R. Raja Sekar ✉
R. Srinivasan
K.Muralidharan

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INVESTIGATION OF THE PERFORMANCE AND EMISSION CHARACTERISTICS OF CEIBA PENTANDRA BIODIESEL BLENDS IN A VARIABLE COMPRESSION RATIO ENGINE

Summary

In the current scenario, the production of biodiesel from non-edible oil is a promising way to overcome the problems associated with the energy crisis and environmental issues. In this research, non-edible biodiesel blends of B10, B20, B30, B40, and B100 methyl esters of Ceiba pentandra oil with standard diesel fuel are used to investigate the performance, combustion and emission characteristics of a variable compression ratio engine at different load conditions compared to diesel. The compression ratios 16.5:1, 17.5:1, 18.5:1 are employed in a 1500 rpm constant speed, single-cylinder with a variable compression ratio, direct injection, four-stroke diesel engine for experimental investigation. Performance and combustion characteristics such as brake specific energy consumption, brake thermal efficiency, net heat release rate and emission characteristics such as carbon monoxide, carbon dioxide, hydrocarbons and oxides of nitrogen are investigated. The biodiesel blend B10 and B20 showed optimal performance with fewer emissions.

Key words: *methyl esters of Ceiba pentandra oil, compression ratio, emissions performance, variable compression ratio engine*

1. Introduction

Energy has played a significant role since the start of human evolution [1]. Among various energy sources, fossil fuels contribute 80% of global energy demand. The abundant availability of fossil fuels and the use of diesel engines have lulled the world into forgetting about the environmental impacts and global warming. For the past three decades, the decline of fossil fuel reserves and rigorous emission regulations imposed by local governments have encouraged researchers to examine alternative resources to face the global energy crisis and reduce the environmental impacts of diesel engine emissions.

According to the International Energy Agency report (2015), biofuels and waste contributed 10.2% of the world's total primary energy demand in 2013 [2]. Biodiesel is a mono-alkyl ester of long-chain fatty acids obtained from animal fat or vegetable oil [3, 4] which can be mixed with any kind of diesel and is considered to be a potential alternative fuel. Among all non-edible oils, Jatropha curcas oil biodiesel B20 is used directly in existing engines as a substitute fuel in many countries [5]. For a greener environment, using biodiesel in a compression ignition (CI) engine is an optimal resource that contains more oxygen (O_2) and produces fewer emissions of carbon monoxides (CO), hydrocarbons (HC), and smoke [3]. The features of biodiesel that make it a renewable resource, safer to store, one that is clean burning, carbon neutral, free from toxic gases and sulphur have prompted researchers to use it in IC engines as an alternative fuel [3]. A study conducted in the US in 2010 reported a decline in greenhouse emissions of between 57 and 86% [6]. Adopting variable compression in an IC engine offers superior performance, an increase in fuel efficiency and only minor emissions of harmful gases, for example, HC, CO, carbon dioxide (CO_2), and oxides of nitrogen (NO_x) for entire load conditions [7]. A variable compression engine (VCR) fuelled with biodiesel offers improved control at peak cylinder pressure and thus a reduction in fuel consumption, power, noise, friction, and particulate emissions (PM) [8]. A higher compression ratio (CR) of 18:1 gives better results in terms of performance than a CR of 16:1. However, by varying the CR from 14 to 18 gradually, the brake thermal efficiency (BTE) also increases by 7% for all blend ratios of Karanja biodiesel [9]. Karanja oil was used as fuel in a VCR engine with CR15, 16, 17, and 18, and observations revealed that at CR18, the engine performance was better with higher BTE for the B25 blend. [10]. The blends of Jatropha and Karanja mixed with diesel were used as fuel in a VCR direct injection (DI) diesel engine with CR 16 and 18, and K20J40D showed fewer NO_x emissions [11]. Waste cooking oil offers higher combustion pressure at a high CR [12].

The Ceiba pentandra or kapok tree belongs to the Malvaceae family and contains high percentages of monoalkyl fatty acid esters which make it a prospective non-edible alternative fuel in diesel engines [13]. The Ceiba pentandra methyl ester (CPME) possesses superior calorific value (CV), viscosity, flash point, cloud point, and pour point. The cetane number of Ceiba pentandra oil is found to be like that of diesel which conforms with the ASTM 6751-02 and ASTM 6751-08 standard and can be used as a potential alternative fuel [14]. Non-edible Ceiba pentandra feedstock has great potential for second-generation biodiesel production in Malaysia for the next 20 years, up to 2038 [15]. Experiments have been conducted with B20, B30, B40 and B100 blends of kapok oil methyl ester (KOME) in a single-cylinder DI diesel engine. It has been reported that the BTE of the B30 blend is similar to that of diesel, although a higher exhaust gas temperature (EGT) and brake specific fuel consumption (BSFC) was observed [16]. A single-cylinder VCR engine operated with a B10, B20, B30, and B40 blend of silk cottonseed oil and B10 fuel was found to be optimum and at an injection timing order of 18° bTDC. Here, the CO emissions were nearer to those of diesel [17]. The various blends of Kapok methyl ester (KME) with a CR of 17.5:1 showed that the lean blend of KME had better fuel atomization and lower viscosity, resulting in full combustion. BTE, TFC (total fuel consumption) and specific fuel consumption (SFC) increased with an increase in the concentration of blends and an increment in engine loads [18, 8]. CPME with a blend ratio of B25, B50, B75, and B100 powered a DI single-cylinder diesel engine under full load conditions with a constant CR of 17.5:1. The B25 blend showed a 6.2% increment in BSFC and a reduction in BTE, CO, HC, NO_x and suggested that a B25 biodiesel blend can be used as a substitute fuel [19]. KME biodiesel was tested in a single-cylinder diesel engine with a constant CR of 17.5:1 and it was found that the thermal efficiency of the engine is 4% greater and the emission and combustion data are analogous with diesel for the B25 blend. The increments in the blend ratio cause a minor decline in BTE [13]. The Ceiba pentandra oil methyl esters (CPOME) biodiesel blends B10, B20, B30 and B40 were fed into a VCR engine and it was found that the increase in CR led to an increase in BTE for the B10 fuel blends. At CR 18, a rise in CO_2, HC, and NO_x was observed with a longer ignition delay [6].

