INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
S. N. Nagesh, Vol.12, No.2, June 2022

Experimental and Numerical analysis of VCR diesel engine fuelled with Blends of *Jatropha curcas* Methyl Esters

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Received: 03.01.2022 Accepted: 14.02.2022

Abstract- : In this paper, an attempt was made with *Jatropha curcas* methyl esters (*JCME*) blends to evaluate the diesel engine combustion, emission and performance characteristics at different compression ratios. The detailed experimental analysis has been made by considering *JCME20*, *JCME40* and *JCME60* blends and related with diesel fuel (*D100*). *JCME* blends exhibits better combustion behaviour and lower emissions compared with *D100* fuel. The computational engine model was developed for CFD analysis and the detailed study of combustion phenomena in the engine cylinder was done with flame initiation propagation profiles. The experimental results shows increased peak cylinder pressure with *JCME* blends and *JCME60* exhibits increased maximum heat release rate (27.98 J/CA) compared with *D100* (25.38 J/CA) at CR-18. Also, BSFC of *JCME* blends shows lower values, whereas the BTE of *JCME* blends were found to be more at 28% rated load on the engine operated at the compression ratio (CR-18) compared with counterpart *D100*. In this work, significant reduction in CO (44.17%) and HC (29.03%) emissions were noticed for *JCME60* blends at compression ratio CR-18 and *JCME20* exhibits lower NO_x emissions at lower and moderate loads compared with the *D100* fuel. The results from experiment were validated using CFD simulation results and variation of cylinder pressure and heat release rates for *JCME60* and *D100* were found be within 10%.

Keywords CFD simulations, transesterification, cylinder pressure, heat release rate, brake thermal efficiency, compression ratio

1. Introduction

World is facing scarcity of energy due to urbanization, fast growing population and standard living style [1, 2]. Liquid fossil fuels are the prime fuels used widely in vehicles, industries and even in agriculture field [3, 4]. The rapid consumption of fossil fuels leads to the depletion of the fuel sources and exponential increase in the environmental pollution, makes the researchers to do work on alternate fuels [5]. The economic conditions of any country also depends on the available energy sources, hence development of sustainable energy and research on alternative fuel source such as biofuels, wind, solar energy etc. has to be supported at national and international levels. In the present context, extensive work has to be done on the biofuels, environmental issues and energy conversion technology and protection of the environment. Biofuel is one among the renewable energy got attention due to its biodegradable nature and nontoxic behaviour. It has less environmental effects related to the petroleum fuels [6–8]. .

Vegetable oil derived as biofuels gain the popularity as it contains 90% heating value when related to the diesel fuel [9]. Across the globe, different types of raw vegetable oils are available having high oil content. So, there is a need to cultivate the oil plant to meet the energy demand by increasing its productivity. Vegetable oils are present in two varieties, one edible oil and another non edible oil. Countries like US and Europe produces biodiesel using edible oil, since it contains low FFA content. They are using *Soybean* and *Rapeseed* oils as prime stock for biodiesel production. Whereas, South East Asian countries cannot afford the edible oil usage for biodiesel production, due to food scarcity and cost of production is high. Hence, developing countries gives more priority for non-edible oils crops for biodiesel production which reduces the overall cost. The oils extracted from *Azadirachta indica, Pongamia pinnata, Hevea brasiliensis, Jatropha curcas* etc. are used for biodiesel productions[10,11].

Direct usage of raw vegetable oil in engines is not advisable, even though it is economical. The vegetable oil is usually having more viscous and low volatile nature will create problems on the engine. Most of the vegetable oil viscosity is 10 to 17 times greater than diesel fuel create severe problems on the fuel injection system. This in turn results in heavy carbon deposit in the engine piston leads adverse effects like poor performance and engine fouling[7], [12]. Biodiesel is derivative converted from vegetable oil or animal fat in to mono-alkyl esters, using a method called transesterification process[11],[13]–[15].The primary constituent of biodiesel are the esters exhibits certain specific properties like high viscosity, low heating value, high flash point and high cetane number when compared with diesel fuel. The biodiesel contains esters chemically, whereas diesel fuels usually paraffinic and aromatic in nature [16]. Combustion and emissions of an engine fuelled with blended biodiesel get altered and the deficiency of pure biodiesel can be overcome with the use of stable biodiesel blends along with slight alterations in the engine design.

In the present scenario, more priority is given on the study of engine combustion behavior, performance and exhaust emissions of biodiesel from various feed stock in diesel engine operated at different engine parameters. The engine parameters such as load, compression ratio (CR) and injection timing are play prime factors in the combustion and performance of an engine. The combustion phenomena is monitored by the chemical kinetics of fuel mixture, ignition timing and rate of combustion. The combustion parameters are difficult to control, since it mainly depends on engine compression ratio, speed and load. In the present conditions, more focus is given on the CFD analysis to understand detailed combustion phenomena, complexity involved in the flow of the fluid and fuel spray [17]. The CFD simulations helps in the design of the engine, thereby reduces the time and overall cost incurred by the manufacturer, biodiesel producer and consumer [18]

