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Performance and Combustion Characteristics of a DI Diesel Engine Fueled with Jatropha Methyl Esters and its Blends

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Abstract

This study discusses the performance and combustion characteristics of a direct injection diesel engine fueled with Jatropha methyl ester (JME). In order to determine the performance and combustion characteristics, the experiments were conducted at the constant speed mode (1500rpm) under the full load condition of the engine on a single cylinder 4-stroke CI engine. The results indicate that when the test engine is fuelled with JME, the engine performance slightly weakens, the combustion characteristics slightly change when compared to a petroleum based diesel fuel. The biodiesel causes reduction in carbon monoxide (CO), unburned hydrocarbon (HC) emissions, but they cause increases in nitrogen oxides (NOx) emissions.

The useful brake power obtained is similar to diesel fuel for all loads. The oxygen content in the exhaust is more with JME blend due to the fact that fuel itself contains oxygen .The trend of oxygen emission is similar to diesel fuel for all loads. Since JME contains 11% oxygen by weight and this oxygen helps to oxidize the combustion products in the cylinder, especially in rich zones, the addition of JME decreases CO emission. Although there has not been a significant difference in NO_X emissions at part load. NO_x is slightly increased due to the higher combustion temperature and the presence of fuel oxygen with the blend at full load. JME as a new Biodiesel and its blends can be used in diesel engines without any engine modification.

***Keywords**: Biodiesel, Combustion, CI Engine, Jatropha Curcas Oil, Performance and Emission.*

1. Introduction

Increasing global concern due to air pollution caused by internal combustion engines has generated much interest in the environmental friendly diesel fuels. However, increasing number of diesel vehicles will probably bring the same air pollution problem again in the coming years. These forecasts have triggered various research studies in many countries to replace petroleum based diesel fuel with oxygenated fuels such as biodiesel, ethanol, etc. Although the fuel properties of biodiesel show some variations when different feedstocks are used, it has a higher cetane number, near-zero aromatic, and free sulphur, compared to conventional diesel fuel [1]. The fuel properties of biodiesel are affected by its fatty acids content, which causes differences in the injection, combustion, performance and emission characteristics of the engine. Many researchers have concluded that biodiesel holds a promise as an alternative fuel for diesel engines, since its properties are very close to diesel fuel. The fuel properties of biodiesel such as cetane number, heat of combustion, gravity, and viscosity influence the combustion and so the engine performance and emission characteristics because it has different physical and chemical properties from petroleum-based diesel fuel [2]. The combustion timing in CI engines is mainly affected by the start if injection and the ignition delay, which is the time between the start of injection and start of combustion. The ignition delay time is mostly affected by cetane number. The biodiesel has a higher cetane number than diesel fuel; therefore, it shortens the ignition delay time and advances the combustion timing [7].

The objective of the current study is to investigate the use of Biodiesel and to reduce the emissions of all regulate pollutants from diesel engines. A single cylinder, water-cooled constant speed direct injection diesel engine was used for experiments. HCs, NOx, CO, CO_2 of exhaust gas were measured to estimate emission; various engine performance parameters, such thermal efficiency, brake specific fuel consumption, etc., were calculated.

2. Production of Jatropha Methyl Ester from Jatropha Curcas

Jatropha curcus L. is a draught resistant annual shrub that belongs to the family of Euphorbiaceae. The oil has a golden yellow color and is prepared from the seeds of jatropha curcas. These seeds are black in color and oval. Biodiesel, which is synthesized by transesterification of

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vegetable oils or animal fats sources, is a realistic alternative of diesel fuel because it is produced from renewable resources and involves lower emissions than petroleum diesel. The processed form of vegetable oil (biodiesel) is considered as the potential fuel to replace petroleum diesel in CI engines. In addition, it is biodegradable and contributes a minimal amount of net greenhouse gases or sulfur to the atmosphere [6]. The transesterification process combines the oil with an alcohol. The most common form of biodiesel is made with methanol and vegetable oils in the presence of a suitable catalyst. Additionally, the process yields glycerol. It is derived from crushing the Jatropha seed and by using large mechanical expellers. It is also important to note that most of the experiments conducted on biodiesel are mainly obtained from refined edible type oils only. The price of refined oils such as sunflower, soybean oil and palm oil are high as compared to that of diesel [10].

