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Optimization of injection timing and injection pressure of a DI diesel engine fueled with preheated rice bran oil

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Abstract
In the present study experiments were carried out in a constant speed, stationary direct injection diesel engine and the performance was investigated. Initially the engine fueled with diesel, rice bran biodiesel (methyl ester), raw rice bran oil and preheated rice bran oil with standard injection timing and injection pressures at different load conditions and the performances were compared. With the help of a heat exchanger and using the exhaust gases, the rice bran oil was preheated. It was found that the pre heated rice bran oil exhibits a closer performance as compared to rice bran biodiesel. Then the injection timing and injection were varied and the performance and emission parameters were investigated using preheated rice bran oil. It was found that the brake thermal efficiency and oxides of nitrogen were found to be higher and BSFC and smoke were found to be lower at 21° CA bTDC of injection timing and 230 bar injection pressure. From the test results the optimum injection timing and injection timing for the engine fueled with preheated rice bran oil were evaluated.

Keywords: Injection timing; Injection pressure; Optimization; Preheating; Rice bran oil.

1. Introduction

The world is currently facing dual crisis of fossil fuel depletion and environmental degradation. Also due to ever increasing number of vehicles energy demand is increasing. This has revived interest in the use of vegetable oils as a fuel substitute, with re-evaluation of their performance in unmodified diesel engines. Among the many different types of alternative fuels, vegetable oils and their esters come across as good choices [1-4]. Most of the western countries use edible oils such as soybean, sunflower, saffola etc. for production of biodiesel. India is a net-importer of edible vegetable oils hence biofuels research in the country cannot be based on edible vegetable oils. In India, variety of non-edible oils like Linseed, Mahua, Karanji, Rice bran, Jatropha are available in abundance, which can be utilized for production of biodiesel & utilization in diesel engines [5]. Few literatures are available on the use of rice bran oil on diesel engine [6]. Different physical and chemical structures exist in spite of part similarities between vegetable oils and diesel fuel. Due to the high viscosity and lower volatility of vegetable oils, use of straight vegetable oils in diesel engines presents problems [7].

Since straight vegetable oils are not suitable as fuels for diesel engines, they have to be modified to bring their combustion related properties closer to diesel. This fuel modification is mainly aimed at reducing the viscosity to eliminate flow/atomization related problems. Four techniques can be used to reduce the viscosity of vegetable oils; namely heating/pyrolysis, dilution/blending, micro-emulsion, and transesterification [8-9]. One of the methods being investigated for reducing vegetable oil viscosity is fuel pre heating to enable direct use of neat vegetable oil in diesel engine. Also the extent of performance modification will depend on the fuel used and on the engine compassion to fuel injection and combustion characteristics [10-11].Transesterification is well established and best suited method of using vegetable oils in CI engine without significant long-term durability issues. In spite of this, this adds extra cost of processing because of the transesterification reaction involving chemical and process heat inputs. In rural and remote areas of developing countries, where grid power is not available, vegetable oils can play a vital role in decentralized power generation for irrigation and electrification. In these remote areas, different types of vegetable oils are grown/produced locally but it may not be possible to chemically process them due to logistics problems in rural settings. Hence using heated or blended vegetable oils as petroleum fuel substitutes is an attractive proposition [12].

The performance and emission characteristics of diesel engines depends on various factors like fuel quantity injected, fuel injection timing, fuel injection pressure, shape of combustion chamber, position and size of injection nozzle hole, fuel spray pattern, air swirl etc [13]. In this present work, the effect of preheated rice bran vegetable oil on the performance of a diesel engine is discussed. The exhaust gas temperature was used to preheat the rice bran vegetable oil. The performance results were compared when running on rice bran biodiesel under similar operating conditions. Subsequently, the injection timings and injection pressures were varied and the performance results were investigated using preheated rice bran vegetable oil. Based on the experiment results, optimum injection timings and injection pressures were evaluated.

1.1 Rice bran oil

Rice is the main cultivation in subtropical southern Asia, and it is a staple food for a large part of the world’s human population especially in east, south and south-east Asia, making it the most consumed cereal grain. Rice bran oil is extracted from the germ and inner husk (called bran) of the rice. Rice bran is mostly oily inner layer of rice grain which is heated to produce rice bran oil. RBO is not a common source of edible oil compared to other traditional cereal or seed sources such as corn, cotton, sunflower or soybean. . Until recently, rice bran was used mostly as animal feed and the most of the oil production is used for industrial applications. One of the best ways for the potential utilization of RBO is the production of biodiesel [14].

