Performance, Emission and Combustion Characteristics of Direct Injection Diesel Engine Running on Rice Bran Oil / Diesel Fuel Blend

B.K.Venkanna, C. Venkataramana Reddy, Swati B Wadawadagi

***Abstract*—**Triglycerides and their derivatives are considered as viable alternatives for diesel fuels. Rice bran oil is used as diesel fuel. Highly viscous rice bran oil can be reduced by blending it with diesel fuel. The present research is aimed to investigate experimentally the performance, exhaust emission and combustion characteristics of a direct injection (DI) diesel engine, typically used in agricultural sector, over the entire load range when fuelled with rice bran oil and diesel fuel blends, RB10 (10% rice bran oil + 90% diesel fuel) to RB50. The performance, emission and combustion parameters of RB20 were found to be very close to neat diesel fuel (ND). The injector opening pressure (IOP) undoubtedly is of prime importance in diesel engine operation. Performance, emission and combustion characteristics with RB30 at enhanced IOPs are better than ND. Improved premixed heat release rate were noticed with RB30 when the IOP is enhanced.

***Keywords*—**Rice bran oil, injector opening pressure, performance, emissions.

I. INTRODUCTION

THE continuous rise in global prices of crude oil, increasing threat to environment due to exhaust emissions, the problem of global warming and the threat of supply fuel oil instabilities have adversely impacted the developing countries, more so to the petroleum importing countries like India. From the point of view of long term energy security, it is necessary to develop new alternative fuels with properties comparable to petroleum based fuels. Vegetable oils are one such alternative source. Vegetable oil as an alternative fuel for diesel engine offers an advantage because of its comparable fuel properties with diesel fuel. The major limitation of vegetable oil is its viscosity. The magnitude of which is higher than that of diesel fuel. Hence, only a partial replacement of diesel fuel is possible. Vegetable oil and diesel fuel blending (dilution) is one of the methods to reduce their viscosity [1,2,3,4,5]. Vegetable oil poses inherent oxygen in the fuel molecules which helps in combustion.

Gaseous emissions and performance of DI diesel engines are primarily influenced by combustion process, in turn oxygen concentration in the air fuel mixture [6]. It was reported that utilization of raw vegetable oils as an alternative diesel engine fuel has resulted in higher brake specific fuel consumption (bsfc) and emissions such as CO, HC and smoke opacity compared to neat diesel fuel [7,8,9,10]. This was attributed to the lower heating value, high viscosity, poor atomization, low volatility and polyunsaturated characteristic of neat vegetable oils. Some studies were found to give a lower smoke, NOx and higher CO, HC [1]. It has been reported that use of vegetable oil results in increased bsfc [11]. It was concluded that emissions of CO, HC and SOx were increased, where as NOx and PM emissions were decreased compared to diesel fuel [12, 13]. Utilization of 100% vegetable oil is also possible and emissions of polycyclic aromatic hydrocarbons and PM were reduced [2]. Few literatures are available on the use of rice bran oil on diesel engine [14, 15].

First part of the present research work is aimed to investigate experimentally the performance, exhaust emissions and combustion characteristics by exploring technical feasibility of rice bran oil and diesel fuel blends in direct injection compression ignition engine. Second part is aimed to investigate experimentally the performance, emissions and combustion characteristics of RB30 at enhanced IOP.

II. MATERIALS AND METHODS

A. Oil Characterization

The properties of neat rice bran oil (RB100) and ND were determined as per the methods approved by Bureau of Indian Standards.

B. Experimental set up and plan

Experimental tests were conducted on a DI diesel engine, typically used in agricultural sector. The specifications of the engine are given in Table I. The exhaust gas composition was analyzed by using exhaust gas analyzer (make: MRU, Germany, model: DELTA 1600 S) and smoke opacity was

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measured using smoke opacity meter (make: MRU, Germany, model: Optrans 1600). Two fuel tanks were used in the present investigation with switch over arrangement, so that supply of fuel can be changed without stopping the engine operation. The engine was started with diesel fuel and data was collected after attaining steady state. Then the experiment was switched over to blend of rice bran oil and diesel fuel.

