Combustion Characteristics of CI Diesel Engine Fuelled With Blends of Jatropha Oil Biodiesel

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Abstract. Jatropha Curcas oil is a non-edible oil which is used for Jatropha biodiesel (JBD) production. Jatropha biodiesel is produced using transesterification technique and it is used as an alternative fuel in CI diesel engine without any hardware modification. Jatropha biodiesel is used in CI diesel engine with various volumetric concentrations (blends) such as JBD5, JBD15, JBD25, JBD35 and JBD45. The combustion parameters such as in-cylinder pressure, rate of pressure rise, net heat release, cumulative heat release, mass fraction burned are analyzed and compared for all blends combustion data with mineral diesel fuel (D100).

1. Introduction

Energy is the prime mover of every activity and the economic growth. The demand of energy increases rapidly from the last two decades. The reserves of energy sources are limited and depleting day by day such as coal, natural gas and petroleum based fuel. The India’s population is projected to rise by 1.6 billion in 2040. The urbanization rate in India is also projected to increase from 33% in 2016 to 47% in 2040 [1-3]. India’s total primary energy demand is forecast to increase by 22.9 mboe/d (million barrel oil equivalent per day) between 2015 to 2040, rising from 16.8 mboe/d to 39.7 mboe/d with an average annual growth rate of 3.5% from 2015 to 2040 [3]. The imports of primary energy are looked to be raised considerably. Oil and gas will be responsible for this raise in imports and are figured to be 81-88% and 35-51% respectively. Due to increment in energy supply by 2.7-3.2 times, India's dependency on supply from overseas is expected to rise [2]. India will be the region with the second largest overall oil demand growth with the fastest average growth of 3.6% per year, adding 5.9 mb/d (million barrels per day) between 2016 to 2040. India is the region with the fastest passenger car fleet growth with an average 9% per annual, will add almost 160 million cars by the end of 2040. India's car fleet was only 23 million in 2016 and its increase 179 million in 2040. India will also add 46 million commercial vehicles by the end of 2040. The commercial vehicle fleet in India was 14 million in 2016 and its increase 59 million in 2040[3]. Extensive consumption of fossil fuels has led to environmental degradation at global, such as green house effect, ozone depletion, acid rain, that affects the climate [4]. As per rise of energy demand due to rising income, modernization, increasing population, increasing vehicles fleet, increasing...
environmental concerns which make the attention for producing more reliable and environmentally safe alternative fuels. Biodiesel is one of the renewable energy sources which are produced from pure or used oils (edible/ non-edible) and animal fats. Biodiesel offers several advantages such as, non-toxicity, biodegradability, non containing sulphur or aromatic compounds; therefore, it leads to the decrease in exhaust emissions. Biodiesel is produced locally/domestically, thus cutting down dependence on foreign/ imported fuel from long distances [4]. Agarwal et al. [5] optimized the transesterification process for producing biodiesel from vegetable oil and many researchers [6-11], analyzed the combustion, performance and emission characteristics of CI diesel engine when it is operated on neat vegetable oil and vegetable oil derived biodiesel to find it’s suitability in CI engines. Present work deals with the details combustion characteristics of CI diesel engine when it is fuelled with blends of Jatropha biodiesel and CI diesel engine is operated at 60% rated engine load. The Jatropha biodiesel produced through transesterification method and blended with mineral diesel to find its combustion behaviors in CI diesel engine.

2. Experimental Setup and Methodology
In the present investigation, non-edible Jatropha curcas oil has been chosen to explore its possibility and potential as CI diesel engine fuel. The non-edible Jatropha curcas oil, Methanol (CH₃OH) and Catalyst Potassium Hydroxide (KOH) were purchased from Rajasthan. These are materials used for transesterification process of Jatropha curcas oil. The mineral diesel fuel purchased from nearest petrol pump to generate baseline combustion data. The crude Jatropha curcas oil was converted into biodiesel (methyl esters) by using transesterification process. Transesterification is a process of transforming the large and branched, triglyceride molecules of vegetable oils and animal fats into smaller and straight chain molecules. The process utilizes vegetable oil and alcohol in which alkaline or acidic catalyst is used to improve the reaction rate. Alcohol such as methanol, ethanol and butanol may be used. If, a methanol molecule links to a fatty acid molecule, it will bond and form biodiesel molecules. The hydroxyl group in the catalyst stabilizes the glycerine [5]. The biodiesel thus produced by this process is totally miscible with mineral diesel in any proportion. Flash point of the biodiesel is brought down after transesterification and the cetane number increases. Density, viscosity, flash point, fire point, cloud point, pour point, and calorific value of biodiesel moves into very close range to that of mineral diesel [4]. The Jatropha biodiesel blends manually with mineral diesel with different volume proportions. These blends of Jatropha biodiesel used for investigating the combustion characteristics of CI engine with baseline mineral diesel combustion data. Figure 1 shows the different blends of Jatropha biodiesel in mineral diesel.
Figure 2 shows the CI engine experimental set-up which consists of various equipments such as a CI engine, eddy current dynamometer, calorimeter, temperature transmitter, piezoelectric pressure transducer, rpm encoder, crank angle encoder, rotameter (engine and calorimeter), control panel, water pump, high speed data acquisition system with IC engine combustion analysis software etc.

