Combustion analysis of HCV engine with CRBME

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Abstract

Investigations were carried out to study the combustion characteristics of crude rice bran oil methyl ester (CRBME) derived from high free fatty acid (FFA) as a fuel for a heavy commercial vehicle (HCV) compression ignition (CI) engine . A four stroke, 6 cylinder direct injection 117.6 kW turbo-charged engine was used for the work. Tests were conducted at different speeds and torques starting from idle condition. It was observed that cylinder pressure variation of the engine when operating with the CRBME was comparable to that of diesel. Shorter delay period and lower peak pressure were obtained for CRBME when compared to diesel. Maximum heat release rate of CRBME was lower and occurs earlier than diesel. Experimental results show that as a fuel for a heavy commercial engine, CRBME shows comparable combustion characteristics as that of diesel and can be utilized as a substitute for diesel. When compared with other biodiesels CRBME is derived from non-edible source with more availability and hence efforts can be taken to utilize this potential of CRBME as an automotive engine fuel.

Keywords: *diesel engine, automotive engine, combustion, biodiesel, rice bran oil, delay period*

1. Introduction

Biodiesel derived from vegetable oil and animal fats is recognized as a promising alternate fuel for petroleum diesel. Several research works recommended the biodiesel as an alternate to diesel in neat and blended form without any engine modifications [1- 6]. Most of the research works are concentrated on single cylinder stationary diesel engines [1-5] and less work was focused on automotive engines [6].

In India there is a significant development in transport and industrial sector. Automotive vehicles manufactured increased dramatically during the past ten years. The cumulative production data for April-June 2011 shows 18.4 percent production growth for automobile industry and the overall commercial vehicles segment registered growth of 14.1 percent during April-June 2011[www.indianbusiness.nic.in]. This also increases the demand on diesel fuel and necessitates to extend the feasibility of biodiesels as a fuel for an automotive engine. Hence the present work investigates the suitability of biodiesel as an automotive engine fuel.

Biodiesel used in this investigation was derived from high free fatty acid (FFA) crude rice bran oil (CRBO) which is a non-edible vegetable oil derived from rice bran [7, 8]. Rice bran oil is extracted from rice bran, which is a by-product of rice milling process. Since rice is the staple food for most countries and as rice production is a renewable process, the availability of rice bran for oil extraction is renewable in nature. As per the global rice production rate, 7.25 Mt of rice bran oil per year can be extracted, which is 1% of the world's diesel consumption of 620 Mt for the year 2005 [7]. Only a small quantity (6.5%) of the extracted crude rice bran oil (CRBO) is subjected to any further refining process to make it suitable for edible purpose which is consumed in some Asian countries like India, Japan etc [7]. The higher free fatty acid (FFA) content of the remaining CRBO restricts its utility as edible oil. Hence CRBO with high FFA content can be utilized as a feedstock for biodiesel production and the obtained crude rice ban oil methyl ester (CRBME) can be utilized in a CI engine as an alternate to diesel fuel. [9-12]. The present investigation was carried out using CRBME as an automotive engine fuel. The measured properties of CRBME and conventional diesel fuel are given in Table 1. Table 2 shows the chemical formulae and molecular weights of fatty acids present in crude rice bran oil [13]. The main objective of this investigation was to investigate the combustion characteristics of heavy commercial vehicle (HCV) diesel engine fuelled with CRBME.

Table 1 Properties of CRBME compared with diesel

Fuel property	Diesel	**CRBME**	ASTM D 6751-07b
Viscosity at 40°C (mm^2/sec)	3.522	4.03	1.9 - 6
Flash point (°C)	70	169	130min.
Calorific value (kJ/kg)	43356	38853	~38912.7
Distillation temperature T90 (°C)	335	345	360 max
Specific gravity	0.8	0.89	0.88
Calculated Cetane Index	48.9	53.3	ASTM D 4737

Table 2 Chemical formulae and molecular weights of fatty acids present in crude rice bran oil

