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Experimental Investigations of a Compression-Ignition Engine Fuelled with Transesterified-Jatropha Biodiesel-Diesel Blends

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ABSTRACT

Jatropha-curcas biodiesel has recently been considered as one of the potential renewable energy sources in Asia. This biodiesel is produced through the transesterification process of the non-edible oil obtained from Jatropha-curcas. The properties of this biodiesel are quite similar to those of diesel fuel. However, high viscosity of pure Jatropha-curcas biodiesel adversely affects engine performance. Hence, the percentage of Jatropha-curcas biodiesel that will not cause any adverse effect on the engine must be determined. In this context, this paper experimentally investigates the performance and exhaust emission characteristics of a direct injection compression ignition engine fuelled with 25%, 50% and 100% volume basis Jatropha-curcas biodiesel with diesel. Results showed that the Jatropha-curcas biodiesel and its blends demonstrated lower values for brake thermal efficiency and exhaust emission levels than diesel, but not for nitrogen oxide levels and brake specific fuel consumption. It was observed that the blend containing 25% Jatropha-curcas biodiesel (BD25) was the best alternative for diesel fuel based on engine emissions and overall performance. Therefore, BD25 could be considered a potential alternative fuel for compression ignition engines.

Keywords: Jatropha-Curcas, Biodiesel, Blends, Diesel Engine, Emission.

1. INTRODUCTION

Today the fossil fuel crisis, global warming, and the related environmental issues have raised significant interest in the scientific community that has triggered the need to search for environment-friendly fuels, such as biofuel or vegetable oil, to sustain the high-quality fuel. Out of these, biodiesel holds the most potential owing to its similarity to mineral diesel oil. Biofuels could be indirectly or directly extracted from various biomass sources [1-3].

Biodiesel molecules or methyl-esters contain a reasonably high amount of oxygen approximately 10% to 11% (by weight)) that is involved in the combustion process. These oxygenated biodiesel fuels can effectively improve combustion and reduce emission in 4-stroke Compression Ignition (CI) engines. Although these oxygen-rich fuels improve combustion temperature, they also lead to minor increase in Nitrogen Oxides (NO_x) emission [4, 5].

CI engines can be run on biodiesel with no or minor modifications. Biodiesel can either be used in pure form or in conjugation with fossil fuels [6]. However, with respect to CI engines, biofuel imparts an advantage over conventional diesel, since it can be used both solo and as an additive without the requirement of any engine modifications [7]. Although, vegetable oil-derived fuels have high viscosity and low Cetane number, volatility and boiling point are the characteristics that are important for CI engines. Such properties of these fuels lead to incomplete combustion, engine deposits, higher

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exhaust emissions, and engine oil contamination, restricting the direct use of biofuels in CI engines [8, 9].

There has been extensive research on emission and performance characteristics of conventional 4-stroke CI engines when fueled with raw or pure as well as the ethyl or methyl esters of vegetable oils derived from Jatropha [10, 11], Palm [12-14], Mahua [15], Karanja [16], Soybean [17] and Rapeseed [18]. However, pure vegetable oils as fuel have been discouraged by various studies. High viscosity and low volatility are two crucial properties of vegetable oils which adversely affect fuel spray pattern and atomization leading to incomplete combustion causing several problems, such as carbon deposition, injector choking, fuel pump failure, and piston ring sticking. Previous studies have proposed various techniques that decrease the vegetable oil viscosity, such as blending, transesterification, and pyrolysis [19]. Among them, transesterification has been shown to be most useful to produce biodiesel and lower the viscosity of vegetable oil [1].

Jatropha-biodiesel has adequate potential and advantages because it has similar characteristics as diesel fuel and is environmental-friendly. Previously published analyses have revealed that biodiesel decreased Carbon Dioxide (CO_2), Carbon Monoxide (CO), Particulate Matter (PM) and Hydrocarbons (HC) emission in CI engines barring NO_x emission. However, high oxygen levels in biodiesel raises the combustion temperature causing higher NO_x emission [20].

