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# Performance and Emission Characteristics of Jatropha Biodiesel Blends in a Direct Injection CI Engine

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## Abstract

The Jatropha seed oil is non edible, contains high amount of oil and less expensive feedstock. So, in this study a methyl ester biodiesel was produced from Jatropha seed oil following two step transesterification process using methanol, sulphuric acid and sodium hydroxide. The effect of Jatropha biodiesel blends and petroleum-based diesel on the performance and emission of four strokes, naturally aspired, water cooled and a direct injection diesel engine at five engine loads with a constant engine speed of 1500 rpm were examined. The physical and thermal properties of 20 % Jatropha-biodiesel and 80 % diesel (JB20) were tested on American Society for Testing and Materials (ASTM) standards and found to be within the standard. The engine performance parameters for biodiesel blends such as Indicated Power (IP), Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), Torque, Mechanical Efficiency (ME) and Exhaust Gas Temperature (EGR) were obtained and compared with diesel fuel. At higher load, the IP of 15 % Jatropha-biodiesel and 85 % diesel (JB15) is lower than diesel and other blends. BTE of 10 % Jatropha-biodiesel and 90% diesel (JB10) increases to 5 % mainly on 50 % loading condition and at higher loading BTE of diesel is higher than Jatropha biodiesel blends. For Jatropha biodiesel blends SFC was 19 % higher than diesel but at high load, SFC was nearly same for all test fuels. Mechanical efficiency of JB15 was found to be 18 % higher than diesel at higher loading. The highest exhaust gas temperature was 352.46 $^0$C, 358.61 $^0$C, 353.51 $^0$C and 343.79 $^0$C for diesel, JB10, JB15 and JB20, respectively at 3 kW loading. Also, experimental results show that the smoke opacity reduced by 31.6 % with JB20 compared to diesel. From the fuel property, engine performance and emission characteristics, it is concluded that the Jatropha biodiesel up to 20 % can be blended with diesel and can be used as an alternative fuel in existing diesel engine without any modification.

**Keywords:** Biodiesel, Transesterification, Jatropha Curcus, Engine Performance, Emission.

## 1. Introduction:

The increase in utilization of conventional energy and the increasing cost of crude oil forces the engineers and scientist to look for an alternative of diesel fuel for diesel engines. Various renewable oxygenated fuels have been used according to their safety, cost, accessibility and compatibility with diesel engines [1]. Among various fuels, biodiesel is a most investigated alternative and has also shown a positive impact in mitigating the challenges related to insufficient energy demand. Biodiesel is a non-explosive, non-flammable, renewable, non-hazardous, non-toxic, and biodegradable and can extensively reduce toxic, noxious and carbon dioxide emissions from engines [2]. Bio-diesel is also a viable fuel and can be mixed directly with diesel in different proportions. It has similar properties with diesel fuel. The major advantages of biodiesel are; it can be blended with diesel fuel at any proportions, can be used in a diesel engine without any modification, does not contain any harmful substances and produce less harmful emissions to the environment [3]. Biodiesel is alkyl esters of fatty acids and can be obtained through transesterification treatment of vegetable oils, animal fats, Jatropha oil and restaurant greases. Vegetable oil can be obtained from both edible (Palm oil, Rapeseed oil, Sunflower oil, Coconut oil, Peanut oil etc.) and non-edible (Jatropha, Neem, Cotton, Jojoba, Rubber, Mahua and Castor etc.) oil sources. But use of edible crops as a biofuel is highly controversial because of the prevailing food security issues and environmental risks. So, to overcome these disadvantages, most of the researches are focused in non-edible oils which are not suitable for human consumption because of the presence of some toxic components in oils. Jatropha curcas L., a multipurpose plant, contains high amount of oil in its seeds compare to the other non-edible oil sources and this plant is probably the most highly promoted oil seed crop at the present world due to its availability, sustainability and of less expensive feedstock [3]. Jatropha grows in tropic and sub-tropic regions, with cultivation limits at 300 N and 350 S. It also grows in lower altitudes of 0-500 meters above sea level. It is a succulent shrub that sheds its leaves during the dry season, with deep roots that make it well suited to semi-arid conditions. It can survive with as little as 250 to 300 mm of annual rainfall. The climatic condition such as weather, annual precipitation, altitudes and soil characteristics for Jatropha cultivation are favorable in Nepal [4].