Name of Fatty acid	No of Carbon :Double bonds	Chemical Formulae	Molecular weight	Percentage by volume in the Oil [14]	Type of fatty acid and its percentage
lauric	C12:0	$C_{12}H_{24}O_2$	200.31	0.2	Saturated Fatty acids (19.2%)
Myristic	C14:0	$C_{14}H_{28}O_2$	228.37	0.8	
Palmitic,	C16:0	$C_{16}H_{32}O_2$	256.25	17.7	
arachidic	C20:0	$C_{20}H_{40}O_2$	312.52	0.2	
Behenic	C22:0	$C_{22}H_{44}O_2$	340.58	0.3	
Stearic,	C18:0	$C_{18}H_{36}O_2$	284.47	2.2	
palmitoleic	C16: 1	$C_{16}H_{30}O_2$	254.40	0.23	Mono-unsaturated Fatty acids (40.83%)
Oleic	C18: 1	$C_{18}H_{34}O_2$	282.45	40.6	
linoleic,	C18: 2	$C_{18}H_{32}O_2$	280.4	35.6	Poly-unsaturated Fatty acids (37.4%)
Linolenic,	C18: 3	$C_{18}H_{32}O_2$	278.42	1.8	

2. Materials and methods

2.1 Experimental Setup

Figure 1 shows the schematic diagram of the experimental setup of the HCV engine and the specifications of the engine as given in the manufacturers manual are given in Table 3. The HCV engine used in the investigation was Ashok Leyland Hino W06D-TI, 117.6 kW diesel engine. This type of engine is usually used in the transport and power sector. The engine was coupled to an ECB-450 450 HP eddy current, dry gap dynamometer with a U-joint coupler.