After reviewing the literature, it was noticed that broad research has been carried out globally on diesel engines with a constant CR using diesel, bio-diesel, or its blends. But no literature highlights the drawback of using biodiesel in an engine at a constant CR [6]. To increase fuel efficiency and engine performance and to minimize harmful emissions [7], a VCR engine can be operated with biodiesel blends by varying the CRs as needed. The effect of the CR has a significant effect on the BSFC [18]. Mostly, when more than two test fuels possess a similar CV and similar density values, then the BSFC is the opt parameter that can be recommended to evaluate the performance of the engine. But for fuel blends with a different density and CV values, instead of the BSFC, using brake specific energy consumption (BSEC) can be the right indicator for the performance study of the engine [20]. Ceiba pentandra biodiesel showed superior CV, augmented engine performance, viscosity, and flash point, BTE, BSFC, and TFC with minor emission characteristics. A superior kinematic viscosity with a value of 4.5 mm^2/s of Ceiba pentandra methyl ester has been noted. From the literature, it is apparent that most of the researchers employed diverging blending ratios of B10, B20, B30, B40, B50, B60, B75, B80, and B100 for engine testing. It has been consistently found from the literature study that a few researchers have adopted a constant compression ratio in VCR engines fuelled with CPOME biodiesel. So this work mainly concentrates on variable compression ratios aimed at investigating the optimal CR and blend ratio suitable to run VCR diesel engines. This testing was conducted to experimentally investigate underutilized non-edible Ceiba pentandra biodiesel and methyl esters of Ceiba pentandra oil biodiesel (MECPO) with variable CRs 16.5:1, 17.5:1, and 18.5:1 in a VCR engine and the impacts of these biodiesel blends on the performance and emission characteristics of engines fuelled with B0 (100% neat diesel), B10(MECPO-10%+Diesel-90%), B20(MECPO-20%+ Diesel-80%), B30(MECPO-30%+Diesel-70%), B40(MECPO-40%+Diesel-60%), B100 (MECPO-100%). The above CR combinations with these MECPO blends have not so far been studied. Therefore, in this research, an attempt was made to conduct an experimental investigation in this field to study VCR engine performance and emission parameters.

2. Materials and Methods

Ceiba pentandra is generally called Kapok or silk cotton. In India from the ancient period, Ceiba pentandra cotton has been used to stuff pillows and mattresses. The seeds of Ceiba pentandra were collected from local pillow and mattress manufacturers from the villages in Dindigul and nearby districts of southern Tamilnadu in India. The oil is extracted using a mechanical crusher from the local oil extraction units. The oil yield is 22% to 25%. The optimum methyl ester yield obtained for MECPO is 95.44%. The total yield of oil can be calculated as a weight percentage by the ratio between the weight of oil extracted and the weight of seeds [13]. The tree, pods, and dry seeds are shown in Figure 1.

2.1 Transesterification

In the nozzle, forceless cavitation, a low injection jet spray, a bigger size of droplets, and the lower accessibility of the nozzle tip are detected when biodiesel is used as fuel [21]. This is due to its highly viscous nature, higher density, and higher volatility. Hence, using straight vegetable oils directly in the engine is restricted [19]. To reduce the viscosity and density of straight vegetable oils, transesterification is a broad, suitable and promising method. In this work, CPO was transesterified to obtain MECPO using the addition of a methoxide solution (methanol + potassium hydroxide) to CPO using a standard procedure. Glycerol was separated from biodiesel. The esterified vegetable oil (biodiesel) was heated to 110°C under a vacuum to remove leftover moisture after the water wash. The final clear, light-yellow liquid biodiesel methyl esters of Ceiba pentandra oil (MECPO) were produced in-laboratory and are shown in Figure 2. The presence of cyclopropene fatty acids in Ceiba pentandra leads to higher viscosity, and thus quicker oxidation of the biodiesel occurs compared to palmitic acid [18]. The physical and chemical properties of raw CPO, 100%

MECPO compared with standard diesel, are given in Table 1. They were experimentally investigated in our laboratory using standard laboratory procedures. Table 2 shows the fatty acid content of the MECPO 100% biodiesel blend.

Fig. 1 Ceiba pentandra - Tree, Pods & seeds

Fig. 2 MECPO Biodiesel Preparation

Table 1 Physical and thermal properties of MECPO, diesel & raw CPO as per ASTM standard D6751-08

Properties	Diesel	Raw CPO	MECPO (B100)	Biodiesel Standard
Density (kg/m^3)	840	980.7	859.43	850-900
Kinematic viscosity (mm^2/s)	3.35	6.2	4.2	1.9-6.0
CV (kJ/kg)	41000	30850	39000	37000-42500
Flash Point(°C)	54	298	172	130
Fire point (°C)	64	315	192	130
Cloudpoint (°C)	-28 to -7	1	3	-3 to 12
Pour point (°C)	-5.62 to 11.1	5	-2	-15 to 10
Cetane Number	49	37	48	-

3. Experimental Procedure

The schematic arrangement of the test engine with its parts is detailed in Figure 3 and the test engine specifications are tabulated in Table 3. The fuel characteristics were investigated using a Kirloskar make TV1 single-cylinder VCR engine four-stroke, vertical, water-cooled diesel engine at a constant speed. The emissions of CO, HC, CO_2, O_2, and NO_x were measured using an AVL DI GAS 444N gas analyzer with a measuring range of 0-10% vol for CO, 0-20000 ppm vol for HC, 0-20% vol for CO_2, 0-22% vol for O_2 and 0-5000 ppm vol for NOx. An AVL 437C continuous flow smoke meter measuring a range of 0-100% with a resolution of ±1 was used to measure the smoke opacity. The tests were performed for B0, B10, B20, B30, B40, and B100 in a VCR engine at steady conditions by varying the compression ratio of 16.5, 17.5, and 18.5 and the results were recorded. The engine performance analysis software package ENGINESOFT LV was used to acquire data from the engine. The loads were varied and the procedure repeated for 0%, 20%, 40%, 60%, 80% and 100% load conditions. In most literature, 23°CA bTDC is kept constant for various biodiesel fuel blends [22, 23]. In this study, injection timing of 23°CA bTDC was also adopted for all observations of the engine testing. The fact that the CV of the MECPO biodiesel blends is more likely equal to standard diesel fuel was the prime reason to maintain the constant injection timing. Before starting the experimental observation, the engine was warmed up to reach the steady-state condition by making it run for 5 minutes. For precise and reliable data, the experiment was repeated 3 to 4 times for each biodiesel blend at every CR value for the same operating conditions. From this set of observations, the optimum output data was taken for analytical purposes. The particular CR values were adjusted every time by tilting the block by loosening the Allen bolts provided in the engine. The setup facilitated the study of the BP, indicated power (IP), frictional power (FP), BMEP, IMEP, BTE, EGT, indicated thermal, mechanical, and volumetric efficiency, SFC, air-fuel (A/F) ratio, and heat balance for the VCR engine

