

Experimentally Combustion Analysis of Diesel Engine Using Medium Concentration of Jatropha biodiesel

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ABSTRACT: Jatropha curcas oil is a non-edible oil which is used for Jatropha biodiesel (JBD) production. Biodiesel is a promising renewable source as an alternative substitute fuel in diesel engine & has gained significant attention due to shortness of fossil fuels & environmental degradation in future. The biodiesel is produced from crude vegetable oil by the transesterification process.

In the present experimental study, the utilization of Jatropha biodiesel in Single cylinder, four stroke, compression ignition diesel engine for ascertain the combustion characteristics of Jatropha biodiesel in medium concentration form. The various blends of Jatropha biodiesel in diesel fuel is used such as JBD5, JBD15, JBD25, JBD35 & JBD45. The combustion characteristics of these blends compared with conventional pure diesel fuel(D100). The maximum blend of Jatropha biodiesel (JBD45) shows the 2% cylinder pressure rise, 7.2% rate of pressure rise drop, 2.8% mass fraction burned faster, 10.7% net heat release drop, 14% cumulative heat release drop, 2.5 % mean gas temperature drop & 44% improve the ignition delay than conventional pure diesel fuel (D100) at full load condition on engine.

KEYWORDS: Compression ignition engine, Transesterification, Jatropha biodiesel, Cylinder pressure, Rate of pressure rise, Mass fraction burned, Net heat release, Cumulative heat release, Mean gas temperature, Ignition delay.

I. INTRODUCTION

Energy is the most important component of human life & being an essential input for every activity. It is the gift of the nature to the mankind in various forms such as Solid (Coal), liquid (Petroleum fuel) & Gases (Natural gas). With ever growing population, improvement in the living standard of people, industrialization of developing countries, the global demand for energy is expected to increase further significantly in the near future & fossil fuel depletion correspondence. The world's two energy crises in the years 1973 & 1978. World population is projected to grow by nearest 1.8 billion people from 2015-2040 & surpass 9 billion people. Total primary energy demand is forecast to increase by 40% in the period to 2040 to reach 382 million barrels of oil equivalent per day (mboe/d). India population is projected to grow by nearest 0.32 billion people from 2015-2040 & surpass 1.6 billion people. India primary energy demand is forecast to increase by 60% in the period to 2040 to reach 41.2 mboe/d. [1,2]

As per energy demand & population is increase, the new sources of energy that can full fill the energy demand is required, which is renewable, clean & pollution free. Many researchers, scientists & engineers have come up with various alternate sources of fuel among which biodiesel is a viable substitute that may be reduce the complexity of energy crisis to some extent. Biodiesel is an alternative source for substitute of diesel fuel because characteristics of biodiesel are similar to diesel fuel. The concept of using biofuels in diesel engines was originated from the demonstration of the first diesel engine by the inventor of diesel engine "Rudolf Diesel" at the exhibition in Paris in 1900 by using Peanut oil as fuel. [3,4]

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Biodiesel is biodegradable, oxygenated, non-toxic & environmentally safe & it derived from vegetable oil or animal fats. Biodiesel are classified into two categories such as edible & non-edible oils. Edible oil are such that Sunflower, Corn, Rapeseed, Palm, Soybean etc. & non-edible oils are such that Jatropa, Jojoba, Karanja, Polanga oils etc. [5] Vegetable oils consists of 97% triglycerides & 3% both diglycerides & mono glycerides. The process of converting vegetable oil into biodiesel fuel is called transesterification. Biodiesel hydrocarbon chains are generally 16-20 carbons in length & contain oxygen at one end. Biodiesel contains about 10% oxygen by weight. [6] The Jatropa plant growing almost throughout India & Jatropa curcas is belonging to the family of Euphorbiaceae. The oil content in Jatropa seed is approximately 40%. Jatropa curcas plant grow rapidly almost anywhere even on gravelly, sandy & saline soils. Its water requirement is extremely low & yields within 4-5 years with long productive period of around 50 years. The viscosity of Jatropa oil is higher than diesel but cetane number is very close to diesel. [7]

II. MATERIAL & METHODOLOGY

2.1 Material

In the present study non-edible vegetable Jatropa oil has been chosen to explore its possibility & potentiality as diesel engine fuel. The Jatropa curcas plant grow all parts of India. Figure 1 shows the Jatropa plant, fruits & seeds.



Fig. 1. Jatropa Plant, Fruits & Seeds

The Jatropa oil purchased from Jodhpur district in Rajasthan. Methanol & Catalyst Potassium Hydroxide (KOH) purchased from local market in Bikaner district in Rajasthan & Diesel fuel purchased nearest petrol pump.

2.2 Methodology

The crude Jatropa oil converted into biodiesel by using transesterification process. Transesterification process also called alcoholysis & in this process displacement of alcohol from an ester by another alcohol in a process similar to hydrolysis. This process is used to reduce the viscosity of triglycerides. The transesterification equation is shown in figure 2.

In this investigation, for transesterification process magnetic stirrer hot plate mechanism is used. The hot plate mechanism is consists of a temperature & speed controller, magnetic stirrer, beaker, vessel for reaction, temperature sensor. Figure 3 shown the transesterification kit.

