COMBUSTION AND EMISSION CHARACTERISTICS OF DIESEL ENGINE FUELLED WITH RICE BRAN OIL METHYL ESTER AND ITS DIESEL BLENDS

by

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There has been a worldwide interest in searching for alternatives to petroleum-derived fuels due to their depletion as well as due to the concern for the environment. Vegetable oils have capability to solve this problem because they are renewable and lead to reduction in environmental pollution. The direct use of vegetable oils as a diesel engine fuel is possible but not preferable because of their extremely higher viscosity, strong tendency to polymerize and bad cold start properties. On the other hand, Biodiesels, which are derived from vegetable oils, have been recently recognized as a potential alternative to diesel oil. This study deals with the analysis of rice bran oil methyl ester (RBME) as a diesel fuel. RBME is derived through the transesterification process, in which the rice bran oil reacts with methanol in the presence of KOH. The properties of RBME thus obtained are comparable with ASTM biodiesel standards. Tests are conducted on a 4.4 kW, single-cylinder, naturally aspirated, direct-injection air-cooled stationary diesel engine to evaluate the feasibility of RBME and its diesel blends as alternate fuels. The ignition delay and peak heat release for RBME and its diesel blends are found to be lower than that of diesel and the ignition delay decreases with increase in RBME in the blend. Maximum heat release is found to occur earlier for RBME and its diesel blends than diesel. As the amount of RBME in the blend increases the HC, CO, and soot concentrations in the exhaust decreased when compared to mineral diesel. The NO_x emissions of the RBME and its diesel blends are noted to be slightly higher than that of diesel.

Key words: *diesel engine, biodiesel, performance, emissions, combustion, rice bran methyl ester*

Introduction

The world is on the brink of an energy crisis. The limited fossil fuel resources are unable to provide for the continuously increasing demand for energy. This, associated with increasing price of fossil fuel and the awareness of the impacts of environmental pollution and global warming, has forced a search for an alternative source of energy, which is renewable, safe and non-polluting.

Since compression ignition (CI) engines are more widely used compared to spark ignition (SI) engines, greater attention is being devoted to develop an alternative source of fuel for the same. Since vegetable oils satisfy the major requirements, necessary for a diesel engine fuel, their suitability as alternative to diesel fuel has been a topic of active research. However, their higher viscosity and storage ability issues restrict their direct use as alternate fuels [1]. Transesterification is the method to reduce the viscosity of vegetable oil. In this process, the vegetable oil reacts with alcohol in the presence of acid/base catalyst to produce biodiesel *i. e.* ester of vegetable oil [2, 3]. This is biodegradable, non-toxic, sulphur free and, most importantly, renewable. Generally, methyl esters are preferred because methanol is non hygroscopic and is less expensive than other alcohols.

Many researchers have conducted experiments with biodiesel. Biodiesels produced from various vegetable oils such as sunflower oil [4], soybean oil [5], rapeseed oil [6], Jatropha oil [7], Pongamia oil [8], and used cooking oils [9] have been successfully tested. In the above investigations, Biodiesel and its blends with diesel were employed as a fuel for a CI engine without any modification in the existing system. It was found that the performance and emissions of these biodiesels are comparable to those of diesel. Most of these investigations have revealed that the methyl esters of vegetable oils have the potential to replace diesel.

However, the most of the earlier research works on biodiesels are mainly focused on performance and emission study only. Machacon *et al*. [10] studied the variation in combustion parameters of a diesel engine using coconut oil-diesel blend as fuel. Hamasaki *et al*. [11] analyzed heat release rate of waste cooking oil methyl ester and compared it with diesel. Breuer [12] studied the effect of fuel properties on heat release through experiments conducted with rapeseed oil and its methyl ester. Vaughn *et al*. [13] arrived at the ignition delay of a number of bio-esters by droplet ignition delay experiments. Kinoshita *et al*. [14] evaluated the combustion characteristics of biodiesels derived from coconut oil and palm oil.

In the present work, rice bran oil (RBO) is used for production of biodiesel. RBO is extracted from the rice bran, which is a by-product obtained during the grinding of paddy. Since rice is the staple food in a large part of India, there is a huge potential to produce and utilize RBO. Though India is the second largest producer of paddy, hardly 50% of the bran is utilized for producing RBO and only 19% of edible grade RBO is consumed as a cooking media [15]. Hence RBO is commercially feasible for biodiesel production [16]. The fatty acid profile of crude RBO (% v/v) is 0.2 0.1 lauric, 0.8 0.1 myristic, 17.7 0.53 palmitic, 0.23 0.1 palmitoleic, 2.2 0.15 stearic, 40.6 0.77 oleic, 35.6 0.5 linoleic, 1.8 0.22 linolenic, 0.2 0.1 arachidic, 0.3 ± 0.1 behenic, and 0.6 0.26 lignoceric [17]. Even though the RBO has a potential to replace diesel, limited work has been performed so far to test its ability as a CI engine fuel. In the initial stage of investigation, tests are conducted with neat RBO to test its suitability as a CI engine fuel [18, 19]. From these tests, it is found that the fuel, which is prepared by blending rice bran oil with diesel, produced better results than neat RBO. Later, the work is extended to test the engine with esters of RBO [20]. All the above-mentioned studies are restricted to evaluation of only the performance and emission characteristics.