2. Experiments

2.1 Fuel preparation and properties

The raw rice bran oil was purchased from Annai Biocrop Pvt. Ltd, Chennai. The rice bran biodiesel was produced in the authors’ laboratory through transesterification. Transesterification is a process of producing a reaction in triglyceride and alcohol in the presence of a catalyst to produce alkyl ester and glycerol. Alkali (Sodium hydroxide, pottosium hydroxide), acids (Sulphuric acid Hydro chloric acid) catalyze reaction [15, 16, 17]. Alkali catalyzed transesterification is faster than acid catalyzed transesterification and is most used commercially [18]. If the free fatty acid (FFA) content and moisture content are less than 0.8 %, good quality of biodiesel can be produced. The objective of the transesterification process is to reduce the viscosity of vegetable oil. In the present work, single stage transesterification process was followed. The fuel properties were determined following the methods specified in ASTM standards. The properties of raw rice bran oil and rice bran biodiesel are listed in Table 1. Similarly, the fatty acid composition of rice bran oil is given in Table 2.

Table 1. Properties of test fuels

Property	Unit	Diesel	Rice bran vegetable oil	Rice bran biodiesel
Density (at 15°C)	kg/m^3	830	995	882
Kinematic Viscosity (at 40°C)	mm^2/s	3.40	33.92	4.92
Cetane number	-	48.0	39.0	51.0
Heating Value	MJ/kg	42	36	39
Flash point	°C	50	198	165
Moisture content	wt %	-	-	0.06

Table 2. Fatty acid composition of rice bran oil

Fatty acid chain	C:N	Type	Wt (%)
Lauric	C12:0	Saturated	0.11
Myristic	C14:0	Saturated	0.24
Palmitic	C16:0	Saturated	12.46
Stearic	C18:0	Saturated	8.32
Oleic	C18:1	Unsaturated	27.78
Linoleic	C18:2	Unsaturated	37.65
Linolenic	C18:3	Unsaturated	13.44

In C: N, C indicates the number of carbon atoms and N the number of double bonds of carbon atoms in the fatty acid chain.

2.2 Experimental set-up and test procedure

Tests were carried out on a Kirloskar TAF-1 single cylinder air-cooled; direct injection, four-stroke diesel engine and the specifications are given in Table 3. This type of engine is mainly used for agricultural purpose in India. The dynamometer used to load the engine comprised of a shunt- wound DC generator and a load bank. The fuel supply system was modified by adding a three-way, hand operated, two-position directional control valve, which allowed rapid switching between the diesel used as a standard fuel and the test fuel. A MUP (Mechanical Unit Pump) of helical plunger type made by Mico Bosch was used to deliver the fuel to the multi-hole orifice with sac volume. An orifice meter connected to an air surge tank was attached to inlet manifold of the engine to measure airflow. The fuel flow rate was measured on volume basis using a burette and a stop watch.

Table 3. Test engine specification

SI. No.	Parameters	Specification
1	Make	Kirloskar
2	Model	TAF-1
3	No. of cylinders	One
4	Type of cooling	Air cooled
5	Bore x Stroke	87.5 x 110 mm
6	Compression ratio	17.5:1
7	Piston bowl	Hemispherical
8	Rated power	4.4 kW @ 1500 rpm
9	Injection opening pressure	200 bar
10	Fuel injection timing	23° CA bTDC

Experiments were conducted on a single cylinder, four-stroke, air cooled, direct injection, 4.4 kW compression ignition engine with a constant speed of 1500 rpm. Initially the engine was started and allowed to stabilize for 45 minutes. At each operating point, the readings were taken with 30 minutes of time interval. The engine fueled with neat diesel, straight vegetable oil derived from rice bran, and biodiesel derived from rice bran vegetable oil called rice bran oil methyl ester respectively. The performance and emission parameters were measured at different loads. Finally, the rice bran vegetable oil was preheated using the exhaust gas temperature and used as fuel. A heat exchanger was used for preheating. The performance of the engine was evaluated in terms of brake specific fuel consumption, brake thermal efficiency, and emissions like oxides of nitrogen (NO_x) and smoke. The NO_X emission was measured by QROTECH, QRO- 401 exhaust gas analyzer. Smoke density was measured by a Bosch type smoke meter. The schematic of the experimental set up is shown in Figure 1. The preheated rice bran vegetable was used in the engine with different injection timing (23, 21, 19, and 17° CA bTDC) and injection pressure (210, 220, 230, and 240 bar) at full load conditions at which the performance and emission parameters were measured. An optimum injection timing and injection pressure values were evaluated from the test results. It was observed from the figure that the rice bran oil requires a heating temperature of 158°C to bring down its viscosity to that of diesel and to 138°C as that of rice bran oil methyl ester i.e. rice bran biodiesel.