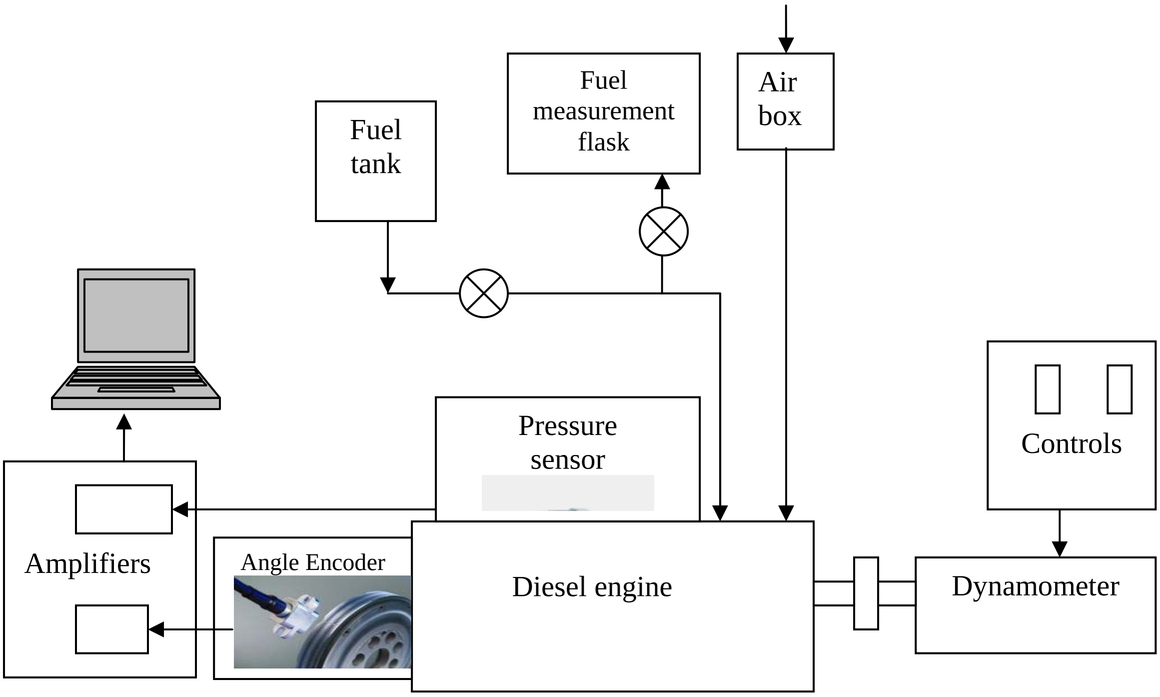

Fig. 1 Experimental setup

2.2 Measurement of Combustion Parameter

The pressure inside the combustion chamber was measured using an AVL GH12D miniature pressure transducer (sensitivity of 15 piezo charge (pC)/bar) connected to an AVL3066A02 Piezo Charge Amplifier. The pressure transducer was mounted on the cylinder head of one of the engine's cylinder (cylinder 1). The crank angle and the position of top dead centre (TDC) were measured using an AVL364 Angle Encoder (resolution of 0.5 deg. CA) mounted rigidly on the camshaft of the engine. The outputs of the charge amplifier and the encoder were connected to an AVL 615 Indimeter A/D card, which converts analog input to digital output. AVL 615 Indimeter software was used to analyse the output data of the A/D card. This generates a pressure-crank angle diagram that indicates the pressure variation with crank angle.

2.3 Emissions Measurement

Various constituents of exhaust gases like unburned hydrocarbons (UBHC), nitrogen oxides (NOx), and carbon di-oxide (CO_2) were measured with a 5-gas MRU 1600 Delta exhaust gas analyser. The analyser uses the principle of NDIR for the measurement of UBHC emissions while NO_x measurement was by means of electrochemical sensors. Smoke levels were measured with an AVL 415 variable sampling smoke meter.

Table 3 Specifications of the engine

Type	Diesel four stroke, 6 cylinder direct injection, inline over head valve
Aspiration	Turbo charged
Maximum output	117.6kW @ 2400 rpm
Maximum torque	490 Nm @ 1600 rpm
Bore	104 mm
Stroke	113 mm
Compression ratio	17.9:1
Injector Nozzle Type	Multi hole nozzle type
Injector Nozzle opening pressure	220 bar
Injection timing	11 deg. CA bTDC, No.1 cylinder on compression stroke

2.4 Test Procedure

Before starting the engine, the blowers and the entire cooling system were switched on. The engine was then started and allowed to run at idle speed. After attaining the steady state condition, the combustion parameters were recorded. Then the engine is throttled to increase the speed and the engine speed was varied in quantified steps to a maximum of 2300 rpm which is closer to the rated speed of the engine at rated power. At each speed, the engine was loaded through dynamometer by applying torque. Testing was carried out on the engine fuelled with diesel and CRBME at different torques and speeds.

3. Results and discussion

The results of the investigation on a HCV diesel engine with CRBME are discussed by comparing it with diesel.

3.1 Cylinder pressure

The variation of cylinder pressure with crank angle degree (CAD) for CRBME and diesel at brake mean effective pressure (BMEP) of 8.7 bar is given in Figure 2.