From the earlier evaluations it is inferred that rice bran oil methyl ester (RBME) have the potential to replace diesel. To strengthen the above inference this paper presents an in-depth analysis of RBME by its combustion parameters and its impact on the performance and emission characteristics of the engine. Apart from complete replacement of diesel by RBME, the present work also makes an attempt to investigate the possibility of a partial replacement of RBME as a CI engine fuel by evaluating the different blends of RBME and diesel. This results in four more test fuels in addition to RBME and diesel. In the present study, RBO is used as feedstock to produce biodiesel by transesterification process. In this process, RBO with methanol in the presence of potassium hydroxide (KOH) catalyst to produce RBME. One litre of RBO requires 7.9 grams of KOH and 200 ml of methanol in order to be converted into RBME.

Experimental dates

Engine setup

The test setup used for this investigation is shown in fig. 1. Test to evaluate the feasibility of RBME and diesel oil blends have been performed on a 4.4 kW, constant speed, single cylinder, four-stroke, naturally aspirated, air-cooled, direct injection diesel engine coupled to an electrical dynamometer is used. The specifications of the engine are given in tab. 1.

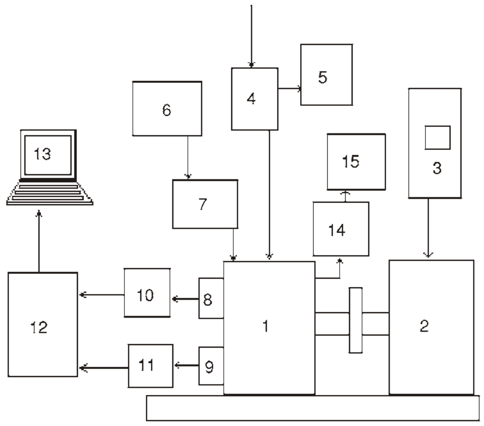

Figure 1. Experimental setup
(1) – Diesel engine, (2) – Electrical dynamometer, (3) – Dynamometer controls, (4) – Air box, (5) – U-tube manometer, (6) – Fuel tank, (7) – Fuel measurement, (8) – Pressure transducer, (9) – TDC position sensor, (10) – Charge amplifier, (11) – TDC amplifier circuit, (12) – Analog to digital card, (13) – Personal computer, (14) – Exhaust gas analyzer, (15) – AVL smoke meter

Various measurement systems

Table 1. Specifications of engine

Make	Kirloskar
Model	TAF 1
Type	Direct injection, air cooled
Bore × stroke [mm]	87.5 × 110 mm
Compression ratio	17.5:1
Swept volume	0.661 L
Rated power	4.4 kW
Rated speed	1500 rpm
Start of injection	23.4 deg bTDC
Connecting rod length	220 mm
Injector operating pressure	250 bar

AVL GH12D miniature pressure transducer with AVL 3066A02 piezo charge amplifier and angle encoder is used to obtain the variation of pressure in the combustion chamber. The mean pressure history in the combustion chamber is obtained by averaging 100 cycles in sequence. The AVL 615 indimeter software is used to compute the heat release rates from the measured values of pressure and crank angle (CA). A five-gas analyzer is used to measure CO, unburned hydrocarbons (UBHC) by infrared sensors and NO_x by electrochemical sensors. The smoke intensity is measured by AVL 415 variable sampling smoke meter. A burette is used for measuring fuel consumption and a chrommel alumel thermocouple is used along with a digital temperature indicator for measuring the exhaust gas temperature.

Experimental procedure

For those investigation six types of fuels have been testing: petrol diesel, 20, 40, 60, 80% of RBME blends (on volume basis) and diesel fuel and 100% RBME. The comparison of physical properties of RBO, RBME, and diesel oil are shown in tab. 2. It is observed that the properties of RBME, are with in the range of biodiesel standards [21]. The instruments are calibrated according to the suppliers' instructions before conducting the engine tests. The tests are conducted as per the IS 1601:1960 of Bureau of Indian standards. The engine is started and after warming up, tests are conducted at various loads with diesel followed by RBME and its diesel blends. At each load, the engine is operated for 15 minutes to stabilise under the new condition. For every fuel change, the fuel lines are completely cleaned, and the engine is allowed to operate for at least 30 minutes under this condition. The RBME-diesel blends are specified according to the percentage of RBME present in the test fuel.