Chauhan, Kumar and Cho[19] analyzed combustion behavior and exhaust gases of CI engine running with *Jatropha* biodiesel blends. They observed lower rate of release of heat, shorter ignition delay, and lower brake thermal efficiency with biodiesel blends operated at various engine loads and constant compression ratio. The study also revealed that the biodiesel blends exhibits lower HC and CO emissions, whereas the brake specific fuel consumptions and NO_x emissions were found be more than the diesel fuel. They concluded that the blends up to 30% can be used in diesel engine without any modifications. Qi et al. [2] studied the combustion behavior of *Soyabean* blended biodiesel in diesel engine. They observed higher peak pressure, start of combustion at the earlier stage and increased heat release rate results in better combustion and reduced CO and smoke emissions. But minor increase in BSFC and decreased BTE were noticed by them. Uyumaz [20], prepared biodiesel blends using *mustered oil* got 6.8% decrease in indicated thermal efficiency with 10% blend, whereas BSFC was increased by 4.8%. In contradicting to the above researchers work, Sathiyagnanam, and Saravanan [21] noticed minor increase in BTE and BSFC by using *cotton seed oil* biodiesel blend. The increase in BTE is due to the biodiesel blends have high content of oxygen and cetane number. Muralidharan, Vasudevan, and Sheeba [22] observed increased brake thermal efficiency of 4.1% for the *waste oil* methyl ester blend B40 and it exhibits higher cylinder pressure for the compression ratio of 21 compared to diesel fuel. Baweja, Trehan, and Kumar [13] prepared the *mustered oil* biodiesel blends up to 40% with diesel fuel for their studies. They observed B10 blend exhibits highest BTE, when compared with other blends. Purushothaman, and Nagarajan [23] taken the *orange oil* as fuel observed lower emissions of unburned HC and CO, but increase in NO_x emissions were noticed. Chauhan, Kumar, Cho, and Lim [24] evaluated performance parameters using *Karanja* blended biodiesel and observed lower peak pressure and heat release rate. Lower HC and CO emissions of biodiesel blends were observed, whereas higher NO_x emissions were noticed at all the loads applied on the engine. Rajak, and Verma [25] observed higher piston force with biodiesel blends runs at high CR of the engine. Dhar, and Agarwal [26] obtained lower BSFC at lower blends and increased BSFC were noticed for higher blends of *Karanja* biodiesel. At lower engine load, they observed decreased BTE and it becomes almost same as the engine load increases. The biodiesel blends exhibits lower emissions of HC and CO emissions, whereas relative increase in the NO_x emissions were noticed.

Hawi et al [27] taken Jojoba methyl ester blends to analyze the compression ratio effect on engine combustion, emissions and performance behavior. Numerical simulations were made by considering the 3D engine model operated at constant load and speed using ANSYS Forte code. They observed increased unburnt HC, CO and NO_x emissions for 100% biodiesel and decreased cylinder peak pressure even the CR varied from 21.5 to 23. The numerical analysis results were used for the experimental validation. Asadi et al [28] analyzed biomass derived biofuel numerically using AVL fire software. The NO_x emissions and soot formation in an engine analyzed with the help simulation results indicates the premixing of the biodiesel improves the performance of the engine.

From the various research works, it is observed that the biodiesel blends can be used effectively in diesel engine with minor modifications. *Jatropha curcas* methyl esters exhibits lower thermal efficiency and more fuel consumptions. In order better characteristics of performance, it is required to do the engine run at different compression ratios. Also, literatures admits that the work on experimental and numerical analysis of *Jatropha curcas* methy ester *(JCME)* blends on diesel engine has not been done. Hence, the present work aims detailed study of combustion parameters, performance and exhaust emission characteristics of *JCME* blends in diesel engine operated at different loads and compression ratios. Numerical analysis has been investigated for diesel fuel and JCME60, revealed flame initiation and propagation helps better understanding of the combustion phenomena. Computational model was created using CATIA software and CFD simulations were carried out using Richardo Vectis software. Finally, the experimental combustion results were validated with the CFD simulation results.

2. Experimental Setup and Methodology

2.1. Test Fuel

In the present work, *Jatropha curcas* oil available locally was taken for the fuel preparation. The method adopted to get the *Jatropha curcas* methyl esters was alkaline transesterification process[25], [26], [29], [30]. In this process, the *Jatropha curcas* oil free fatty acid (FFA) content was converted in to esters. The mixture of *Jatropha curcas* oil, 20% of methyl alcohol, 1.6% sodium hydroxide (NaOH) as catalyst were taken in a reaction chamber. The mixture was stirred at 300rpm for 1hr at the reaction temperature of 55°C-60°C. Then, the mixture was left in the beaker for 8hr and two clear layers were observed. The methyl ester was extracted from the mixture using water wash method and repeated for 4 to 5 times until pure biodiesel was obtained.

Jatropha curcas methyl ester blends *JCME20, JCME40* and *JCME60* were prepared with diesel fuel on volume basis. The prepared *JCME* blends were sent for characterization and analyzed according to ASTM standard. The essential properties of the *JCME* blends and diesel were tabulated in the Table1.

2.2. Experimental Setup and Procedure

The prepared fuels were tested on the Kirloskar diesel engine test rig shown Figure1.The modified engine is a variable compression ratio diesel engine. The engine was applied with different loads using eddy current dynamometer. The details of an engine used for the experimentation are specified in Table 2.The engine compression ratio was altered by using tilting cylinder head mechanism. The data acquisition system capture the pressure data by using piezo electric pressure transducer. The pressure data were synchronized with crank angle by using the encoder having the resolution of 1°. The engine speed sensor having the measurement range 0-9999 rpm helps to capture engine speed. K type thermocouples (0 -1500°C) were adopted to measure inlet and temperatures of exhaust of the engine. The test rig was connected with differential transducers (0-99 kg/h) capture the data related to air flow and fuel flow to engine. All these data were transferred to the acquisition system to capture the data and interpretations were done to determine the engine performance parameters and combustion related parameters.

Exhaust gases were drawn from the exhaust manifold and pass to AVL five gas analyser to measure the important pollutants. Exhaust analyser is very sensitive to low emissions, detect its presence in spite of other gases interference. Pollutants viz CO, HC, and NO_x were effectively measured by the analyser, works on the principle of Non-dispersive infrared (NDI) method. Analyser identifies the traces of gases in the flow and removes completely using zero calibration.

