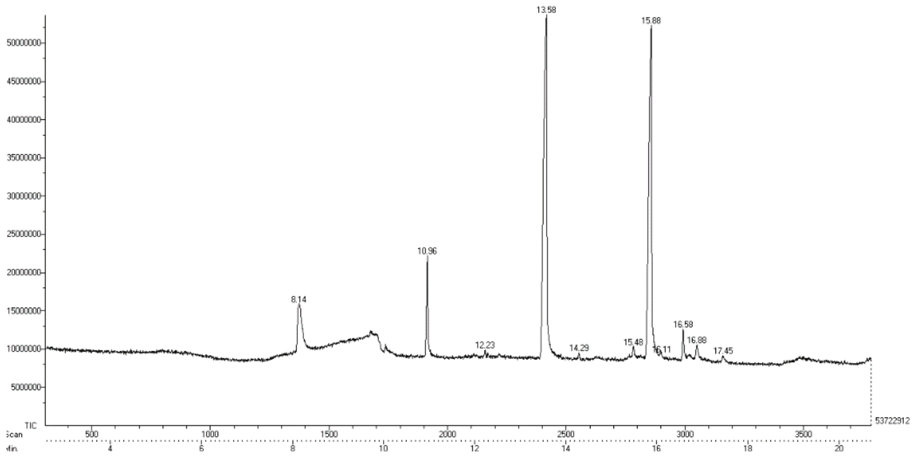

Figure 1. Gas Chromatography Mass Spectrometry spectrum of Rice bran ethyl ester

Table 1. Fatty acid ethyl esters of Rice bran ethyl ester

Retention time	Name of ester	Name of fatty acid	No of Ions	Scan
8.15	Octanoic acid ethyl ester	Caprylic acid	2418	1375
10.96	Decanoicacid ethyl ester	Capric acid	2247	1915
13.59	Dodecanoic acid ethyl ester	Lauric acid	2507	2419
15.89	Tetradecanoic acid ethyl ester	Myristic acid	2533	2861

Table 2. Properties of RBEE and Straight diesel

Property	Units	RBEE	St. Diesel
Flash point	^oC	125	56-58
Fire point	^oC	114	62-64
Calorific value	MJ/Kg	33.14	42.6
Kinematic viscosity	at 40^{o}C (CST)	6.21	2.62
Density	at 40^{o}C (kg/m^2)	884	832
Cetane number	-	44	45-60

III. EXPERIMENTATION

A single cylinder, four stroke, air cooled, constant speed direct injection compression ignition engine was used in the experimental study with the following specification as given in table (3). The engine speed was noted using inductive pickup sensor calibrated with digital speed indicator. The mass flow rate of blended fuel was calculated using volumetric basis using a burette and a stop watch. The exhaust gas temperature was measured using a thermocouple attached with digital temperature indicator was employed. The engine was slightly modified in the dual fuel mode by connecting LPG lines to the intake manifold with flame trap and mixing unit as shown in figure (2).

Table 3. Test engine specification

Engine type	Single cylinder, four stroke, constant speed, vertical mounted, air cooled, direct injection, compression ignition engine
Make & model	Kirloskar DM 10
Bore & Stroke	102 x 118 mm
Capacity	984 cc
Maximum power	10 HP
Compression ratio	17.5 : 1
Injection timing	27^o bTDC
Injection pressure	110 bar
Rated speed	1500 rpm