Table 2 Fatty acid composition of CPO & MECPO

Sl. No	Parameters	Results	
		MECPO	CPO
1	Arachidic acid	0.8%	0.89%
2	Capric acid	9.42%	Nil
3	Lauric acid	0.1%	0.1%
4	Linoleic acid	30.00%	35.1%
5	Linolenic acid	1.2%	1.3%
6	Malvalic acid	7.34%	9.1%
7	Myristic acid	0.22%	0.1%
8	Oleic acid	17.88%	19.6%
9	Palmatic acid	23.17%	23.2%
10	Stearic acid	4.73%	3.2%
11	Sterculic acid	2.64%	2.8%

Table 3 Test Engine Specifications

Make	Kirloskar
Model	TV1
Type	VCR engine
No. of cylinders	Single
Strokes	Four
Engine cooling system	Water cooled
Ignition	CI
Fuel	High speed diesel
Bore Dia	87.5mm
Compression ratio	12:1 to18:1
Stroke Length	110 mm
Nozzle opening pressure	200 bars
Injection timing	23° CA bTDC
Brake power @1500 rpm	3.5 kW
Speed	1500 rpm
Loading	Eddy current Dynamometer

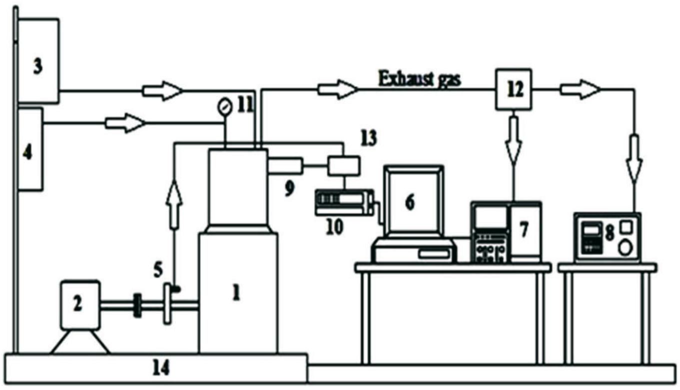

Fig. 3 Schematic arrangement of the test engine

4. Results and Discussion

In this research, the engine performance and emission characteristics of biodiesel at different engine speeds and loads for various biodiesel blend ratios compared with diesel fuel were investigated. Characteristics such as BSEC, BTE, CO, CO_2, HC, NO_x and NHRR were investigated and discussed for various MECPO biodiesel blends fuelled in a VCR engine.

4.1 Brake Specific Energy Consumption

The graph plotted in Figure 4 depicts the brake specific energy consumption of MECPO biodiesel in contrast to the load. BSEC is defined as the amount of supplied energy in kilo Joules (kJ) or Mega Joules (MJ) to operate an engine to generate one kilowatt of output power in one hour. BSEC can be estimated by using the formula below:

$$BSEC = \left(\frac{(TFC \times 3600)}{BP} \right) \times CV \; in \; \text{MJ/kWh}, \tag{1}$$

where BSEC is the brake specific energy consumption, BP is the brake power of the engine and CV indicates the calorific value of the test fuel blends [20]. The increase in CR trims down the BSEC value at all load conditions, as shown in Figure 4. This is due to rich combustion and complete atomization. In the graph, BSEC at a 0% load condition is not estimated, as BP is in zero kW. However, MECPO biodiesel blends exhibit higher BSEC than diesel fuel at all load conditions, but as the load increases, there is a decline in BSEC. From the graph, it is apparent that the higher blend ratio such as B30, B40, and B100 showed higher BSEC than other blends. The probable reason for this is a lower CV and the higher kinematic viscosity of the biodiesel blends, a low atomization rate, and more fuel required to compensate for the similar output of diesel [24, 25].