This increases the overall production cost of the biodiesel as well. Biodiesel production from refined oils would not be viable as well as economical for the developing countries like India. Hence, it is better to use the non-edible type of oils for biodiesel production. In India, non-edible type oil yielding trees, such as linseed, castor, karanji, neem, rubber, jatropha and cashew, are available in large numbers. The production and utilization of these oils are low at present, because of their limited end usage. Utilization of such oils/biodiesel as fuels in internal combustion engines does not only reduce the petroleum usage, but also improves the rural economy. Efforts are made here to produce biodiesel from a refined Jatropha seed oil, and to use it as the fuel in diesel engines.

3. Transesterification Process

JME was synthesized in a reactor vessel using both NaOH & KOH as a catalyst. The ester preparation involved a two-step transesterification reaction followed by washing and drying. The two-step reaction utilized a 100% excess methanol, or a total molar ratio of methanol-to-oil of 6:1 with methanol equally divided in two steps. 1000gm was placed dry flask equipped with a magnetic stirrer and thermometer. In another flask, approximately 300gm of methanol was mixed with 7gm of NaOH until all of the catalyst dissolved.

This mixture was quickly added to the oil and stirred vigorously for 1 hr maintaining temperature 55-60degree Celsius [11]. After 24 hr, ester layer is set up on the upper part and glycerol is set up on the lower part. Then using a separating funnel glycerol is separated and ester is poured into another flask. Finally, the ester is dried by silica gel.

4. Properties of Pure Biodiesel

Table 1. Properties of pure biodiesel

S. N	Properties	ASTM standards	JME100	DIESEL
1	Density in gm/cc	ASTM D4052	0.88	0.825
2	Viscosity in centistoke	ASTM D 445	3.5	2.25
3	Flash point ^{0} C	ASTM D 93	170	66
4	Pour Point ^{0}C	ASTM D 2500	6	10
6	Calorific Value (MJ/Kg.)	ASTM D 6751	38.8	42.00
7	Cetane number	ASTM D 6751-02	52	48

Table 2. Engine Details:

Engine	KIRLOSKAR
General Details	Single cylinder, Four Stroke, CI, Water cooled, TV1
Bore X Stroke	87.5mm X 110mm
Compression Ratio	17.5:1
Capacity	661cc
Rated Output	5.2kW at 1500 rev/min
Injection pressure	200 kg/cm^2
Dynamometer	Rope brake with Mechanical loading

5. Experimental Setup

The experiment was set up using the following equipment. The engine used for experimentation is a Kirloskar make computerised diesel engine used in agricultural applications. The piezo sensor has a range of 5000 PSI. The crank angle sensor has a resolution 1 Deg, speed 5000 rpm with TDC marker pulse. Engine indicator is used for data scanning and interfacing, with speed indicator. Rotameter is used for the water flow measurement. Digital thermocouple type temperature sensors are used as a temperature indicator.

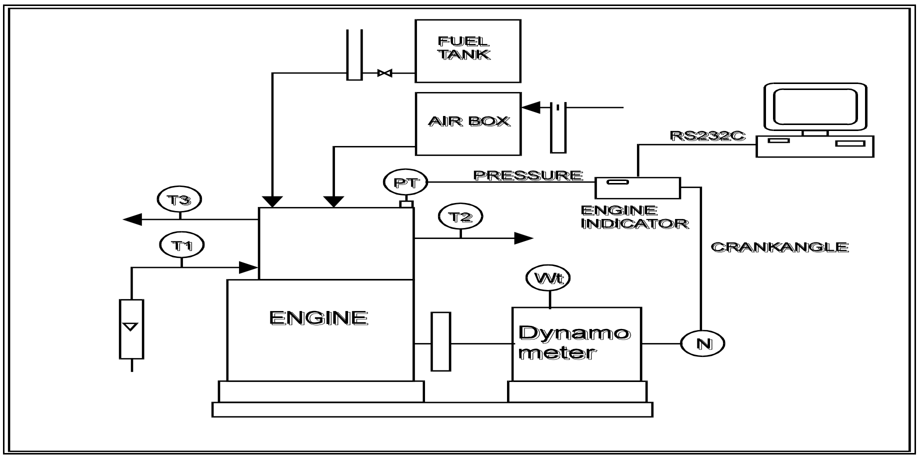

Figure 1. Schematic of Experimental Setup

6. Methodology and Experimental Procedure

Tests have been conducted on a four stroke, direct injection; a naturally aspirated single cylinder diesel engine is employed for the present study. The detail specification of engine is given in table 1. The injection was performed at a static injection timing (optimum) of 23o BTDC set for diesel fuel. To obtain the baseline parameters, the engine was first operated on diesel fuel. Performance and emission tests are carried out on the diesel engine using JME, and its various blends. The tests are conducted at the rated speed of 1500 rpm at various loads and blends are prepared by volume basis, i.e. JME10, JME20, JME30, JME40, JME50. Similar experiments were conducted over the same diesel engine. The experimental data generated are documented and presented here using appropriate graph.