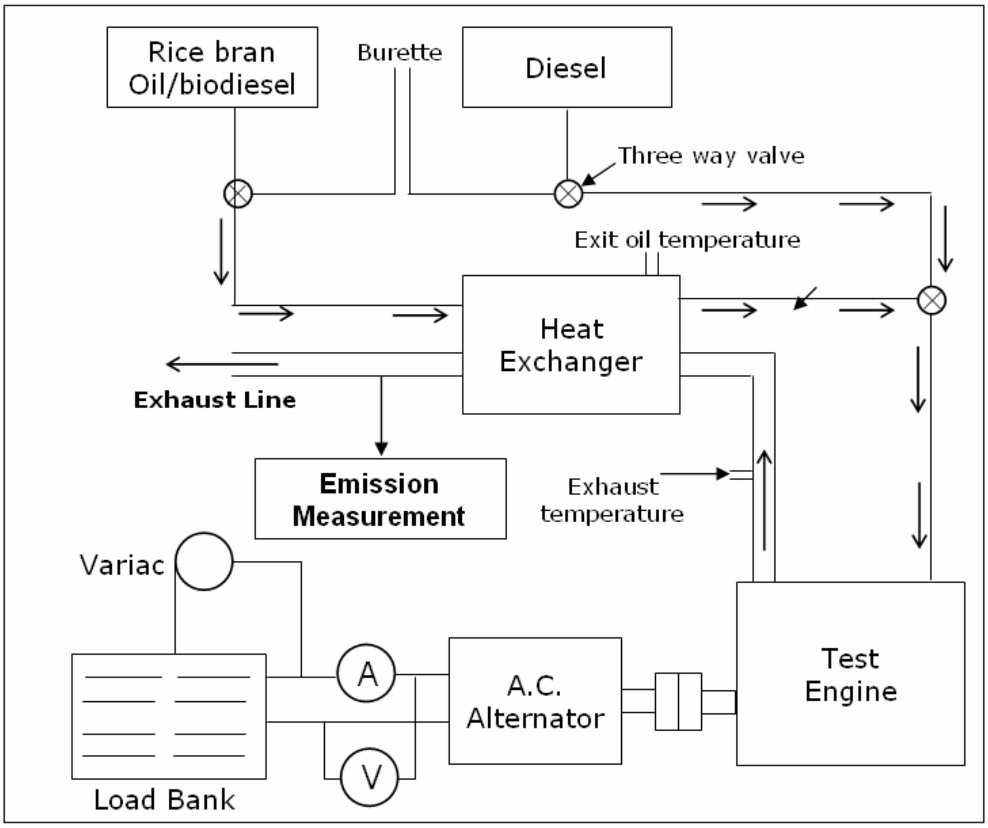

Figure 1. Experimental set-up schematic

3. Results and discussion

3.1 Performance and emission parameters at standard injection timing (23° deg bTDC) and injection pressure (200 bar)

The performance and emission parameters at the standard injection timing and pressure were investigated. The variation of BSFC with load for different test fuels is illustrated in Figure 2. The variation of brake thermal efficiency with load for different test fuels is depicted in Figure 3.

From the Figure 2, it can be seen that the diesel has a lower BSFC and rice bran oil has a higher BSFC at all loads. The BSFC of rice bran biodiesel is higher than that of diesel. This is because the heating value of biodiesel is lower than that of diesel. That is to develop the same power output; rice bran biodiesel requires more energy than that of diesel. Similarly, due to the lower heating value, rice bran vegetable oil has a higher BSFC as compared to rice bran biodiesel. When comparing the BSFC of preheated rice bran oil and rice bran oil without preheated, the former has a lower BSFC as compared to the later. This may be due to the improvement in viscosity that leads to better atomization in the case of preheated rice bran oil. From the Figure 3 it can be observed that the order of magnitude of the brake thermal efficiency of the test fuels is exactly the reverse order of the magnitude of BSEC of the respective fuels at all loads. This is already explained that the brake thermal efficiency can be considered as a reciprocal of the BSEC. At all loads the engine with diesel operation shows a higher and with rice bran oil shows a lower efficiency as compared to the rest of the fuels. The magnitude of the preheated rice bran oil falls between rice bran oil and rice bran biodiesel at a given load. At full load the preheated rice bran oil shows an increase of 0.4 % (absolute %) and 1.5 % (relative %) in thermal efficiency as compared to rice bran oil without preheating.

