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Full Length Article

Experimental analysis of combustion characteristics of CI DI VCR engine using mixture of two biodiesel blend with diesel

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ABSTRACT

To meet the ever increasing energy demand of the world needs an urgent research to find an alternate fuel for diesel. Biodiesel can be a promising alternate for diesel engine in the years to come. The objective of the present experimental work is to investigate the combustion characteristics of VCR engine using mixture of two biodiesel blend with diesel at 100% or rated load, at constant speed. Simarouba and Jatropha oil are used to prepare, respective biodiesel and mixed in the volume ratio of 75:25, and is designated as B100. The combustion characteristics investigated are cylinder gas pressure, net heat and cumulative heat release, rate of pressure rise, and the mass fraction burned. Investigation is carried out varying load from zero to 100% or rated load of engine with an increment of 20% each time. Influence of blends and compression ratio on the combustion characteristics of engine is investigated. The results reveal that blends results in higher cylinder gas pressure, lesser heat release, higher rate of pressure rise and increased combustion duration. Increasing CR improve the combustion characteristics of engine.

1. Introduction

Petroleum fuels are depleting at a rapid rate because of increased number of automobiles and their liberal consumption in view of improved world economy. Automobiles are the main contributors to environmental pollution, creating human health problems and also a source of global warming particularly in metros. Hence there is a need to address the problem of fuel and emissions by substituting alternate energy sources like biodiesel. This has triggered the researchers to find the fuel which can replace the petroleum fuel and can also reduce harmful emissions. Biodiesel are the alternate source of energy for automobiles and other energy sectors. Biodiesel can be produced from different source of vegetable oils such as edible and non edible oils. Vegetable oils are transformed to their respective methyl esters using the transesterification method which is widely used for production of biodiesel [1,2]. Biodiesels are renewable, biodegradable, non-toxic, oxygenated fuel [3–5]. Physical and chemical properties of biodiesel fuel are comparable to diesel. India is fourth largest petroleum fuel consumer in the world and is not self sufficient [6,7]. To satisfy the energy needs of the country, 70–80% of petroleum fuel is imported spending huge amount of foreign exchange [8]. Producing liquid fuel indigenously can attain two requirements, first producing biodiesel as substitute fuel to diesel and reduce the import of petroleum fuel [9]. Second India turns out to be energy independent and increases its economic status by saving foreign exchange.

Biodiesel or methyl esters hold the promise as alternate fuel to diesel engine with or without modification to present day engines [10,11]. Number of researchers carried out experimental investigations using different types of biodiesel. The outcome of the research done by various researchers' shows the similar results with a little variation in the thermal performance compared to neat diesel. It may be also observed that biodiesel enhances lubrication, reduces the wear of engine components [12,13]. The reduction in harmful emissions like CO, HC, particulate matter [14–17] and enhance the CO_2, and NO_x emissions in comparison to diesel is noted [11,18].

Diesel engine performance is characterised by measuring the different parameter such as brake specific fuel consumption, brake thermal efficiency, brake mean effective pressure, cylinder pressure and heat release [19–22].

The work carried out by various researchers on the combustion characteristics of CI engine using methyl ester blends are discussed in the following paragraphs.

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Nomenclature

aTDC	after top dead centre, °CA	MFB	mass fraction burned, %
bTDC	before top dead centre, °CA	NHR	net heat release, J/°CA
CA	crank angle, °	p	cylinder pressure, bar
CHR	cumulative heat release, J	RPR	rate of pressure rise, bar/°
CP	cylinder pressure, bar	S75	75 volume of Simarouba, %
CI	compression ignition, –	J25	25 volume of Jatropha, %
DI	direct injection, –	VCR	variable compression ratio, –

Performance, emissions and combustion characteristics of VCR engine were investigated using Waste plastic oil and diesel blends and it is observed that the cylinder gas pressure and heat release was higher for the blends as compared to diesel. Increase in CR was results in improvement of thermal performance and reduction in the emissions as compared to diesel [23].

Combustion, performance and emission characteristics of VCR engine were investigated using rice bran biodiesel and diesel blends and it was resulted in higher cylinder gas pressure for blends in comparison to diesel. Cylinder gas pressures increased with increase in CR from 15 to 18 and improve the performance of engine with reduced emissions of blends in comparison to diesel. Peak cylinder pressure attained at 11° aTDC in the expansion stroke for B40 blend which was lower than B20 blend and was at 6° aTDC [24].

Combustion, performance and emission characteristics of a VCR engine was investigated using Waste cooking oil methyl esters and its blends and the results indicated an improved pressure rise rate, lesser heat release, longer ignition delay, increased mass fraction burned in comparison with diesel [25].

Combustion characteristics were investigated using Corn oil methyl ester (COME) with DI diesel engine. COME be preheated for three different temperatures and supplied to engine. Cylinder gas pressure was higher; with lower heat release for the blends compared to diesel. Ignition delay was lesser, mass fraction burnt was slower and combustion period was lesser for COME blends as compare with diesel [26].

Combustion characteristics were investigated with Castor oil biodiesel and diesel blends using DI VCR engine. Results show improved combustion, performance characteristics of engine at higher compression ratio for the blends. Blends have lower ignition delay in comparison to diesel. Cylinder pressure was higher at CR18 for B50 blend. Heat release was higher for diesel at CR of 18. Mass of fuel burned was faster for B20 blend for CR of 15–18 [27].

Combustion characteristics were investigated using CI DI engine at constant speed with Waste cooking oil biodiesel it is noticed that BTE was lesser and BSEC was higher for biodiesel blends at rated load with reduced emissions in comparison to diesel. It was noticed that reduced ignition delay, lower heat release and longer combustion time of blends as compared to diesel. Waste cooking oil methyl ester may be a substitute for diesel [28].