Table 2. Properties of RBME and diesel

Property	RBO	Diesel	RBME	Biodiesel standards	
				ASTM D6751-02	EN14214
Density [kg/m^3]	920.4	830	881.2	–	860-900
Viscosity [Cst]	23.87	3.522	5.37	1.9-6.0	3.5-5.0
Flash point [°C]	298	49	165	>130	>120
Calorific value [kJ/kg]	38725	44136	39798.5	–	–
Acid number [mgKOH/g]	3.0	0.2	0.14	<0.8	<0.5

Results and discussion

The variation of combustion, performance, and emission characteristics with load are presented for the various test fuels.

Combustion characteristics

The measured in-cylinder pressure data is used to analyze the combustion process and the events occurring in the combustion chamber. In this section, combustion parameters such as ignition delay, pressure variation, peak pressure, peak pressure rate, and heat release rate are discussed. It is observed that while operating with 100% RBME and its petrol diesel blends, the running of the engine is smooth throughout the entire range of loads without any problems.

The ignition delay for diesel, RBME, and the blends of RBME and diesel oil at various loads shows fig. 2. It can be seen that all the fuels exhibit a general trend of decrease in ignition delay with increase in load. This may be due to the rise in the cylinder gas temperature at the time of injection with increase in load. It is observed that at no load condition the delay period for RBME decreases by 8% while its diesel blends show almost 2% decrease for every 20% addition of RBME when compared to diesel. At 50 and 75% of the rated load the delay period decreases by 10 and 20%, respectively, for RBME compared to diesel. It is also observed that for every 20% addition of RBME in the RBME diesel blend the delay period is decreased by almost 5% at all loads. This is due to the oxygen present in RBME and the break down of higher molecules of RBME to lower molecules of volatile compounds during injection and this advances the start of combustion resulting in decrease in ignition delay.

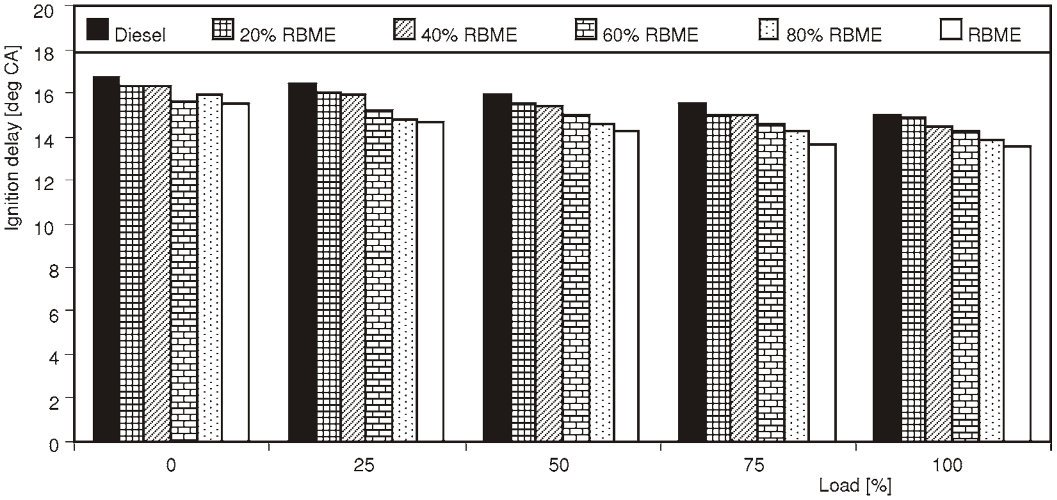

Figure 2. Comparison of ignition delay for diesel and different RBME blends

Figure 3 shows the variation of combustion chamber pressure with CA for various fuels used at rated load. Similar trends are observed at other loads also. RBME and its diesel blends exhibit slightly higher pressure at all CA compared to diesel. This is due to earlier ignition of RBME and its diesel blends, which results in earlier start of combustion and hence higher pressure values compared to diesel.

Figure 4 shows the cycle peak pressure variation for the various fuels used at different loads. It is observed that the peak pressure is not very much affected by using RBME and its diesel blends compared to diesel. The percentage increase in peak pressure is less than 1% for RBME and its diesel blends at all loads when compared to diesel. As seen in fig. 2, the ignition delay decreases with increase in percentage of RBME, and this results in earlier combustion consequently leading to higher peak pressures.