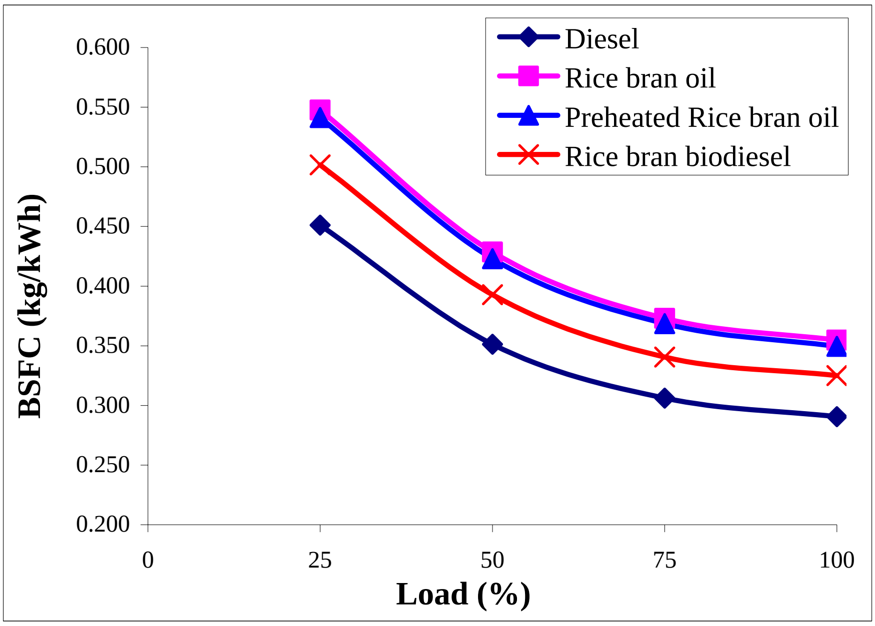

Figure 2. Variation of BSFC with load for different test fuels

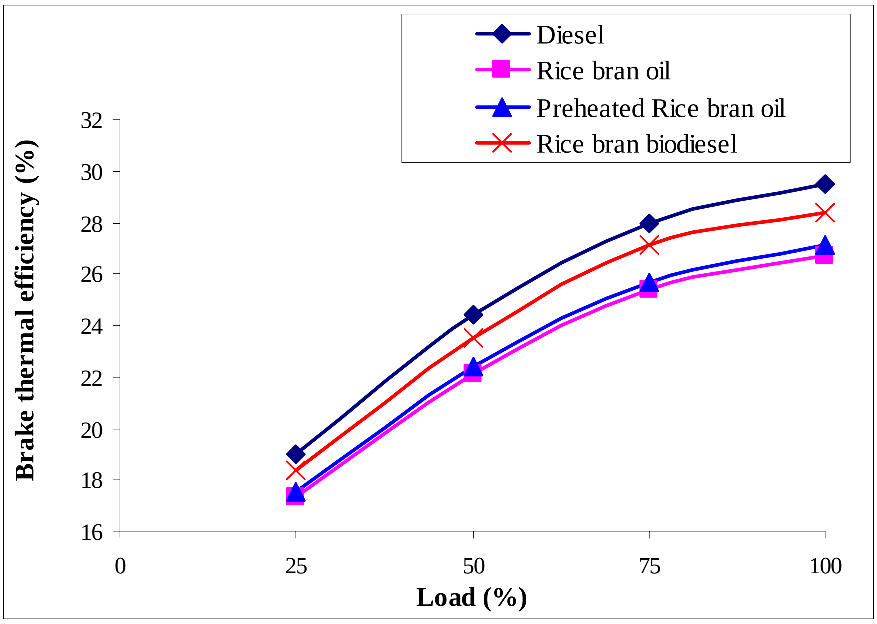

Figure 3. Variation of brake thermal efficiency with load for different test fuels