TABLE I
ENGINE SPECIFICATIONS

Bore /stoke	80 mm / 110 mm
Speed	1500 rpm
Compression ratio	16:1
Injection pressure	200-205 bars
Injection advance	23^{o}bTDC
Cylinder pressure	0 – 200 bars
Line pressure	0-2000 bar
Resolution	0.1bar for Cp / 1 bar for Fp
Type of sensor	Piezo electric (5000 PSI for Cp and 10000 PSI for Fp)
Response time	4 micro seconds
Sampling resolution	1 degree crank angle
Crank angle sensor	360 degree encoder with resolution of 1 degree

TABLE II
PROPERTIES OF THE FUEL

Properties	Units	Method IS:1448	ND	B100
Density	kg/m^3	P:16	830	901
Boiling point	^{o}C		180- 360	---
Auto ignition temperature	^{o}C		250-315	----
Cetane number			45-55	
Flash point	^{o}C	P:69	56	302
Kinematic viscosity at 40^{o}C	cSt	P:25	3.12	42.55
Heating value	kJ/kg	P:6	43000	38952

The engine tests were conducted for the entire load range (0 to 100% i.e., 0 to 5 hp in steps of 25%) at constant speed of 1500 rpm. The cooling water temperature was maintained constant (70 to 75^{O}C). The engine parameters, such as fuel consumption, air consumption, exhaust gas temperature (EGT) and exhaust gas emissions were measured using each fuel sample (ND and RB10 to RB50) thrice and averaged.

In cylinder pressure and top dead centre (TDC) signals were acquired and stored on a high speed computer based digital data acquisition system. The data from 100 consecutive cycles were recorded (hard ware is designed to take the data up to 300 consecutive cycles). These were processed with specially developed software to obtain combustion parameters like, rate of pressure rise, maximum rate of pressure rise, occurrence of maximum rate of pressure rise, net heat release rate, maximum net heat release rate, occurrence of maximum net heat release rate, second derivative of rate of pressure rise, start of combustion, estimated end of combustion, delay period and combustion duration.

II. RESULTS AND DISCUSSIONS

A. Fuel Properties

The proprieties of the RB100 and ND were determined and the results are shown in Table II. Density of rice bran oil is slightly higher than ND. At 40^{o}C, the kinematic viscosity of H100 is 14 times higher than that of ND. The flash point of RB100 oil was quite high compared to ND. Hence, RB100 oil is extremely safe to handle. Presence of oxygen in oil improves combustion and reduces emissions but decreases the heating value of the oil. Heating value of H100 is approximately 90% of the value of ND.

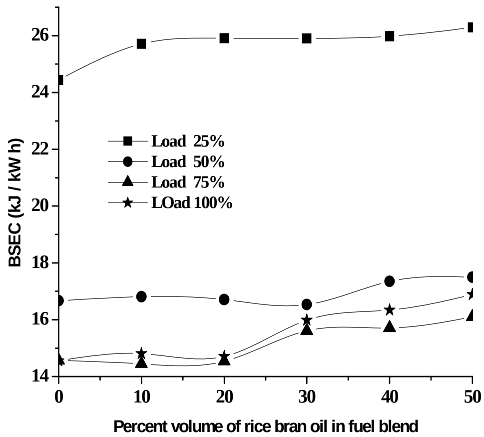

Fig. 1 Effect of the volume of rice bran oil in the fuel blend on BSEC

B. Effect on Performance Parameter

Brake specific fuel consumption (bsfc) can be expressed as brake specific energy consumption (bsec) by normalizing bsfc in terms of the amount of energy released with the given amount of fuel. As shown in Fig. 1, up to 20% rice bran oil blend and at higher loads showed bsec almost same as that of ND. Viscosity of blend ratio up to 20% is almost equal to that of ND, relatively good atomization, and inherent oxygen of the fuel molecules improves the combustion characteristics. This is an indication of relatively more complete combustion [5, 13]. For remaining blend ratio, bsec is higher than that of ND. The reason may be due to higher viscosity, poor volatility and reduction in calorific value of higher percentage of vegetable oil in the blends lead to their poor atomization and combustion characteristics.