The experimental data were captured on a computerized single cylinder, variable compression engine. Initially, engine oil and cooling system was checked the before starting the engine. Once engine start, the compression ratio was set for 14 and load of 14% was applied with the help of eddy current dynamometer. Data were captured after 4min and different loads of 28%, 42%, 56% and 70% were gradually applied on the engine. The experimental values were measured for other compression ratios of 16 and 18, once the loading condition was brought to zero. The results were taken three times at different intervals and average value were taken for the interpretation of different fuels viz diesel, *JCME20*, *JCME40*, and *JCME60*. Finally, the engine was run by diesel fuel for 10 min until all the remaining biodiesel blends in the fuel line completely burnt in the engine. The errors were introduced in the experimental work due to test rig devices and other external factor. The uncertainty of various measuring devices for finding various engine parameters was determined and found to be ±4.66. The complete details for calculating the uncertainty was shown in previous work [14].

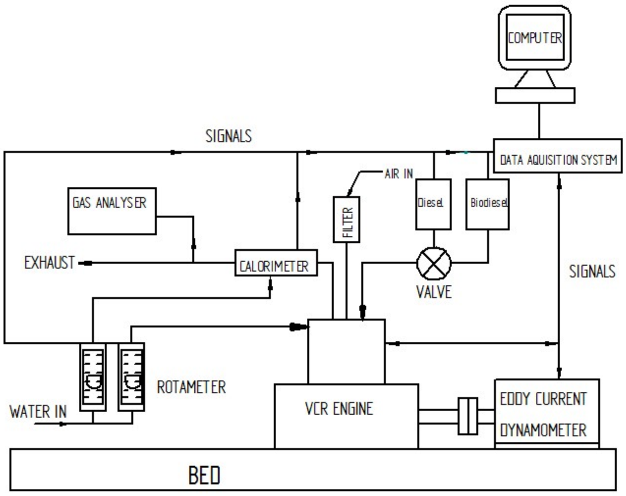

Figure 1. Diesel engine test rig block diagram.

2.3 CFD Analysis

First, the engine model was created for CR-18 by considering the technical features of experimental test rig. The modelled engine cylinder with the combustion chamber was meshed using Richardo Vectis, calculates flow field behaviour based on the governing equations along with the chemical kinetics of the fuel. The modelled geometry was meshed for the cylinder region and bowl region area. If finer mesh is used in the analysis require more computational time but accuracy of the simulation results are found to be better. Whereas the coarser mesh reduces the analysis time and simulated results will be inaccurate. Hence, finer meshes were considered for the bowl region and coarser meshes for cylinder region for getting the better results with optimized computational time. The computational meshes were created for different crank angle geometries varying from 180° to 360°. The computational grid model for 180° and 360° crank angle in shown Figure2. In Richardo Vectis simulations involves two steps analysis i.e., compression and combustion steps. The solver file in the software has more potentialities of graphical user interface (GUI), utilizes dynamic meshes for getting the solution by using finite volume method. K-ε model was selected in the analysis to address the turbulence effects and diffusivity of the transport variable. Patterson and Reitz break up model was selected to account breaking of fuel droplets during fuel atomization. RTZF combustion model with model coefficient $C_{mix}=20$ was used to address the combustion phenomena locally for burned and unburned regions

3. Results and Discussions

3.1 Combustion Characteristics

3.1.1 Cylinder Pressure (CP)

The pressure data variation of diesel (*D100*) fuel and *Jatropha curcas* methy ester blends were plotted for the CR-18 and load of 28% versus crank angle shown in Figure 3a. It is observed that the *JCME* blends showed more peak cylinder pressure than *D100*. The peak cylinder pressure values of *D100*, *JCME20*, *JCME40* and *JCME60* at regular engine speed of 1500rpm were 43.01 bar, 45.1 bar, 44.64 bar and 45.95 bar respectively. Peak pressure J*CME60* was 6.84% more than *D100* fuel. The accumulation of fuel occurs during delay period, results in premixed combustion [13]. Similar trend was observed in Dhar, and Agarwal [26].

Table 1. Important properties of diesel and *Jatropha curcas* methyl esters blends

Property	**diesel**	***JCME* blends**			**Measured standard**	**Equipment used**
	D100	*JCME20*	*JCME40*	*JCME60*		
Density (kg/m^3)	826	835	849	849	ASTM 1298	Hydrometer
Kinematic viscosity (cSt)@40°C	2.576	3.301	3.871	4.439	ASTM D-445	Redwood viscometer
Flash point(°C)	46	52	56	59	ASTM D-93	Pensky marten closed cup tester
Fire point(°C)	54	73	82	91	ASTM D-93	Pensky marten closed cup tester
Heating value(kJ/kg)	44500	43380	42416	40545	ASTM D-420	Bombs calorimeter

Table 2. Specifications of diesel engine test rig

Make	**Kirloskar**
Engine type	1 cylinder, 4-stroke, water cooled, diesel engine
Bore × stroke	80 ×110mm
Connecting rod length	235 mm
Torque applied on the engine	Eddy current dynamometer, 240N-m(Max)
Compression ratio (Variable)	14:1 to 22:1
Fuel injector pressure	200 bar
Injector hole diameter and number	0.25mm and 3
Pressure transducer	Piezoelectric (5000psi)
Encoder for crank angle	1° Resolution
Sensors for detecting temperature	K type, RTD
Load cell	0-50 kg
Rated power	3.75 kW
Engine speed	1500rpm