Figures 4 and 5 illustrate the variation of oxides of nitrogen and smoke with load respectively. Figure 4 indicates that the rice bran biodiesel shows a higher NO_X emission than that of diesel at full load. As mentioned earlier, the formation of NO_X is favoured by higher combustion temperatures and availability of oxygen. Unlike diesel, biodiesel contains oxygen. This fuel-borne oxygen, together with higher combustion temperatures, favour production of more NO_X than diesel fuel combustion. The rice bran oil without preheating exhibits a lower value of NO_X as compared to diesel at full load. The reduction in NO_X emission with rice bran oil may be believed due to the reduced premixed burning rate following the delay period. That is the lower air entrainment and fuel air mixing rates with the rice bran oil may result in low peak temperature and NO_X levels. The NOx emission with preheated rice bran oil is higher than that of rice bran oil without preheating. However, the values are still lower than diesel The increase in NO_X with preheated fuel may be due to the rapid burning with an increase in fuel inlet temperature.

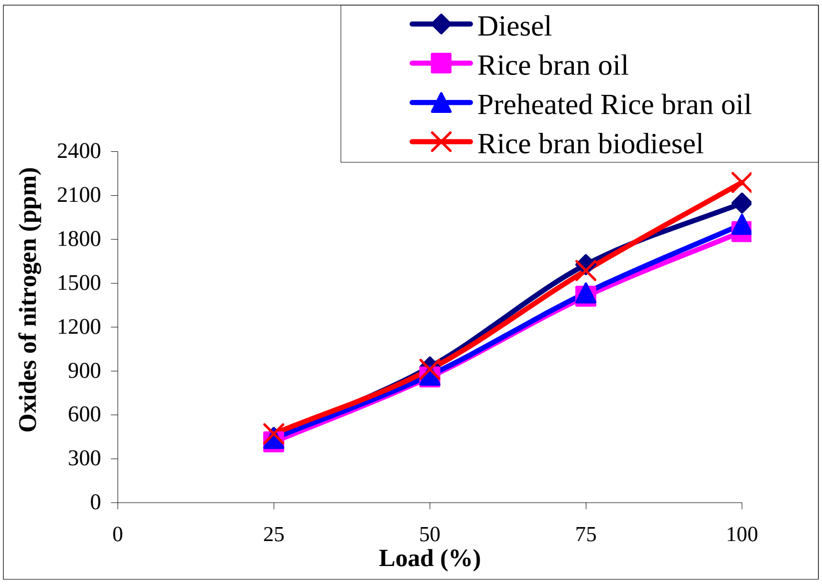

Figure 4. Variation of NO_X with load for different test fuels

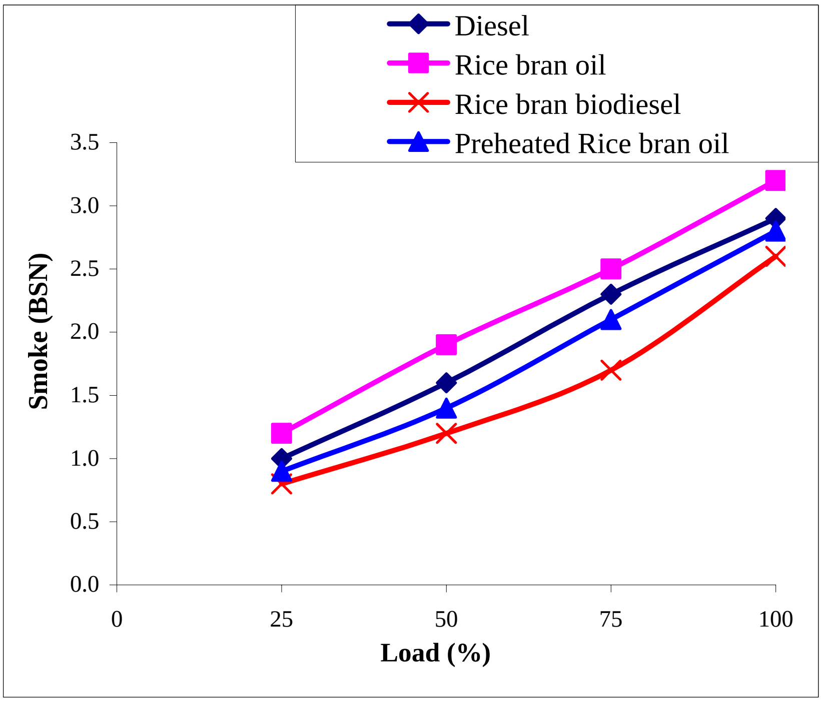

Figure 5. Variation of smoke with load for different test fuels

At full load, the smoke density is 3.2 BSN with rice bran oil and 2.9 BSU with diesel. With neat rice bran oil, due to its heavier molecular structure and higher viscosity, atomization becomes poor and this may lead to a higher smoke emission as compared to diesel. However the smoke density decreases with preheated rice bran oil. The smoke emission is 2.8 BSU with preheated rice bran oil, which is lower than that of diesel. With preheated rice bran oil, lower smoke level as a result of improved combustion can be achieved due to the reduction in viscosity and a better fuel air mixing rates. The smoke emission is reduced with the use of rice bran biodiesel, which is less viscous than the neat rice bran vegetable oil.