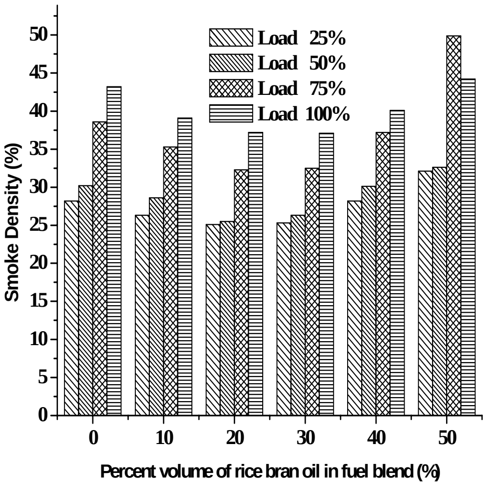

Fig. 2 Effect of the volume of rice bran oil in the fuel blend on smoke density

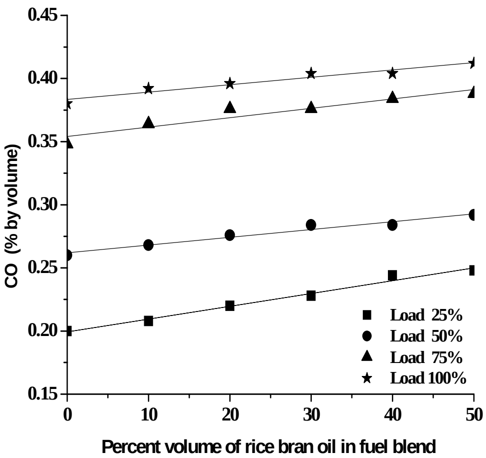

Fig. 3 Effect of the volume of rice bran oil in the fuel blend on CO emissions

C. *Effect on Emission Parameters*

Diesel combustion is heterogeneous in nature. A lean to rich air fuel ratio exists within the combustion chamber. Smoke formation mainly takes place in the rich zone of fuel at high temperature and pressure, specifically within the core region of each fuel spray [16, 17]. Fig. 2 shows the smoke opacity emissions of the rice bran oil blend under consideration. The smoke opacity emissions increased with the increase of the engine load as expected. Smoke opacity emissions first decreases up to 30% of the rice bran oil in the blend and then increases with further addition of rice bran oil in the blend.

The reasons for smoke opacity decreasing up to 30% of the rice bran oil in the blend are: (i) absence of aromatics and presence of oxygen molecules in the rice bran oil. Aromatics are known to contribute to soot formation, while the inherent oxygen molecule in the fuel, which helps to promote stable and complete combustion by delivering oxygen to the pyrolisis zone of the burning fuel by reducing locally over rich region and limit primary smoke formation, results in lower smoke emissions. These results agree with the results [5, 1] but the degree of reduction is not same.

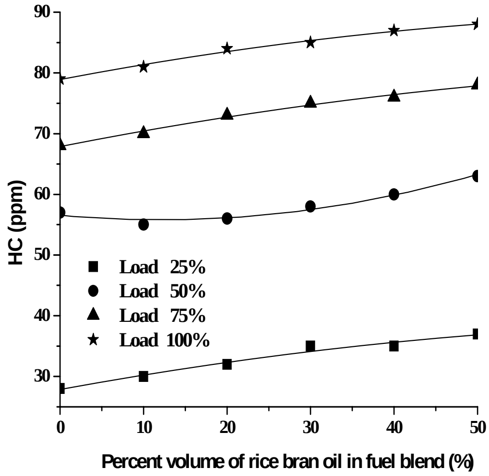

Fig. 4 Effect of the volume of rice bran oil in the fuel blend on HC emissions

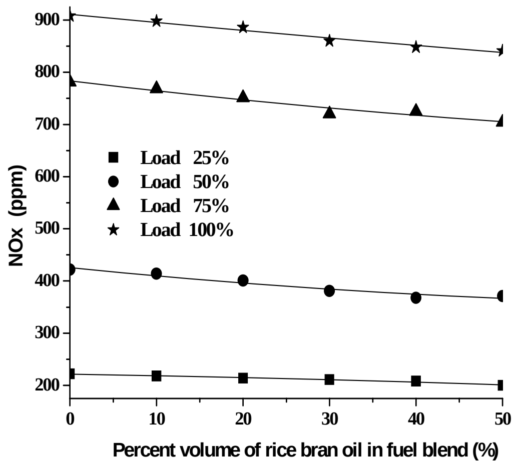

Fig. 5 Effect of the volume of rice bran oil in the fuel blend on NOx emissions

Higher smoke emissions above RB30 may be due to poor atomization of the rice bran oil. Higher viscosity and bigger size fuel molecules result in poor atomization of fuel blends. In the present investigation a maximum of 15% reduction in smoke opacity emissions is observed. Smoke opacity decreased through out the entire load range for the entire blend ratio and a maximum of 36% reduction is observed [1].