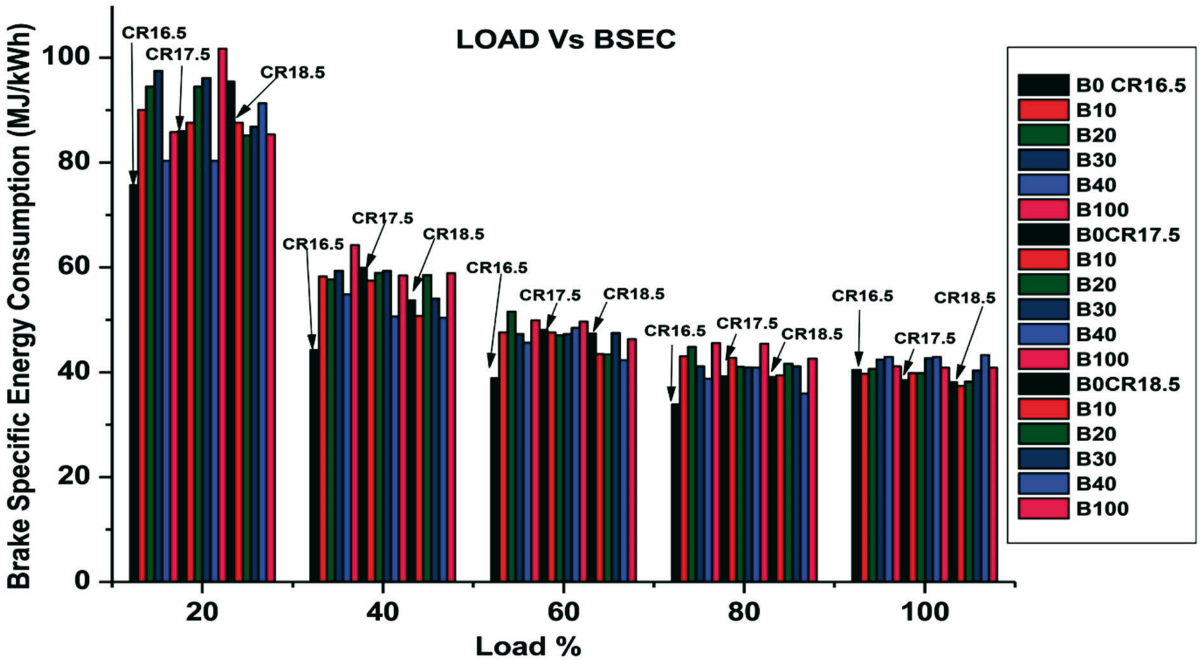

Fig. 4 Comparative analysis for Load Vs BSEC at CR16.5, CR17.5 & CR18.5

4.2 Brake Thermal Efficiency

The investigation of brake thermal efficiency correlated with the BP for CR16.5, CR 17.5, and CR18.5 is plotted in Figure 5. BTE rises as the load increases. The improvement in BTE with the engine load was due to the lower amount of power utilized at an enhanced engine load. The investigation indicates that BTE increases with an increase in the CR. The higher BTE for B10 and B20 at CR18.5 at 33.18% and 33.51% are detected respectively and an elevated BTE for the B20 blend is noted at all CRs. The trend of complete combustion, reduced ignition delay and the better lubricity properties of MECPO lead to higher BTE at higher CRs [26]. At lower CRs, the air-fuel mixtures are not stable owing to the tendency of poor combustion. The BTE of the MECPO blends B10, and B20 for CR18.5 is observed to be high at a maximum load condition and slightly higher than diesel. The boost in BTE is due to improved peak pressure and the combustion temperature. The B30, B40, and B100 MECPO blends showed lower performance due to the existence of O_2 in the MECPO blends. The presence of O_2 in the biodiesel blends raises the supply of fuel and so the reduction in the combustion process leads to lower BTE for B30, B40, and B100 than for B10, B20 and diesel [3,18].

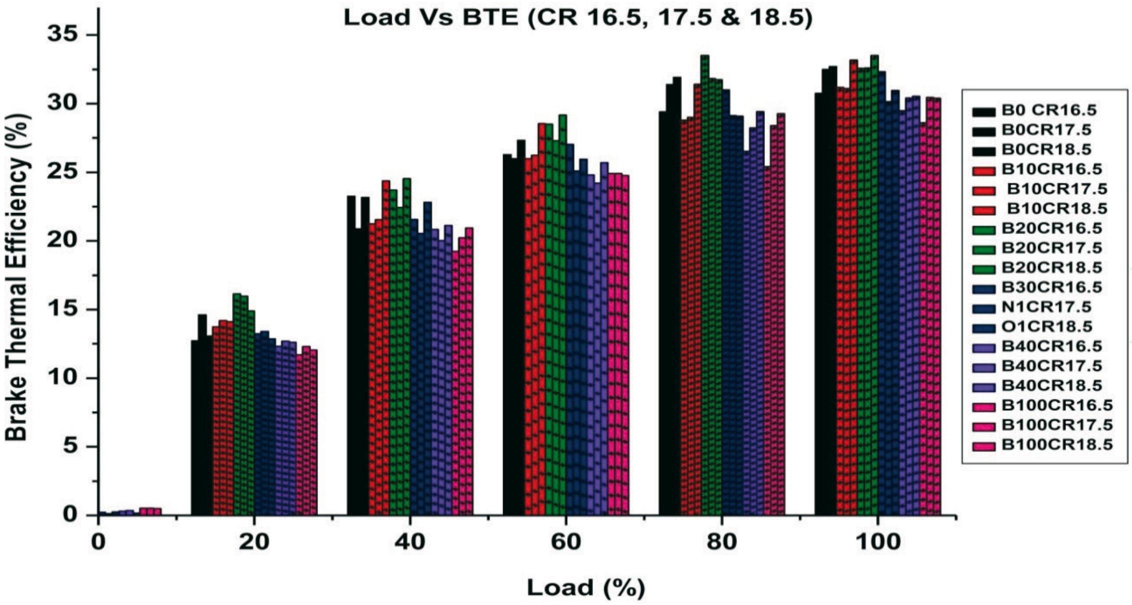

Fig. 5 Comparative analysis for Load Vs BTE at CR16.5, CR17.5 & CR18.5

4.3 Carbon monoxide

Carbon monoxide emissions for B0, B10, B20, B30 B40, and B100 against loads are compared at different CRs of 16.5, 17.5, and 18.5 as shown in Figures 6 (a), (b) and (c). The CO emissions decrease with an increase in engine load. They decrease up to 80% load and then increase. The augmented temperature inside the combustion chamber, the greater fuel intake, the loss of O_2 at high speed, and the reduction in the loading time lead to incomplete combustion, promoting an increase in CO emissions for all fuel blends from an 80% to 100% loading condition [10, 13, 16, 22].