Puhan *et al.* [15] analyzed the effect of mahua ethyl-ester biodiesel on CI engine and reported an increase in Brake Specific Fuel Consumption (BSFC) as compared to diesel. Also, with a mild increase of 0.22% in Brake Thermal Efficiency (BTE), the HC, NO_x, smoke, and CO emission decreased by 63%, 12%, 70%, and 58%, respectively, while using the animal fat-ethanol blends [21, 22] and methanol [23] blends of Jatropha biodiesel in CI engine under high loading conditions. Kumar *et al.* [21] revealed significant reduction in CO, HC and smoke emission as compared to pure fat or diesel.

Nursal *et al.* [24] conducted an experimental study using biodiesels such as Jatropha-Curcas Oil (JCO),

Waste Cooking Oil (WCO) and Crude Palm Oil (CPO), in a direct-injected CI engine. Studies were carried out on 5% blending ratios on no-load, half-load, and 90% loading conditions with variable speeds of 800, 1200, 1600, and 2000 rpm. Overall engine performance was found to increase with Palm and Jatropha biodiesel and decrease with WCO. Moreover, fuel economy and thermal efficiency improved mildly, and exhaust emission reduced as compared to diesel. In addition, CO_2, HC, and CO emission was reduced with CPO while NO_x, CO_2, and HC emission reported marginal increase with JCO, and CO_2, NO_x, and CO emission and observed to increase with WCO.

Thus, biodiesel has shown greater potential for CI engines, but further in-depth analysis of engine performance is still needed. Analysis of the literature survey revealed that the research done so far is inadequate and somewhat vague. The main aim of the present work is to investigate the performance and exhaust emission of Jatropha biodiesel-diesel blends experimentally for CI engine to assess its suitability as perspective alternate to standard diesel.

2. METHODS AND MATERIALS

Approximately 200,000 metric tons of Jatropha-curcas biodiesel is produced annually in India. It can be grown quickly on barren mountains and wasteland. It is an excellent renewable energy source with high seed oil productivity. To elucidate the potential of Jatropha oil, thermal release rate of a CI engine fuelled with Jatropha-curcas oil needs to be studied [25]. The Jatropha biodiesel is produced from raw seeds using transesterification. It has been widely accepted worldwide for the production of biodiesel. Jatropha kernel possesses 63.16% oil content [23], which is higher compared to the oil contents in Palm Kernel (44.6%), Linseed (33.33%), and Soybean (18.35%) [26]. Hence, Jatropha-curcas biodiesel could be the most viable biodiesel, being more economical with respect to chemical composition or oil content. Table 1 shows properties of diesel, Jatropha-biodiesel and their blends.

2.1 Cost Challenges due to the New Biofuel Policy

Table1: Properties of Diesel (D), Jatropha-biodiesel (BD) and their blends (BD50 and (BD25)

Test Fuel	Kinematic Viscosity (cSt)	Density (kg/m^3)	Calorific Value (MJ/kg)	Flash Point (°C)	Cloud Point (°C)
D	2.9	850	44	76	6.5
BD	4.18	873	42.73	148	10.2
BD50	3.59	857	43.33	113	7.3
BD25	3.12	851	43.78	85	6.8

The Indian government launched the National Policy on Biofuels (NPB) to increase the generation of biofuels, which was adopted on May 16, 2018. According to NPB-2018, the current blending rate of biodiesel in mineral diesel is less than 1%, and the aim is to increase this blending rate to 5% by 2030. Historically, the Government of India had significantly reduced taxes to promote the use of biofuels till June 2017 [27].