CO and HC production depends upon mixture strength i.e., oxygen quantity and fuel viscosity, in turn atomization. At low load range air fuel ratio is high, availability of oxygen is more, and hence production of CO and HC emissions is also low. Fig. 3 and 4 shows the comparison of the CO and HC emissions of different blend ratio at different engine load respectively. The emissions of CO and HC increase with increasing load. CO and HC emissions increase with increasing amount of rice bran oil in the fuel blend. The results are similar as that in reference [5]. Lower heating value of blends leads to higher quantity of fuel injection as compared to ND for the same load conditions. More the amount of rice bran oil in the fuel blend (more the inherent oxygen in the fuel molecule) more is the viscosity. Viscosity effect, in turn atomization, is more predominant than the oxygen availability, either inherent in fuel molecule or present in the charge. It is reported that CO and HC emissions increase with load as well as increasing amount of vegetable oil in the fuel blend [1, 12]. The results [18] show the entirely opposite trend. The present results agree with the results at higher load range [2].

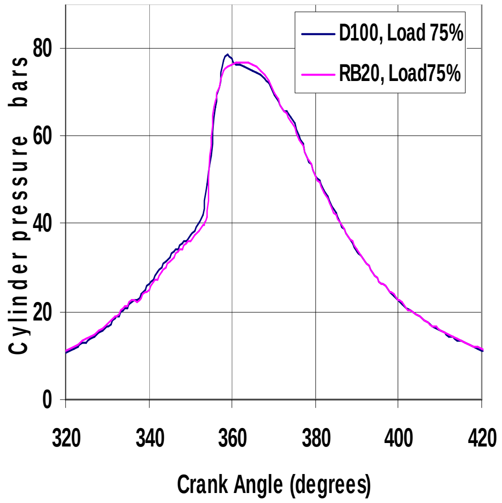

Fig. 6 Effect of the volume of rice bran oil in the fuel blend on cylinder pressure

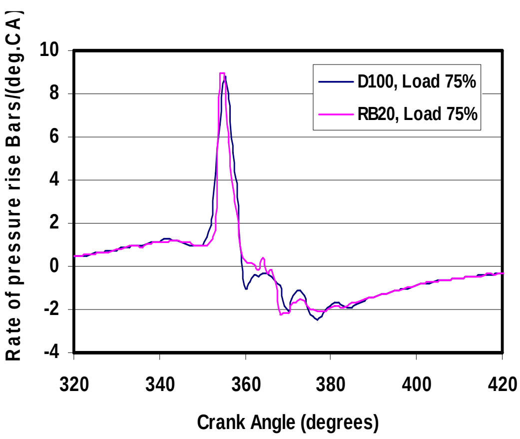

Fig. 7 Effect of the volume of rice bran oil in the fuel blend on rate of pressure rise

The increase in emissions (CO, smoke opacity and HC) for RB30-RB50 could be due to relatively incomplete combustion. This is also a reason for increase in bsec (Fig. 1). Soot, CO and HC compete for the available oxygen in the rich combustion zone.

Fig. 5 shows the NOx emissions for all the blend ratios under considerations. The important factor that causes NOx formation is due to high combustion temperatures and availability of oxygen. The NOx emissions increased as the engine load increased, due to the increase in combustion temperature as expected. It is seen that within the range of tests, the NOx emissions of RB20-RB50 were lower than that of ND. The peak cylinder pressure (Fig. 7) is less in case of RB20 compared to ND leading to less dominant premixed combustion phase (Fig. 10) results in lower combustion temperature in turn lowering formation and emissions of NOx. This is the most important emission characteristic of rice bran oil and its blends, as the NOx emission is the most harmful gaseous emissions from engines, the reduction of it is always the target for engine researchers and engine manufacturers. This emission character of NOx for rice barn oil and its blends is a very useful character for the application of vegetable oil and its blends to diesel engines in the form of alternative fuel for the diesel fuel. Similar results are found in references [1,2,18,19].