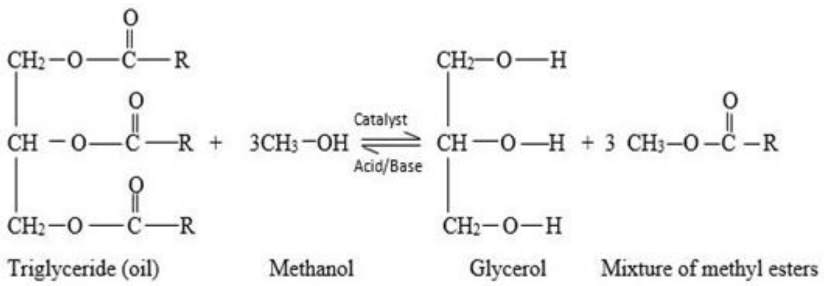

Figure 1: Transesterification reaction

There are several problems that are encountered while using biodiesel in comparison to petroleum products mainly occurred due to high viscosity of this oil. The higher viscosity results in poor atomization of fuel in spray that caused deposit causing coking in different parts like valves and injectors. Different chemical and physical processes, such as, pyrolysis, blending with ethanol or petroleum derived diesel, transesterification and micro-emulsification are carried out to decrease viscosity to make it more compatible for CI engines. Among all the process, the most convenient method is transesterification process. This process makes physical-chemical properties of vegetable oil closely similar to petrol diesel by reducing the viscosity. Though Transesterification process requires some extra cost compared to other process, it is relatively straight forward. In this process alcohol is used in the presence of sodium hydroxide (NaOH) or potassium hydroxide (KOH), which converts raw renewable oil into methyl or ethyl esters that may be directly burned in unmodified diesel engines. Also, acid and alkaline esterifications were performed to get the final product. The transesterification reaction is affected by molar ratio of glycerides to alcohol, catalysts, reaction temperature, reaction time and free fatty acids and water content of oils or fats.

The crude Jatropha curcus L. oil has very high free fatty acid (FFA) which obstructs the transesterification reaction. As a result, it provides low yield of biodiesel production. So, acid or enzymatic esterification followed by an alkaline catalysis is recommended to achieve higher biodiesel production. In fact, several researchers have obtained biodiesel yields up to 98 % using oils with high FFA content as feedstock, by implementing a two-step process of acid esterification and alkaline transesterification reaction [5, 6].

The crude Jatropha oil sample (FFA: 4.5 %) was subjected to pretreatment step under reaction condition of 0.225 v/v sulfuric acid ($H_2SO_4$), 6:1 w/w methanol ($CH_3OH$) to oil mole ratio, reaction temperature of 65 °C, and 180 min of reaction time. Then, the esterifies oil samples was subjected to alkaline base step using base-catalyst process parameters of 1.2 w/w potassium hydroxide (KOH), 4.5:1 w/w methanol to oil mole ratio, reaction temperature of 60 °C and 120 min of reaction time. The final biodiesel yield obtained was 82 % [7].

The optimum combinations for reducing the acid level of oil to less than 1 % after pretreatment was 0.32 v/v methanol-to-oil ratio, 1.24 % v/v $H_2SO_4$ catalyst and 1.26 h reaction time at 60 $^0$C. After the pretreatment of oil, transesterification reaction was carried out with 0.25 v/v methanol-to-oil ratio (6:1 molar ratio) and 0.7 % w/v KOH as an alkaline catalyst to produce biodiesel [8].

Due to its high FFA content, the crude Tobacco seed oil was processed in two steps, i.e., the acid pretreatment was followed by the base-catalyzed methanolysis. The first step reduced the FFA level from about 35 % to less than 2 % in 25 and 50 min for the molar ratio of 18:1 and 13:1, respectively. The second step converted the product of the first step into FAME and glycerol. The maximum yield of FAME was about 91 % for 30 min [9].