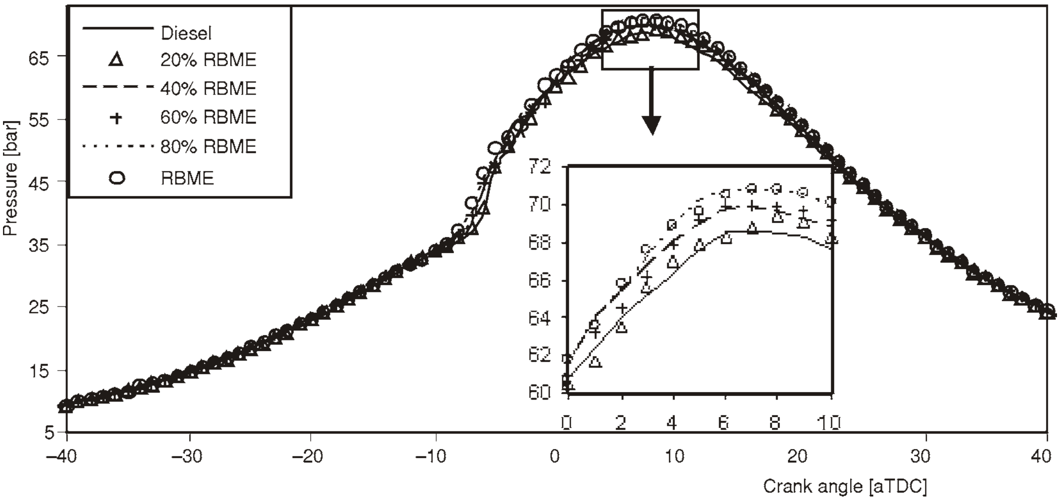

Figure 3. Comparison of pressure variations for diesel and different RBME blends

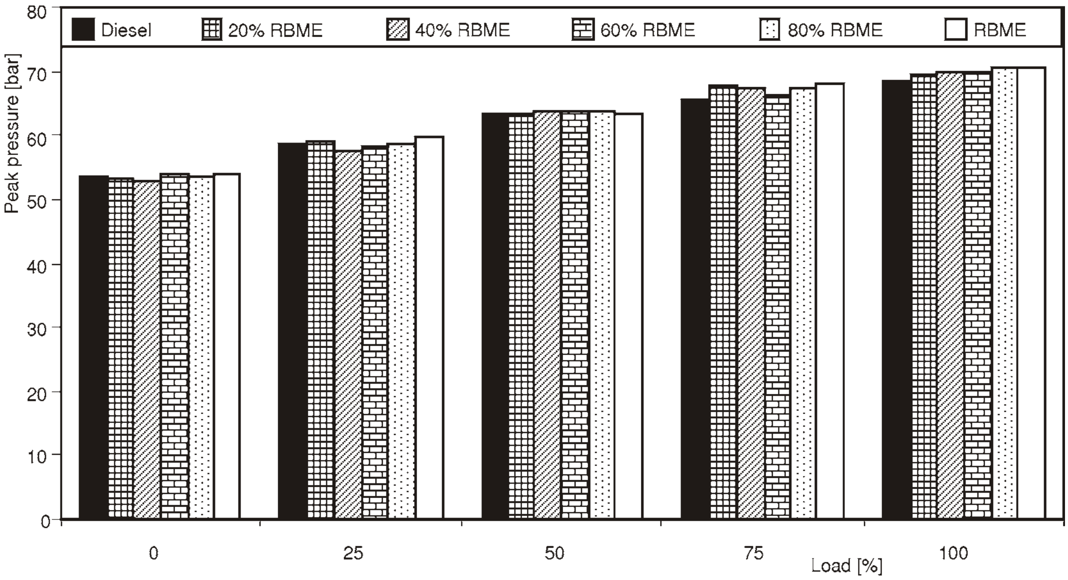

Figure 4. Comparison of cycle peak pressure for diesel and different RBME blends

Figure 5 shows the rate of pressure rise of different fuels at rated load with respect to CA. Diesel has a higher value of maximum rate of pressure rise compared to RBME and its diesel blends. It is also observed that, the maximum rate of pressure rise decreases with increase of RBME in the fuel. This may be a consequence of the decrease in ignition delay with increase in percentage of RBME in the fuel. The reduced ignition delay implies that the quantity of accumulated fuel during ignition delay is lesser than during higher ignition delay. Hence the pressure rise is not as drastic as in the case of diesel.

Figure 6 shows the rate of heat release of diesel, RBME and its diesel blends at rated load. The results show that the maximum heat release rate decreases with increase in percentage