Various combustion characteristics were investigated using Cotton seed biodiesel and blends in DI diesel engine, it results into higher cylinder pressure for the blend compared to diesel. Heat release, ignition delay and pressure rise rate was lower for blends as compared to diesel. Combustion was advanced and combustion time was increased for the blends as compared to diesel which may deteriorate the performance of the engine using biodiesel blend compared to diesel [29].

Combustion characteristics were investigated with micro algae and waste cooking oil biodiesel and their blends using common rail, turbocharged, and indirect injection engine. Cylinder gas pressure was higher for diesel at higher load compared to blends. There was no considerable variation in the cylinder gas pressure of methyl ester blends. Pressure rise rate was higher and heat release was lower for the methyl ester and its blends in comparison to neat diesel at 25% load, further increase in load eliminate the difference in the pressure rise rate and comparable with diesel. Increase in load on engine increases heat release for biodiesel blends and are comparable with diesel [30].

Combustion characteristics were investigated using single cylinder E6 Ricardo engine with waste fish oil biodiesel it was observed that cylinder pressure was higher compared to diesel. Heat release of biodiesel starts earlier compared to diesel was because of early start of combustion and also close to TDC [31].

Investigation of combustion and emission characteristics was carried out using waste cooking oil biodiesel and its blends using CI DI engine it was resulted into higher cylinder gas pressures for blends in comparison with diesel. Increased load on the engine increases cylinder gas pressure for the blends as well as diesel. Heat release for biodiesel blends was lower due to reduced delay for methyl ester blends as compared to diesel. Commencement of combustion was advanced and combustion duration was lesser for blends compared to diesel [32].

Combustion characteristics were investigated with cotton seed methyl esters and blends using diesel engine it was resulted into higher cylinder gas pressures, higher net and cumulative heat release rate for diesel in comparison to methyl ester blends. Maximum cylinder gas pressure for lower percentage of blends was comparable with diesel. Ignition delay, injection duration and combustion period were lesser for methyl ester blends compared to diesel. Pressure rise rate was lower for blends in comparison with diesel [33].

It is observed from literature review that combustion characteristics of constant CR and VCR engines were investigated using methyl esters and diesel blends. In open literature little work is available on the study of combustion characteristics of VCR engine using mixture of two biodiesel blend with diesel as fuel.

The main objective of the research is to propose an amicable blend of biodiesels with diesel and hence to increase the quantity of the potential biodiesel source as an alternate to the neat diesel and neat biodiesels. The reason behind the idea is, many oilseeds are available in small quantities and if the oil is extracted from these oilseeds and converted to their respective biodiesels the quantity available may be not be sufficient to rely upon a neat biodiesel. If two or more biodiesels are blended in proper proportion and used as an alternative, the total available fuel source will be increased and this will enhance the chances of using the biodiesels.

The present work is focused to test whether the biodiesel can be mixed and used as a blend with diesel in the engines. It is also intended to investigate the performance, emission and combustion characteristics of the engine using mixture of two biodiesel blends with diesel using CI DI VCR engine. The Simarouba and Jatropha biodiesel are produced and considered for the current investigations.

2. Materials and methods

Simarouba and Jatropha are mixed in volume ratio of 75:25 (S75 + J25) and mixture is designated as B100. Various blends are prepared using B100 and diesel. Blend B20 means 20% of B100 + 80% of diesel, B40, B60 are prepared using B100 with similar composition.

Schematic layout of the experimental setup is shown in Fig. 1. The technical specifications of the setup are given in Table 1. Experimental investigation is carried out with vertical single cylinder, 4-stroke, constant speed (1500 rpm), water cooled, computerized, CI DI VCR engine coupled to eddy current dynamometer. Air and fuel flow are measured using calibrated transmitters, various temperatures are measured using calibrated thermocouples. Load on engine is measured with load cell. Flow of water to engine and calorimeter are measured and controlled by using rota meter. Pressure sensors are used to measure the cylinder pressure and injection pressure. The pressure sensors are water-cooled to ensure longer life and excellent thermodynamic behaviour. Engine is fitted with mechanical fuel pump with static injection timing i.e. 23° bTDC. All the discussions are based on static injection timing. The test set up is provided with a data logging system and uses dedicated software (Engine soft' version-9).

The parameters used in the study are: compression ratio, blend ratio, and the engine load. First the experimental investigations are carried out using neat diesel as fuel at different CR for various loads. The results obtained from diesel fuel are the base line results and used for comparison with blends. The engine is run with diesel fuel at no load condition for five minutes to attain the stable operating conditions, before the measurements are taken. Load test is done with 0%, 20%, 40%, 60%, 80% and 100% of rated load with an increment of 20% each time. The experiment is repeated at CR of 16, 17 and 18 using diesel and blends of mixture of two biodiesel and diesel at different loads. In order make the meaningful comparison and check repeatability of the investigation, engine is loaded from zero to rated load and reversed from rated load to zero load with similar operating conditions. There is perfect repeatability of results with set up used.

The uncertainty is calculated and presented as per the procedure mentioned in the published literature of Moffat [34]. The uncertainty is estimated using the equation shown below

Table 1
Engine Specifications.