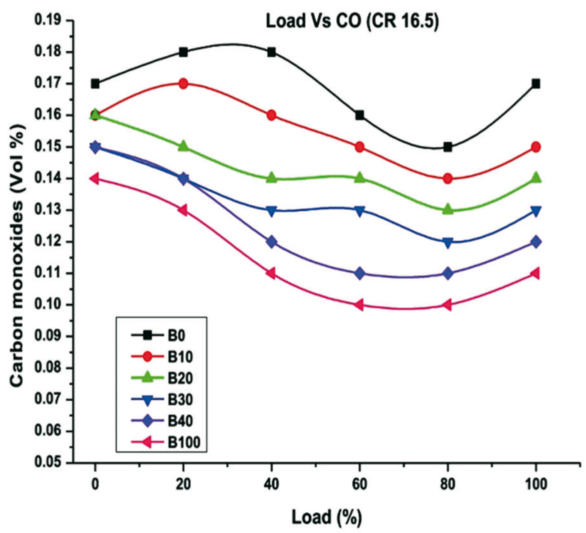

Fig. 6(a) Load Vs CO for CR16.5

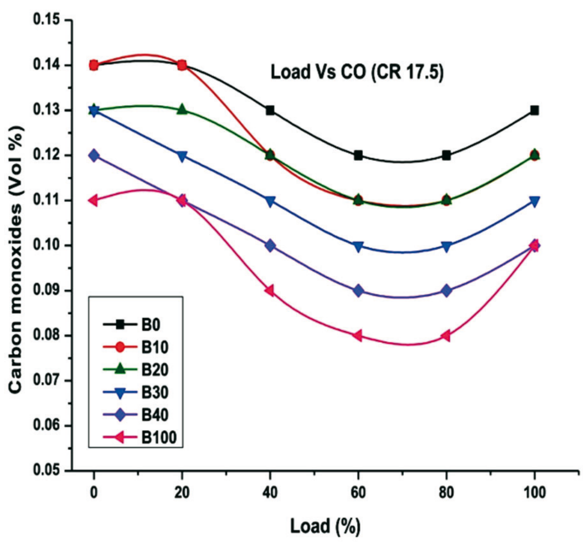

Fig. 6(b) Load Vs CO for CR17.5

At a lower CR, the CO emission is higher. The poor in-cylinder temperature and greater delay period which causes the incomplete burning of the fuel is the probable reason for the higher formation of CO at lower CRs [27]. The increase in CR is indirectly proportional to the CO emissions, and the trend is observed when the CR is increased from CR16.5 to CR18.5. The CO emissions are found to be satisfactory for all MECPO blends rather than for diesel in all CRs, while B100 produces much lower CO emissions than all other blends. The O_2 content, the higher CN value of the MECPO blends and the shorter ignition delay lead to lengthier combustion duration owing to lower CO emissions by enriching the fuel properties. The extra O_2 molecules in the biodiesel blends facilitate complete combustion, oxidation, lower carbon content and thereby reductions in CO emissions [13].

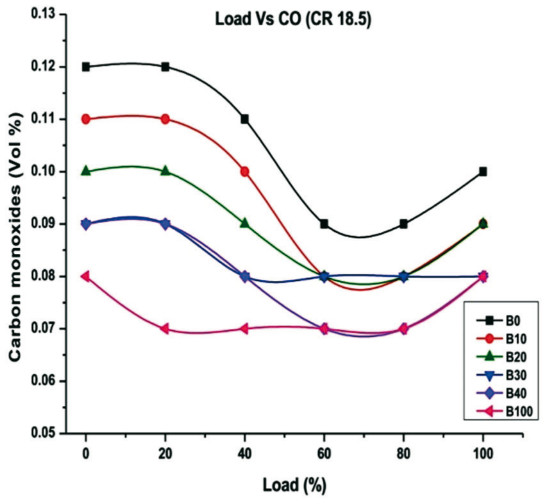

Fig. 6(c) Load Vs CO for CR18.5

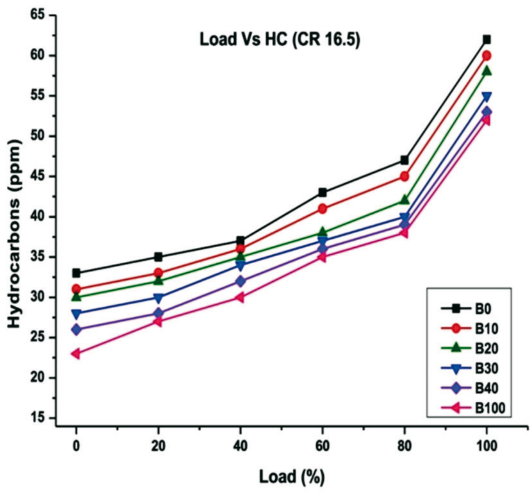

Fig. 7(a) Load Vs HC for CR16.5

4.4 Hydrocarbons

Hydrocarbon emissions are the criteria to determine the emission behaviours of the engine. HC emissions for MECPO blends and diesel are shown in Figures 7 (a), (b), and (c). The increment in HC emissions is observed with an increase in loads. The increment in CRs reduces the HC emissions [28]. The elevated gas temperature and CN value of biodiesel blends lead to this drop-off in HC emissions. At CR 18.5, the diesel and other biodiesel blends produce fewer HCs than at CR16.5 and CR17.5 [4, 13, 14].

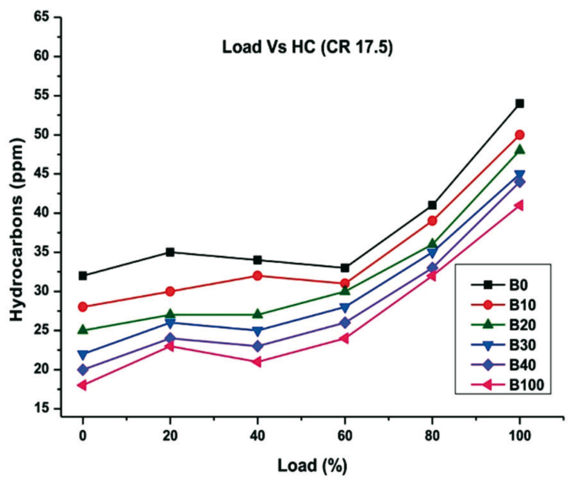

Fig. 7(b) Load Vs HC for CR17.5

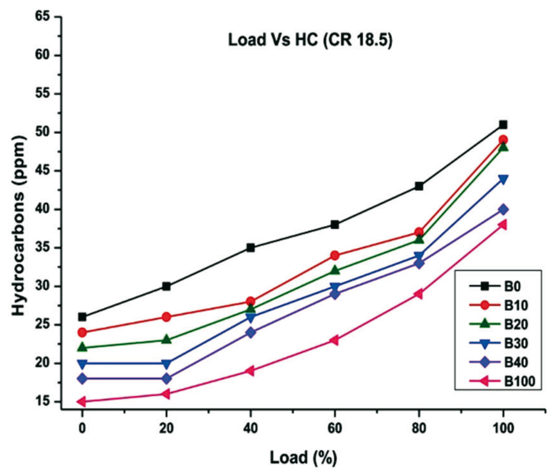

Fig. 7(c) Load Vs HC for CR18.5

For example, at CR18.5 at a full load condition, the higher blend of MECPO (B100) emits fewer HCs with 38ppm (particles per million) whereas at CR 17.5 it is slightly increased with 41ppm. When the blend ratio increases from B0 to B100, the HC emissions decrease. This is due to the availability of the rich O_2 atoms of the MECPO blends which leads to better combustion. The lean blends B10 and B20 have a value of HC emissions closer to that of diesel. The CV of B10 and B20 being closer to diesel is the reason for this phenomenon.