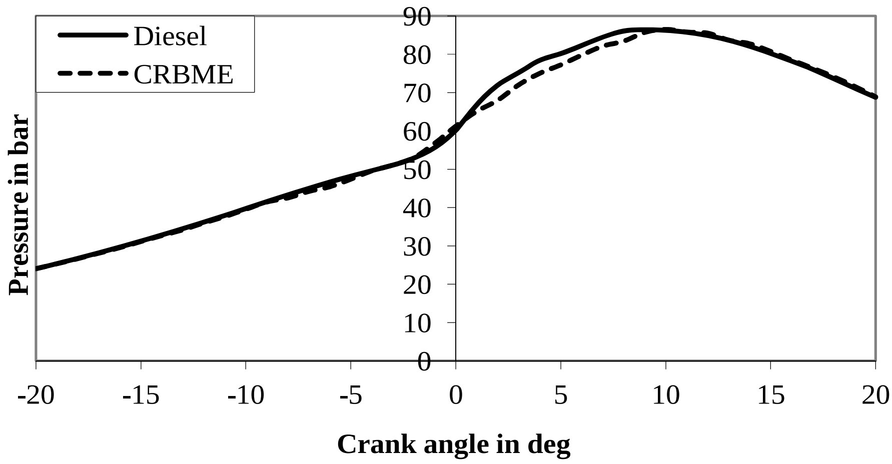

Fig. 2 Variation of combustion chamber pressure

It is observed that the CRBME shows lower pressure when compared to diesel. It can also be observed that CRBME shows a marginally higher pressure than diesel for small crank angle duration during the initial stage of combustion. This is due to their early start of combustion as evident from Figure 3 which shows a shorter delay period for CRBME compared to diesel at all BMEPs. This leads to a significant pressure rise before top dead centre (TDC) and further movement of the piston compresses the combustion products which increases the pressure obtained in the cylinder.

It can be observed that after the occurrence of peak pressure the CRBME shows a marginally higher pressure than diesel. This is due to the burning of higher molecular weight esters present in CRBME at higher temperatures [15]. This can be ensured from Table 2 which shows the molecular weight of fatty acids present in CRBO from which CRBME was derived. Similar trends were observed at other BMEPs also.

3.2 Delay period

Figure 3 shows the variation of delay period of CRBME with BMEP compared with diesel.

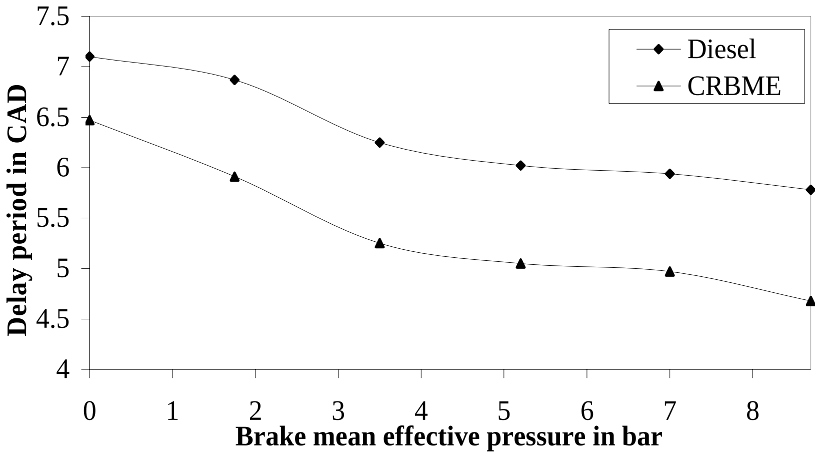

Fig. 3 Variation of delay period

It is observed that the delay period decreases with increase in BMEP for both the fuels. At higher loads the residual gas and the combustion chamber walls will be hotter which results in higher charge temperature during fuel injection, thus shortening the ignition delay [16]. It can also be observed that the delay period of CRBME is shorter by about 15 % than that of diesel. As the cetane number increases the delay period decreases. From Table 1 it can be seen that the cetane index of CRBME is higher than diesel which causes a shorter delay period than diesel. This shorter delay period is also due to the effective oxidation of CRBME as a result of its more unsaturated fatty acids content. Crude rice bran oil which is a feedstock for CRBME contains 80 % of unsaturated fatty acids. Fuel oxidation is directly proportional to the level of its unsaturation [17]. When exposed to an oxygen rich environment in the engine cylinder these unsaturated fatty acids become oxidised which increases the oxygen concentration of charge and reduces the ignition delay [16, 18]

3.3 Peak pressure

Figure 4 compares the cylinder peak pressure of CRBME with diesel at different BMEPs.