The eddy current dynamometer is connected with engine from flywheel end by the shaft and using for apply the different loads on engine. A pipe in pipe type calorimeter was used for conducting heat balance and it is connected to the exhaust end of the engine. The rpm and crank angle encoder is used to measure the engine speed and crank angle history of engine for analysis of the different combustion parameters. The piezoelectric pressure transducer is mounted on the engine head as shown in figure 2, which evaluates the in-cylinder pressure. The high speed data acquisition system acquire signal from pressure transducer and display on computer monitor screen. Pressure-crank angle data was recorded, stored and analyzed in combustion analysis software in computer. The piezoelectric pressure transducer and crank angle encoder is most important sensors which is used for analysis of the combustion characteristics of CI engine in every degree of crank angle (°CA). The experiment was performed firstly with the mineral diesel (D100) for generating baseline combustion data and then with blends of Jatropha biodiesel (JBD5, JBD15, JBD25, JBD35, JBD45). Here, 5, 15, 25, 35 and 45 indicates the volume percentage of Jatropha biodiesel in mineral diesel.

3. Result and Discussion

3.1 In-Cylinder Pressure

In a CI engine, the in-cylinder pressure gives the information about the combustion efficiency. The cylinder pressure is mainly dependent on fuel burnt fraction throughout the premixed burning phase, i.e., initial combustion phase. The ability of the fuel to mix well with air and burn is characterized by cylinder pressure. The amount of fuel burned in premixed combustion stage (early stages of combustion) corresponds to peak pressure [4, 6-8]. Figure 3 represent the variation of in-cylinder pressure phenomenon of CI engine from compression to expansion (180°CA to 540°CA) process at 60% rated engine load. The peak cylinder pressure obtained 63.74 bar for D100 at 371°CA, 63.66 bar for JBD5 at 371°CA, 63.55 bar for JBD15 at 370°CA, 63.24 bar for JBD25 at 370°CA, 62.96 bar for JBD35 at 371°CA and 62.45 bar for JBD45 at 370°CA. In case of biodiesel blends the peak pressure must occurs after TDC for efficient, otherwise it occurs near to TDC or before which may result as engine knock [9]. The peak cylinder pressure is highest for mineral diesel than blends of Jatropha biodiesel owing to superiority in volatility of mineral diesel that ensures better mixing of air.
and fuel. The peak cylinder pressure is lowest for Jatropha biodiesel blend due to higher viscosity, lower volatility and calorific value of biodiesel blends which leads to poor atomization [7, 10].

3.2 Rate of Pressure Rise

Figure 4 represent the variation of rate of pressure rise phenomenon of CI engine from compression to expansion (240°C to 480°C) process at 60% rated engine load. The maximum rate of pressure rise obtained was 4.54 bar/°CA for D100 at 360°C, 4.47 bar/°CA for JBD5 at 359°C, 4.45 bar/°CA for JBD15 at 359°C, 4.3 bar/°CA for JBD25 at 359°C, 4.23 bar/°CA for JBD35 at 359°C and 4.05 bar/°CA for JBD45 at 359°C. The rate of pressure rise is higher for diesel compared to that of Jatropha biodiesel blends. In premixed combustion stage, the large amount of fuel burned occurs due to maximum rate of pressure rise [4].

The reason for this could be the lower volatility and higher viscosity of biodiesel. The rate of pressure is directly related to engine life and noise of the engine. The rate of pressure rise should be low as far as possible to reduce the engine noise and to increase the engine life [7]. The results indicate that the Jatropha biodiesel shows the lower rate of pressure rise, so it is good for CI engine life.
3.3 Net Heat Release

Figure 5 represent the variation of net heat release phenomenon of CI engine from compression to expansion (330°CA to 405°CA) process at 60% rated engine load. After that burning rate is controlled by accessibility of combustible air fuel mixture, before that diffusion combustion takes place. On analyzing this diagram, it is found that, when engine is fuelled with blends of Jatropha biodiesel, the combustion starts earlier under all operating conditions and also blends of Jatropha biodiesel blends indicates shorter ignition delay as compared to mineral diesel.

![Net heat release for diesel and blends of Jatropha biodiesel.](image)

The premixed combustion heat release is more prominent for diesel, which leads to higher peak pressure and higher rate of pressure rise [4]. All fuels experiences negative heat release in the beginning owing to cooling of cylinder charge on account of vaporization of the fuel collected during ignition delay, which becomes positive after initiation of combustion [10, 11]. In CI engines, the ignition delay may be defined as "the period between the beginning of fuel injection and commencement of combustion" [8]. The maximum net heat release obtained 44.95 J/deg. for D100 at 361°CA, 42.97 J/deg. for JBD5 at 359°CA, 42.72 J/deg. for JBD15 at 359°CA, 41.32 J/deg. for JBD25 at 359°CA, 40.62 J/deg. for JBD35 at 359°CA and 38.83 J/deg. for JBD45 at 359°CA. The maximum net heat release occurred relatively earlier for blends of Jatropha biodiesel as compared to mineral diesel, because enhancement in combustibility of mixture is because of availability of oxygen in the fuel, indicating relatively shorter ignition delay and improved combustion [6, 11]. The net heat release for blends of Jatropha biodiesel is lower as compared to that of diesel fuel. The reason for this is the lower calorific value of blends of Jatropha biodiesel. The premixed combustion phase with blends of Jatropha biodiesel is shorter compared to that of mineral diesel, and this has resulted in lower heat release rate [7].