Type of engine	Kirloskar, TV-1, Four Stroke, Single Cylinder, Naturally aspirated engine
Power	3.5 kW at 1500 rpm
Stroke x Bore	110 mm × 87.5 mm
CR	17.5 (VCR 12–18)
Injection pressure	200 bars
Injection timing	23° bTDC
Dynamometer	Eddy current type

Uncertainty = square root of [(uncertainty of TFC)^2 + (uncertainty of BP)^2 + (uncertainty of BSFC)^2 + (uncertainty of BTE)^2 + (Uncertainty of EGT)^2 + (Uncertainty of pressure)^2]

For e.g. Uncertainty = Square root of $[(2.3)^2 + (1.6)^2 + (1.8)^2 + (1.8)^2 + (1.6)^2 + (1.01)^2] = \pm 4.1\%$

3. Results and discussions

Investigations are carried out using VCR engine varying the load from zero to 100% rated load of engine with an increment of 20% each time at CR of 16, 17 and 18 using various blends and diesel. The Simarouba and Jatropha biodiesel are mixed in volume percentage ratio of 75:25 (S75 + J25) and the mixture is designated as B100. The blend B20 is 20% of B100 + 80% diesel, B40 and B60 blends are prepared using B100 and diesel in the similar composition. Various combustion characteristics discussed are cylinder gas pressure, CHR and NHR, MFB and RPR.

The properties of the test fuel are given in Table 2.

3.1. Influence of load on cylinder pressure with diesel (B00) as fuel at CR17

Cylinder pressure data is the most useful parameter for combustion characteristics analysis of engine. In-cylinder pressure provides directly the performance parameters of engine such as power output, emissions and combustion characteristics. Variation of in-cylinder pressure with CA at CR17 using B00 (diesel) at different load is shown in Fig. 2.

It can be noticed from figure as load on engine increases cylinder gas pressure increases which may be accredited to increased

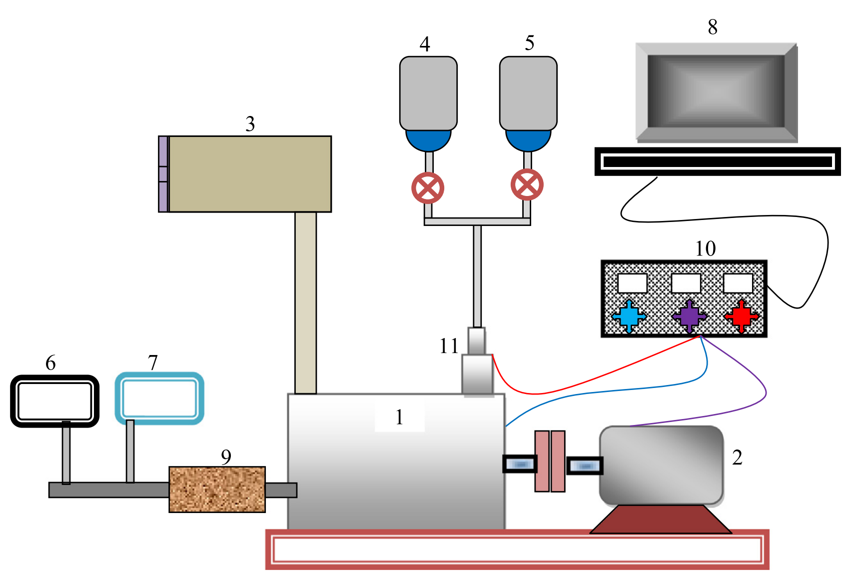

Fig. 1. Schematic of experimental layout. 1. Engine 2. Dynamometer 3. Air box 4. Diesel tank 5. Bio diesel tank 6. Smoke meter 7. Five gas analyzer 8. Computer 9. Calorimeter 10. Control panel 11. Fuel injector.

Table 2
Properties of diesel and blends.

Properties	Diesel	Simarouba biodiesel	Jatropha biodiesel	B100 (S75 + J25)	B20	B40	B60
Density, kg/m^3	830	880	874	877	840	849	859
Heating value, MJ/kg	44	39.8	41	40.1	43.22	42.44	41.66
Viscosity, at 40 °C	2.27	5.09	4.99	5.06	2.28	3.39	3.94
Flash point, °C	56	152	146	151	76	96	115
Cetane number	48	52	55	53.5	–	–	–
Oxygen content	–	11%	11.5%	11.25%	–	–	–

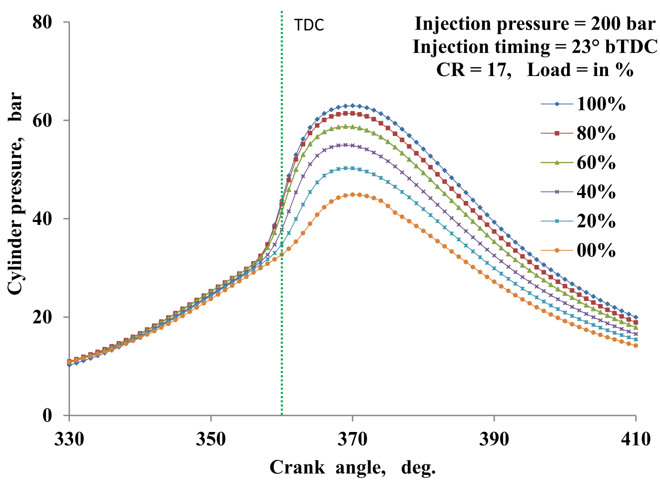

Fig. 2. Variation of cylinder pressure with CA at CR17 for B00 (diesel) fuel.