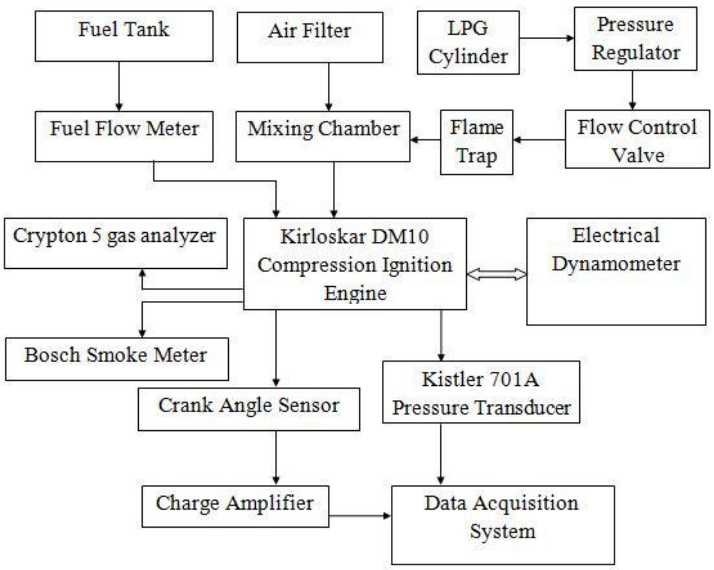

Figure 2. Experimental setup

Kistler 701A quartz pressure transducer was fitted on to the cylinder head and a crank angle encoder was fixed on the engine shaft for cylinder pressure and crank angle measurement. The signals were routed to the personal computer through high speed data acquisition system for further studies. The pilot flow rate of RBEE was varied using fuel injection pump and the LPG flow rate was adjusted using flow control valve as shown in figure (2). All the investigationswere carried out at 1500 rpm at full loading condition. Initially pilot injection of RBEE was inducted during cranking of engine and gradually LPG was allowed to enter through the mixing chamber and intake manifold. The pilot injection was increased upto 5.5 mg/cycle and maintained at a constant engine speed of 1500 rpm by increasing the flow rate of LPG. Finally, the pilot injection was increased upto 7.5 mg/cycle at constant engine speed of 1500 rpm. During this period, important observations like LPG flow rate, air flow rate, cylinder pressure, exhaust gas temperature and emission were recorded. The same procedure was repeated by varying the engine load.

IV. RESULTS AND DISCUSSIONS

Performance Analysis

The performance parameters like brake thermal efficiency, brake specific fuel consumption, brake specific energy consumption and mechanical efficiency were analyzed and discussed below.

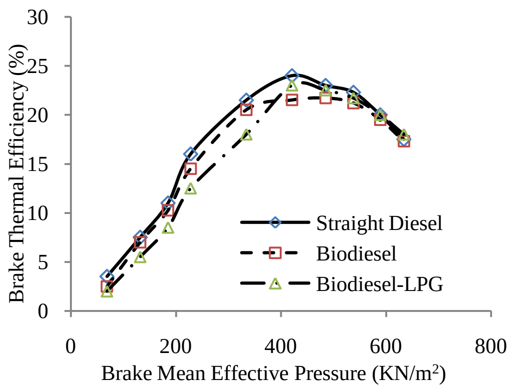

Figure 3. Variation of Brake thermal efficiency with Brake mean effective pressure

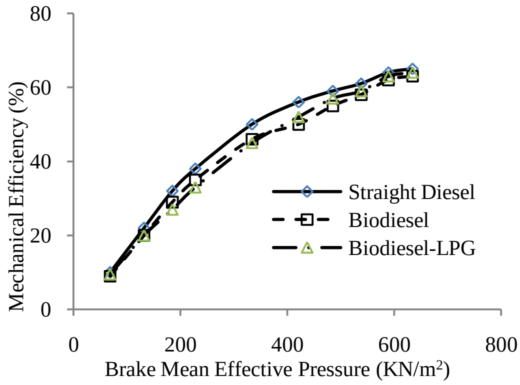

Figure 4. Variation of Mechanical efficiency with Brake mean effective pressure

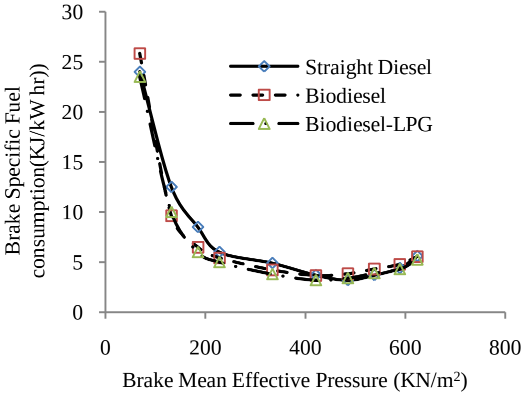

Figure 5. Variation of Brake specific fuel consumption with brake mean effective pressure

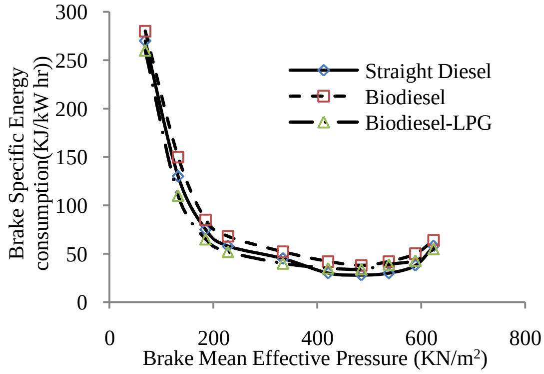

Figure 6. Variation of Brake specific Energy consumption with brake mean effective pressure