Kumar *et al.* [28] conducted a market survey in 2012 for a cost analysis of Jatropha biodiesel production. The estimated market cost was approximately Rs. 47 per litre for Jatropha biodiesel, while diesel was available at Rs 52 per litre. However, the Government of India has introduced a new taxation system Goods and Services Tax (GST) from July 2017 under which tax has increased from 6% to 18%. As a result, biodiesel became costlier by Rs 10–12 per litre than mineral diesel. As a result of this 18% tax, there has been a decrease in biofuel customers due to which companies have stopped production of biofuels [27]. Currently, the burden of taxes has created a huge gap between the production and use of biofuels. To overcome this, the Biodiesel Blending Programme suggests that the current GST rate on biodiesel should be reduced or waived off. As suggested, the cost of biodiesel can be reduced by 10–20% as compared to petroleum-based fuels. Along with this, experts believe that NPB-2018 policy will prove to be a milestone in the future, as policy seeks to promote biofuels production and reduce dependency on crude oil [27].

3. TEST EQUIPMENT

For this study, we used a Kirloskar-make, 4-stroke, single-cylinder, naturally aspirated, direct-injection, air-cooled, compression-ignition engine. Fig.1 and Fig. 2 depict test-setup and schematic diagram of 4-

Fig. 1: Photograph of a 4-stroke CI Test-Setup

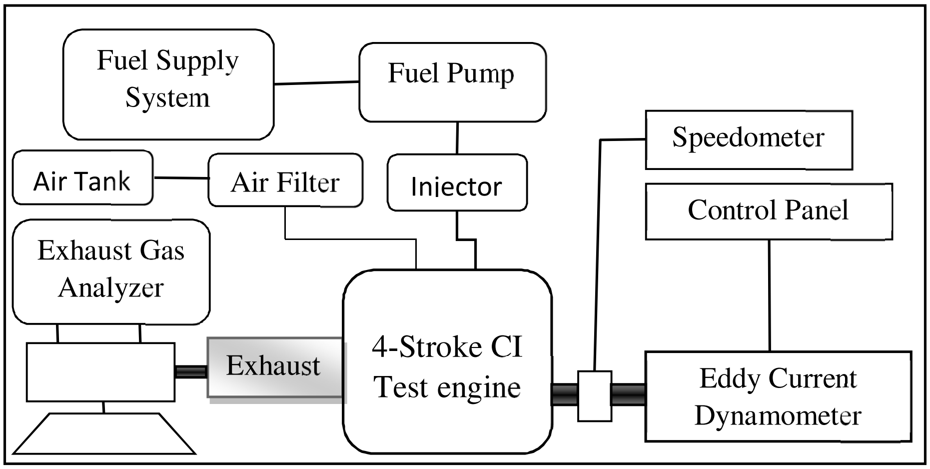

Fig. 2: Test-setup of the 4-stroke CI engine

stroke CI engine, respectively. An eddy current type dynamometer (AG10) was attached to the test-setup. This type of CI engine is widely used in the agriculture field in India. Table 2 lists the detailed specifications and working conditions of the test-setup.

Table 2: Engine Specification

Type of Engine	4-Stroke, Direct-injected
Make	Kirloskar Diesel Engine
Mode of cooling	Air-Cooled
No. of Cylinders	1
Compression Ratio	17.5:1
Bore	87.5 mm
Stroke	110 mm
Injection Pressure	21 MPa
Nozzle Diameter	0.28 mm
Injection-Timing	23° btdc
Dynamometer Type	Eddy Current

4. TEST PROCEDURE

Engine emission and performance tests were conducted using Jatropha-biodiesel and its blends for various operating conditions. The engine was operated on standard conditions recommended by the manufacturer. All test fuels were injected at injection timing and pressure 23°BTDC and 21MPa, respectively. These emission and performance values were defined as baseline values during the experiment compared to the results obtained from tests with different test fuel and load conditions. All tests were performed at a constant speed of 1500 rpm under varying loads of 0%, 25% 50% 75% and 100%. NO_x, CO and HC emission were monitored using AVL-make (CDS-250) exhaust gas analyzer. The smoke intensity was measured by means of a Bosch-make smoke meter.