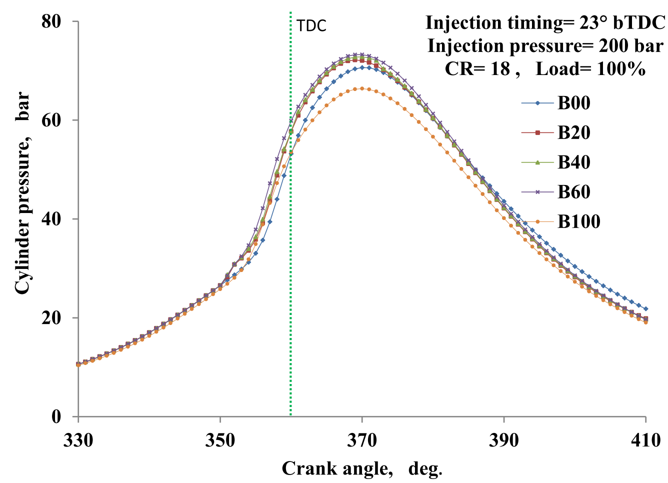

Fig. 3. Variation of cylinder pressure with CA for different blends at CR18.

fuel supply and increased temperature consequently enhances the combustion. Maximum in-cylinder gas pressure is the result of combustion of fuel and air mixture in premixed or uncontrolled combustion stage. Peak cylinder pressure is close to TDC as the cylinder volume and heat rejection are minimum. Maximum cylinder pressures recorded at CR17 are 62.97 bar at 100% load and 43.88 bar at zero loads respectively. Lower cylinder pressure for zero loads is accredited to lesser quantity of fuel supply. It is seen from figure that irrespective of load, start of combustion is at the same CA. The location of the peak pressures are at the same crank angle for all the loads (10°).

3.2. Influence of blends on cylinder pressure

Variation of cylinder pressure for different crank angles for various blends at CR of 18 for 100% load is shown in Fig. 3. It can be noticed that cylinder gas pressure of biodiesel blends follow similar trend as the diesel. Peak cylinder gas pressure for B20, B40 and B60 blends are higher in comparison to diesel may be accredited to advanced start of injection and ignition of blends. Injection and ignition advance for the blends may be accredited to higher bulk modulus and higher cetane number of methyl ester blends [35]. Inherent oxygen molecule in biodiesel leads to improve the combustion reaction and accelerates the ignition and combustion [36] of blends consequently higher cylinder pressure. Lower cylinder pressure for diesel is accredited to increased ignition delay. Cylinder pressure is decreases further for diesel with progress in combustion since piston is into expansion stroke. Cylinder pressure for mixture B100 is lesser in comparison to diesel and other blends. This may be accredited to lower energy content; lower volatility and higher viscosity of biodiesel may diminish the combustion of B100. Maximum cylinder pressure values for B00, B20, B40, B60, and B100 are 70.63 bar, 72.17 bar, 72.88 bar, 73.26 bar and 66.38 bar respectively occurs at 9° aTDC for biodiesel blends and 10° aTDC for diesel. Premixed and mixing controlled combustion for mixture of two biodiesel blend with diesel is higher compared to diesel may be attributed to advanced start of injection and ignition for the blends. The in-cylinder pressure for the after burning stage is higher for diesel compared to blends may be attributed to increased ignition delay for diesel.

3.3. Influence of blend ratio and CR on cylinder pressure

Variation of cylinder pressure with change in crank angle for CR of 16, 17 and 18 for various blends are presented in Fig. 4. Increase in CR increases pressure and temperature of air inside the combustion chamber. Higher CR increases the density of air hence improves the mixing of fuel-air. Increase in the vaporization improves the quality of uncontrolled combustion resulting in higher cylinder pressure. B20, B00 and B100 blends at CR18 has

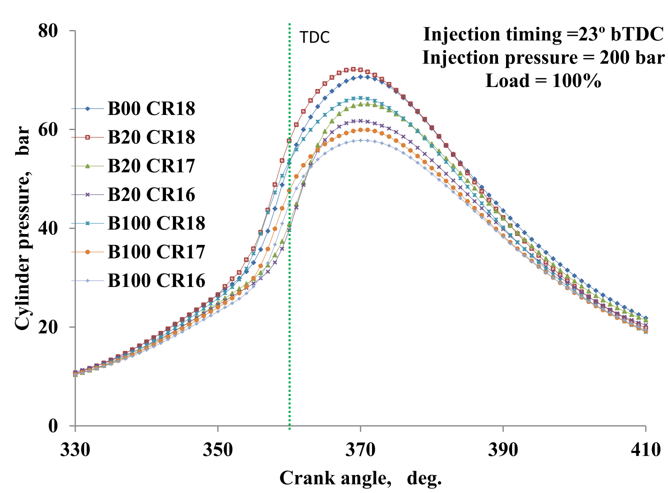

Fig. 4. Variation of cylinder pressure variation with CA for different blends and CR.

higher peak cylinder pressure followed by B20 at CR17 and CR16, B100 at CR17 and CR16, the values of pressure are 72.17 bar, 70.63 bar, 66.38 bar, 65.16 bar, 61.73 bar, 59.89 bar, and 57.79 bar respectively. The peak pressures vary in the span of 4° crank angle for the range of blends investigated. It shows comprehensible influence of CR and blend ratio on the in-cylinder pressure.

3.4. Influence of blends on net (apparent) heat release (NHR)

NHR is result of rapid burning of premixed fuel-air mixture accumulated all through delay period releasing heat energy from chemical energy of the fuel. Variations of NHR with change in CA for various biodiesel and diesel blends for 100% load at CR18 is presented in Fig. 5. Negative NHR is observed initially for all the fuels used, this may be attributed to absorption of heat for evaporation of fuel and the heat is consumed rather than generation all through the ignition delay. As the combustion progresses the NHR curve crossover abscissa. During diffusion combustion, fuel burns instantaneously as soon as injected into cylinder. Combustion of biodiesel blends starts earlier to diesel at all operating conditions of engine. NHR is higher for diesel as compared to B20, B40; B60 blend is accredited to higher volatility, lower viscosity and density of diesel which leads to more heat release as compared to blends [36]. The blend reaches higher NHR earlier when compared to diesel because of early start of injection and combustion [37]. Mixture B100 has lower net heat release may perhaps be accredited to lower heat value and higher viscosity and inferior volatility which may influence mixing of fuel-air and hence the combustion. Higher heat release of diesel fuel may be attributed to higher heating value and lower viscosity of diesel leading to the better spray formation during premixed combustion. Net heat release values are 51.45 J/°CA, 42.18 J/°CA, 41.75 J/°CA, 41.58 J/°CA, and 35.14 J/°CA for B00, B20, B40, B60 and B100 respectively.