From the above discussion, it can be observed that the preheated rice bran oil shows almost a closer performance and emission results as compared to rice bran biodiesel. Hence the preheated rice bran oil can be considered as a better alternative for biodiesel. In the succeeding section, the results of varied injection pressure and injection timing with preheated rice bran oil are discussed.

3.2 Performance and emission parameters at varied injection timing and injection pressure using preheated rice bran oil

The variation BSFC with injection pressure at various injection timings is exemplified in Figure 6 The dependence of BSFC on injection pressure at different injection timings was analysed. The trend of Figure 6 reveals that the BSFC decreases with injection pressure and reaches a minimum value. It starts increasing with subsequent increase in injection pressure. To generate the same power output, the fuel consumption would be lesser with higher injection pressure due to extra finer spray formation and hence better atomization. The better atomization leads to effective utilization of fuel-air mixture and better combustion can be realized which result a reduction in BSFC eventually. Whilst relatively a poorer mixing formation with lower injection pressures consume more fuel quantity to generate same power output. However a further increase in injection pressure will result in an increase of BSFC. This is because of over-penetration due to higher injection pressure which produces unburned spices which do not take part in the combustion. Therefore to develop the same power output the fuel consumption would be higher. Figure 7 illustrates the variation of brake thermal efficiency with injection pressure at different injection timings.

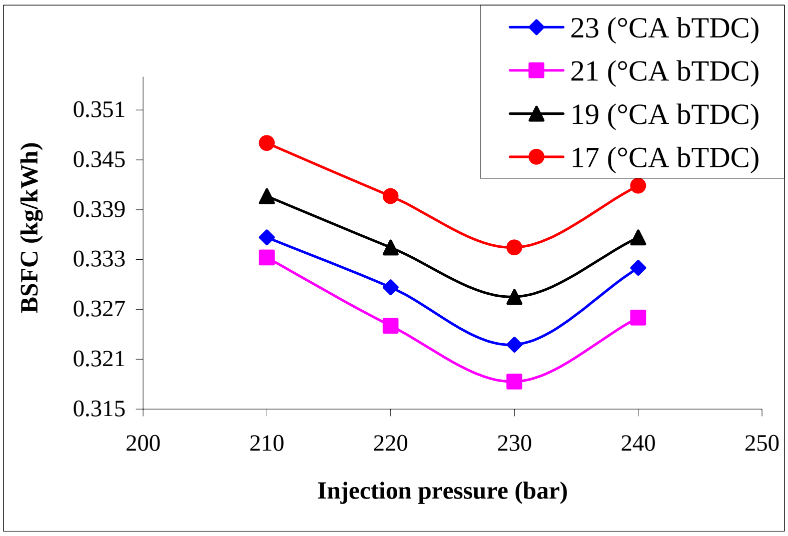

Figure 6. Variation of brake specific fuel consumption with injection pressure at different injection timings