Forson et al. used Jatropha oil and diesel blends in compression ignition engines and found its performance and emissions characteristics similar to that of mineral diesel at low concentration of Jatropha oil in blends [10]. B. S. Chauhan, N. Kumar compared engine performance and reduction engine emissions of a diesel engine, it can be concluded and biodiesel derived from Jatropha and its blends could be used in a conventional diesel engine without any modification. The brake thermal efficiency of Jatropha methyl ester and its blends with diesel were lower than diesel and brake specific energy consumption was found to be higher. However, HC, CO and $CO_2$ and smoke were found to be lower with Jatropha biodiesel fuel. $NO_x$ emissions on Jatropha biodiesel and its blend were higher than Diesel [11].

## 2. Experimental Methods and Materials:

The flow chart of complete experimental procedures is as follows,

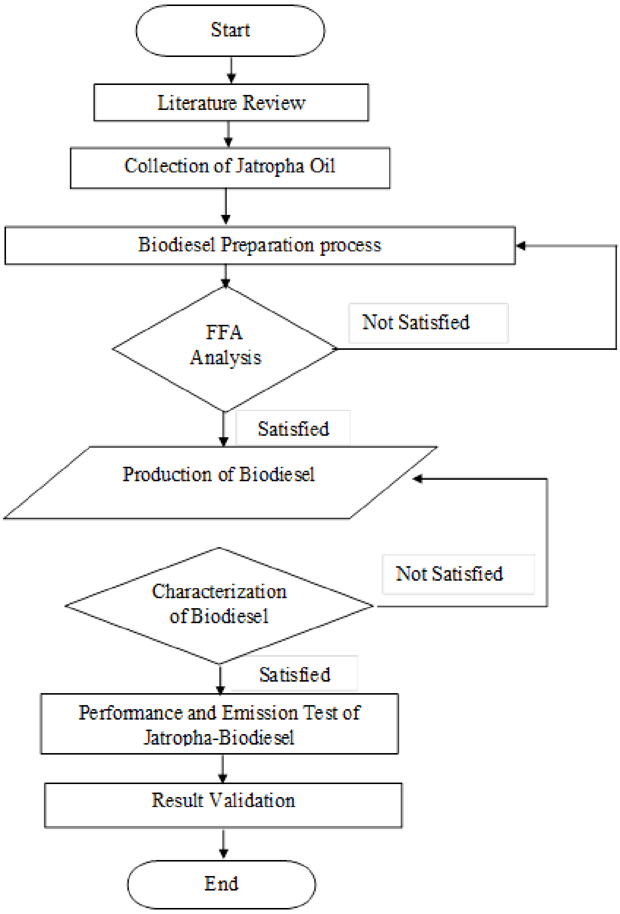

Figure 2. Methodology Flow Diagram

### 2.1. Preparation of Biodiesel:

For the preparation of biodiesel, Jatropha seed oil was collected from Alternative Energy Promotion Center (AEPAC), Lalitpur.

The acid value and FFA of the oil sample was determined by titration technique ASTD D664. The initial acid value was 8.64 mg KOH/ g oil and FFA was 4.32 % which was beyond the limit so two step catalyzed transesterification process was applied for higher yield of biodiesel. The production of biodiesel was performed at Chemistry laboratory of ACME Engineering College, Sitapaila, Kathmandu. The chemicals used in experiment were Sulphuric acid ($H_2SO_4$), potassium hydroxide (KOH) and methanol ($CH_3OH$) purchased from local chemical shop, whose purities were 98 %, 95 % and 99.55 %, respectively.

### 2.2. Acid Catalyzed Esterification:

The objective of this step is to reduce FFA of crude Jatropha oil to less than 1 %. The operating parameter used in this step to optimize the acid catalyzed esterification reaction includes methanol to oil ratio, catalyst concentration and reaction time. The crude Jatropha oil (250 g) was poured into a beaker and heated to $60^0$C. The mixture of 30 % w/w methanol to oil and 0.75 % w/w conc. $H_2SO_4$ to oil was heated at 50 $^0$C and then slowly added into the Jatropha oil stirring at 300 rpm using magnetic stirrer. After one hour of reaction time, the mixture was allowed to settle in separating funnel for 2 hours at room temperature (27 $^0$C). Then gum, methanol and water fraction formed at the bottom layer was removed. After this, the % FFA was again determined and the product was then used for alkaline catalyzed transesterification.