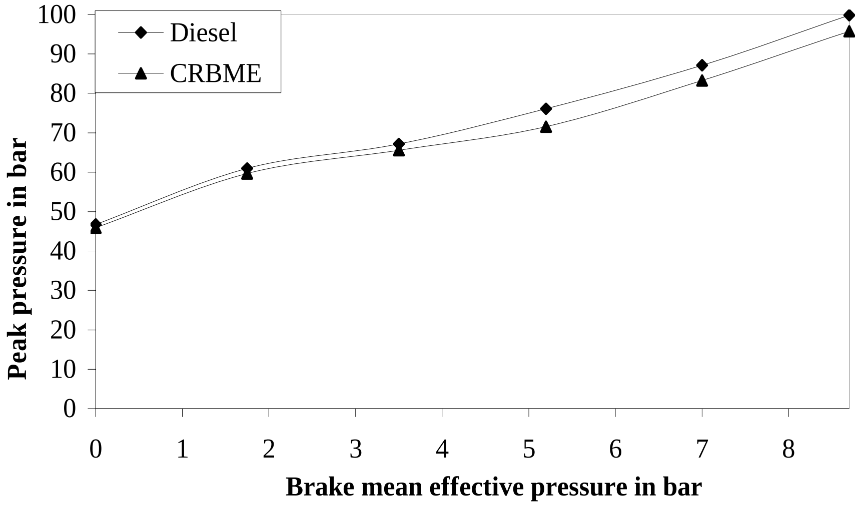

Fig. 4 Variation of peak pressure

It is observed that the peak pressure increases with BMEP for the tested fuels and the magnitude of variation between the fuels is marginal. The peak pressure depends on the ignition delay and also the heat released during combustion. It can be observed from figure 3 that, the delay period of CRBME is shorter compared to diesel and hence the amount of fuel injected during the delay period is less resulting in a lower energy release during combustion. This results in a lower peak pressure for CRBME compared to diesel.

3.4 Heat release rate

Figure 5 compares the heat release rate of CRBME with that of diesel at the maximum BMEP of 8.7 bar.

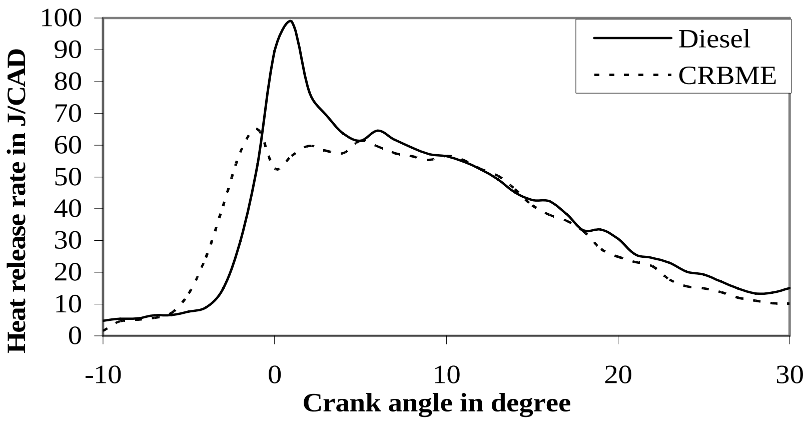

Fig. 5 Variation of heat release rate

The heat release curve is an indication of availability of heat energy which can be converted into useful work. It is observed that the maximum heat release rate for CRBME is less than that of diesel by about 34 %. The occurrence of maximum heat release rate for CRBME is advanced by 2 crank angle degree (CAD) than diesel. This is due to its shorter delay period. As a result of the early start of combustion the products get compressed by the movement of the piston during the end of compression stroke. This results in an increase in the heat release rate in CRBME for a smaller duration before TDC. An increase in the heat release rate for CRBME after TDC can also be noticed. It can be seen from Table 1 that the distillation temperature (T90) for CRBME is higher than that of diesel due to the higher molecular weight of ester present in CRBME. This higher molecular weight ester requires higher temperatures to complete the burning. From Figure 2 it can be seen that, the maximum pressure occurs after TDC and the maximum temperature also likely to occur after TDC. This supports the burning of higher molecular weight esters after TDC which increases the heat release rate of CRBME higher than diesel. Since the distillation temperature (T90) of diesel is lower than CRBME, burning will be completed earlier than CRBME.