The comparison of brake thermal efficiency and brake mean effective pressure for diesel, blended biodiesel and blended LPG are shown in the figure (3). It can be observed that at low loading conditions, all the three variants of fuel show minimal efficiency at about 3 to 5%. The brake thermal efficiency of biodiesel, biodiesel-LPG at low loading conditions was 9.6% and 10.9% respectively which may be due to lower cylinder temperature. At part load condition, the efficiency of blended biodiesel-LPG and biodiesel was found to be 23% and 21.7% respectively which was due to complete combustion of LPG at high temperature and pressure [4]. When the load is increased to full load, the efficiency of diesel, biodiesel blend and LPG gradually decrease as shown in figure (3). It can be also seen that for all loading conditions, the brake thermal efficiency of biodiesel blends was lower than straight diesel due to lower calorific value.

The figure (4) shows the variation in mechanical efficiency between diesel, biodiesel blend and biodiesel-LPG in dual fuel mode. The mechanical efficiency remains almost similar to each other during starting and low loading conditions which may be due to low in-cylinder temperature and effect of residual gases.At part load condition, mechanical efficiency of straight diesel and biodiesel-LPG in dual fuel mode was found to be 52% and 46% respectively. During full load, the mechanical efficiency reaches a maximum of 55% for dual fuel mode which may be due to reduced combustion efficiency caused by increased compression work due to extensive air-gas induction.Figure (5) and Figure (6) show the variation between brake specific fuel consumption and brake specific energy consumption with straight diesel, biodiesel blends and biodiesel-LPG in dual fuel mode. From the figure (5), it can be seen that BSFC for all fuel variants remain high initially at low loading conditions. At part load, biodiesel-LPG in dual fuel mode exhibits lower BSFC which may be due to higher calorific value and continue to be lower at higher loading conditions due to complete combustion process.Figure (6) shows variation in BSEC for all blends and dual fuel mode which resemble a similar trend to BSFC. The BSEC for biodiesel-LPG in dual fuel mode was found to be higher for all loading conditions which may be due to better atomization, spray characteristics and initiation of complete combustion [1,2].

Exhaust Emission analysis

The variation of unburned hydrocarbon emissions for straight diesel, biodiesel blend and biodiesel-LPG in dual fuel mode is shown in figure (7). Hydrocarbon emission was found to be higher for Biodiesel-LPG in dual fuel mode for the entire range of loading and operating conditions which may be due to insufficient ignition sources which resulted in incomplete combustion especially at low loads. At part load and high loading conditions, the HC emission for dual fuel mode was found to be 1.34 g/KWh and 0.79 g/KWh respectively. Diesel and biodiesel blends exhibit low HC emission than dual fuel mode at high loading conditions which was less than 0.7 g/KWh.

Carbon Monoxide emissions are formed due to incomplete combustion, insufficient air and improper ignition delay. Figure (9) shows the variation of carbon monoxide between straight diesel, biodiesel blends and biodiesel-LPG in dual fuel mode for various loading conditions. CO emission was found to reduce gradually with increase in load throughout all blends and dual fuel mode at shown. Higher CO emission was found to be as 69.2 g/KWh for biodiesel-LPG in dual fuel mode at low loading conditions which may be due to incomplete combustion and presence of residual gases. At part loading conditions, CO emission for straight diesel, biodiesel blend and biodiesel-LPG in dual fuel mode was found to be 35.5 g/KWh, 24.6 g/KWh, 18.92 g/KWh respectively. The variation of carbon monoxide was very minimal at full load condition with 3-5% variation as shown in figure (9).

The variation of oxides of nitrogen with BMEP for straight diesel, biodiesel and biodiesel-LPG in dual fuel mode is shown in figure (8). The NO_x emission constitutes of nitric oxide, nitrous oxide and nitrogen dioxide in various proportions which are formed mainly due to peak in-cylinder temperature during combustion. At low loading conditions, NO_x emission was found to be high for straight diesel and biodiesel due to better mixing and combustion but for dual fuel mode, it was found to be 4.3 g/KWh due to reduced in-cylinder temperature. The part load operations showed increased NO_x emissions up to 5% to 8% for dual fuel mode as shown. At full load conditions, straight diesel, biodiesel and biodiesel-LPG showed 6.2 g/KWh, 5.6 g/KWh and 5.9 g/KWh of NO_x emission [12].