In the transesterification process Jatropa crude oil, Methanol & KOH as Catalyst was used. 1 litre of Jatropa crude oil taken into the reaction vessel & put it on to the hot plate for preheating process for removing crude oil moisture. At the other end 250 ml excess methanol was taken in the beaker & 1% (10 gm) catalyst KOH pellets taken as by volume of Jatropa crude oil. The excess methanol & Catalyst KOH pellets mixing in the beaker till the pellets of KOH

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properly dissolved in the excess methanol. This liquid of methanol & KOH is called methoxide solution. Now this solution is put in the reaction vessel with Jatropha crude oil & start the magnetic stirrer. The reaction temperature maintain at 60 °C & stirrer speed is maintained at 250 rpm. The time taken for complete the reaction about an hour. Now pour this solution into the bottle to settle down for 24 hours. After 24 hours, two layers are formed in the bottle, the above layer is Jatropha methyl easter (Biodiesel) & below layer is glycerol. Figure 4 shows the biodiesel & glycerol.

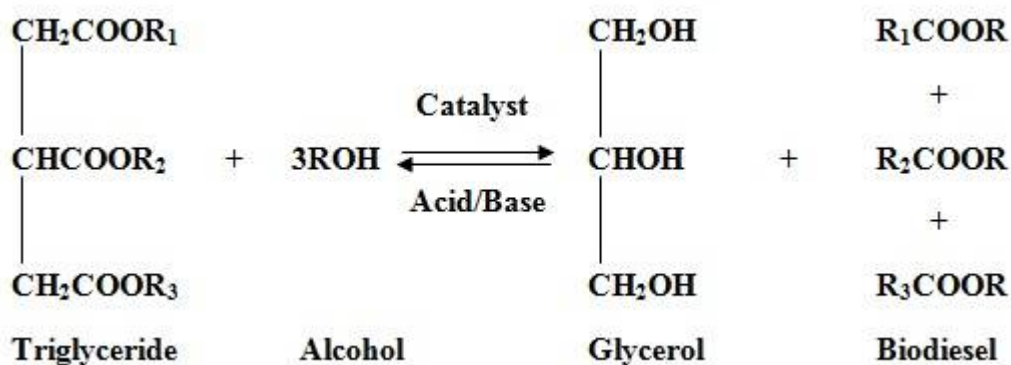


Fig. 2. Transesterification general equation



Fig. 3. Transesterification kit

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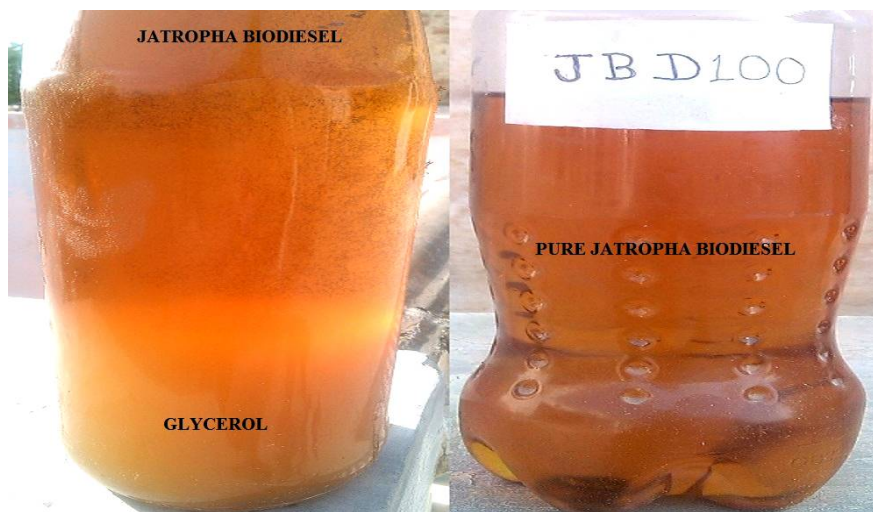


Fig. 4. Separation layers of biodiesel & Glycerol

Now this transesterified Jatropha oil become Jatropha biodiesel & this biodiesel have almost similar properties of diesel fuel. Table 1 shows the properties of Jatropha oil, Jatropha biodiesel & diesel fuel.

Table 1 Properties of Jatropha oil, Jatropha biodiesel & Diesel fuel

Properties	Jatropha Oil	Jatropha Biodiesel	Diesel
Density (Kg/m ³)	0.935	0.880	0.830
Kinematic Viscosity @ 40°C (Centistokes)	32.50	4.12	2.75
Cloud Point (°C)	9	6	-5
Pour Point (°C)	4	2	-12
Flash Point (°C)	210	118	57
Fire Point (°C)	250	126	64
Calorific Value (MJ/Kg)	37.00	38.50	42.00
Cetane Number	38	51	47
Free Fatty Acid (%)	13.7	-	-

The Jatropha biodiesel now blends with diesel manually with different volume proportions to investigate the diesel engine combustion characteristics. The different blends of Jatropha biodiesel diesel blends is shown figure 5 & table 2 shows the fuel specifications.

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Fig. 5. Different blends of Jatropha Biodiesel in diesel for testing

Table 2. Specification of fuel composition

Fuel	Fuel Blends
100% (1000 ml) Pure Diesel + 0% (0 ml) Jatropha Biodiesel	D100
95% (950 ml) Diesel + 5% (50ml) Jatropha Biodiesel	JBD5
85% (850 ml) Diesel + 15% (150 ml) Jatropha Biodiesel	JBD15
75% (750 ml) Diesel + 25% (250 ml) Jatropha Biodiesel	JBD25
65% (650 ml) Diesel + 35% (350 ml) Jatropha Biodiesel	JBD35
55% (550 ml) Diesel + 45% (450 ml) Jatropha Biodiesel	JBD45

III. EXPERIMENTAL SETUP & PROCEDURE

3.1 Experimental Setup

The experimental set-up is shown in figure 6 & consists of different components such as an engine, eddy current dynamometer, calorimeter, water pump, pressure transducer, thermocouples, rpm encoder, crank angle encoder, engine & calorimeter rotameter, control panel & a data acquisition system. The engine have single cylinder, four stroke, compression ignition diesel engine & its specifications tabulated in the table 3.