In each experimental phase, the engine parameter is related to the thermal performance of the engine such as brake thermal efficiency; specific fuel consumption and applied load are measured. Mainly, at the given loading conditions, a comparative analysis of the engine performance on the PME, and its blends with diesel and their emission were investigated. Load on the engine is steadily increased.

At each interval, the readings are taken on the manual instrumentation or logged onto the computer analysis software; the variables gathered can then be used with the engine specifications to calculate the characteristics which determine the performance of the fuel on the engine during operation.

Combustion process and Combustion rate in CI engine

Combustion is the process of burning of the fuel in the presence of oxygen to produce heat. The formation of NOx is dependent on the temperatures during the combustion, the amount of O_2 and N_2 in the charge, and the time available for them to react with each other in the combustion chamber. The combustion process in CI engines is mainly divided into three phases. The first phase of combustion is called ignition delay, in which the tiny fuel droplets evaporate and mix with high temperature (or high pressure) air. This period depends mainly on cetane number, and temperatures of fuel and air. The second phase of combustion is called period of rapid combustion or premixed combustion. In this phase, the air-fuel mixture undergoes rapid combustion; therefore, the pressure rise is rapid and releases maximum heat flux. The third phase of combustion is called period of controlled combustion. In this period, the fuel droplets, injected during the second stage, burns faster with reduced ignition delay due to high temperature and pressure. In the third phase, the pressure rise is controlled by the injection rate and the combustion is diffusive mode.

The combustion rate has an effect on NOx production. More premixed combustion means a high initial rate of combustion, which increases NOx. Premixed combustion corresponds to the fuel that is mixed with air and prepared to burn during the ignition delay period. When this fuel auto ignites, it usually burns very quickly. Cetane number and fuel volatility are the two most important properties that determine the combustion rate. A biodiesel with a high cetane number is expected to shorten the ignition delay period and, thus, lower the amount of fuel that is involved with the premixed portion of the biodiesel combustion, thus lowering NOx emission.

7. Results and Discussions

7.1. Engine Performance and Emission Test Analysis

The performance of DI-CI engine was evaluated in terms of fuel consumption, brake specific fuel consumption and brake thermal efficiency, which are discussed as follows:

7.1.1. Brake Thermal Efficiency

The variation of brake thermal efficiency with respect to load for both fuels and their blends is shown in the following graph. Brake thermal efficiency of JME and its blends is slightly lower as compared to that of diesel. The BTE increases as the output power increases for both the fuels.

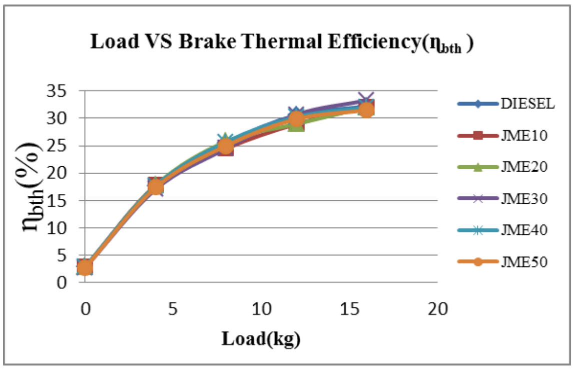

Figure 2. Variation of brake thermal efficiency for JME Blends and diesel

7.1.2. Brake Specific Fuel Consumption

The variation of brake specific fuel consumption with respect to load for both fuels and their blends is shown in the following graph. JME has a lower calorific value than that of the diesel. Hence the specific fuel consumption is higher than that of diesel for JME and its blends. For all loads, the fuel consumption of JME is more than that of diesel. It is also observed that the fuel consumption slightly decreases for lower percentage blends of JME and the reason is attributed to the improved combustion caused by increased evaporation and spray characteristics.