3.5. Influence of CR and the blend ratio on NHR

Influence of CR and the blend ratio on NHR with crank angle for 100% load is shown in Fig. 6. Duration of uncontrolled combustion depends on the type fuel injected, CR, injection pressure, injection timing, speed and load on the engine. It is noticed that NHR is higher for diesel compared to biodiesel blends may be accredited to higher heat content and better quality of combustion. NHR at CR of 16 and 17 for B20 blend is higher as compared to CR of 18 may be accredited to lesser pressure and temperature of air inside the combustion chamber and hence increases ignition delay. Increased ignition delay for CR 16 and 17 allows more fuel to be accumulated by the time of ignition, consequently higher heat release for B20 blend. NHR values for B20 at CR18, 17 and 16 are 42.18 J/°CA, 45.13 J/° CA and 50.12 J/° CA respectively and are at 4° bTDC and 1° bTDC and 1° bTDC. Lower NHR for mixture of B100 as compared to diesel and B20 blends at different CRs is credited to lower heat value, higher viscosity and lesser volatility of biodiesel in blends. Increase in CR decreases the NHR for the fuels used.

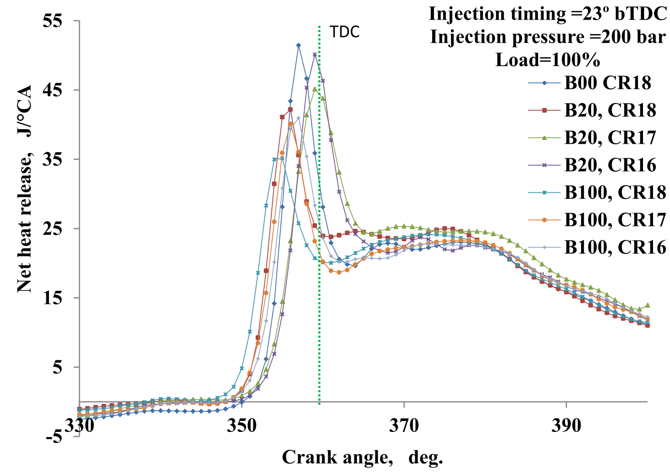

Fig. 6. Influence of blends and CR on NHR with CA at 100% load.

3.6. Influence of blend ratio on cumulative heat release (CHR)

Cumulative heat release provides more information about the progress of combustion. CHR is the total heat released from chemical energy of the fuel. Cumulative or gross heat release with change in crank angle for different blends at CR18 for 100% load is presented in Fig. 7. CHR is lesser for diesel in the early stage of combustion may be accredited to delayed start of combustion of diesel compared to blends. As the combustion progress cumulative heat release for blends follows the similar trend as that of diesel [38]. Even though start of combustion of diesel fuel is delayed compared to biodiesel blends, the CHR of diesel exceeds the blends with the progress of combustion. This trend is because of rapid burning of diesel due to better ignition property of diesel. CHR decreases with increased in volume fraction of biodiesel in the blends may be accredited to lower energy content of biodiesel in the blends. CHR values are: 1527.8 J, 1358.6 J, 1355.0 J, 1344.9 J,

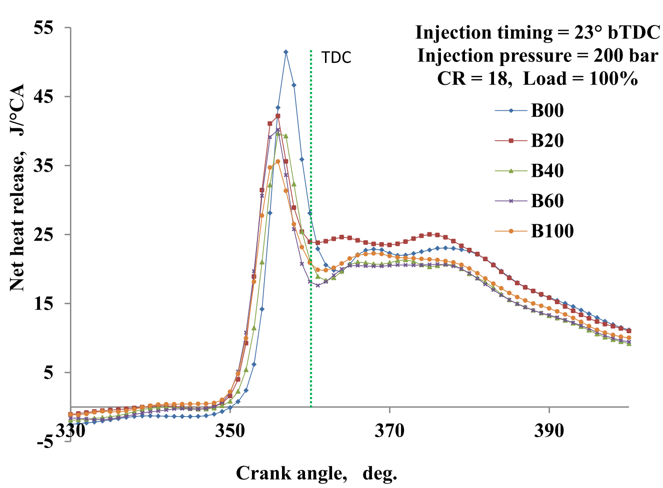

Fig. 5. Influence of blends ratio on NHR with CA at 100% load.

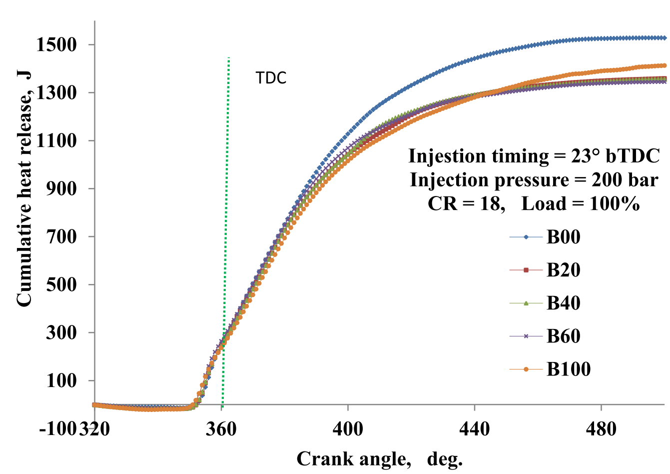

Fig. 7. Influence of blends on CHR at CR18 for 100% load.

and 1412.6 for B00, B20, B40, B60 and B100 respectively. Cumulative heat release for B100 is lower initially compared to other blends and diesel might be attributed to lower volatility and higher viscosity may delayed start of combustion and also may be due to slow burning of B100.