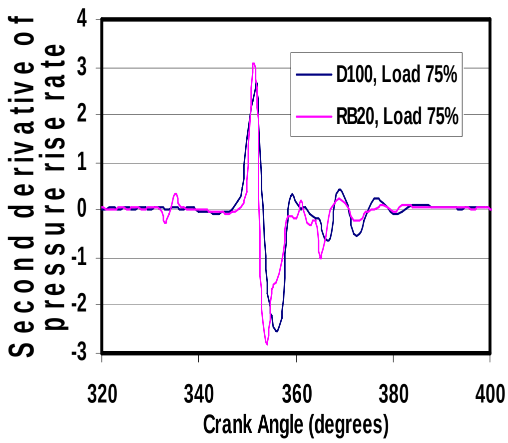

Fig. 8 Effect of the volume of rice bran oil in the fuel blend on second derivate of pressure rise

D. Combustion characteristics

The effect of crank angle on cylinder pressure and rate of pressure rise at 75% load are shown in Figures 6 and 7. RB20 follows the trend similar to the neat diesel pressure diagram. Same trends obtained for other blend ratios of the entire load under consideration. In a CI engine, the peak pressure depends on the combustion rate in the initial stages, which is influenced by the amount of fuel taking part in the uncontrolled combustion phase, which in turn governed by the delay period [6]. RB20 results in lower peak pressure and lower maximum rate of pressure rise as compared to neat diesel. The occurrence of peak pressure and maximum rate of pressure rise of RB20 moved away compared to neat diesel. Generally, if delay is more occurrence of peak pressure moves away compared to lower delay combustion. Thus, the slight higher viscosity and poor volatility of the RB20 results in lower peak pressure and maximum rate of pressure rise as compared to neat diesel.

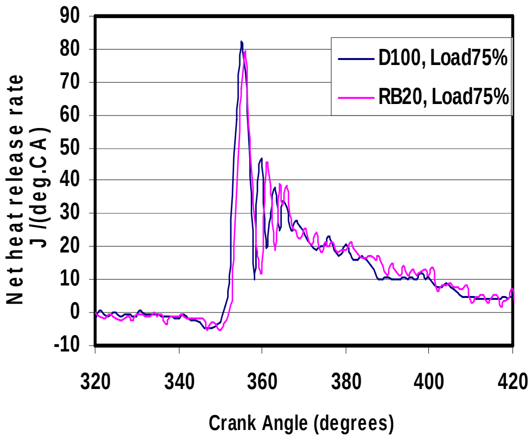

Fig. 9 Effect of the volume of rice bran oil in the fuel blend on net heat release rate

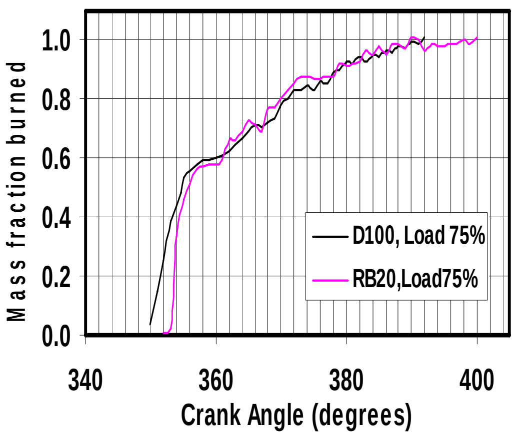

Fig. 10 Effect of the volume of rice bran oil in the fuel blend on mass fraction burned

The effect of crank angle on second derivative of the rate of cylinder pressure rise at 75% load is shown in Fig. 8. The ignition delay period (IDP) is calculated based on the static injection timing (SIT). The duration of the point of SIT to the point of start of combustion (SOC) is taken as the IDP. According to ASTM D316, the SOC is defined as the point at which the second derivative of the combustion chamber pressure versus time becomes positive. This also shows a sudden rise in the slope at the point of ignition due to the high premixed heat release rate.

Ignition delay of RB20 is slightly higher as compared to neat diesel due to low cetane number and higher self ignition temperature of the RB20 (even though it is not measured, self ignition temperature and cetane number is higher and lower respectively). The reason may be due to the inferior atomization and vaporization, physical delay of RB20 becomes larger as compared to neat diesel fuel.

Figure 9 shows the comparison of the net heat release rate curves for neat diesel and RB20 for 75% load. It is clear that RB20 changes the combustion pattern that is peak of the heat release rate curves for RB20 is rather lower than that of neat diesel fuel. It is seen that the premixed combustion region is lesser for RB20 indicating that with neat diesel fuel greater mixing is enhanced. The slight high viscosity and density of RB20 result in inferior atomization and vaporization and lead to reduction in fuel air mixing rates. Hence, more burning occurs in the diffusion phase (Fig.10). This could explain the lower NO_x, higher CO and HC emissions with RB20. However, this does not explain the decrease in smoke as shown in Fig. 2.