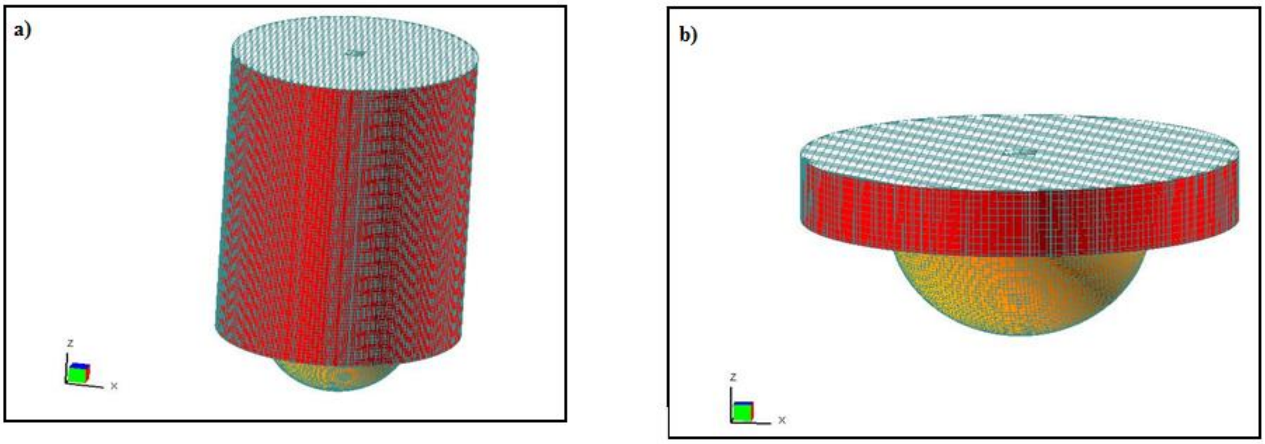

Figure 2. Computational grid model at a) 180° CA and b) 360° CA

Also, graph reveals that the cylinder pressure of the *JCME* blends exhibits mixed combustion phase than diesel fuel. This ensure that the complete burning of *JCME* blends occur due the higher oxygen content in the blend.

Figure 3b, reveals the influence of CR on the cylinder pressure of the blend *JCME*60. It is observed that the peak pressure of 45.93 bar was obtained at high CR-18 compared with the other CR. The occurrence of this trend is due to high cylinder temperature and the existing of remaining gases, leads to increased temperature of the fuel injection charge. This in turn improves the fuel–air mixing characteristics of blend and earlier injection and better combustion occurs due to the presence of volatile combustion compounds [2]. On the other hand, the peak cylinder pressure of *JCME*60 was 27.14 bar observed to be very low for the CR-14. This trend is due to random blending of the fuel with air in the premixed phase results in incomplete combustion.

3.1.2 Heat Release Rate (HRR)

The variation of HRR of *D100* and *JCME* blends in the engine shown in the Figure 3c and the graphs were plotted from the test rig operated at the CR-18 and 28% load. It is revealed from the graph that the *JCME20*, *JCME40* and *JCME60* exhibits earlier combustion occurs at 347° CA, 346° CA and 344° CA BTDC than *D100* (348° CA). Early combustion of blends of *JCME* leads to maximum HRR, due to premixed air-fuel mixture burns rapidly. After the fuel is injected in to the cylinder block, starts accumulated in the delay period of ignition and evaporation of liquid fuel takes place results in negative HRR and after beginning of combustion, positive HRR was observed. In this work, the blend *JCME20* and *JCME60* reveals comparatively increase in maximum HRR of 25.84 J/CA and 27.98 J/CA than the *D100* (25.38 J/CA) was observed. This is due to more free oxygen available for the combustion in the premixed combustion phase. On the other hand, JCME40 shows lower maximum HRR of 24.015 J/CA due to reduction in premixed burning and ignition delay period [2], [31]. The variation of HRR of blend *JCME60* at different CR depicted in Figure 3d. The maximum rate of heat release at CR-16 (28.2 J/CA) and CR-18 (27.98 J/CA) were found to be remains almost same and heat release was attained peak values at the beginning of start of combustion. At CR-14, maximum rate of heat release (13.52 J/CA) was found to be lower at the beginning of combustion. This is due to incomplete combustion occurs due to irregular blending of the fuel with air results in reduced cylinder temperature.

3.2 Performance and Emission Characteristics

3.2.1 Brake Specific Fuel Consumption (BSFC)

The *JCME* blends effects on BSFC at different loads at CR-18 as shown in Figure 4 a. BSFC of all the tested fuels were found to be decreases with increase in the load. *JCME40* and *JCME60* shows higher values of BSFC at higher loads than the BSFC of *D100 f*uel. This trend is due to lower heating value, more density and viscosity of the *JCME* blends. From the graph, BSFC of the *JCME20* (0.53kg/kWh) and *JCME60* (0.53kg/kWh) were observed to be lower at 28% load compared with D100 (0.56kg/kWh). This trend is due to maximum heat release rate of JCME blends. Also, it is observed that the *JCME20* shows 5.4%, 13.04%, 2.85% and 5.26% reduced BSFC than *D100* fuel at 28%, 42%, 56% and 70% respectively. The decrease of BSFC of *JCME20* blend is due to prior combustion start and burning of the blended fuel in the later phase of the combustion.

The variation of *JCME60* vs. different CR were studied in the Figure 4b. BSFC of *JCME60* at 28% load reveals lower values for CR-18. The decreased trend of BSFC reveals better combustion process at higher operating conditions. This observation is due to the development of more temperature in the engine cylinder at higher compression ratio leads to catastrophic breaking of large fuel droplets in to small droplets. Usually, the oxygen content in the small droplet is ready to mix with air to form a proper air fuel mixtures, results in early start of combustion process, and peak cylinder pressure develops in the premixed combustion phase and complete burning of the fuel in the later stages develops more power of the engine, which in turn reduces the BSFC [29].

3.2.2 Brake Thermal Efficiency (BTE)

JCME blends and *D100* fuel effects on diesel engine operated at various loads for CR-18 indicated in Figure 4c. BTE of blends *JCME20*, *JCME40 and JCME60* were observed to be more than *D100* at different loading conditions. BTE of blends *JCME60*, *JCME40* and *JCME20* shows 15.78%, 8.9% and 8.48% higher values than D100 fuel at 28% loading condition. This is due to higher O_2 content of *JCME* blends at high cylinder pressure, which apply more force on the piston results in more engine power and reveals the occurrence of good burning process. Similar results trends were observed in An et al. [32] work. BTE of *JCME60* at CR-18 was more than other compression ratios at rated engine load of 28% shown in Figure 4d. This is because the increase of higher cylinder temperature results in early ignition and possibility of more oxygen release occurs yields to better combustion and which in turn develops more power [26].