3.7. Influence of CR and blend ratio on cumulative heat release (CHR)

Influence of CR and blend ratio on CHR with CA is presented in Fig. 8 for 100% load.

Cumulative heat release for diesel is higher as compared to biodiesel blends may be accredited to higher heat content and better combustion property of diesel fuel. Initially biodiesel blends have higher cumulative heat release in contrast to diesel may perhaps be accredited to higher cetane number and inherent oxygen of biodiesel in the blends. As combustion progresses cumulative heat release of diesel exceed the blends. CHR is higher for B20 at CR of 18 compared to CR 17 and 16. This may be attributed to rapid combustion of B20 at CR18 due to higher density, pressure and temperature of air. CHR is decreases at the end of combustion for B20 at CR18. Increase in the CR increases the density, temperature and pressure of the air which enhances the combustion phenomenon in CI engine. This may be accredited to the higher value of CHR for B20 at CR 18.

3.8. Influence of blends on rate of pressure rise (RPR)

RPR variation for blends and diesel with change in crank angle is shown in Fig. 9 at CR18 for 100% load. It is noticed that RPR for B20, B40; B60 blends is higher in comparison to diesel. Higher RPR for biodiesel blend may be accredited to rapid burning (uncontrolled combustion) of blends. The reasons for the rapid burning may be attributed to higher cetane number and inherent oxygen, and increase in fuel supply for blends.

B100 blends have lower rate of pressure rise which may be accredited to lower energy content, high viscosity and lower volatility of biodiesel in the blends. Higher viscosity and lower volatility may diminish the fuel-air mixing which may influence the combustion of blends. The values of pressure rise rate are 4.79 bar/°CA, 5.04 bar/°CA, 4.80 bar/°CA, 5.02 bar/°CA and 4.32 bar/°CA respectively for B00, B20, B40, B60 and B100 at 100% load.

3.9. Influence of CR and blend ratio on rate of pressure rise (RPR)

Influence of CR and blend ratio on RPR with change in crank angle for various blends at 100% load is presented in Fig. 10. RPR is higher for B20 blends at CR18 in comparison to diesel and other blends. Density of air at CR18 is higher which may improve the fuel-air mixing and accelerate the combustion. This might be accredited to rapid burning of B20 blend releasing heat energy all through uncontrolled combustion. Lower RPR for B20 at CR of 16 and 17 may be attributed lower density of air which may diminish the fuel-air mixing consequently the rate of combustion. The rate of pressure rise of B20 blend is higher at all the CR considered for investigation.

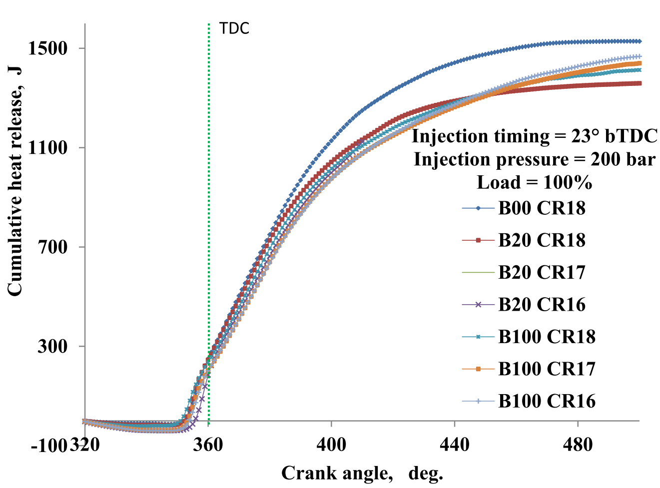

Fig. 8. Influence of blend ratio and CR on CHR at 100% load.

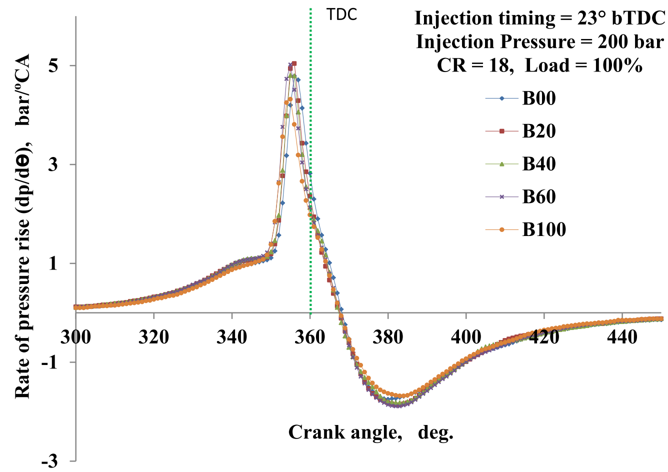

Fig. 9. Influence of blends on RPR with change in CA.

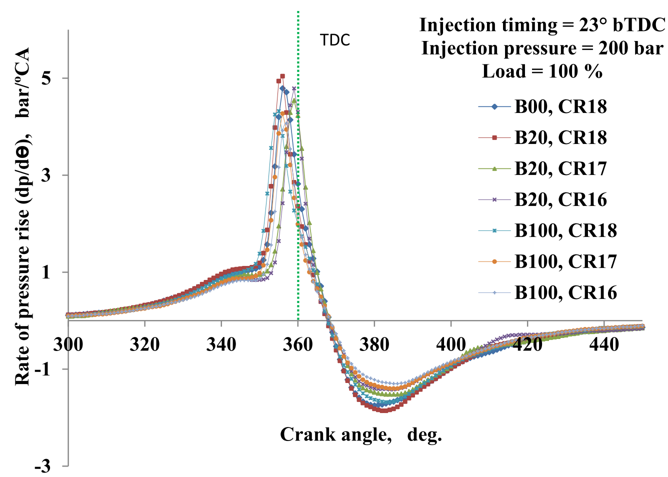

Fig. 10. Variation of RPR with CA for blends and CR.