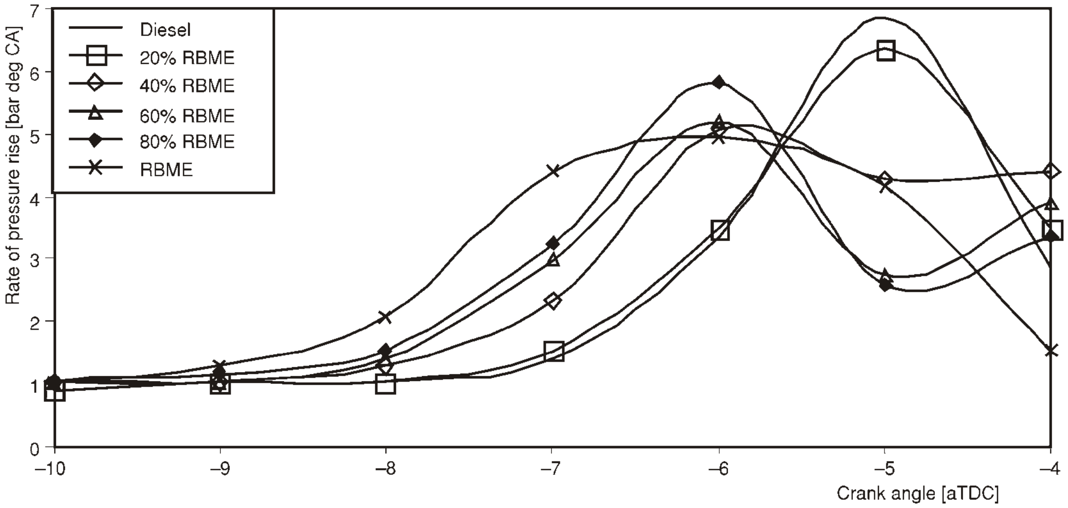

Figure 5. Comparison of rate of pressure rise for diesel and diferent RBME blends

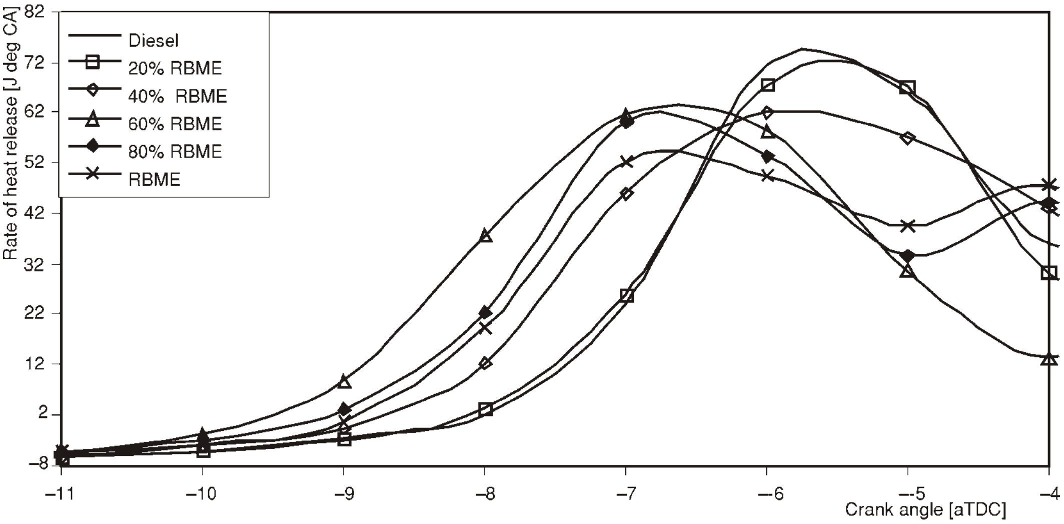

Figure 6. Comparison of heat release rate for diesel and different RBME blends

of RBME in the fuel. It can also be observed that maximum heat release rate occurs earlier with the increase in the percentage of RBME in the blend. This trend may also be attributed to the smaller ignition delay of RBME and its diesel blends and can be explained in a similar manner as rate of pressure rise.

Performance characteristics

Figure 7 showed that, the brake thermal efficiency of the various fuels increases with increase in load. The brake thermal efficiency is slightly higher (about 1%) for diesel compared to RBME and its diesel blends at all loads. The early initiation of combustion for RBME and its

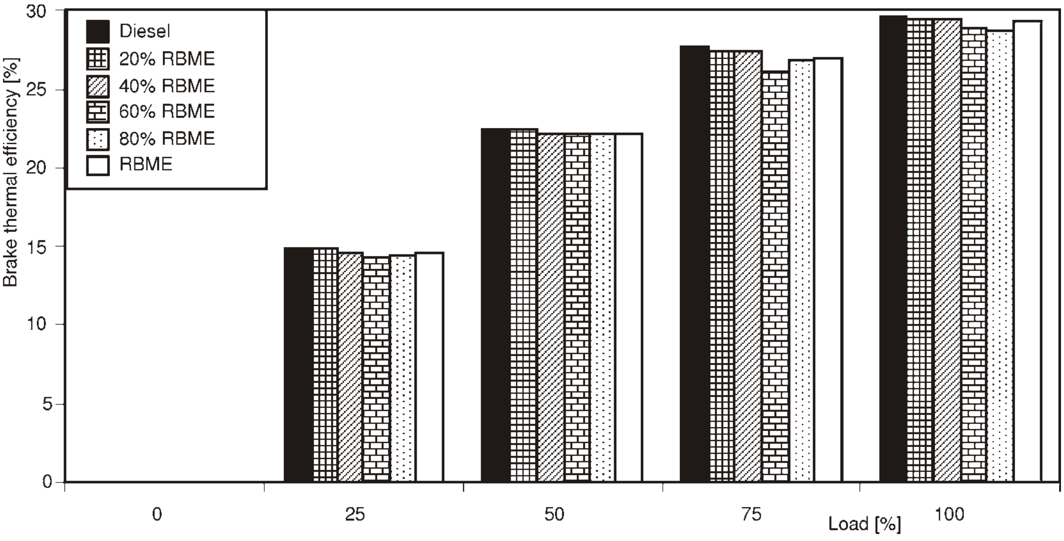

Figure 7. Comparison of brake thermal efficiency for diesel and different RBME blends

diesel blends may lead to a significant pressure rise before TDC and may contribute to increased compression work and heat loss resulting in a decreased brake thermal efficiency.