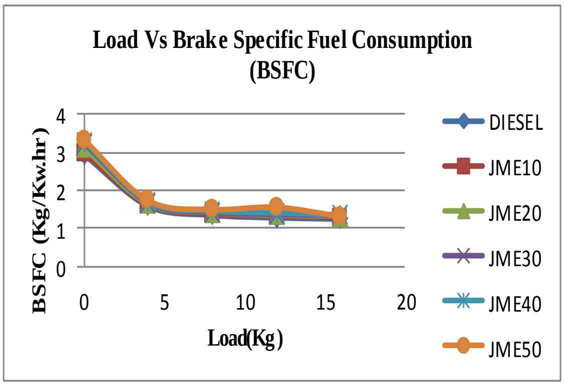

Figure 3. Variation of brake specific fuel consumption for JME blends and diesel.

7.1.3. Indicated Power

The variation of indicated power with respect to load for both fuels and their blends is as shown in the following graph: The indicated power is slightly lower for JME blends than diesel.

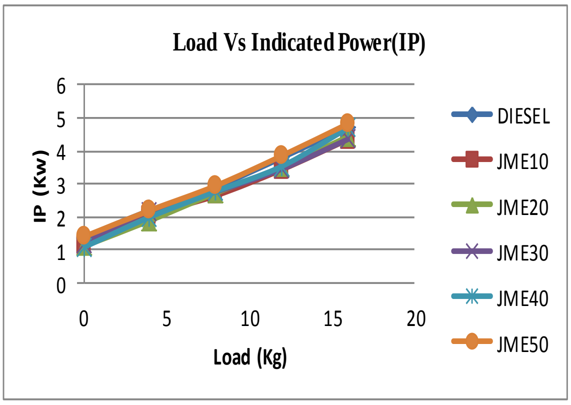

Figure 4. Variation of indicated power for JME Blends and diesel

The biodiesel also contains some amount of oxygen molecule in the ester form. It also takes part in the combustion. For JME20, this reveals that the effective combustion takes place and there is saving with respect to exhaust gas energy loss. This fact is reflected in brake thermal efficiency and brake specific fuel consumption as well.

7.1.4. Mechanical Efficiency

The variation of mechanical efficiency with respect to load for both fuels and their blends is as shown in the following graph. The mechanical efficiency for JME blends and diesel are close to each other.

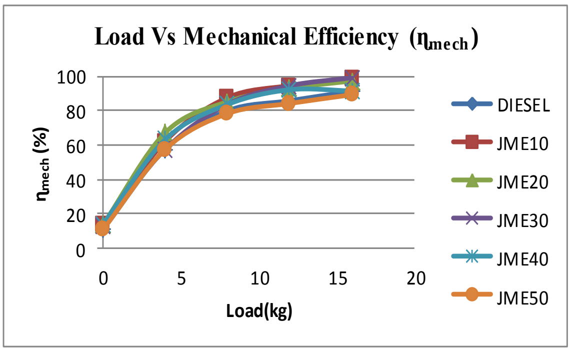

Figure 5. Variation of Mechanical efficiency for JME Blends and diesel

7.1.5. Exhaust Gas Temperature

Figure 6 shows the variation of exhaust gas temperature with load for both fuels and their blends. It is observed that the exhaust gas temperature increases with load because more fuel is burnt at higher loads to meet the power requirement.

It is also observed that the exhaust gas temperature increases with percentage of JME in the test fuel for all the loads. This may be due to the oxygen content of the JME, which improves combustion and thus may increase the exhaust gas temperature.

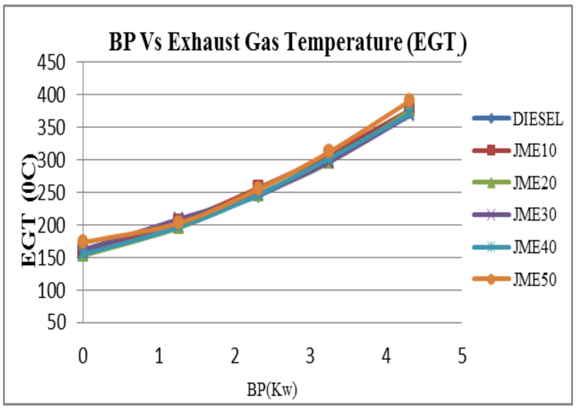

Figure 6: Variation of exhaust gas temperature for JME Blends and diesel

Two fuels and their blends were tested. It is found that specific fuel consumption decreased with the increase in the load. Using lower percentage of JME in JME-diesel blends, the brake specific fuel consumption of the engine is lower than that of diesel for all loads. In case of PME50, the brake specific fuel consumption is found to be higher than that of diesel. At full load condition, the specific fuel consumption of JME is 15% higher than that of the diesel. It may be noted that the calorific values of JME is 7% lower than that of the diesel. With the increase in JME percentage in the blends, the calorific value of fuel decreases.