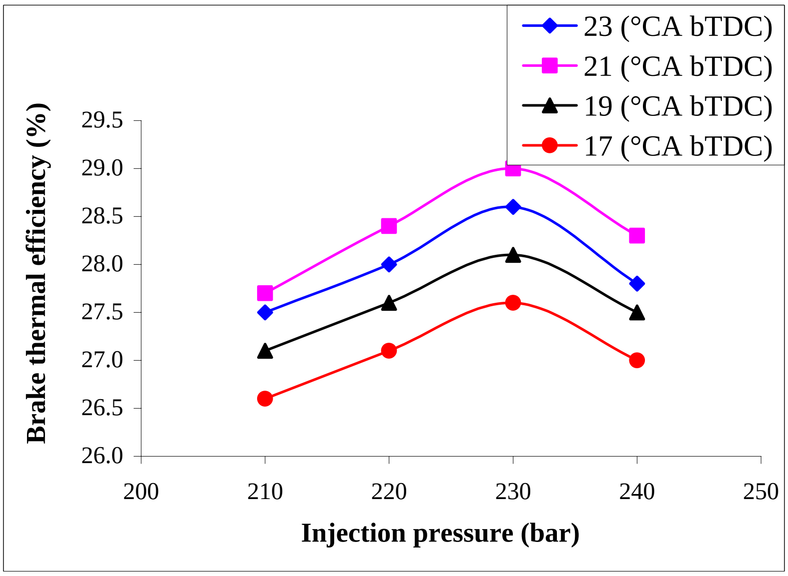

Figure 7. Variation of brake thermal efficiency with injection pressure at different injection timings

It can be noticed from Figure 7 that the brake thermal efficiency at all injection timings increases with injection pressure, attains a maximum value and then start decreasing with further increase in injection pressure. This is believed due to the finer atomization and smaller sized fuel droplets with higher injection pressure which is explained already in the BSFC section. Similarly a further increase in injection pressure will result in a decrease of thermal efficiency due to increase in BSFC.
The variation of oxides of nitrogen with injection pressure at different injection timings is shown in Figure 8. The effect of injection pressure on NO_X at different injection timings was investigated. It was found that the NO_X emissions were increased with increase in injection pressure at all injection timings. However the NO_X emissions start decreasing with further increase injection pressure. From Figure 8, it can be seen that the NO_X increases and reaches a maximum value at 230 bar from 210 bar of injection pressure. At higher injection pressures, finer atomization and better mixing would be expected. This will result in reduction of partially burned and unburned species during combustion which leads to a better combustion. The enhancement in combustion would result in high in-cylinder temperature and hence increase in NO_X eventually. A further increase in injection pressure may cause over-penetration of fuel spray which results in increased unburned or partially burned species as discussed in peak pressure section. Increase in partially burned or unburned species lead to a poorer combustion that causes a low peak combustion temperature, and hence reduction in oxides of nitrogen emission finally.

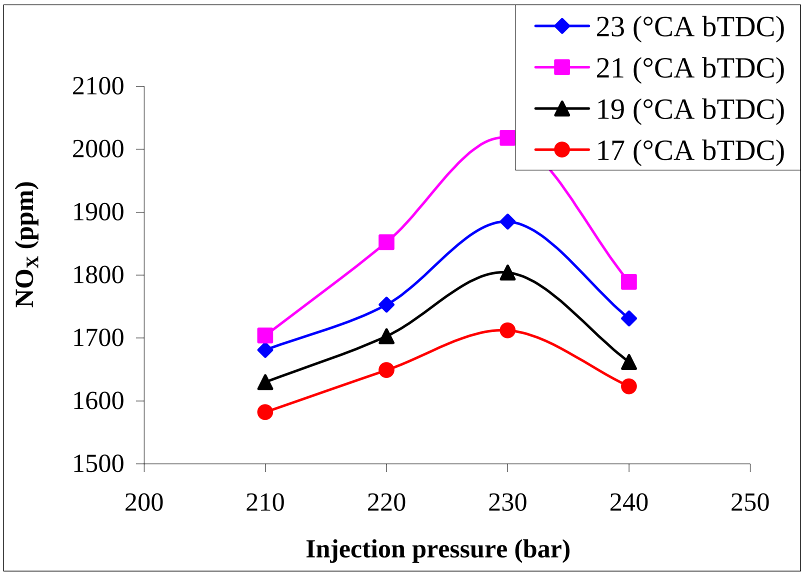

Figure 8. Variation of NO_X with injection pressure at different injection timings