3.2.3 CO Emissions

CO emissions were varied for *D100* and *JCME* blends at different loads for a CR-18 as shown in Figure 5a. It is observed from the graph that the CO emissions of *JCME* blends exhibits lower at all the loading conditions. *JCME60* shows drastic reduction of CO emissions of 32.72%, 44.17%, 30.89%, 27.71% and 20.40% compared to D100 fuel at 14%, 28%, 42%, 56%, and 70% loading conditions respectively. The occurrence of this results is due to higher oxygen content in blends helps in better burning results in conversion of CO in to CO_2. Whereas diesel fuel have low oxygen content shows more CO emissions at different loads. Compression ratio is the engine parameter helpful in large reduction in CO emissions observed in the Figure 5b. CO emissions of *JCME60* were observed to be emitted lower at higher compression ratios (CR-16, CR-18), as it contains more available oxygen in the *JCME* blended fuel at higher temperature of engine cylinder and pressure results in better burning and oxidation, leads to conversion of CO to CO_2 [24].

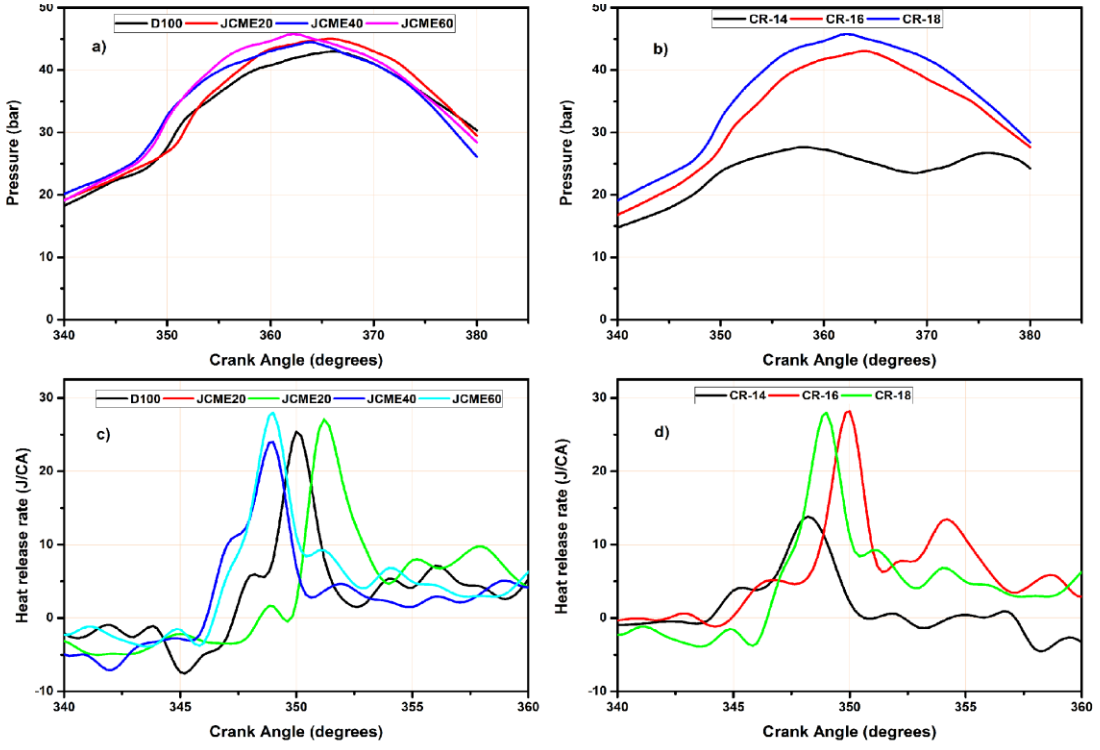

Figure 3. a) & b) cylinder pressure, c) & d) Heat release rate

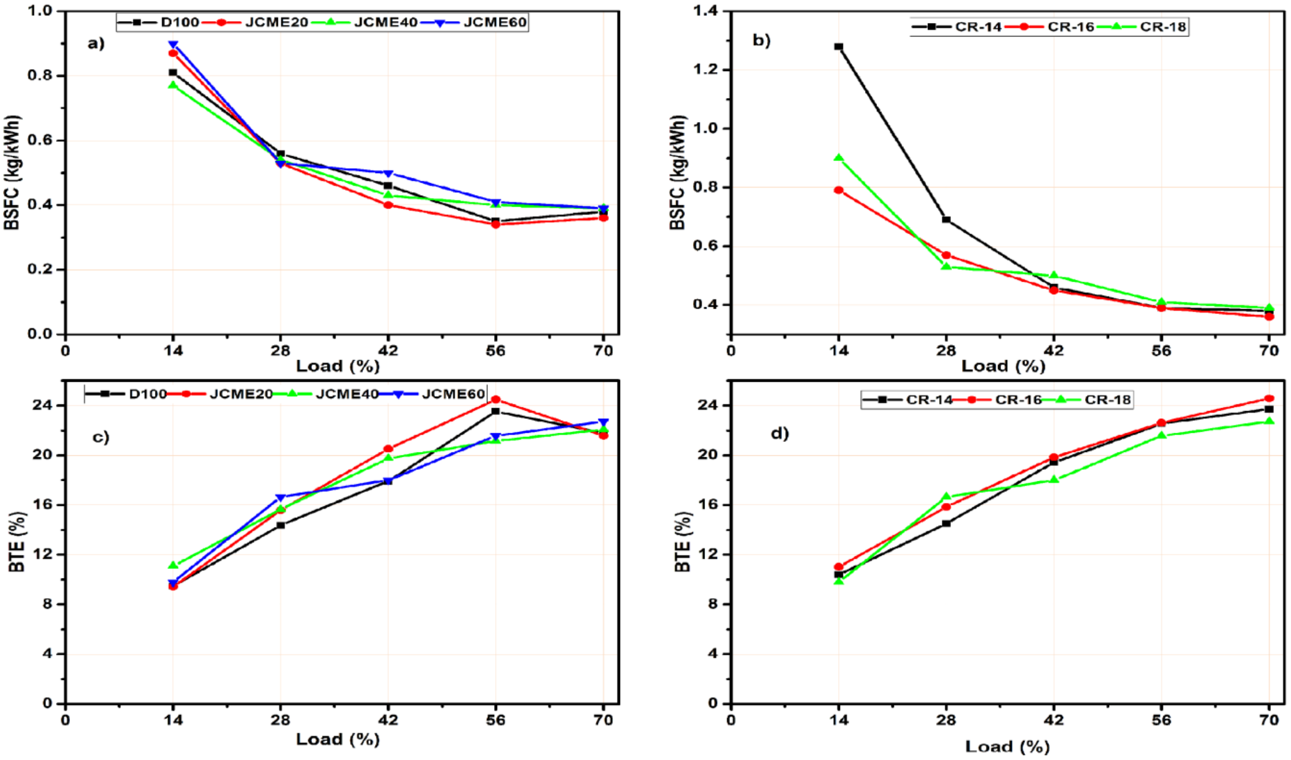

Figure 4. a) &b) Brake specific fuel consumption, c) &d) Brake thermal efficiency

3.2.4 HC Emissions

HC emissions of *D100* and *JCME* blends at different loads for a CR-18 were represented in Figure 5c. *JCME* blends emits lower HC emissions than *D100* fuel. The reason for this is due to the *JCME* blends improves the fuel–air mixing characteristics as it contain more oxygen and better combustion occurs, which in turn reduces HC emissions [24]. *JCME60* exhibits maximum of 11.66%, 29.03%, 26.47%, and 17.91% reduced HC emissions than *D100* at the rated loads of 14%, 28%, 42% and 56% respectively. *JCME60* shows fall in emissions of HC at CR-18 compared with CR-14 and CR-16 shown in the Figure 5d. The reason for this observation is due to breaking of larger fuel droplets of *Jatropha* methyl ester in to smaller one make the blend more volatile results in better mixing with air causes the better combustion. At lower compression ratio, *JCME* blends exhibits higher HC emissions indicates poor decomposition of the fuel drops results inappropriate mixing with air reveals incomplete combustion.