3.5 Brake thermal efficiency

Figure 6 shows the variation of brake thermal efficiency with respect to BMEP for diesel and CRBME.

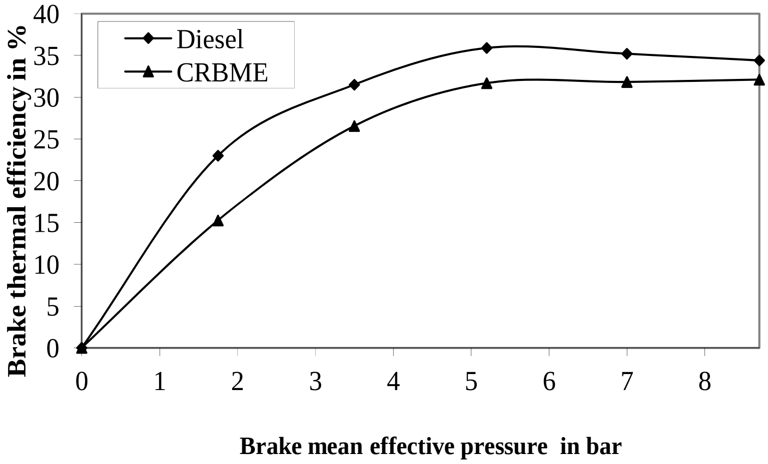

Fig. 6 Variation of brake thermal efficiency

From the figure it is observed that the brake thermal efficiency increases with increase in BMEP. This is due to the increased quantity of fuel burned at higher BMEPs. The brake thermal efficiency for CRBME is lower by about 8 % when compared to diesel. The oxygen present in CRBME initiates the combustion earlier than diesel [15, 19] which may lead to a significant pressure rise before top dead centre (TDC) and may also contribute to increase compression work and heat loss resulting in a decreased brake thermal efficiency. While running with CRBME the efficiency is lesser than diesel at all BMEPs due to its lower energy content when compared to diesel.

3.6 Brake specific energy consumption

Figure 7 shows the variation of brake specific energy consumption (BSEC) with respect to BMEP for diesel and CRBME. SEC is a function of efficiency of energy conversion and calorific value. From the figure it is observed that the SEC decreases with increase in BMEP. This is due to the decrease in brake specific fuel consumption at higher BMEPs. The BSEC with CRBME is higher compared to that of diesel at all BMEP's. The BSEC for CRBME is higher by about 18 % compared to diesel. This is due to their lower calorific value and higher density. Lower calorific value requires larger fuel flow rates to maintain constant energy input to the engine

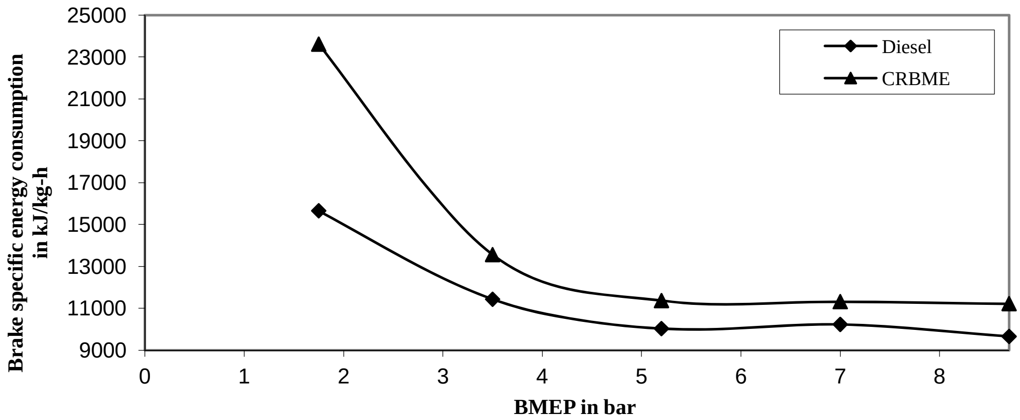

Fig. 7 Variation of brake specific energy consumption

3.7 UBHC emission

Figure 8 compares the unburnt hydro carbon (UBHC) emission of CRBME with that of diesel. It is observed that both the fuels tested the UBHC emission increases with increase in BMEP. As the BMEP increases, the quantity of fuel injected increases and hence the UBHC emission starts increasing with BMEP. It is also observed that the UBHC emission of CRBME is lower than diesel by about 64 %. As an oxygenated fuel CRBME improves the combustion process inside the engine cylinder and promotes oxidation. This results in reduced UBHC for CRBME compared to diesel.