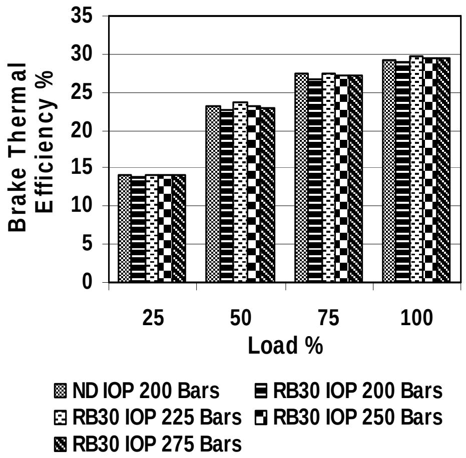

Fig. 11 Effect of Load on Brake Thermal Efficiency at different IOPs

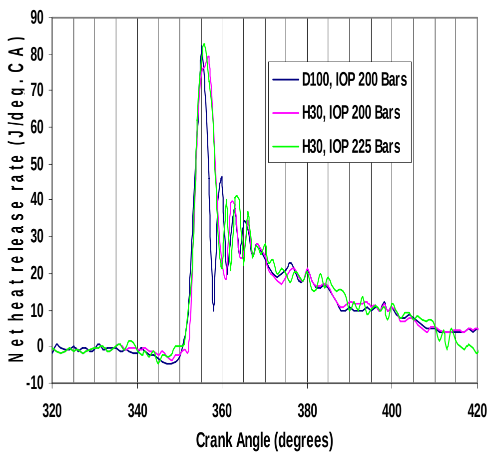

Fig. 12 Effect of crank angle on net heat release rate at different IOPs for ND and H30 at 75% load

Table III shows the combustion duration (CD), peak pressure, occurrence of peak pressure, maximum rate of pressure rise, occurrence of maximum rate of pressure rise, maximum net heat release rate, occurrence of maximum net heat release rate, SIT, SOC, IDP and estimated end of combustion (EEOC).

The duration of SOC to the point of EEOC is taken as the CD. Higher CD was obtained with H20 compared to neat diesel fuel. This is due to the injection of more amounts

RB20 than diesel fuel. Also due to the more diffusion burning with RB20, more amount of RB20 burn in the expansion stroke and results in longer CD. This also indicates that with RB20 the crank angle at which mass fraction burned (mfb) attains maximum is longer than diesel fuel. This is shown in Fig. 10.

TABLE III
IMPORTANT COMBUSTION PARAMETERS AND THEIR OCCURRENCE AT 75% LOAD

Combustion parameters	Units	IOP, bars ND 200	RB20 200	RB30 220	RB30 225
Peak pressure	bar	78.3	76.6	77.4	78.9
Occurrence of peak pressure	^{0}CA	359	362	362	359
Maximum pressure rise rate	bar/^{0}CA	8.8	8.9	7.5	7.6
Occurrence of maximum pressure rise rate	^{0}CA	355	355	355	355
Maximum net heat release rate	J/^{0}CA	81.9	79.6	77.5	78.4
Occurrence of maximum net heat release rate	^{0}CA	355	355	357	356
Static injection timing	^{0}CA	337	337	337	337
Start of combustion	^{0}CA	350	352	353	352
Ignition delay period	^{0}CA	13	15	16	15
Estimated end of combustion	^{0}CA	394	399	400	400
Combustion duration	^{0}CA	44	47	47	48

E. Performance, Emission and Combustion Characteristics of RB30 at different IOPs

Brake thermal efficiency of RB30 for the entire load range at different IOPs is shown in Fig. 11. This clearly indicates that a maximum brake thermal efficiency is obtained corresponding to 225 bars and it is slightly higher compared to neat diesel fuel at 200 bars. This is due to improved spray characteristics, better atomization and mixing with air is good. This will enhance combustion process and in turn improve efficiency. Too high IOP lead to smallest diameter of fuel droplet and affects the spray pattern and penetration. Brake thermal efficiency of RB30 at 225 bars and 250 bars is almost same. High net heat release rate were obtained in case of RB30 at IOP 225 bars compared to ND and RB30 at IOP 200 bars as shown in Fig. 12. Figure 13 shows that smoke opacity emissions steadily decreased with increase in the IOP due to better atomized spray leading to improved mixture formation. Lowest smoke opacity is obtained with the IOP of 275 bars. Better smoke emissions were seen for all the IOPs under consideration compared to neat diesel fuel at standard IOP of 200 bars. Variation of the CO and HC emissions at different IOPs are given in Figures 14 and 15. Least CO and HC emissions were observed at 275 bars and 250 bars respectively and this is better than neat diesel fuel at standard IOP of 200 bars. This is due to improvement in the spray pattern improving atomization and leading to a lower physical