Emission characteristics

Variations of exhaust gas temperature with respect to load for different fuels are shown in fig. 8. From the figure it can be observed that the temperature of RBME and its diesel blends are slightly higher than that of diesel. For 20% RBME blend the increase in temperature is 1% at all loads when compared with diesel. Further increasing the concentration of RBME in the RBME diesel blends shows a 2% increase in the temperature for 20% addition of RBME and the increase is maximum for RBME when compared with diesel at all loads. This may be attrib-

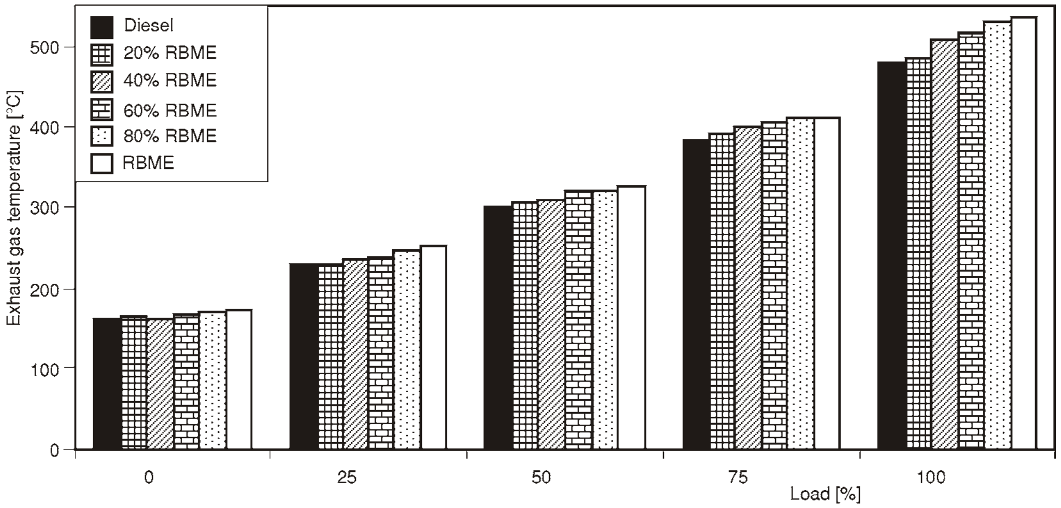

Figure 8. Comparison of exhaust gas temperature for diesel and different RBME blends

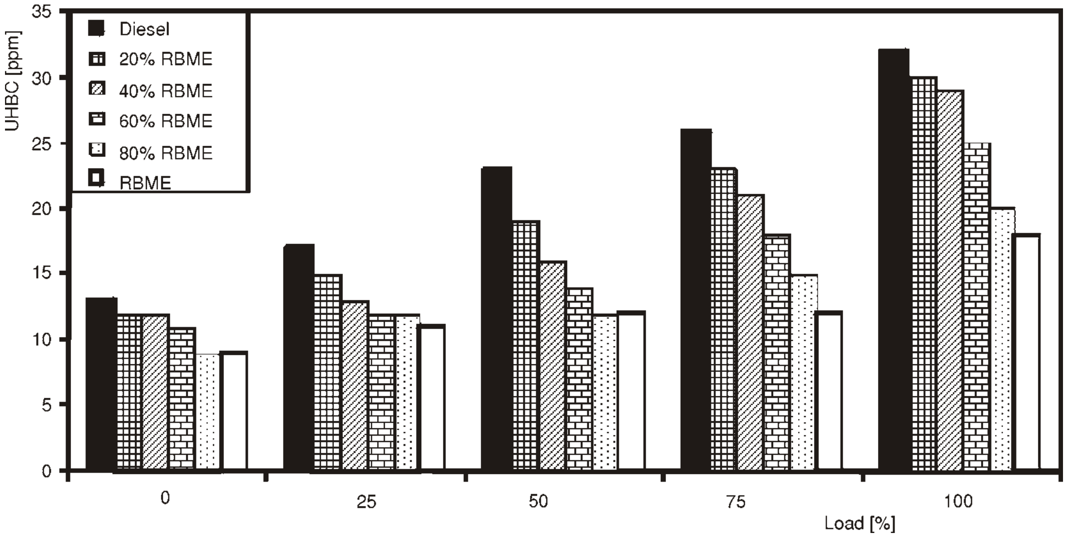

Figure 9. Comparison of UBHC emission for diesel and different RBME blends

uted to the higher oxygen content of RBME, which might accelerate the combustion process and in turn increases the combustion temperature and the exhaust temperature.