### 2.3. Alkaline Catalyzed Transesterification:

At first the oil product that has been pre-treated from the first step was poured into the heating beaker and heated at 50 $^0$C. The solution of KOH was 1.5 % w/w and that of methanol was 20 % w/w of the oil were heated to 50 $^0$C prior to addition and then added to the heated oil.

The reaction mixture was heated and stirred at 65 $^0$C and 400 rpm for 90 minutes. Then the reaction mixture was allowed to settle overnight in separating funnel to separate methyl ester upper layer and glycerine lower layer. Thus, produced biodiesel (FAME) was washed several times with warm distilled water until the biodiesel washed water become fully clear. The same procedure was repeated for other batches also. Then, in order to eliminate the excess water content, the produced biodiesel was excited to over 110 $^0$C in micro-oven for 4 hours.

Figure 3: Transesterification process steps for Jatropha biodiesel production in lab

### 2.4. Preparation of Blends:

Various Jatropha biodiesel blends with petroleum diesel were prepared on volumetric basis using measuring cylinder and names as follows:

JB10: 10 % jatropha biodiesel and 90 % petroleum -based diesel

JB15: 15 % jatropha biodiesel and 85 % petroleum -based diesel

JB20: 20 % jatropha biodiesel and 80 % petroleum- based diesel

### 2.5. Thermo-physical Properties Test of Blended Biodiesel Fuel:

JB20 Biodiesel blend was sent to Nepal Oil Coorporation Lab, Sinamangal, Kathmandu, NBSM and Department of Plant, Thapathali, Kathmadu to find different physical-chemical properties of Fuel. The different properties such as, calorific value, density, kinematic viscosity, pour point and flash point were tested. For characterization, FTIR test was done.

### 2.6. Engine Specifications:

The test engine was Kirloskar diesel engine available in Thapathali Campus, Thapathali, Kathmandu. The technical specifications of test engine are shown in Table 1.

Table 1: Test Engine Specification

| S. No. | Features | Specifications |
|---|---|---|
| 1 | Make | Kirloskar Diesel Engine |
| 2 | Type | Four stroke, Water cooled Diesel |
| 3 | Number of cylinders | 1 |
| 4 | Combustion principle | Compression ignition |
| 5 | Maximum speed | 1500 rpm |
| 6 | Crank radius | 55 mm |
| 7 | Compression ratio | 15:1 |
| 8 | Loading | Eddy current dynamometer |
| 9 | Maximum power | 3.5 kW |
| 10 | Connecting Rod length | 300 mm |
| 11 | Method of starting | Electric motor cranking |

## 2.7. Experimental Test Procedure:

Initially, the test was done at a steady speed of 1500 rpm with diesel fuel about 15 to 20 minutes for attaining stable working environment. It is important to note that the engine coolant is circulated in the engine at a pressure of nearly 1atm, which can be read by the pressure gauge setup in the engine. After that, engine was run with different as-prepared Jatropha biodiesel blends. During the test, engine was loaded with 1-12 kg load at an interval of 3 kg i.e. 1 kg, 3 kg, 6 kg, 9 kg and 12 kg using an eddy current dynamometer maintaining constant speed of 1500 rpm and the required engine performance data for different blends were taken. Similarly, same procedure was followed for diesel fuel and the required data were taken. The rate of flow of biodiesel fuel was measured using a burette and stop watch setup in the engine where fuel consumed during 60 sec time is noted.

The exhaust gas opacity was measured using Bosch Emissions Analysis tester (EAM) on VAAP engine with full throttle opening.