3.10. Influence of blends on mass fraction burned (MFB)

MFB with change in CA for different blends and diesel for 100% load at CR18 is presented in Fig. 11. It is observed from figure, start of combustion for blends are earlier to diesel. This may be accredited to reduced ignition delay for blends due to higher cetane number and inherent oxygen of biodiesel in the blends. Increased volume of biodiesel in blends advance ignition further. Even though combustion of diesel fuel starts after the blends, burning of diesel exceeds and completes the burning prior to blends. This may be accredited to better combustible properties of diesel. As the combustion progresses burning of biodiesel blend decreases which may perhaps be attributed to inferior volatility and higher viscosity of biodiesel in the blends. Combustion durations are increased for biodiesel blends with increased quantity of biodiesel in the blends [34]. Mass fraction burned at TDC is 25.47%, 27.32%,

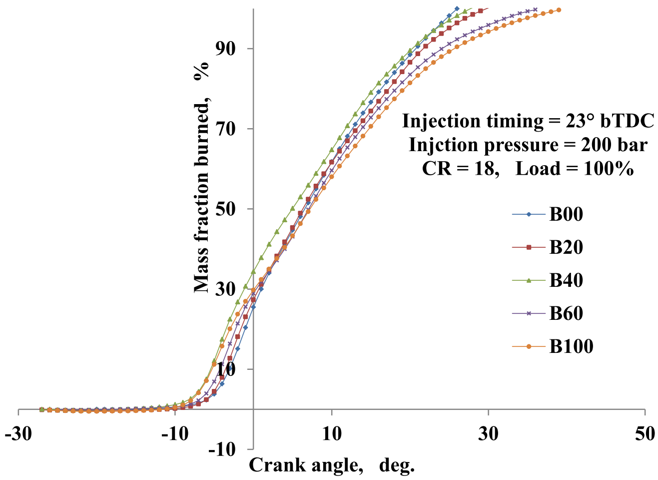

Fig. 11. Influence of blends on mass fraction burned.

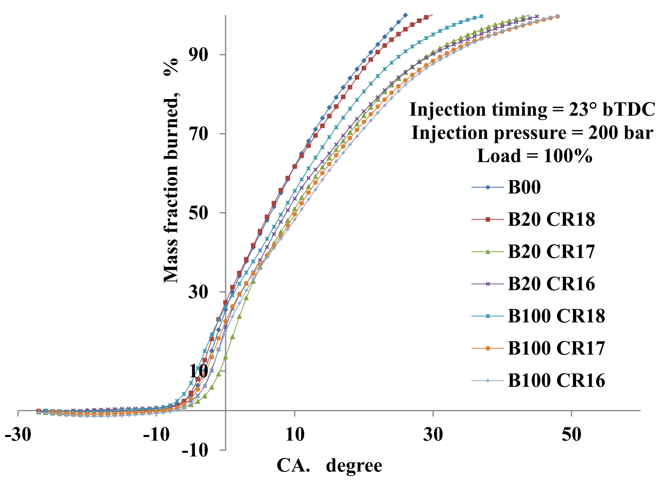

Fig. 12. Influence of blends and CR on mass fraction burned.

34.36%, 28.95%, and 29.74% respectively for B00, B20, B40, B60 and B100. It is observed that blend B40 has better-quality of combustion in contrast to other blends and diesel.

3.11. Influence of CR and blend ratio on mass fraction burned (MFB)

Influence of CR and blend ratio on MFB with change in crank angle for various blends at 100% load is shown in Fig. 12. Even though commencement of combustion for the blends is earlier compared to diesel, burning of diesel quickly exceed and completes the combustion prior to blends. Higher CR increases the density of air may perhaps increase the mixing of fuel-air and accelerate the combustion. Combustion duration for 100% MFB for diesel fuel is earlier for CR of 18 and is followed by B20 and B100 at CR18 and B20 at CR17 and CR16. It is the indication of influence of CR on the combustion process. Increase in CR is more is beneficial to mixture of two biodiesel with diesel blends.

4. Emissions

The exhaust emissions are measured using five gas analyzer and smoke meter for various blends at different CR for 100% load.

The CO and unburnt HC emission for various blends and diesel at different CR at 100% load are shown in Figs. 13 and 14 respectively. The CO and HC emission decrease with increase in CR from 16 to18 which may be accredited to the high density of air enhance the mixing of fuel-air and inherent oxygen in biodiesel improve the combustion [39,40]. The higher cetane numbers of biodiesel helps in complete the combustion [41] and oxidation leads to a reduction in CO emission [39]. Carbon monoxide and hydrocarbon emission increase for higher blends which may be attributed to increased viscosity reduced volatility of blends with the increased volume fraction of biodiesel in the blends. B20 blend results in 36.5% reduction in the CO emission, and 21.4% reduction in HC emission in comparison with diesel at CR18. CO and HC Emission are higher at CR of 16 and 17 which may be accredited to the lesser density of air at lower CR influence the combustion negatively.

The NO_x emission for different blends and diesel fuel at different CR for 100% load is shown in Fig. 14. The NO_x emission increases with increase CR for all the blends and diesel. The NO_x emissions are higher at CR18 for all the blends and diesel which may be accredited to the better combustion of blends leading to higher temperatures consequently increasing the NOx emissions. Biodiesel contains oxygen which may enhance the combustion and increases the cylinder pressure and temperature leads to increase in the NO_x formation. NOx emission increases with increases in volume fraction of biodiesel in the blends. NO_x emission for B100 mixture is lesser compared to diesel and other blends which may be accredited to higher viscosity accompanied by the inferior volatility of B100 mixture may influence the mixing of fuel-air hence the combustion process. NO_x emission of B20 blend is 4.7% higher compared to diesel (Fig. 15).