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Fig. 6. Experimental set-up

Table 3 Specification of diesel engine set-up

Description	Specifications
Make & Model	Legion Brothers, Bangalore (India), TV1 (Kirloskar)
Type	Single Cylinder, Four-stroke, Direct Injection, Vertical, Water -Cooled, Naturally Aspirated Diesel Engine
Power	5.2 kW & 7 BHP
Rated Speed	1500 rpm Governed Speed
Compression Ratio	17.5:1
Cubic Capacity	661 cc
Cylinder Bore	87.5 mm
Stroke Length	110 mm
Connecting Rod Length	234 mm
Injection Pressure	203 bar
Method of Loading	Eddy Current Dynamometer
Inlet Valve Open	4.5 deg. BTDC
Inlet Valve Close	35.5 deg. ABDC
Fuel Injection Start	23 deg. BTDC
Exhaust Valve Open	35.5 deg. BBDC
Exhaust Valve Close	4.5 deg. ATDC
Method of Starting	Manual Crank Start
Overall Dimensions	W 2000 x D 2500 x H 1500 mm ³

The eddy current dynamometer is connected at the engine flywheel end & using for apply the differnt load on engine. The calorimeter have a function for heat balance in the exhaust gas tempertaure with calorimeter water flow & pipe in pipe type calorimeter is used. The water pump is used for supply the water from water tank to engine, calorimeter & dynamometer cooling purpose. The pressure transducer installed in the combustion chamber of the engine to analysis

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the combustion characteristics of the engine such as pressure inside the engine combustion chamber & gas temperature. The thermocouples is used for measure the temperatures & attached various section of the set-up such as water inlet of engine & calorimeter, water outlet of engine & calorimeter, at the exhaust of the engine & calorimeter. The function of rpm encoder is measure the speed of engine in rpm. Crank angle encoder is used for analyzed the combustion characteristics of engine versus crank angle & it measured the crank angle in degree. The function of engine & calorimeter rotameter to set the water flow in liter per hours by the application of control valves. The control panel consists of various indicator such as temperature indicator, load indicator, rpm indicator, loading knob, air flow manometer, fuel measuring burret & fuelcock. The loading knob is used for adjust the load for engine through dynamometer. The data acquisition system is inside the control panel box & the components of data acquisition systems include appropriate sensors that converts any measurement parameter to an electrical signals, which is acquired by data acquisition hardware. It is collect the important data & store it on a personel computer for offline analysis.

3.2 Experimental Procedure

The experiment was performed firstly with the neat diesel fuel & then with five different blends (JBD5, JBD15, JBD25, JBD35 & JBD45) of every biodiesel diesel fuel. The steps for experiment are described as

- Firstly the fuel tank was filled with neat diesel fuel.
- Initially check the fuel line pipe was properly filled with diesel fuel & no air bubbles are there.
- All the connections were checked properly & then electric supply was started.
- After setting the water supply from the water tank, by the water pump, the cooling water for engine flow & calorimeter flow was set up at 90 liter per hour & 50 liter per hour respectively.
- Start the computer & open the IC Engine combustion analysis software.
- Now open the fuelcock supply from burette & start the engine with manual cranking.
- The engine is run at no load condition about 10 minutes then after start the reading with software.
- Now log on to the IC Engine combustion software control panel & save the data given a file name with a specify folder.
- Now change the load and again log on to the software control panel.
- Same procedure is applied for different load & other blends of biodiesel.

IV. EXPERIMENTAL RESULTS

The extensive experimental investigations were conducted for Diesel & Jatropha biodiesel fuel for combustion analysis of diesel engine. The various combustion parameter of engine such as Cylinder pressure, Ignition delay, Mass fraction burned, Net heat release, Rate of pressure rise, Mean gas temperature & Cumulative heat release were analysed.

4.1 Cylinder Pressure

Cylinder pressure versus crank angle data over the compression & expansion strokes of the engine operating cycle can be used to obtain quantitative information on the progress of combustion. Graph 1 is shown the cylinder pressure history versus crank angle at 80% & 100% load conditions of engine. The cylinder pressure increases correspondingly load on engine increase. The graph predicted that the in cylinder pressure trends are almost identical for both neat diesel fuel (D100) & Jatropha biodiesel diesel blends (JBD5, JBD15, JBD25, JBD35, JBD45). At full load condition, the Jatropha biodiesel diesel blends shows slightly higher in cylinder pressure due to improving the cetane number of diesel fuel when blends with Jatropha biodiesel & this fuel rapidly evaporate by absorbing heat from the cylinder. The in cylinder pressure was found to be 67.31 bar at 373°C for diesel, 68.08 bar at 372°C for JBD5, 67.96 bar at 372°C for JBD15, 68.11 bar at 371°C for JBD25, 67.72 bar at 371°C for JBD35 & 68.58 bar at 371°C for JBD45 at full load condition. Therefore, the in cylinder pressure rise about 2% between pure diesel fuel & maximum blend of Jatropha biodiesel diesel fuel (JBD45). The rise of in cylinder pressure also safe & efficient for Jatropha biodiesel diesel blends because it takes place after TDC (360°C). Otherwise, in cylinder pressure occurring very close to TDC or before that causes severe engine knock, & thus affects engine durability. It is conclude that the use of Jatropha biodiesel in diesel engine is safe & efficient.