Figure 9 shows the comparison of UBHC emissions of the various fuels at different loads. From the figure it is clear that there is a general trend of increase in the UBHC emissions as the load increases. This trend is, perhaps, due to presence of fuel rich mixture at higher loads. It can be seen that at no load the UBHC emission is reduced by 30% for RBME compared to diesel while other blends show similar reduction. At 50% and 100% load RBME shows 50% reduction compared to diesel while the increase in percentage of RBME in the blend continuously reduces UBHC emissions by almost 10% for every 20% increase in RBME in the blend.

Figure 10 shows the comparison of CO emissions of the various fuels at different loads. From the above figure it is clear that there is a general trend of increase in the CO emis-

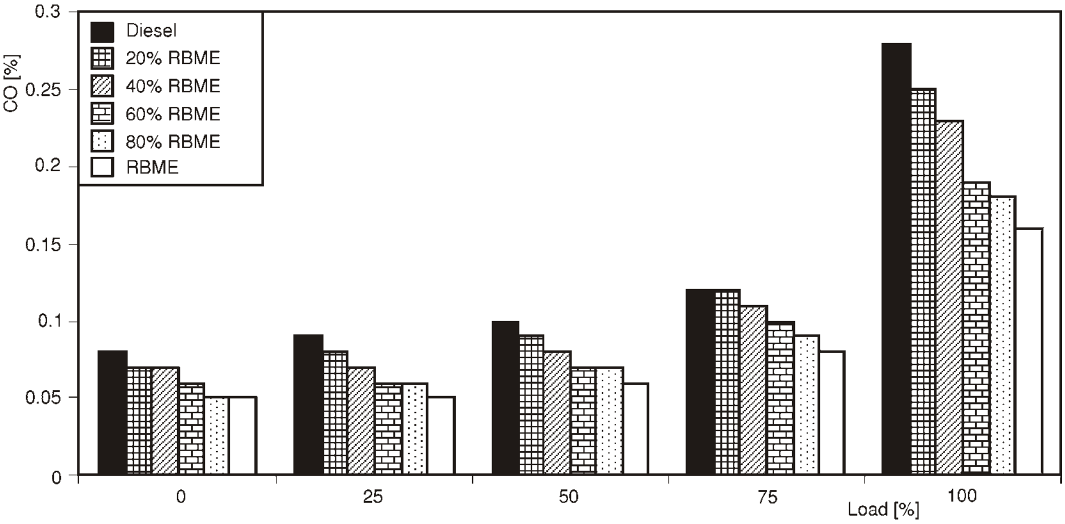

Figure 10. Comparison of carbon monoxide emissions for diesel and different RBME blends

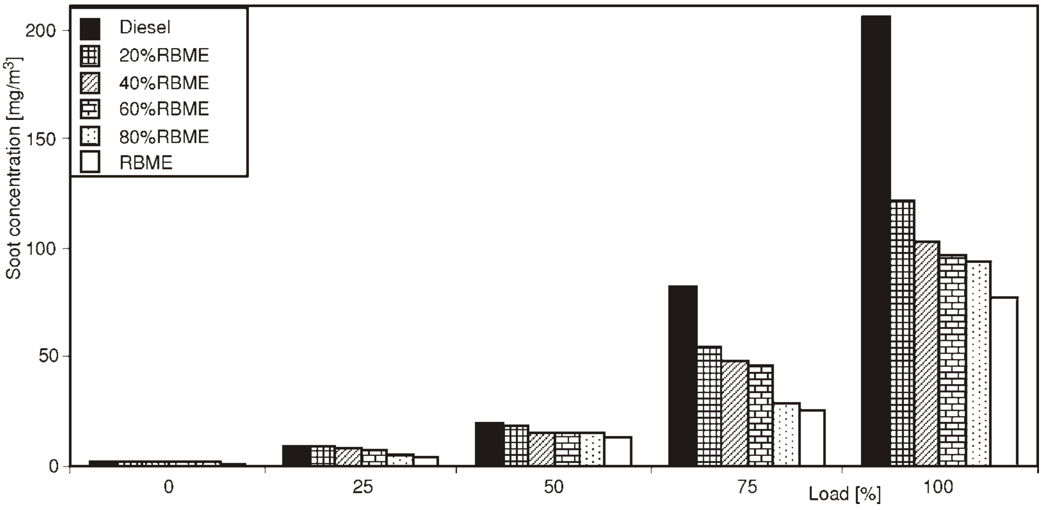

Figure 11. Comparison of soot concentrations for diesel and different RBME blends

sions as the load increases. This trend is, perhaps, due to presence of fuel rich mixture at higher loads. It is also observed that CO emission is function of the percentage of RBME in the blend. For every 20% addition of RBME in the blend the CO emission is reduced by almost 10% and reaches a maximum of 40% reduction for RBME when compared with diesel at all loads.