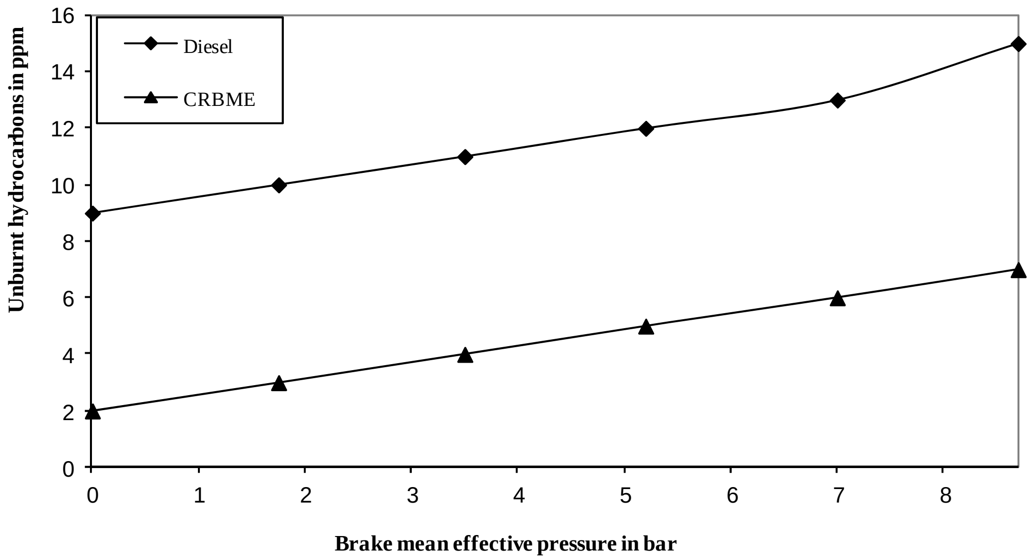

Fig. 8 Variation of UBHC emission

3.8 Smoke density

Figure 9 compares the smoke density of CRBME with that of diesel at various BMEPs. It is observed that smoke density increases with BMEP for all the fuels and at lower BMEPs (upto 4 bar) the variation between the fuels is marginal. At higher BMEPs the fuel injected into the cylinder is high which increases the fuel - air ratio of the mixture and smoke emission. It is also observed that the CRBME shows lower smoke emission when compared to diesel. Even though the fuel - air ratio of the mixture increases with BMEP, the oxygen present in CRBME reduces this ratio which reduces the smoke density.