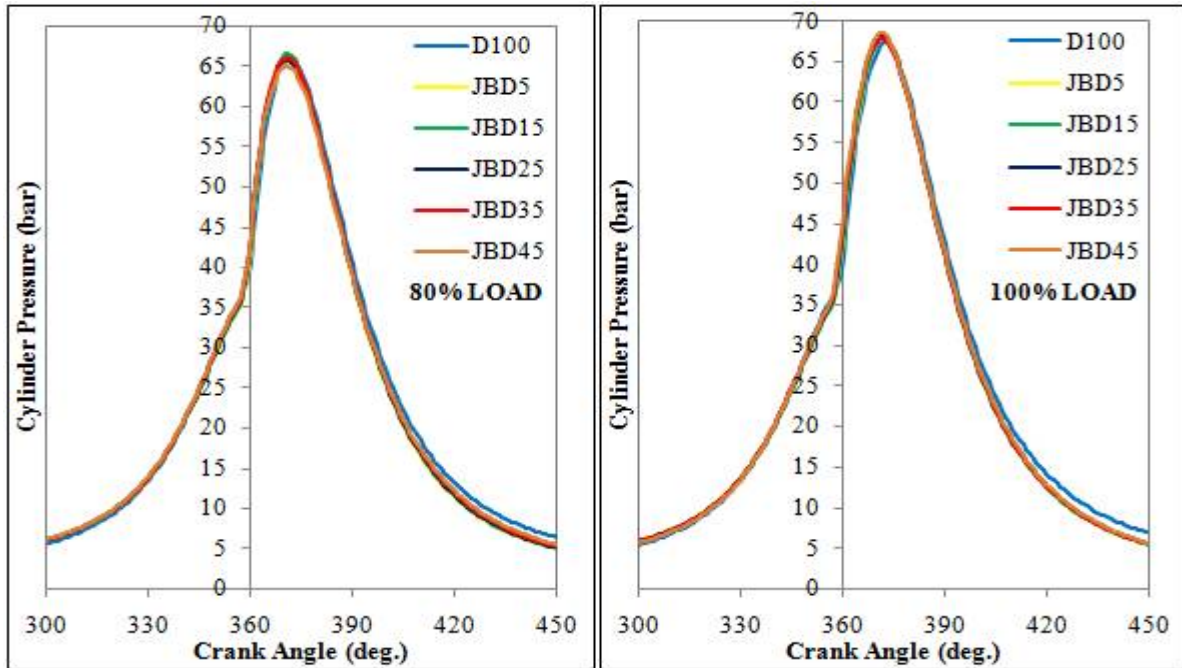
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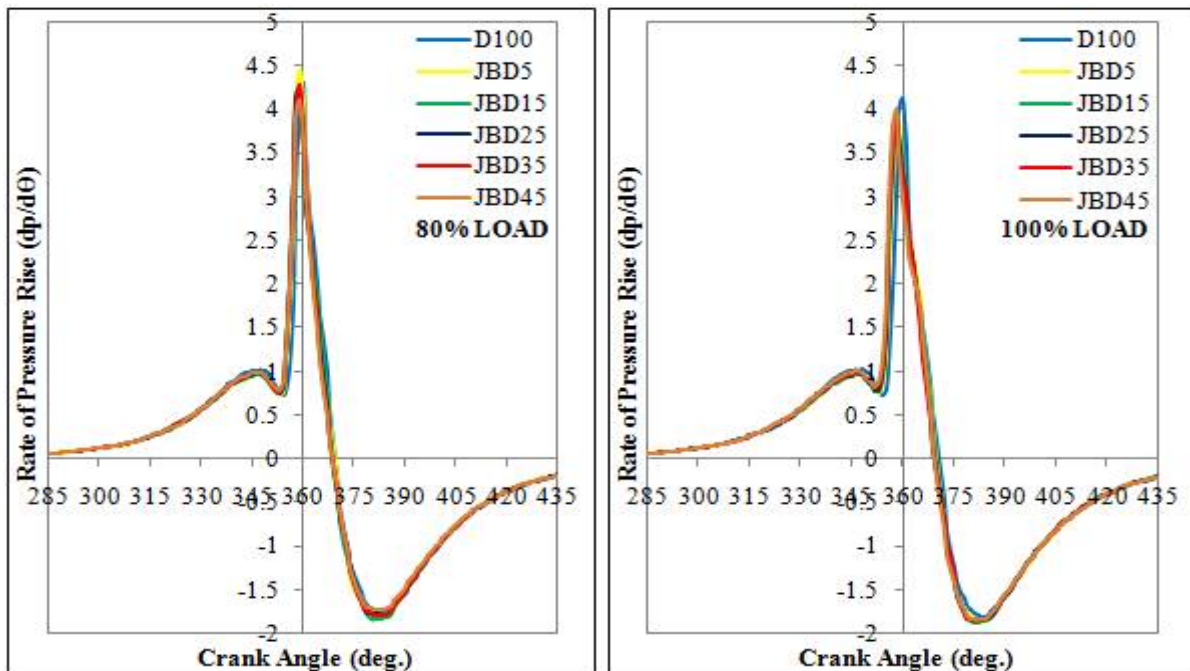
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4.2 Rate of Pressure Rise