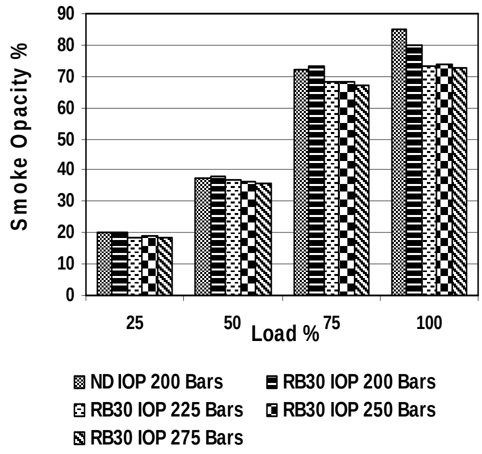

Fig. 13 Effect of Load on smoke opacity at different IOPs

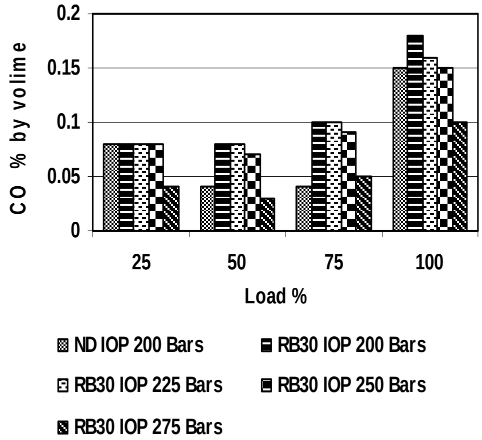

Fig. 14 Effect of Load on CO emissions at different IOPs

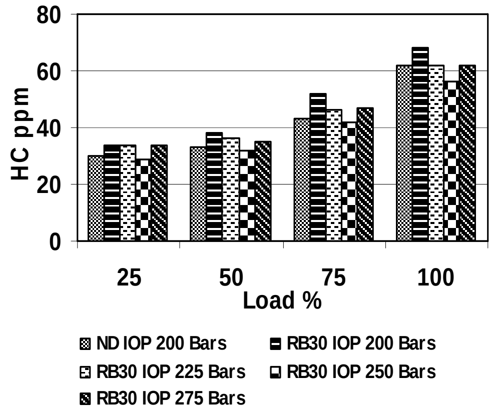

Fig. 15 Effect of Load on HC emissions at different IOPs

delay in turn to a lower IDP. This will enhance performance and emissions with RB30. Figure 16 shows the NOx emissions at different IOPs. The NOx emissions increased as the IOP increased due to improved combustion in turn lead to higher temperature.

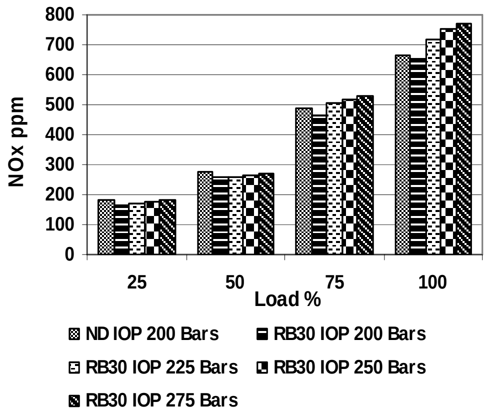

Fig. 16 Effect of Load on NOx emissions at different IOPs

III. CONCLUSIONS

Based on the experimental results of this work, the following conclusions are drawn.

No problem was faced at the time of starting the engine and ran smoothly over the range of rice bran oil percent in fuel blend.

bsfc and emission parameters such as smoke opacity, CO, HC and NO_x up to of RB20 is close to that of diesel fuel. Thereafter increased compared to diesel fuel.

For short term applications, this work establishes that 20% rice bran oil in the fuel blend can be used on direct injection diesel engine without any modification.

Improved premixed heat release rate were noticed with RB30 when IOP is enhanced.

Performance and emissions of RB30 were improved at IOP 225 bars.

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