3.4 Cumulative Heat Release

Figure 6 represent the variation of cumulative heat release phenomenon for CI engine from compression, expansion to exhaust (330°CA to 720°CA) process at 60% rated engine load. The maximum cumulative heat release obtained 1.28 kJ for D100 at 508°CA to 530°CA, 1.21 kJ for JBD5 at 513°CA to 528°CA, 1.2 kJ for JBD15 at 511°CA to 525°CA, 1.18 kJ for JBD25 at 509°CA to 529°CA, 1.17 kJ for JBD35 at 512°CA to 532°CA and 1.14 kJ for JBD45 at 510°CA to 524°CA. This diagram again reconfirm early onset of heat release for Jatropha biodiesel blends. For Jatropha biodiesel blends, cumulative heat release is lower as compared to mineral diesel owing to smaller calorific value of Jatropha biodiesel blends [4].
Figure 6: Cumulative heat release for diesel and blends of Jatropha biodiesel.

3.5 Mass Fraction Burned

Figure 7 represent the variation of mass fraction burned phenomenon for CI engine with respect to crank angle at 60% rated engine load. This figure analysis the fraction of charge mass (air/fuel mixture) has burned with respect to time history of crank angle. This diagram is also evidence for lowest ignition delay for blends of Jatropha biodiesel than mineral diesel.

Figure 7: Mass fraction burned for diesel and blends of Jatropha biodiesel.

Table 1: Mass fraction burned data at 60% rated engine load

| FUEL  | MFB 5%  | MFB 10%  | MFB 50%  | MFB 90%  |
|-------|---------|----------|----------|----------|
| D100  | -0.32 °CA| 0.59 °CA | 8.03 °CA | 22.24 °CA|
| JBD5  | -1.64 °CA| -0.70 °CA| 6.78 °CA | 19.97 °CA|
| JBD15 | -1.68 °CA| -0.75 °CA| 6.68 °CA | 19.87 °CA|
| JBD25 | -1.56 °CA| -0.66 °CA| 6.40 °CA | 19.25 °CA|
| JBD35 | -1.57 °CA| -0.68 °CA| 6.06 °CA | 18.48 °CA|
| JBD45 | -1.63 °CA| -0.67 °CA| 7.20 °CA | 21.17 °CA|
Table 1 shows the mass fraction burned data in different percentage at a particular crank angle. The mass fraction burned 90% occurs at 22.24°CA for D100, 19.97°CA for JBD5, 19.87°CA for JBD15, 19.25°CA for JBD25, 18.48°CA for JBD35 and 21.17°CA for JBD45. The Jatropha biodiesel blends shows faster rate mass fraction burned than mineral diesel fuel due to higher cetane number of Jatropha biodiesel blends which leads lower ignition delay period.

4. Conclusions

The peak value of in-cylinder pressure reaches up to the maximum of 63.74 bar, 63.66 bar, 63.55 bar, 63.24 bar, 62.96 bar and 62.45 bar respectively with D100, JBD5, JBD15, JBD25, JBD35 and JBD45. The maximum rate of pressure rise for D100, JBD5, JBD15, JBD25, JBD35 and JBD45 are 4.54 bar/°CA, 4.47 bar/°CA, 4.45 bar/°CA, 4.3 bar/°CA, 4.23 bar/°CA and 4.05 bar/°CA respectively. Lower net heat release rates are observed with blends of Jatropha biodiesel compared to diesel fuel. The net heat release rate reaches up to the maximum of 44.95 J/deg., 42.97 J/deg., 42.72 J/deg., 41.32 J/deg., 40.62 J/deg. and 38.83 J/deg. respectively with D100, JBD5, JBD15, JBD25, JBD35 and JBD45. The maximum cumulative heat release for D100, JBD5, JBD15, JBD25, JBD35 and JBD45 are 1.28 kJ, 1.21 kJ, 1.2 kJ, 1.18 kJ, 1.17 kJ and 1.14 kJ respectively. The start of combustion of blends of Jatropha biodiesel was earlier than conventional diesel fuel due to oxygenated nature of biodiesel and also higher cetane value. The mass fraction burned was also indicated that the Jatropha biodiesel shows lower ignition delay than mineral diesel fuel because mass fraction burned faster than diesel fuel. Throughout the experimental investigation, the peak-maximum combustion data was obtained almost similar crank angle for Jatropha biodiesel blends than mineral diesel fuel. The Jatropha biodiesel have potential to replace conventional diesel fuel partially, to saving fossil fuels (Petroleum liquid fuels) for some extent and also decreases imports of such fuels by India.

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