Figure 11 shows the comparison of soot concentration of the various fuels at different loads. From the figure it is clear that there is a general trend of increase in the soot concentrations as the load increases. This trend is, perhaps, due to presence of fuel rich mixture at higher loads. It can be seen that at 25% load RBME diesel blends show a reduction in soot concentration and RBME shows maximum reduction of 50% when compared with diesel. At 75% and 100% load RBME shows more than 60% reduction in soot concentration when compared with diesel. It is observed that nearly 40% reduction of soot concentration is obtained for every 20% addition of RBME in the blend at all loads.

Figure 12 shows the comparison of NO_x emissions of the various fuels tested at various loads. The general trend observed is that the emission of NO_x increases with load. It is observed that RBME shows 30% higher value of NO_x emissions when compared with diesel. It is also observed that 2-5% increase in NO_x emission is obtained for every 20% addition of RBME in the blend at all loads. Being an oxygenated fuel, the RBME also supplies oxygen in addition to the air inducted into the combustion chamber and therefore aids in the formation of NO_x. The higher combustion temperature of RBME and its diesel blends may have also contributed to the higher NO_x emissions.

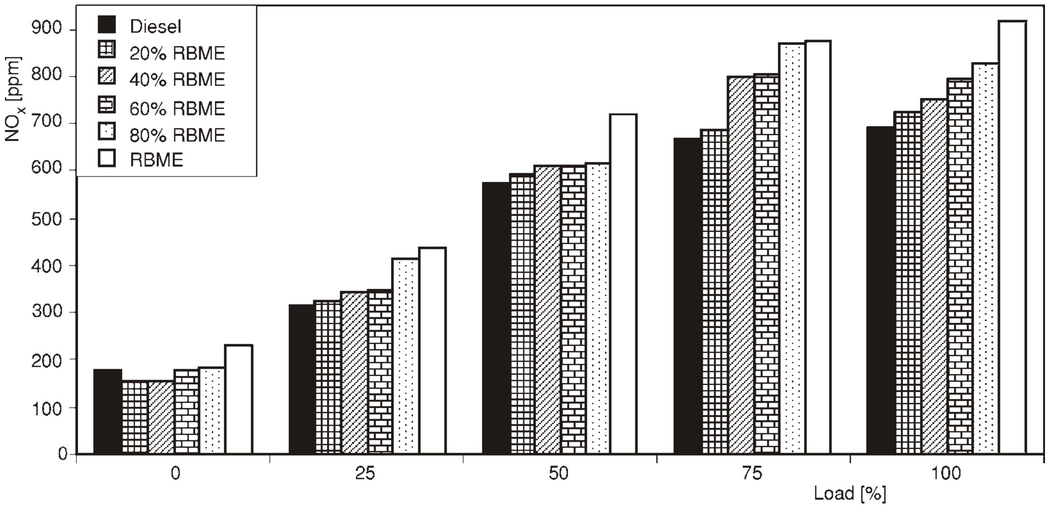

Figure 12. Comparison of NO_x emissions for diesel and different RBME blends

Conclusions

Based on the obtain results the following conclusions can be drawn.

(1) The performance, emission and combustion characteristics of single cylinder DI diesel engine when fuelled with diesel, RBME and its diesel blends are investigated.

(2) The ignition delay and peak heat release for RBME and its diesel blends are found to be lower than that of diesel and the ignition delay decreases with increase in RBME in the

blend. Maximum heat release is found to occur earlier for RBME and its diesel blends than diesel.

(3) The brake thermal efficiency of the RBME and its diesel blends are slightly lower than that of diesel.

(4) As the amount of RBME in the blend increases the UBHC, CO, and soot concentrations in the exhaust decrease, which implies cleaner combustion of RBME and its diesel blends compared to diesel. The NO_x emissions of the RBME and its diesel blends are slightly higher than that of diesel.

(5) From the above analysis the main conclusion is RBME and its diesel blends are suitable substitute for diesel as they produce lesser emissions than petroleum diesel and have satisfactory combustion and performance characteristics.

(6) When comparing these results with sunflower oil methyl ester as a CI engine fuel [22] the same engine, RBME shows 41.9% reduction in NO_x emission, 12.9% reduction in the delay period, and 25% decrease in the rate of pressure rise for the same performance.

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Abbreviations

aTDC – after top dead centre
bTDC – before top dead centre
CA – crank angle
CI – compression ignition
RBME – rice bran oil methyl ester
RBO – rice bran oil
SI – spark ignition
TDC – top dead centre
UBHC – unburnd hydrocarbons

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