3.2.5 NO_x Emissions

NO_x emissions variations of *JCME* blends and *D100* were plotted for various loads depicted in Figure 5e. *JCME40* and *JCME60* exhibits increased NO_x emissions than *D100*. The blends have free content of oxygen available during burning process results in better combustion yields increased peak cylinder pressure and cylinder temperature causes more NO_x emissions. Also it is observed that the blend *JCME20* exhibits 8.47% and 21.73% lower NO_x emissions than *D100* fuel at 28% and 56% loads respectively. But Figure 5f, reveals increased NO_x emissions of *JCME60* with increase in the compression ratio. This is because *JCME* blend have more O_2 content and the cylinder temperature becomes more, when the test rig is operated at higher CR results in early start of combustion causes more oxidation of fuel and better combustion. This process which increases the tendency of formation of NO_x [13].

3.3 CFD Simulations Results

The flame initiation and propagation in the combustion chamber of diesel engine shown Figure 6 and Figure 7 for diesel fuel and *JCME60* blend at CR-18 respectively. The profile clearly indicates that, the combustion process begins at 348° CA BTDC for diesel fuel and 346° CA BTDC for *JCME60*. The beginning of combustion process occurs at the piston bowl, spreads spontaneously across the engine cylinder in the flame propagation stage. Flame contours of the blend *JCME60* shows 2° CA quick flame development and earlier combustion compared with diesel fuel reveals the proper mixing of air fuel in the engine cylinder.

3.4 Model Validation

The engine model validated by considering constant engine speed of 1500 rpm and 28% rated speed. Figure 8 shows the difference between the values of experimental and simulated results of the fuel, which clearly specifies the variation in the values of cylinder pressure. It was found that the difference of 3.46 % and 1.06% in peak cylinder pressure of simulated and experimental results of *D100*