4.5 Oxide of Nitrogen

The oxides of nitrogen emissions versus load against diesel are plotted in Figures 8 (a), (b), and (c). The NO_x emissions are directly related to the engine combustion temperature. The NOx emissions are lower at a low CR than a high CR. During combustion, the decline in the cylinder temperature causes a reduction of the adiabatic flame temperature at a lower CR which in turn reduces emissions due to NOx [28]. At CR18.5, the NO_x is found to be higher as a result of the increase in the combustion temperature and O_2 concentration of biodiesel than at other CRs. It is perceived that NOx emissions are higher with an increase in engine loads for all blends at all CRs.

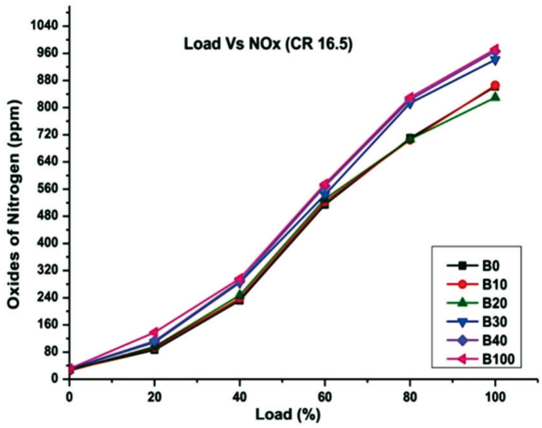

Fig. 8(a) Load Vs NOx for CR16.5

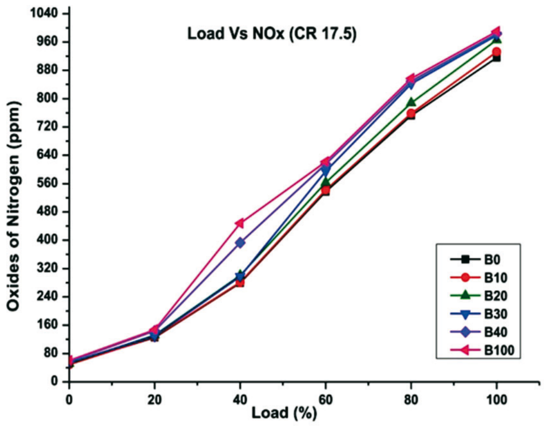

Fig. 8(b) Load Vs NOx for CR17.5

This is due to an increase in the internal temperature of the combustion chamber. The NOx increases as the biodiesel percentage climbs and the NOx for B100 is observed to be higher than other blends. The reason is that the rich content of O_2 molecules in biodiesel stimulates better combustion, a shorter ignition delay and a combustion advance leads to a higher combustion temperature. It is particularly the larger number of double bonded molecules of MECPO biodiesel that raises the adiabatic flame temperature which results in the increase of NOx. The NOx for B10 and B20 are found to be closer to diesel fuel at all CRs.

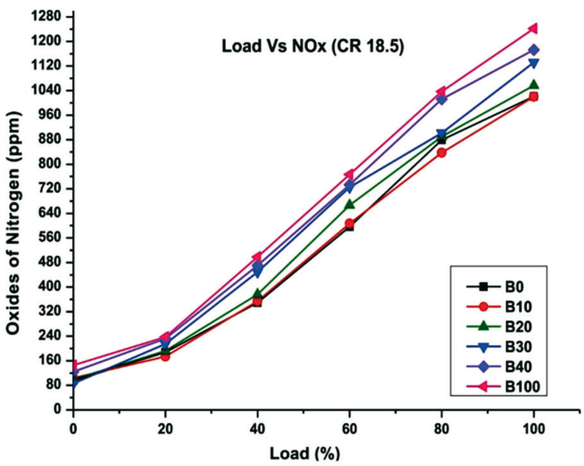

Fig. 8(c) Load Vs NOx for CR18.5

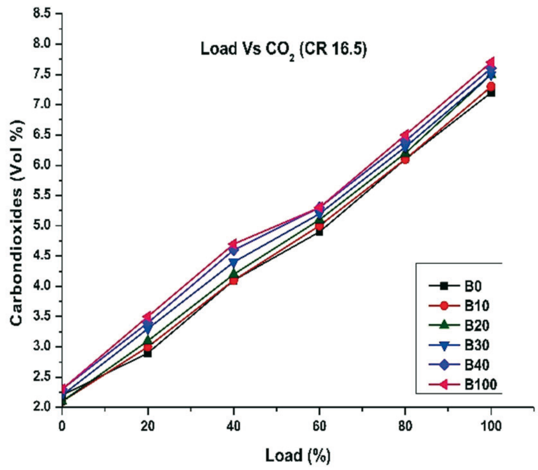

Fig. 9(a) Load Vs CO_2 for CR16.5

4.6 Carbon Dioxide

Carbon dioxide is the major emission of the IC engine and the root cause of the greenhouse effect. The CO_2 emission of the VCR engine fuelled with MECPO and its blends is measured and plotted in Figures 9 (a), (b), and (c). The result shows that the engine emits more CO_2 when MECPO blends are used as fuel. An increase in the engine load also gives a gradual rise in CO_2 at CR 16.5, 17.5, and 18.5 owing to the greater fuel consumption at higher loads. The CO_2 emission increases as the CR grows. This is due to some extra O_2 in the molecules of the biodiesel which initiates complete combustion of the fuel and supplies the essential O_2 for the conversion of CO into CO_2. The rich blend of B80 and B100 discharges elevated CO_2 emissions at all load conditions and CRs which is a sign of effective and absolute combustion [28]. The CO_2 emissions of the lean blends B10 and B20 are comparatively lower and closer to diesel at all CRs which is a sign of effective and absolute combustion [28]. Clearly, these higher CO_2 emissions of MECPO can be readily absorbed by the crops and balanced by nature itself. Hence, it can be noticed that the effective emission of CO_2 is reasonably low [27].