5. RESULTS AND DISCUSSION

5.1 Brake Thermal Efficiency (BTE)

BTE is indicative of engine performance at the expense of fuel-mediated chemical energy [29]. Fig. 3 illustrates BTE variation against engine load in the presence of various Jatropha biodiesel (BD) blends and diesel. BTE was lower for BD and its blends as compared to BTE for diesel for all engine loads. BTE was observed to be highest at full load with diesel fuel. BTE for BD25 blend was comparable to BTE for diesel. At 100% load, BTE's for BD, BD25, and BD50 were lower by 7.54%, 2.84%, and 4.89%, respectively, as compared to pure diesel. The slight decrease in BTE with Jatropha biodiesel and its blends may be caused due to poor air-fuel mixing, weak spray characteristics, lower calorific value and higher viscosity of biodiesel as compared to standard diesel [30].

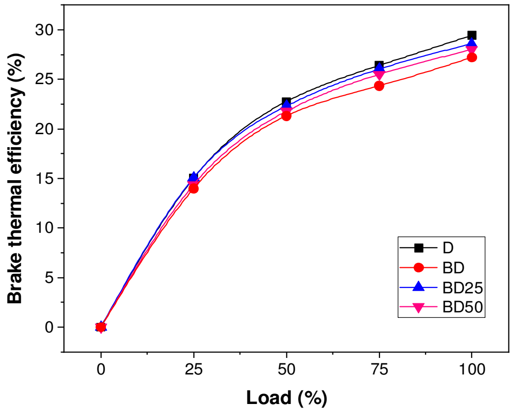

Fig. 3: Influence of engine load on BTE with diesel and Jatropha biodiesel blends

5.2 Brake Specific Fuel Consumption

The ratio of mass of fuel consumed to engine brake power is referred to as the Brake Specific Fuel Consumption (BSFC) [29]. BSFC is indicative of fuel efficiency of the engine. Fig. 4 depicts the effects of engine load on BSFC for diesel and Jatropha-biodiesel blends. Results exhibit that BSFC decreases with increasing load. BD25 had the lowest BSFC compared to that of BD50. However, it was 7.14% higher than that obtained with diesel. Pure Jatropha-biodiesel (BD) exhibited the highest BSFC compared to its blends and was about 21.43% higher than the BSFC of pure diesel. For full load, BSFCs of BD, BD25, and BD50 were 0.34 kg/kW-h, 0.30 kg/kW-h and 0.32 kg/kW-h, respectively, whereas it was 0.28 kg/kW-h for diesel. This result may be attributed to higher density and the lower calorific value of Jatropha-biodiesel; same is also confirmed by Agarwal *et al.* [31].

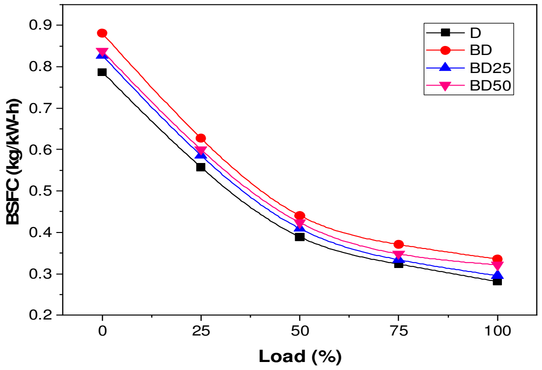

Fig. 4: Influence of engine load on BSFC with diesel and Jatropha biodiesel blends

5.3 Unburnt Hydrocarbon Emission

HC are produced by the incomplete combustion processes that may occur during the working of an internal combustion engine. The engine load effect, in the presence of various fuels, on HC emission is shown in Fig. 5. The results indicated that higher load led to a greater HC emission for all fuels owing to fuel-rich mixtures. For lower load, higher Jatropha biodiesel content in the blends led to increased HC emission. These results may be caused owing to lower viscosity and wider dispersion in the combustion chamber for blends with higher Jatropha biodiesel content. For full load, the use of diesel led to maximum HC emission, and the use of BD, BD25, and BD50 led to a reduction in HC emission of 57.7%, 18.5%, and 48.2%, respectively. Increase in Jatropha biodiesel level of blend significantly decreased the emission of unburned HC, higher oxygen contents in biodiesel may be the main reason leading to improved combustion and, therefore, the higher temperature that triggers HC oxidation. Lowest HC emission was observed in the presence of pure Jatropha biodiesel.