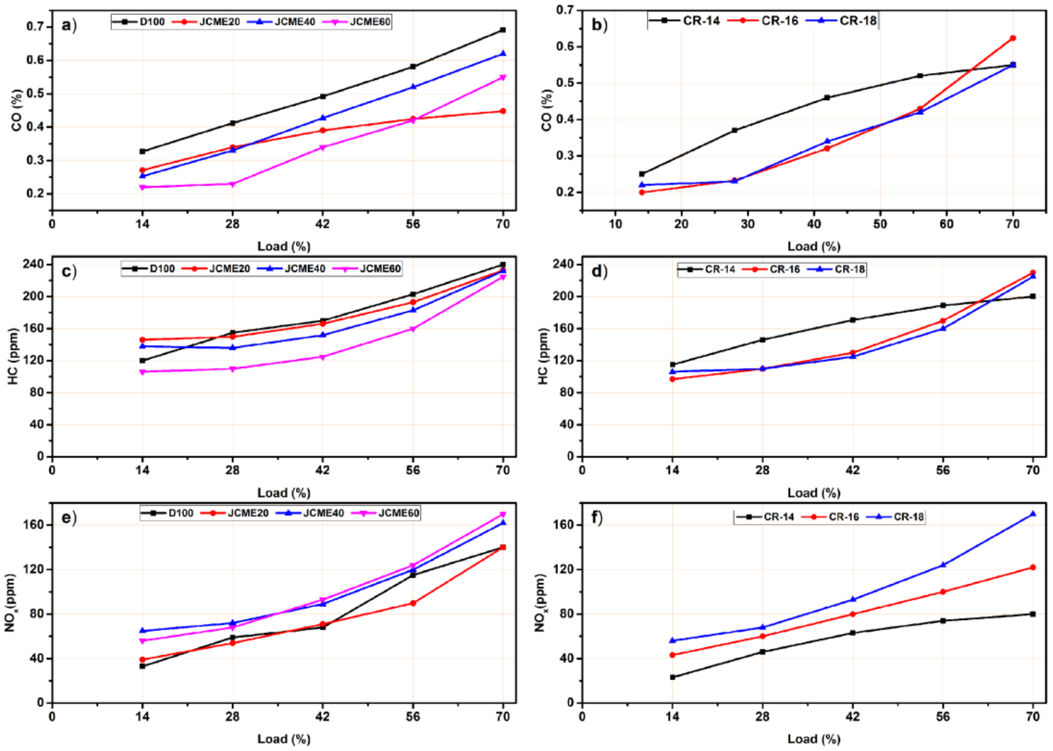

Figure 5. a) &b) CO emissions, c) & d) HC emissions, e) & f) NO_x emissions

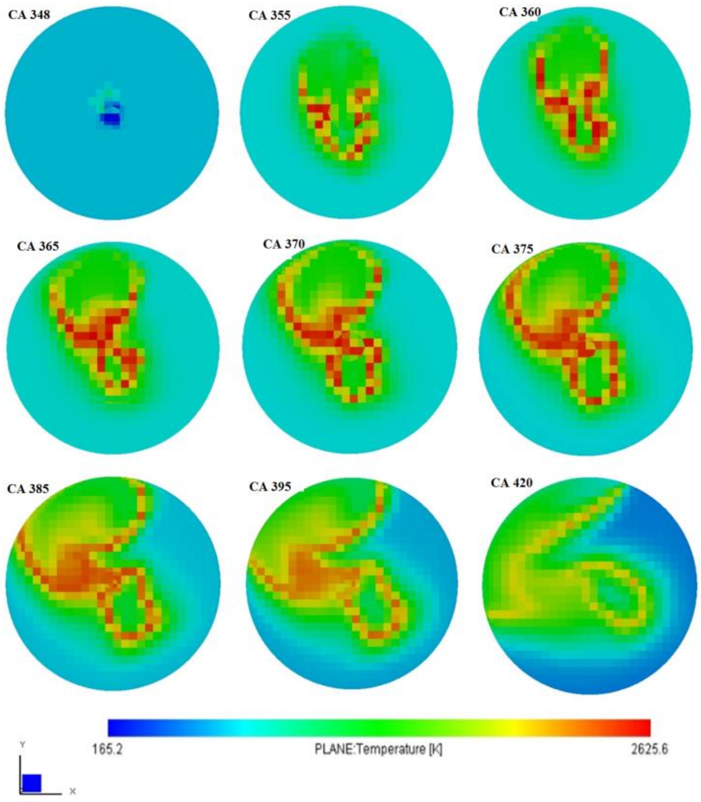

Figure 6. Flame initiation and propagation of diesel fuel

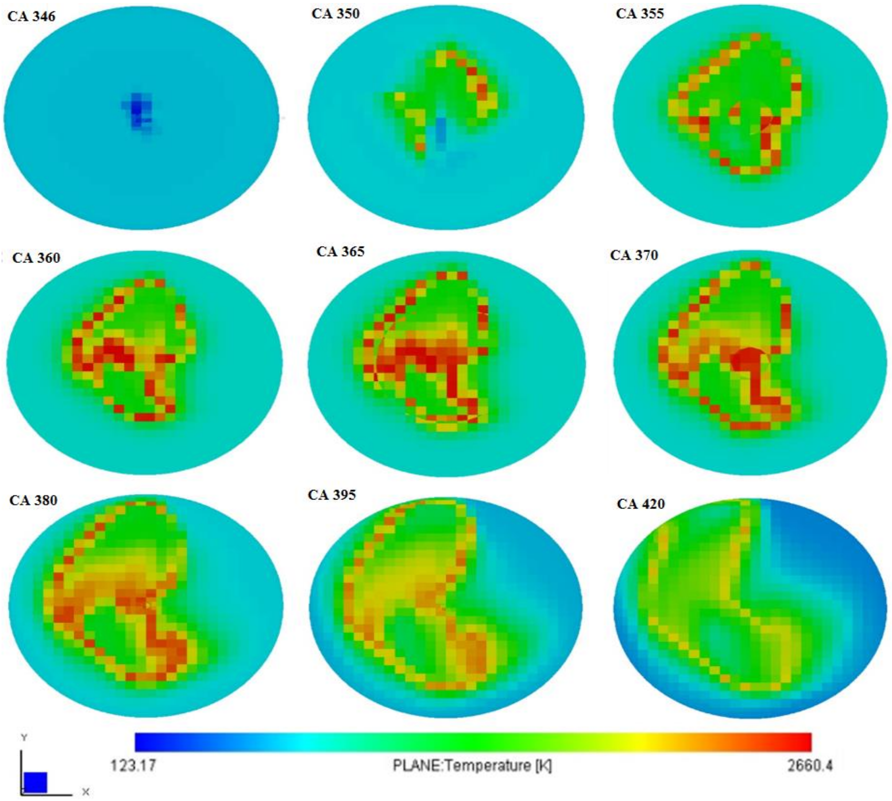

Figure 7. Flame initiation and propagation of *JCME*60

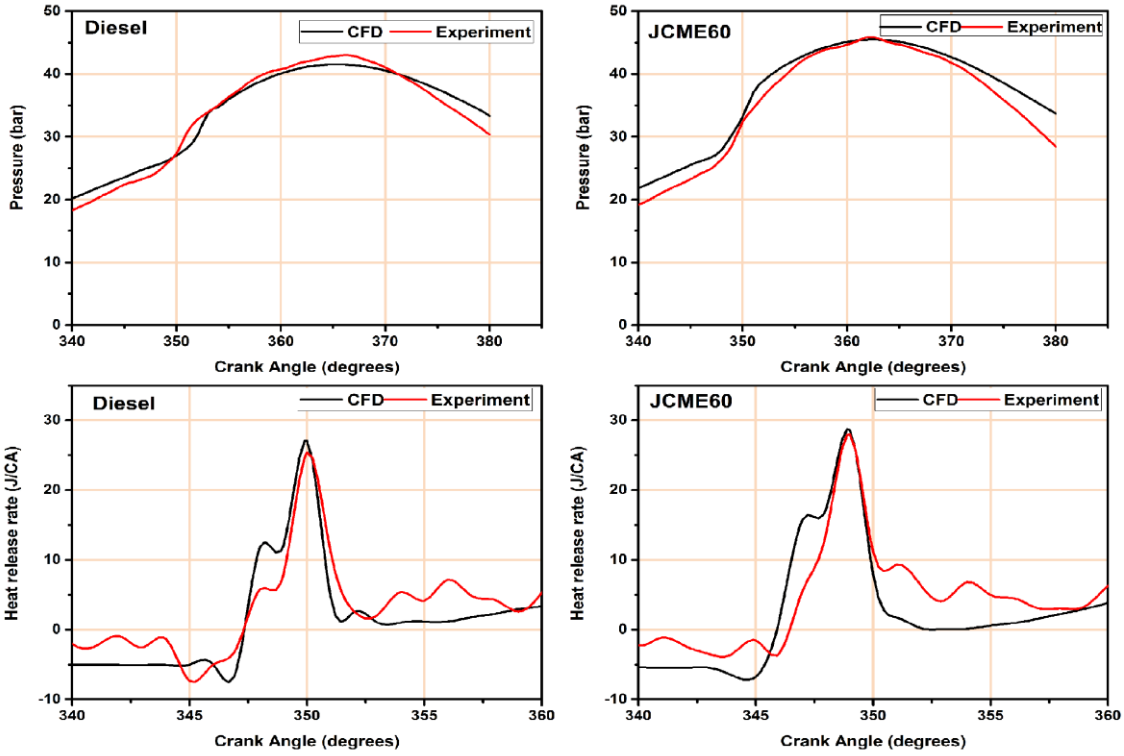

Figure 8. Comparison of experimental and simulation results of cylinder pressure and HRR

and *JCME60*. The overall variation of pressure values for other crank angles were fall within 10%. The heat release rate occur due to combustion of fuels in the engine cylinder indicates, the variation simulated and experimental values of *JCME60* and diesel fuel were found to be 2.22% and 4.2% respectively. Hence, the experimental data for the given input conditions were validated with Richardo vectis simulations results.

4. Conclusion

In this work, detailed study was carried out using *JCME* blends in diesel engine to characterize the engine combustion, performance and emission behaviour operated at different compression ratios and loads. The results of the experiments can be concluded as follows:

- The peak pressure values of *JCME* blends were more than the peak pressure values of *D100* and *JCME60* blend exhibits highest peak pressure at higher compression ratio CR-18.
- *JCME60* reveals slightly increased maximum HRR of 27.98 J/CA, whereas diesel (*D100*) shows maximum HRR of 25.38 J/CA, which is lower than the *JCME60*.
- *JCME60* blend at CR-16 and CR-18 revealed almost same maximum HRR and observed at the early combustion phase.
- BSFC of blend *JCME60* (0.53kg/kWh) at 28% load is lower than BSFC of *D100* (0.56kg/kWh) at CR-18.
- *JCME* blends shows relatively higher values of BTE than D100 at different loads and CR-18. *JCME60* blends exhibits highest BTE, which is 15.78% more than *D100* at the rated load of 28%.
- CO emissions of *JCME* blends shows drastic reductions than *D100* fuels at all the loading conditions. *JCME60* exhibits very low CO emissions than other *JCME* blends and maximum reduction of 44.17% CO emission was noticed at the rated load of 28% than *D100* fuel.