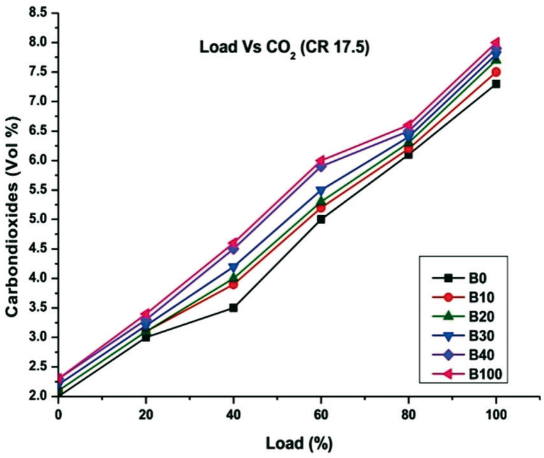

Fig. 9(b) Load Vs CO_2 for CR17.5

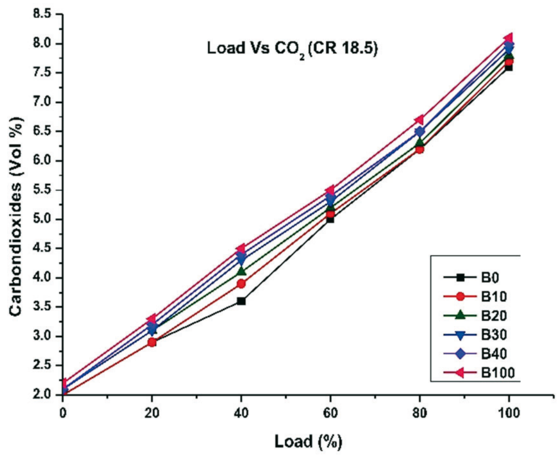

Fig. 9(c) Load Vs CO_2 for CR18.5

4.7 Smoke Opacity

Smoke measurement is carried out in terms of smoke opacity through an AVL 437C continuous flow smoke meter.

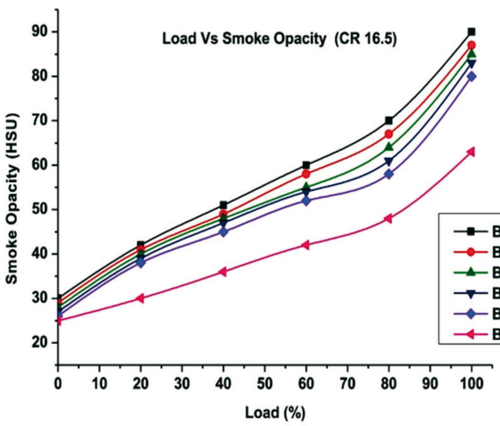

Fig. 10(a) Load Vs Smoke opacity for CR16.5

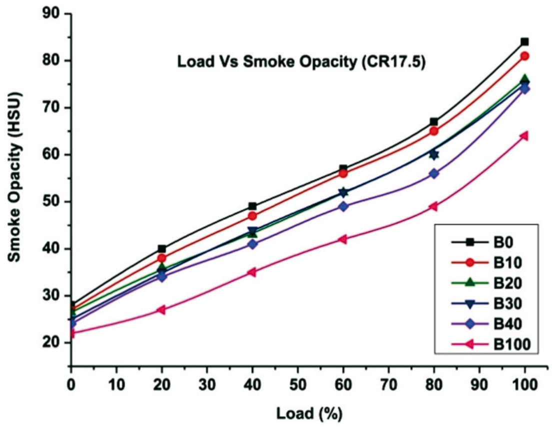

Fig. 10(b) Load Vs Smoke opacity for CR17.5

Smoke was found to be lower at a higher CR as shown in Figures 10 (a), (b) and (c). From the graph, it is observed that at CR18.5 the engine emits less smoke than other CRs at all load conditions for all fuel blends.