7.2. Engine Emission Parameters

With problems like global warming, ozone layer depletion and photochemical smog in addition to widespread air pollution, automotive emission are placed under the microscope and every possible method is attempted to reduce emission. Following Engine Emission parameters are evaluated for JME and its blends with diesel.

7.2.1. Carbon Monoxide

The variation of carbon monoxide with respect to load for both fuels and their blends is as shown in the following graph. The formation of CO emission mainly depends upon the physical and chemical properties of the fuel used. It is observed that the CO emission of jatropha biodiesel is less than that of diesel fuel. The decrease in CO emission for JME is attributed to the high cetane number and the presence of oxygen in the molecular structure of the jatropha biodiesel. CO is predominantly formed due to the lack of oxygen. Since JME is an oxygenated fuel, it leads to better combustion of fuel, resulting in the decrease in CO emission.

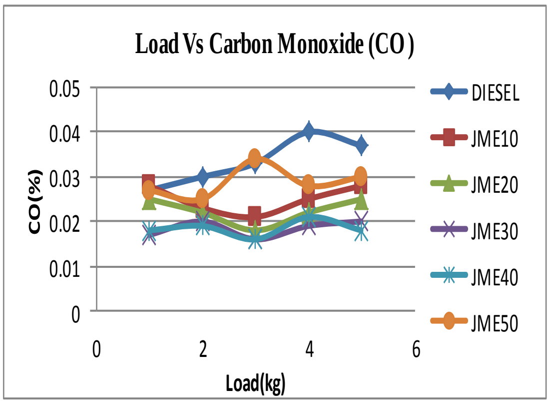

Figure 7. Variation of carbon monoxide for JME Blends and diesel

7.2.2. Hydrocarbons

The variation of hydrocarbons with respect to load for both fuels and their blends is as shown in the following graph. HC emissions reduced drastically, but the higher HC emissions are observed for the blend at low load conditions. At low load conditions, the quantity of fuel injected is lower resulting in a leaner mixture, quenching of flame and lower gas temperature results in incomplete combustion leading to higher HC emissions. The HC emission of the jatropha biodiesel are less than that of diesel fuel due to higher cetane number (52) and inherent presence of oxygen (9%) in the molecular structure of the jatropha biodiesel.

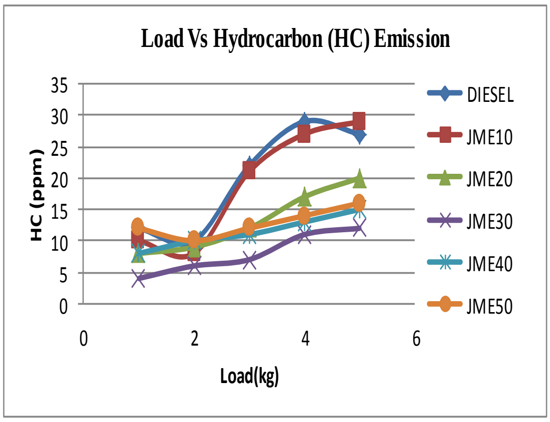

Figure 8. Variation of Hydrocarbons for JME blends and diesel

7.2.3. Carbon Dioxide

Figure 9 shows that, for both fuels, the increasing trend of carbon dioxide (CO_2) emission levels are observed with power output. This increasing trend of CO_2 emission is due to the increase in volumetric fuel consumption. It is observed that the CO_2 emission of jatropha biodiesel is less than that of diesel fuel. This is attributed to the presence of oxygen and high cetane number of jatropha biodiesel.

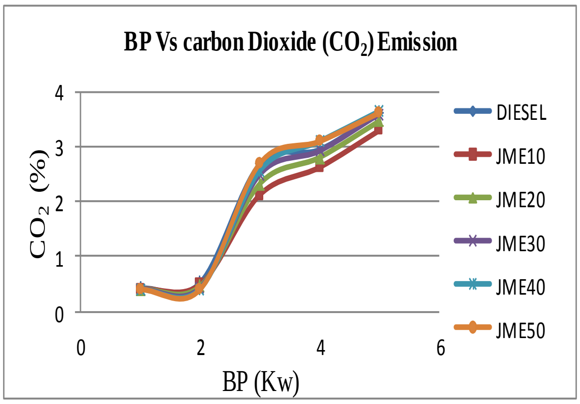

Figure 9. Variation of Carbon dioxide for JME blends and diesel with power output