Graph 1. Cylinder pressure for pure diesel & Jatropha biodiesel diesel blends at 80% & 100% load



Graph 2. Rate of pressure rise for pure diesel & Jatropha biodiesel diesel blends at 80% & 100% load

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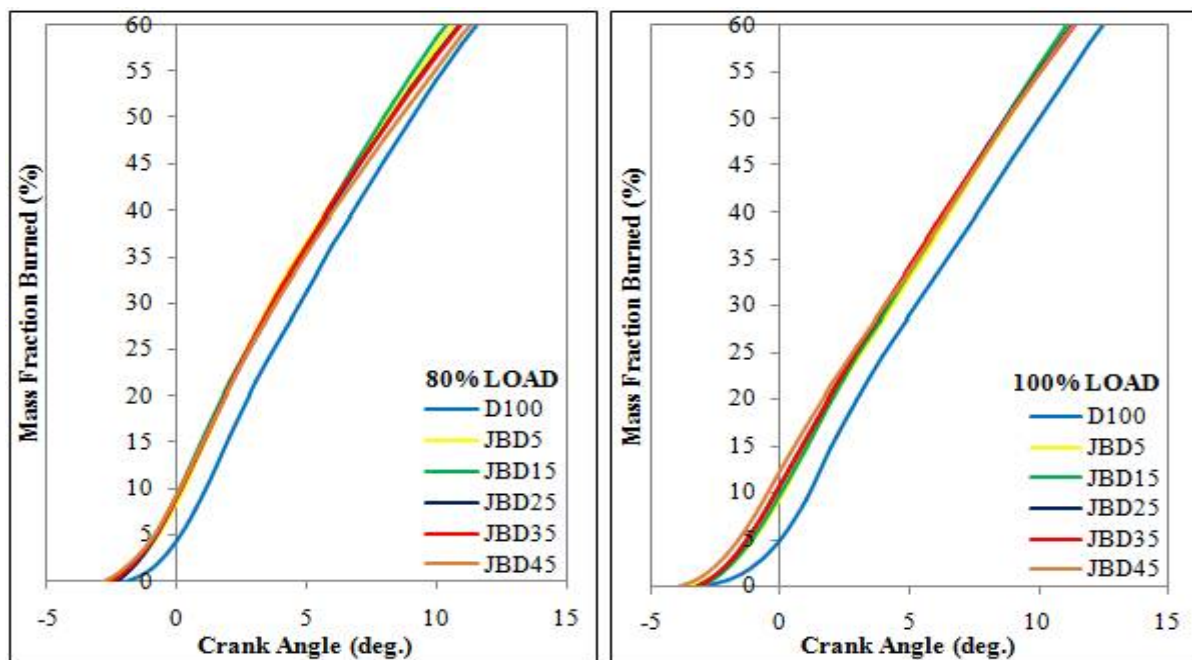
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Graph 2 shows variation of rate of pressure rise with crank angle for neat diesel fuel (D100) & Jatropa biodiesel diesel blends (JBD5, JBD15, JBD25, JBD35, JBD45) in normal engine at 80% & 100% load conditions of engine. The rate of pressure rise is directly related to engine life & noise of the engine. Rate of pressure rise increases with load increases up to 80% then after its slightly decreases for 100% load because engine is heat up & breathing capacity of engine slightly abnormal. The rate of pressure rise was found to be 4.31 bar/°CA at 358°CA for diesel fuel (D100), 3.94 bar/°CA at 358°CA for JBD5, 3.81 bar/°CA at 358°CA for JBD15, 3.96 bar/°CA at 358°CA for JBD25, 3.88 bar/°CA at 358°CA for JBD35, 4.00 bar/°CA at 358°CA for JBD45 at full load condition. Therefore, the rate of pressure rise for diesel was maximum & in Jatropa biodiesel diesel blends, JBD45 shows maximum rate of pressure rise but it has about 7.2% less than pure diesel fuel. Rate of pressure rise for diesel was higher than Jatropa biodiesel diesel blends because the higher viscosity & lower volatility of Jatropa biodiesel.

4.3 Mass Fraction Burned



Graph 3. Mass fraction burned for pure diesel & Jatropa biodiesel diesel blends at 80% & 100% load

Graph 3 shows the trends of mass fraction burned with crank angle during compression & expansion strokes. The fraction of charge mass (air/fuel mixture) has burned with respect to time history of crank angle is called mass fraction burned. Graph 3 shows the mass fraction burned at 80% & 100% load conditions of diesel engine for pure diesel fuel (D100) & Jatropa biodiesel diesel blends (JBD5, JBD15, JBD25, JBD35, JBD45). The mass fraction burned data are tabulated in table 3 at full load condition of engine. The mass fraction burned for Jatropa biodiesel diesel blends are slightly faster than pure diesel.