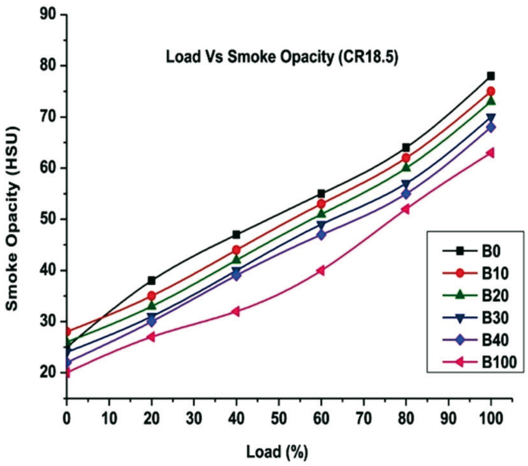

Fig. 10(c) Load Vs Smoke opacity for CR18.5

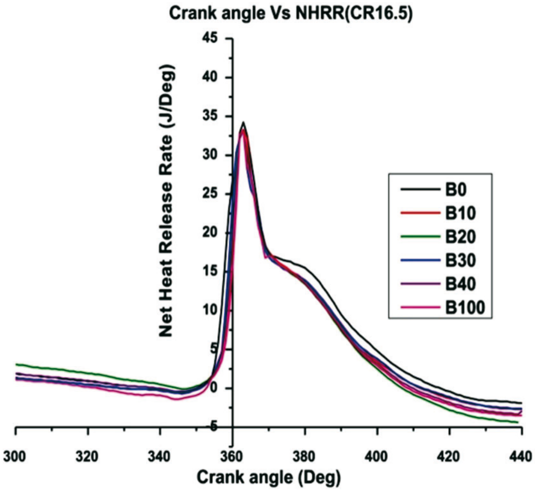

Fig. 11(a) CA Vs NHRR for CR16.5

The temperature of the compressed air is sufficient to produce complete combustion by burning the fuel thoroughly at a higher CR, which is the reason for less smoke at a higher CR, while incomplete combustion occurs at a lower CR which is the reason for more smoke at a lower CR [22]. The smoke emissions gradually increase with the increase in load for all CRs [9]. From the graph, it is also apparent that the MECPO biodiesel blends produce fewer smoke emissions than diesel at all CRs and at all load conditions. The A/F ratios, the heterogeneous nature of combustion while the fuel is burnt, the high pressure and temperature in the engine cylinder, and incomplete combustion are the major causes of this smoke formation in the diesel engine. Oxygenated biodiesel controls the locally enriched fuel combustion and primarily restricts smoke formation. The blends B10, and B20 showed a similar HSU trend with the base fuel owing to the improved combustion of these fuels at every CR.

4.8 Net Heat Release Rate

The NHRR is analysed based on the variations in the crank angle (CA) of the cylinder and is plotted in Figures 11 (a), (b), and (c).

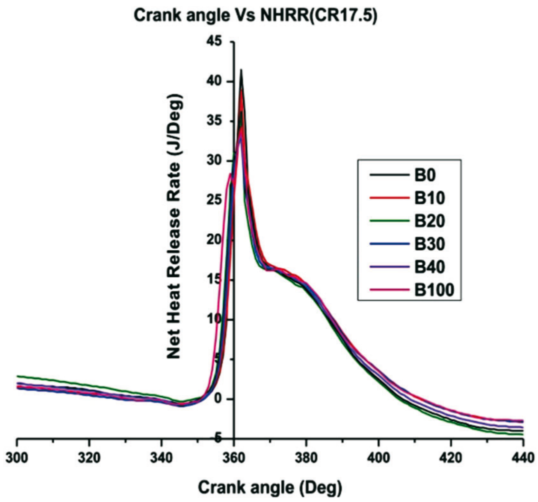

Fig. 11(b) CA Vs NHRR for CR17.5

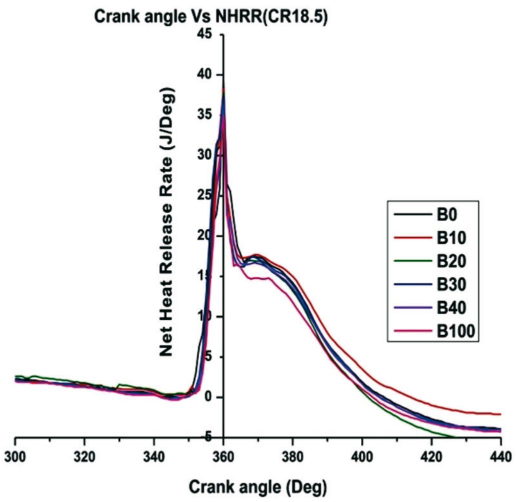

Fig. 11(c) CA Vs NHRR for CR18.5

The results confirm that the NHRR diminishes at the start of combustion and thereafter rises. As the CR increases, the NHRR also climbs from CR 16.5 to CR 18.5. The maximum heat release rate is found at CR 18.5. To make up the HRR, the CRs can be improved accordingly [8]. The NHRR of diesel is superior to the oil blends owing to its abridged viscosity and improved spray formation [29]. The maximum NHRR of MECPO biodiesel and its blends at CR16.5 is mainly lower than diesel, 38.64 J/ deg CA, 37.87 J/deg CA, 37.3 J/deg CA 36.27 J/deg CA, and 35.41 J/deg CA for B10, B20, B30, B40, and B100 compared to 40.55 J/deg CA for diesel. The maximum NHRR values at CR17.5 are 35.6 J/deg CA for B0, 34.4 J/deg CA for B10, 34.1 J/deg CA for B20, 33.43 J/deg CA for B30, 32.4 for J/deg CA for B40 and 32 J/deg CA for B100. This variation happens due to the combination of the lower rate of air/fuel mixing and the viscosity effect of the biodiesel blends [29].

5. Conclusion

The BSEC for B20 is observed to be very much closer to B10 and diesel at CR 18.5. At all CRs, the BTE for B20 was found to be higher and at CR18.5, B20 and B0 showed a closer pattern. At all CRs, for all MECPO blends, CO emissions are acceptable and B100 has the lowest CO emissions. As CR increases, the emissions of HC are lower and B10 and B20 are found to be closer to the value of HC emissions with diesel. At CR18.5, the NOx is found to be higher and B100 emits more NOx, and B10 and B20 are in line with diesel. At all CRs, the CO_2 emissions of B10 and B20 are closer to diesel. As the CR increases, the combustion rate also increases, and the maximum peak pressure drops off with a decline in the biodiesel blends of MECPO. At the higher CR of 18.5, B20 MECPO biodiesel reached higher NHRR, and the maximum heat release rate was found at CR 18.5. In a CRDI engine, slight atomization and more injection of fuel occur when biodiesel is used as fuel. In order to run correctly, modern diesel engines need to meet the specifications provided by the manufacturer as per the ASTM standard. At a lower CR, BTE decreases subsequently but the engine runs smoothly. The soot and NOx emissions decline drastically at a low CR. Better performance and combustion characteristics were shown by CR 18.5 and positive results in emission testing. B10 and B20 of MECPO exhibited greater performance and a good deal with emission standards. A remarkable improvement in performance and a reduction in emission parameters established that MECPO B10 and B20 biodiesel can be used as an alternative fuel to diesel in conventional engines without any modifications to the engine.

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Assist. Prof. Raja Sekar Rengaswamy*
Prof. Srinivasan Rajumani
Department of Mechanical Engineering, RVS College of Engineering, Dindigul-624005, Tamilnadu, India

Prof. Muralidharan Karuppusamy
Department of Mechanical Engineering, PSNA College of Engineering & Technology, Dindigul-624622, Tamilnadu, India

*Corresponding author: rrsekarg@gmail.com