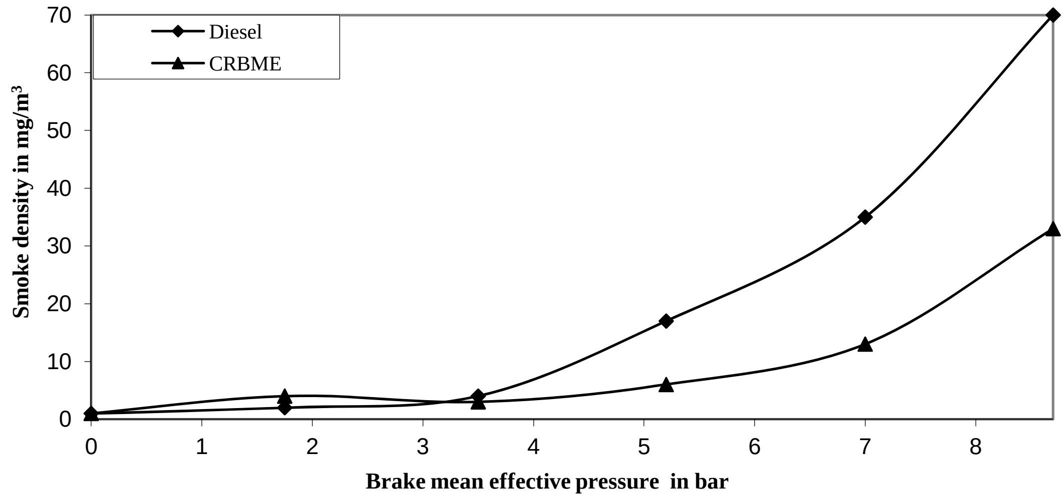

Fig. 9 Variation of smoke density

3.9 NOx emission

Figure 10 shows the variation of NOx emission with respect to BMEP for diesel and CRBME. It is observed that NOx emissions of both the fuels increase with BMEP. It is also observed that NOx emission of CRBME is higher than diesel by about 17 %. As a result of improved combustion, the combustion temperature will be high for CRBME. Oxygen present in CRBME increases the availability of free oxygen which results in higher NOx emission than diesel when the engine is fuelled with CRBME. The variation in NOx emission between diesel and CRBME is due to the oxidation of unsaturated fatty acids (especially poly-unsaturated fatty acids) present in CRBME at higher temperatures which reduces the fuel - air ratio of the mixture and hence results in an increase in the maximum temperature attained in the cylinder. As a result of this the NOx emission of CRBME is marginally higher than diesel.

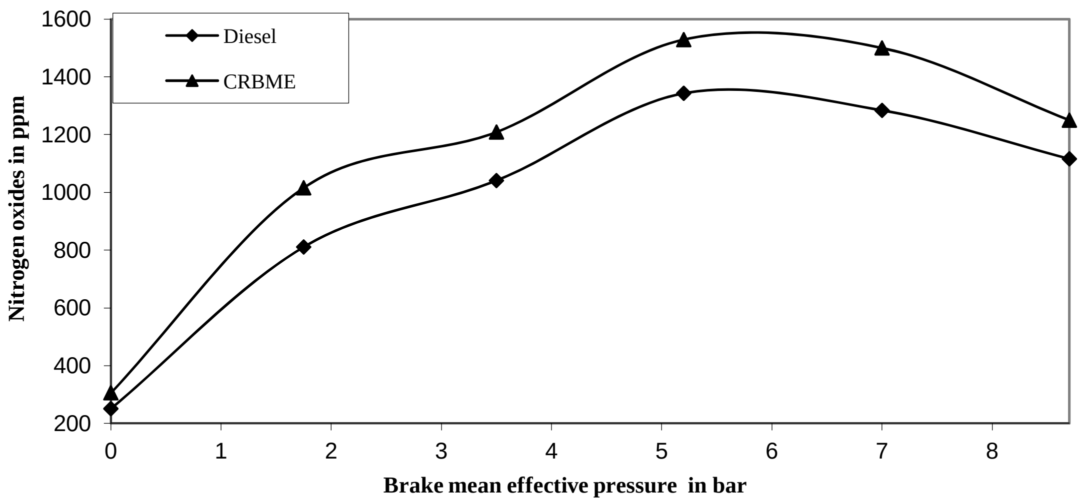

Fig. 10 Variation of NOx emission

4. Conclusions

In the present investigation attempt was made to utilize the biodiesel derived from a non-edible vegetable oil which is available in plenty as a fuel for a heavy commercial vehicle engine. As a HCV engine fuel brake thermal efficiency of CRBME was comparable and marginally lesser than that of diesel. This shows its suitability as an alternative source to diesel fuel. CRBME also shows comparable combustion characteristics as that of diesel with significant reduction in UBHC, and smoke density which ensure its suitability as a HCV engine fuel without any engine modifications.

Since CRBME is derived from a non-edible source with more availability it can be utilized as a HCV engine fuel from renewable source of energy.

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