Table 3. Mass fraction burned at full load condition

Mass Fraction Burned (%)	D100	JBD5	JBD15	JBD25	JBD35	JBD45
5%	-1.01°CA	-2.04°CA	-2.09°CA	-2.30°CA	-2.31°CA	-2.63°CA
10%	0.12°CA	-0.92°CA	-0.96°CA	-1.17°CA	-1.18°CA	-1.49°CA
50%	9.03°CA	7.86°CA	7.72°CA	7.74°CA	7.77°CA	7.80°CA
90%	23.23°CA	21.51°CA	21.00°CA	21.72°CA	21.78°CA	22.59°CA

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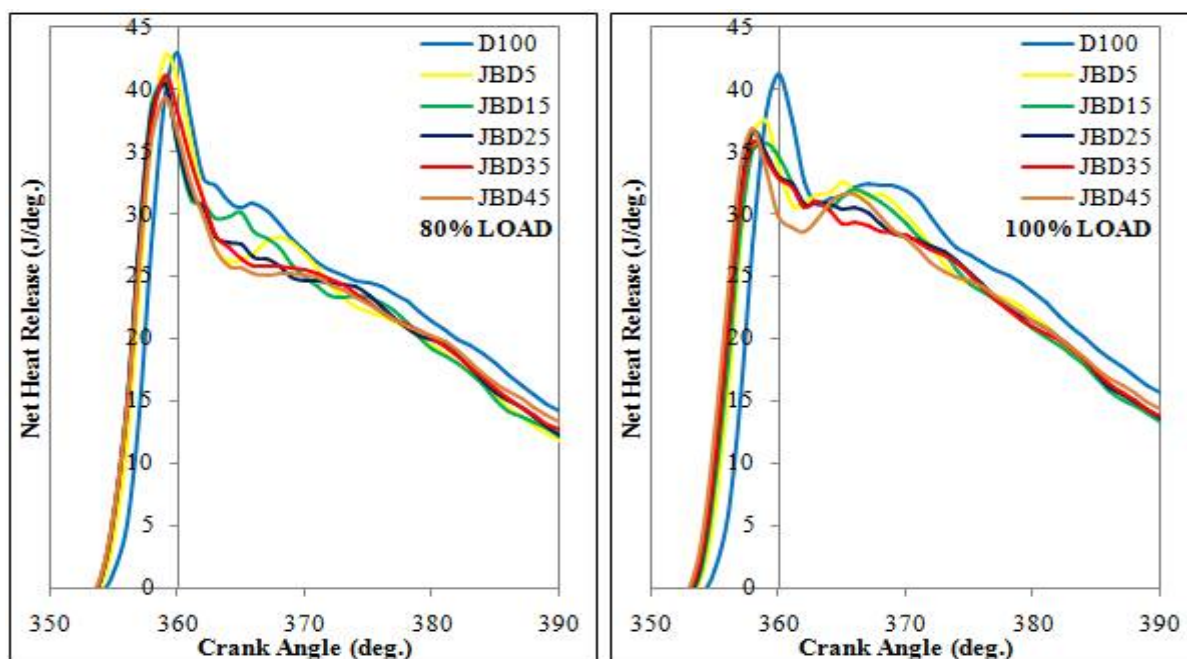
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The maximum Jatropa biodiesel blend (JBD45) shows 2.8% faster mass fraction burned than pure diesel fuel (D100) because Jatropa biodiesel already contain oxygen which leads to faster burning rate of Jatropa biodiesel diesel blends.

4.4 Net Heat Release

Graph 4 shows variation of net heat release with crank angle for pure diesel fuel (D100) & Jatropa biodiesel diesel blends (JBD5, JBD15, JBD25, JBD35, JBD45) in normal engine at 80% & 100% load conditions. The net heat release increases with increase load on engine up to 80% load then after it decrease for 100 % load. The net heat release found to be 41.23 J/deg. at 360°CA for pure diesel fuel (D100), 37.51 J/deg. at 359°CA for JBD5, 35.67 J/deg. at 359°CA for JBD15, 36.55 J/deg. at 358°CA for JBD25, 35.74 J/deg. at 358°CA for JBD35, 36.84 J/deg. at 358°CA for JBD45 at full load condition. The net heat release is decrease for Jatropa biodiesel diesel blends than pure diesel fuel. The net heat release decreases about 10.7% for maximum blend of Jatropa biodiesel (JBD45) than pure diesel fuel (D100) because the lower calorific value of Jatropa biodiesel diesel blends than pure diesel fuel.



Graph 4. Net heat release for pure diesel & Jatropa biodiesel diesel blends at 80% & 100% load

4.5 Cummulative Heat Release

Graph 5 shows the cummulative heat release with crank angle for pure diesel fuel (D100) & Jatropa biodiesel diesel blends (JBD5, JBD15, JBD25, JBD35, JBD45) at 80% & 100% load conditions on engine. Cummulative heat release increases with load increases on engine. The cummulative heat release was found to be 1.50 kJ at 512°CA for pure diesel fuel (D100), 1.32 kJ at 515°CA for JBD5, 1.31 kJ at 518°CA for JBD15, 1.32 kJ at 517°CA for JBD25, 1.30 kJ at 516°CA for JBD35, 1.29 kJ at 514°CA for JBD45 at full load condition. The maximum blend of Jatropa biodiesel diesel (JBD45) shows the 14% less cummulative heat release than pure diesel fuel because the heating value of Jatropa biodiesel is lower than diesel.

4.6 Mean Gas Temperature

Graph 6 shows variation of mean gas temperature with crank angle for pure diesel fuel (D100) & Jatropa biodiesel diesel blends (JBD5, JBD15, JBD25, JBD35, JBD45) in diesel engine at 80% & 100% load conditions.