The variation of smoke with injection pressures at different injection timings is illustrated in Figure 9. The investigation on variation of smoke with injection pressure reveals that the smoke decreases with increase in injection pressure, after reaching a minimum value it starts increasing with further increase in injection pressure at all injection timings.. From Figure 9, it can be seen that the smoke decreases with increase in injection pressure i.e. from 210 to 220 and then to 230 bar where it reaches a minimum value. A better combustion due to finer atomization because of increase in injection pressure could result a reduction in smoke. A further increase in injection pressure that is 240 bar is resulted in increase in smoke. This may be expected due to the over-penetration of fuel spray with increase in injection pressure as discussed earlier. Smoke particles are formed specifically due to the fuel deposition on walls. The increase in injection pressure tends to increase the spray penetration on walls which in turn may increase the smoke emission.
It can be observed from the above discussion that the values of performance and emission parameters are favorable at 21° CA bTDC of injection timing and 230 bar of injection pressure except for NO_X. The ignition delay is neither minimum nor maximum at 21° CA bTDC of injection timing and 230 bar of injection pressure. The NO_X can be found to be higher at 21° CA bTDC of injection timing and 230 bar of injection pressure which is not desired. Except NO_X, all the other parameters were found to be promising at 21° CA bTDC of injection timing and 230 bar of injection pressure. However performance and emissions are always subjected to a trade off. Therefore, for the preheated (158° C) rice bran

vegetable oil, the optimum injection timing and optimum injection pressure can be evaluated as 21° CA bTDC and 230 bar respectively.

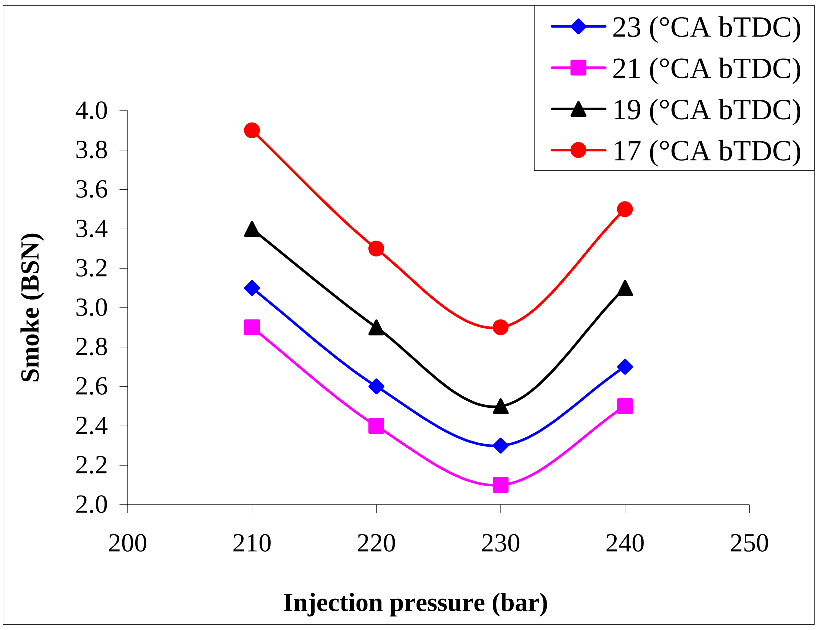

Figure 9. Variation of smoke with injection pressure at different injection timings

4. Conclusion

From the above results and discussion of the experimental investigations on a single cylinder, four strokes, constant RPM, stationary, air cooled, compression ignition engine run on preheated rice bran oil at different injection pressure and injection timing, the following conclusions may be drawn from the present study.

1. Pre heating of rice bran oil can be done by utilizing the heat exchanger of the exhaust gases from the engine. Using heat exchanger, the temperature of rice bran oil could be raised to 158°C at the full load.
2. It was found that the preheated rice bran oil exhibits a closer performance as compared to rice bran biodiesel. Hence it can be considered as a better substitute for rice bran biodiesel.
3. For preheated rice bran oil, the BSFC was found to be lower at 21°CA bTDC of injection timing and 230 bar of injection pressure. Similarly the brake thermal efficiency was lower at 21°CA bTDC of injection timing and 230 bar of injection pressure.
4. The oxides of nitrogen was higher found to be higher and the smoke was found to be lower at 21°CA bTDC of injection timing and 230 bar of injection pressure.
5. The optimum injection timing and injection pressure were evaluated as 21°CA bTDC and 230 bar respectively.

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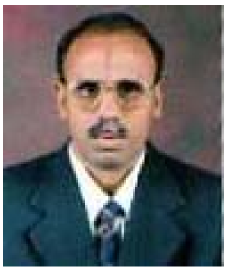

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