7.2.4. Nitrogen Oxide

The variation of nitrogen oxide with respect to load for both fuels and their blends is as shown in the following graph and bar chart. Results show, for both the fuels, the increased engine load promoting NOx emission. Since the formation of NOx is very sensitive to temperature, these higher loads promote cylinder charge temperature, which is responsible for thermal (Zeldovich) NOx formation. The jatropha biodiesel produces slightly more NOx than diesel. The increase in NOx emission is attributed to the presence of mono-unsaturated and poly-unsaturated fatty acids present in the jatropha biodiesel. NOx gradually increases with the increase in percentage of PME in the fuel. The NOx increase for JME may be associated with the oxygen content of JME, since the oxygen, present in the fuel, may provide additional oxygen for NOx formation. The formation of NOx emissions are governed mainly by the magnitude of peak cylinder temperature and the crank angle at which it occurs.

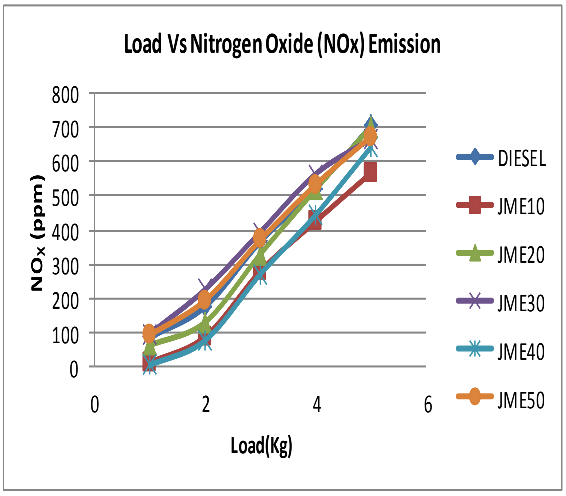

Figure 10: Variation of nitrogen oxide for JME blends and diesel

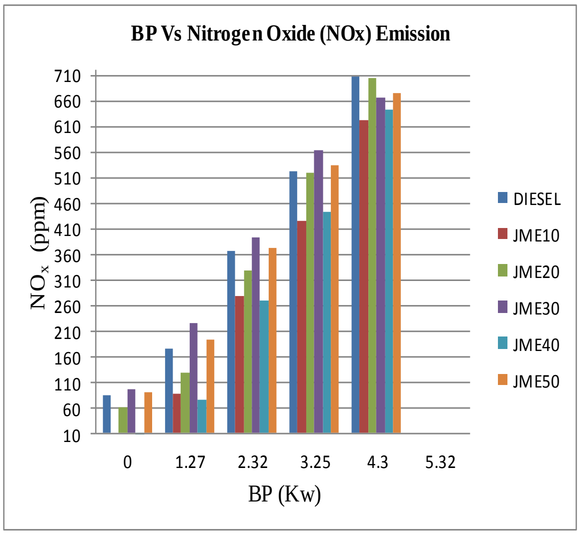

Figure 11: Variation of nitrogen oxide for JME blends and diesel with brake power

8. Conclusion

The performance, emission and combustion characteristics of a single cylinder direct injection CI engine fuelled with JME and its blends have been analyzed and compared to the base line diesel fuel. The results of present work are summarized as follows:

8.1. The specific fuel consumption increases with the increase in the percentage of JME in the blends due to the lower calorific value of JME.
8.2. Methyl ester of Jatropha oil results in a slightly increased thermal efficiency as compared to that of diesel.
8.3. It is also observed that the exhaust gas temperature increases with percentage of JME in the test fuel for all the loads.
8.4. The brake specific fuel consumption values for the engine running with biodiesel are higher than the engine running with normal diesel by a maximum of 10%.
8.5. The tests on engine running with different fuels (biodiesel and diesel) have resulted in almost overlapped P-V diagrams. The engine running with biodiesel has produced slightly higher in-cylinder pressure and peak heat release rate than the engine running with normal diesel.
8.6. CO emission is low at higher loads for methyl ester of Jatropha oil when compared with diesel. The increase in NOx emission of jatropha biodiesel is attributed to the mono and poly unsaturated fatty acids.
8.7. JME satisfies the important fuel properties as per ASTM specification of biodiesel and improves the performance, combustion and emission characteristics of engine significantly.

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