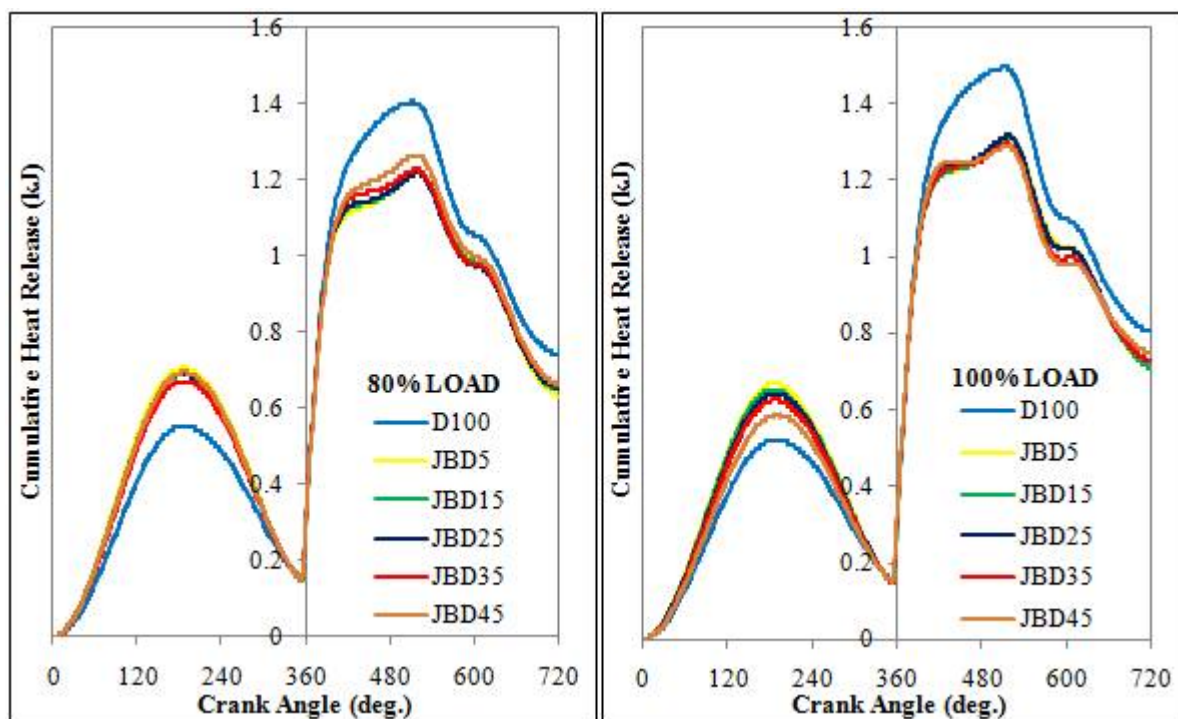
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The mean gas temperature increases with increasing the load on engine & this is an incylinder gas temperature phenomenon. The mean gas temperature found to be 1638.98°C at 386°CA for pure diesel fuel (D100), 1599.26°C at 384°CA for JBD5, 1589.14°C at 385°CA for JBD15, 1599.33°C at 385°CA for JBD25, 1588.45°C at 385°CA for JBD35, 1598.37°C at 385°CA for JBD45 at full load condition. The mean gas temperature for pure diesel fuel remains higher than Jatropha biodiesel diesel blends. The maximum blend of Jatropha biodiesel diesel (JBD45) shows 2.5% lower mean gas temperature than pure diesel fuel (D100) because the lower heating value of the Jatropha biodiesel.



Graph 5. Cumulative heat release for diesel & Jatropha biodiesel diesel blends at 80% & 100% load

4.7 Ignition Delay

Graph 7 shows variation of the ignition delay with different loads (0%, 20%, 40%, 60%, 80% & 100%) on diesel engine for pure diesel fuel (D100) & different Jatropha biodiesel blends (JBD5, JBD15, JBD25, JBD35, JBD45). The ignition delay is defined as the period between the start of fuel injection into the combustion chamber & onset of the combustion. The ignition delay improves i.e. decrease with increases the load on engine because engine is heated continuously when increasing the load then rapid gasification occurs inside the cylinder. Table 4 shows the ignition delay for pure diesel fuel & Jatropha biodiesel diesel blends at full load condition on diesel engine.

Table 4. Ignition delay for test fuels at full load condition

Fuels	Start of injection (°BTDC)	Start of combustion (°BTDC)	Ignition delay (°)
Pure Diesel (D100)	23°	14	9
JBD5	23°	15	8
JBD15	23°	16	7
JBD25	23°	17	6
JBD35	23°	17	6
JBD45	23°	18	5