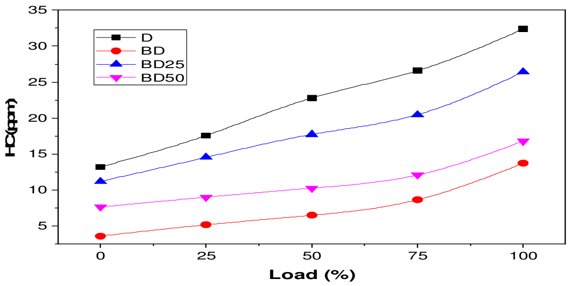

Fig. 5: Influence of engine load on HC emission with diesel and Jatropha-biodiesel blends.

5.4 Carbon Monoxide Emission

CO is one of the key element contributing air pollution that is produced when carbon-containing fuels are incompletely combusted. CO is a strong respiratory irritant. The quality of the combustible fuel determines the CO formation. The high enriched mixture produces high CO, while the lean fuel mixture produces low CO emission. In a diesel engine, combustion is accompanied by a lean mixture and contains a lot of air, which lowers CO emission [29]. Effect of load on CO emission due to various fuels is shown in Fig. 6. Reduction in CO emission was found ith increase in the Jatropha-biodiesel content for all engine loads. Least CO emission was observed in the presence of pure BD, and the highest CO emission was observed in the presence of pure diesel. The use of BD, BD25, and BD50 led to a decrease in CO emission by 42.7%, 16.5%, and 32.4%, respectively.

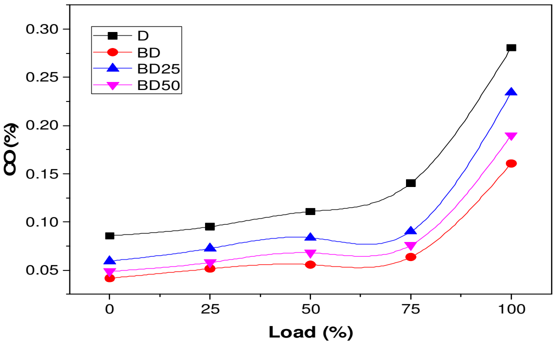

Fig. 6: Variation of engine load with CO emission with diesel and Jatropha-biodiesel blends.

5.5 Nitrogen-Oxides Emission

A diesel engine operates at a higher temperature and pressure as compared to a petrol engine, which promotes NO_x formation. The duration and volume of the hottest part of the flame determines the level of NO_x, due to which diesel engine produces more NO_x as compared to petrol engines. Typically high combustion chamber temperature also contributes to the generation of NO_x [29]. The effect of engine load on NO_x emission in the presence of various fuels is depicted in Fig. 7. NO_x emission increased as content of Jatropha-biodiesel increases. The NO_x emission in the presence of BD, BD25, and BD50 fuel blends increased by 26%, 4%, and 19%, respectively than that in the presence of diesel. The reasons for these observations may be owing to the greater oxygen contents in the biodiesel resulting in rapid combustion, which subsequently leading to the rapid increase in-cylinder pressure and temperature, hence, higher NO_x emission.