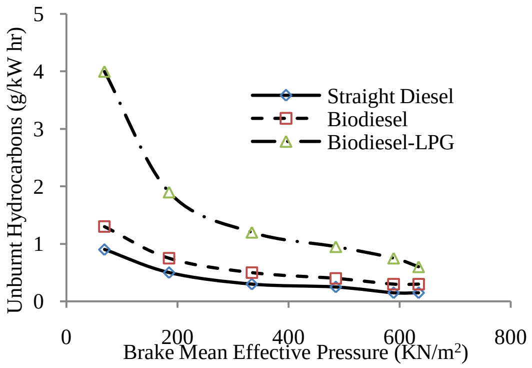

Figure 7. Variation of Unburnt hydrocarbon with brake mean effective pressure

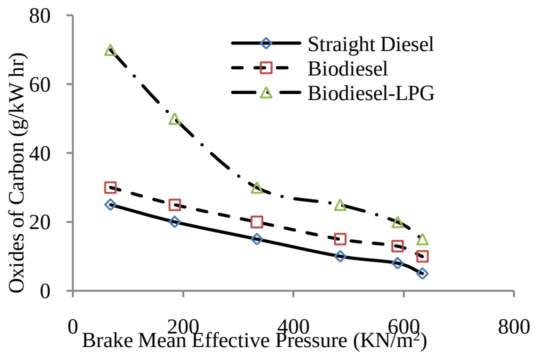

Figure 9. Variation of Oxides of carbon with brake mean effective pressure

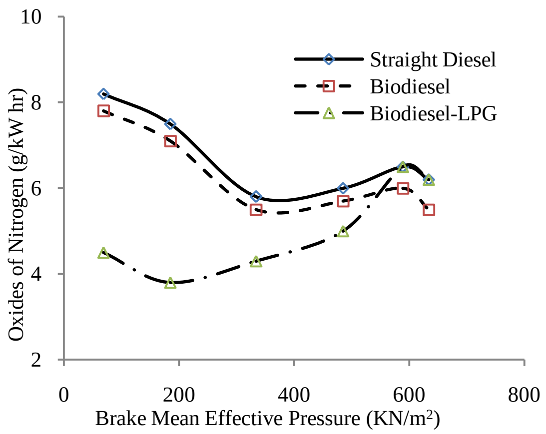

Figure 8. Variation of Oxides of Nitrogen with brake mean effective pressure

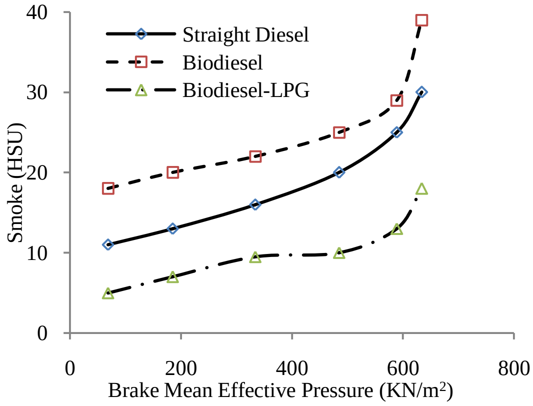

Figure 10. Variation of Smoke emission with brake mean effective pressure

The effect of brake mean effective pressure on smoke formation for straight diesel, biodiesel blend and biodiesel-LPG in dual fuel mode is shown in figure (10). The trend of smoke emission was found to gradually increase from low load to full loading condition. At low load condition, biodiesel blend showed high emission of smoke then straight diesel and dual fuel operation which may be due to lower carbon availability in LPG dual fuel mode and possibility of premixed and homogeneous combustion [12]. At part load, smoke emission was gradually increased from 5% to 8% as shown in figure (10). At full load condition, straight diesel and biodiesel blend showed 30.4 HSU and 39.5 HSU of smoke emission while biodiesel-LPG in dual fuel mode showed 14.5 HSU of smoke emission.

V. CONCLUSION

From the experimental studies, the following conditions were drawn.

- Biodiesel was prepared through Transesterification method using ethanol and sodium hydroxide and 84% of rice bran ethyl ester were obtained.GC/MS analysis revealed the presence of Caprylic acid, Capric acid, Lauric acid and Myristic acid in prominent proportions.
- The smooth function of the engine was seen at 2.5-7.5 mg/cycle of RBEE and rest of LPG with injector opening pressure of 110 bars.
- Brake thermal efficiency and mechanical efficiency was low at minor load and high at part load operations.
- The admittance of 7.5 mg/cycle of RBEE with LPG in dual fuel operation at injector pressure of 110 bar showed better brake thermal efficiency and optimal brake specific energy consumption. But increased HC and CO with low NO_x was also observed.

VI. ACKNOWLEDGEMENTS

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