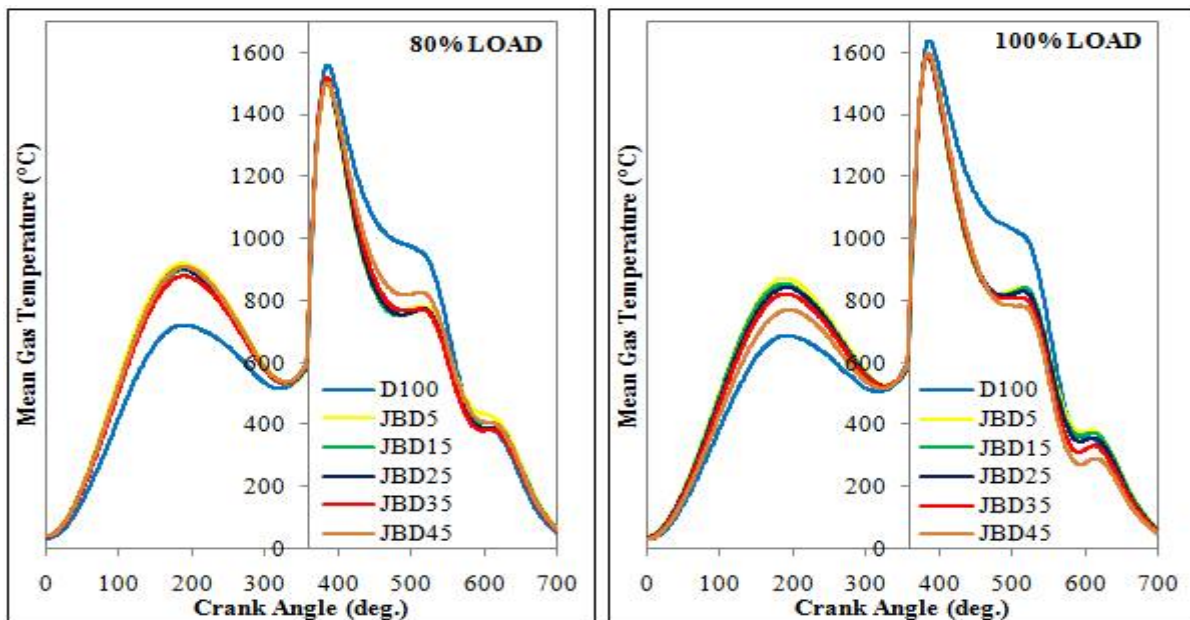
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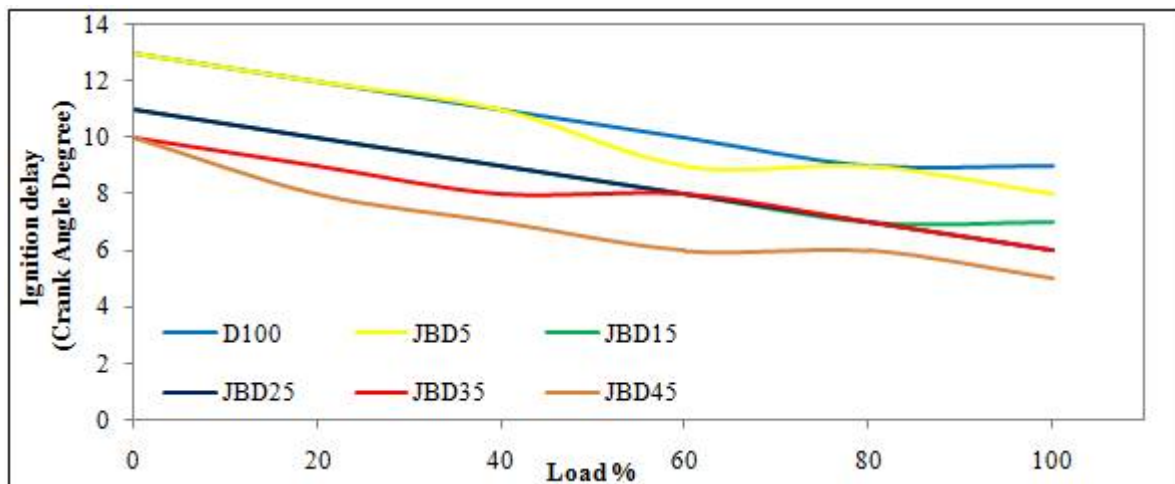
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The maximum Jatropa biodiesel diesel blends (JBD100) shows 44% less ignition delay than pure diesel fuel because Jatropa biodiesel have higher cetane number than pure diesel fuel. Biodiesel derived from Jatropa oil having higher molecular weight than conventional pure diesel fuel which is likely to react identically. Jatropa biodiesel also contains small percentage of diglycerides having higher boiling points than diesel but the chemical reactions during the injection of Jatropa biodiesel at high temperature resulted in the break down of the high molecular weight esters & these complex chemical reactions led to the formation of gases of low molecular weight. When the spray spreads out of the jet then rapid gasification of the Jatropa biodiesel blends, thus volatile combustion compounds ignited earlier & reduced the delay period.



Graph 6. Mean gas temperature for diesel & Jatropa biodiesel diesel blends at 80% & 100% load



Graph 7. Ignition delay for diesel & Jatropa biodiesel blends at 0% to 100% load

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V. CONCLUSION

The in cylinder pressure was found to be 67.31 bar at 373°C for pure diesel fuel (D100) & 68.58 bar at 371°C for JBD45 at full load condition. The cylinder pressure for JBD45 increase about 2% than pure diesel (D100). The rate of pressure rise was found to be 4.31 bar/°C for diesel fuel (D100), 4.00 bar/°C at 358°C for JBD45 at full load condition. The rate of pressure rise for JBD45 decrease about 7.2% than D100. The mass fraction burned for Jatropa biodiesel diesel blends are slightly faster than pure diesel. The maximum Jatropa biodiesel blend (JBD45) shows 2.8% faster mass fraction burned than pure diesel fuel (D100). The net heat release found to be 41.23 J/deg. at 360°C for pure diesel fuel (D100), 36.84 J/deg. at 358°C for JBD45 at full load condition. The net heat release for JBD45 decrease about 10.7% than D100. The cumulative heat release was found to be 1.50 kJ at 512°C for pure diesel fuel (D100), 1.29 kJ at 514°C for JBD45 at full load condition. The cumulative heat release for JBD45 decrease about 14% than D100. The mean gas temperature found to be 1638.98°C at 386°C for pure diesel fuel (D100), 1598.37°C at 385°C for JBD45 at full load condition. The mean gas temperature for JBD45 decrease about 2.5% than D100. The maximum Jatropa biodiesel diesel blends (JBD100) shows 44% less ignition delay than pure diesel fuel. Therefore, it is conclude that the Jatropa biodiesel is good alternative substitute for compression ignition diesel engine.

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