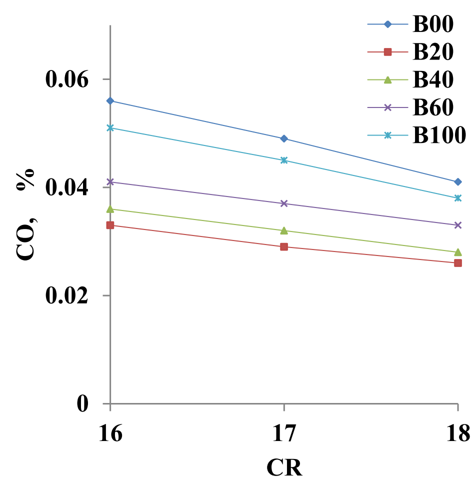

Fig. 13. CO emission for various blends at different CR for 100% load.

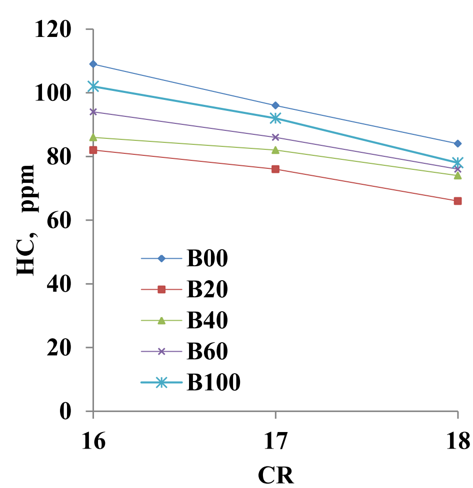

Fig. 14. HC emission for various blends at different CR for 100% load.

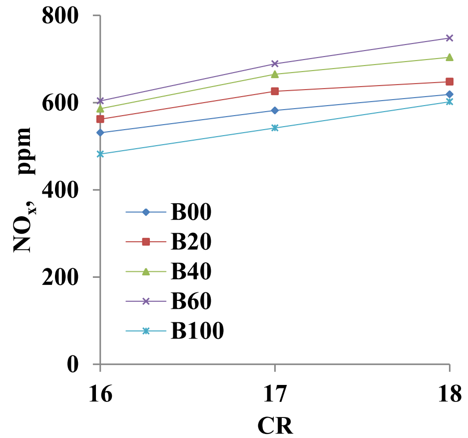

Fig. 15. NO_x emission for various blends at different CR for 100% load.

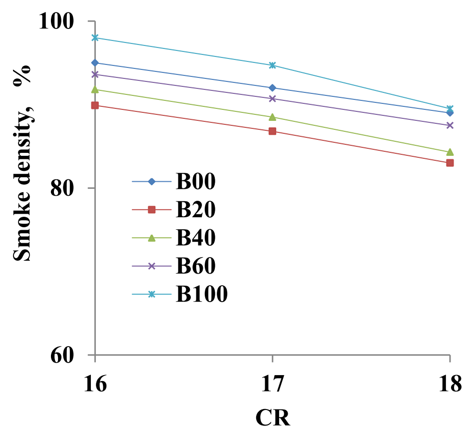

Fig. 16. Smoke density for various blends at different CR for 100% load.

The smoke opacity of various blends and diesel for different CR at 100% load is shown in Fig. 16. Smoke opacity reduces with an increase in CR for various blends and diesel. Smoke opacity for methyl ester blends is lesser may be due to the inherent oxygen of methyl esters completes the combustion of blends consequently lower soot formation hence the smoke opacity [42]. Smoke opacity decreases for CR18 which may be accredited to the improved mixing of fuel-air consequently accelerate the combustion. Smoke opacity for B100 mixture is higher as compared to diesel and other blends which may be accredited to high viscosity, inferior volatility of B100 may influence the mixing of fuel-air and hence the combustion process. Smoke opacity is higher at CR of 16 and 17 for all the blends and diesel may be attributed to lesser density of air associated with sluggish combustion. The smoke opacity of B20 blend at CR18 at 100% load is reduced by 6.7% compared to diesel.

5. Conclusions

Experimental work investigates various combustion characteristics of B00, B20, B40, B60 biodiesel blends and B100 at CR of 16, 17 and 18. The experimental results have to lead to the following conclusions:

- Experimental results reveal that biodiesel blends exhibit the same trend of pressure rise with a variation of crank angle as diesel.
- There is no unusual combustion behavior for blends at different CR.
- Injection and combustion are advanced for blends.
- Maximum cylinder pressures for biodiesel blends are higher and are at earlier crank angles. Diffusion combustion of blends is increased because of the reduced delay period.
- Increasing CR increases peak cylinder pressure, heat release, the rate of pressure rise for a mixture of two biodiesel with diesel blend. Increase in CR improves combustion characteristics of the engine for the all the fuels.
- Combustion duration is increased for the blends in comparison to diesel and increases with an increased volume percentage of biodiesel in blends.
- Combustion rate is faster for blends with an increase in CR. At CR of 17 and 18 mass fraction burned is faster for biodiesel blends throughout uncontrolled combustion stage that shows higher cylinder gas pressure for the blends in comparison to diesel.
- Carbon monoxide, hydrocarbon emissions decreases, and NO_x increases for the blends compared diesel.

It is concluded that biodiesel (Simarouba-Jatropha) blend with diesel can be an alternate fuel to CI engines without major modification with reasonable combustion properties.

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Discloser statement

No conflict of interest among the authors.

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