- HC emissions of *JCME* blends were lower than *D100* fuel at all the different loads for a compression ratio CR-18. HC emissions of *JCME60* were to be found to be lower than other *JCME* blends and maximum of 29.03% reduction in HC emissions were noticed at 28% load, compared with the *D100* fuel.
- *JCME20* exhibits 8.47% and 21.73% lower NO_x emissions than the *D100* for compression ratio CR-18 at the rated loads of 28% and 56% respectively. Whereas other blends *JCME40*, *JCME60* shows increased NOx emissions at all the rated load and compression ratio of the engine.
- Flame contours of the blend *JCME60* shows 2° CA quick flame development and earlier combustion compared with diesel fuel.
- Combustion characteristics of the D100 and JCME 60 at the rated load of 28% and compression ratio CR-18 were obtained from the CFD simulations and validation of results were done with experimental results. The difference in the experimental results and CFD results were found to be within 10%.

From the current study, it is clear that the *Jatropha curcas* methyl esters can be used as the substitute fuels up to 60% blending in diesel engine with little modifications, to operate at the higher compression ratio CR-18 for getting better performance and lower emissions. CFD investigation reveals that the computational engine model can be used for the detailed understanding of the combustion phenomena with help of flame initiation and propagation at different crank angle.

Acknowledgements

Author express deep gratitude for the management of Ramaiah Institute of Technology for their kind support for carrying out this research work

Nomenclature

HRR	Heat release rate
JCME	*Jatropha curcas* methyl esters
BSFC	Brake specific fuel consumption
CO	Carbon monoxide
CR	Compression ratio
CR-18	Compression ratio 18:1
CR-16	Compression ratio 16:1
CR-14	Compression ratio 14:1
D100	diesel
BTE	Brake thermal efficiency
HC	hydrocarbon
NO_x	Nitrogen oxides
*JCME*20	80% *D100* +20% *JCME*
*JCME*40	60% *D100* +40% *JCME*
*JCME*60	40% *D100* +60% *JCME*
BTDC	Before top dead centre
CA	Crank angle
FFA	Free fatty acid
CFD	Computational fluid dynamics
RTZF	Richardo two zone flamelet
GUI	Graphics user interface
NDI	Non-dispersive infrared
CO_2	Carbon dioxide

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