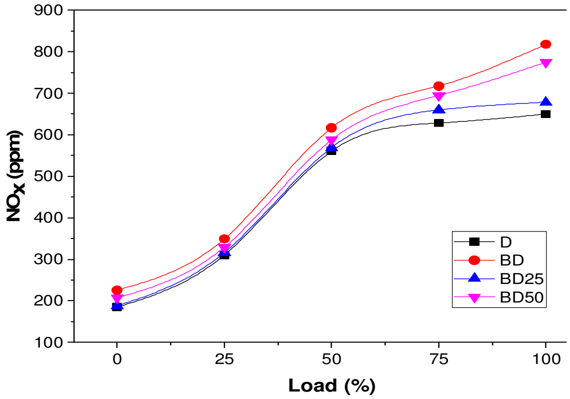

Fig. 7: Engine load variation with NOx emission with diesel and Jatropha biodiesel blends.

5.6 Smoke Intensity

The carbon in the exhaust gases refers to smoke. Fig. 8 depicts the smoke emission due to various fuels with respect to increasing load.

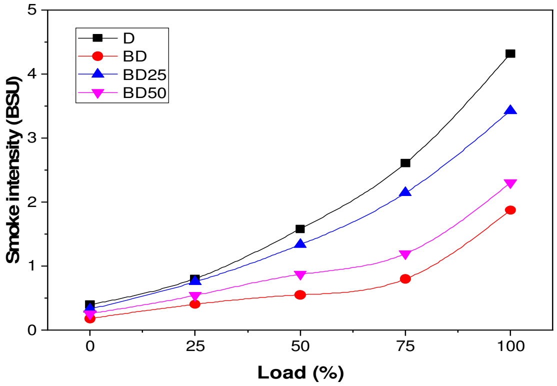

Fig. 8: Engine load variation with smoke emission with diesel and Jatropha biodiesel blends.

For all load conditions, higher Jatropha biodiesel levels in the fuel led to reduced smoke emissions. At full load, smoke emission in the presence of BD, BD25, and BD50 decreased by 57%, 21%, and 47.2% respectively. However, same is in complete contrast with standard diesel. Smoke emission was observed to be least in the presence of pure BD for full load. Jatropha biodiesel and its blends significantly reduced smoke emission for all load, owing to improved combustion for these fuels. Jatropha-biodiesel has greater cetane number and higher oxygen content as compared to diesel. Chauhan *et al.* [32] is also supported this statement.

6. CONCLUSIONS

The present work aimed at studying the effects of the Jatropha-curcas biodiesel blends on the performance and exhaust emissions characteristics of a CI engine. The major conclusions of this research are as follows:

- An increasing Jatropha biodiesel content reduced the BTE. The maximum BTE was observed at full load conditions when using diesel. At full load, BTE was 8.16% higher in diesel than in pure BD and 2.16% higher in BD25 than in BD50.
- An increasing Jatropha biodiesel content increased the BSFC. The BSFC was 16.2% lower in diesel than in pure BD and 8.02% higher in BD25 than in BD50. The BSFC of BD25 was comparable to that of pure diesel.
- A higher Jatropha biodiesel content led to a decreased level of unburned HC emission. The HC emission level was 57.64% higher in diesel than in pure BD and 57.36% higher in BD25 than in BD50 at full load.
- An increasing Jatropha biodiesel content reduced CO emission. The CO emission level was 42.7% higher in diesel than in pure BD and 19.05% higher in BD25 than in BD50 at full load.
- Higher Jatropha biodiesel content led to a decreased smoke emission level, which was 56.54% lower in pure BD than in diesel and 48.87% higher in BD25 than in BD50 at full load.
- The increasing Jatropha biodiesel content increased NO_x emission. The NO_x emission level was 25.88% higher in pure BD than in diesel and 12.43% lower in BD25 than in BD50 at full load. Also, for all fuels, the CO, HC, and

NO_x emission levels and the smoke level increased with increasing engine load.

The above results indicated that the Jatropha biodiesel blends are suitable for engine operation. Moreover, the Jatropha biodiesel blend BD25 is a possible alternative fuel without needing for major engine modifications.

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