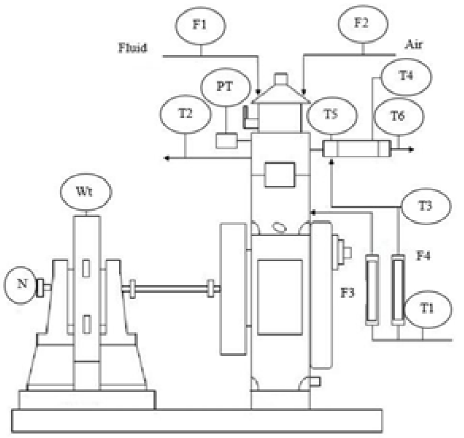

Figure 4: Block diagram of Test Engine

## 3. Results and Discussion:

### 3.1. Biodiesel Production:

The crude Jatropha oil having initial FFA 4.32 % was reduced to 0.53 % after acid pre-treatment. The biodiesel yield was found to be in an average of 70 % from 10 different baches which was calculated by dividing amount of biodiesel formed by the amount of crude Jatropha oil initially taken.

Table 2: Properties of JB20 and Diesel

| Properties | JB20 | Diesel | Test Method |
|---|---|---|---|
| Density at 15 °C, kg/m$^3$ | 840.6 | 820-860 | ASTM D1298 |
| Cetane Number | 55 | 30-65 | ASTM D613 |
| Calorific value, KJ/kg | 39750 | 43200 | ASTM D2382 |
| Kinematic viscosity at 40 °C, Cst | 2.32 | 1.9 - 4.1 | ASTM D445 |
| Flash Point (Min.), °C | 55.5 | 52 | ASTM D3828 |
| Pour Point, °C | -6 | -11 | ASTM D97 |

### 3.2. Thermo-physical Properties of Fuel:

The blended biodiesel prepared in the lab was tested as per the test method of ASTM D1298 standard for density, ASTM D2382 standard for calorific value, ASTM D445 standard for kinematic viscosity, ASTM D3828 standard for flash point and ASTM D97 standard for pour point. The results of the test conducted are shown in Table 2. The obtained numerical values of those physical-chemical properties of blended fuel were comparable to diesel.

### 3.3. FT-IR Analysis:

The FTIR spectrum of the diesel and biodiesel is shown in Fig. 5. The peak around 1195 $cm^{-1}$ of biodiesel indicates C-O/O-$CH_3$ is associated to ester group. Similarly, another sharp peak of biodiesel around 1745 $cm^{-1}$ indicates C=O of stretching vibration, which is allocated to an ester group [12]. The similar peaks of both biodiesel and diesel found around 1450 $cm^{-1}$ region corresponds to typical stretching mode of O-$CH_3$, which is related to methyl ester group. Consequently, some strong peaks of both found in the range of 2800-2950 $cm^{-1}$ correspond to typical stretching mode of $CH_2$ group which is associated with alkane groups [13].

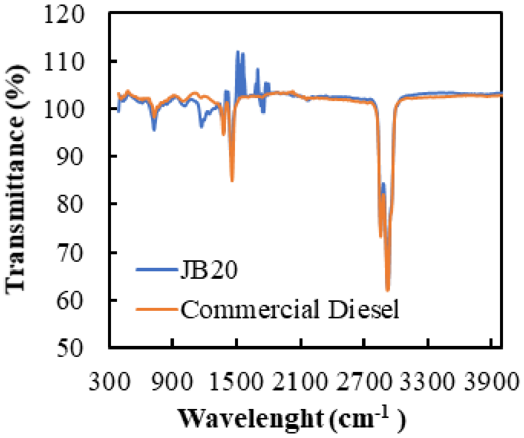

Figure 5: FTIR analysis of JB20 and Diesel

### 3.4. Performance Characteristics:

The performance of the CI engine depends on various parameters, such as injection pressure, combustion duration, mixing of fuel with air, inlet temperature of the air, ignition delay and fuel properties like viscosity, calorific value, flash point, pour point, density, cetane number etc.In this study, experiment was carried out to estimate the engine key performance parameter like IP, BSFC, BTE, ME and EGR of a CI engine using jatropha biodiesel blends fuel. The obtained results were compared with diesel fuel and different on values on both conditions were discussed based on the properties of both diesel and biodiesel blends.

### 3.4.1. Indicated power and Torque:

To maintain the constant RPM of the running engine, piston has to move fast to overcome the increased load. At that time, indicated mean effective pressure increases due to the fast burning of the air fuel mixture which increases the indicated power of the engine. Figure 6 shows the increase in IP with increase in load for both diesel and biodiesel blends.

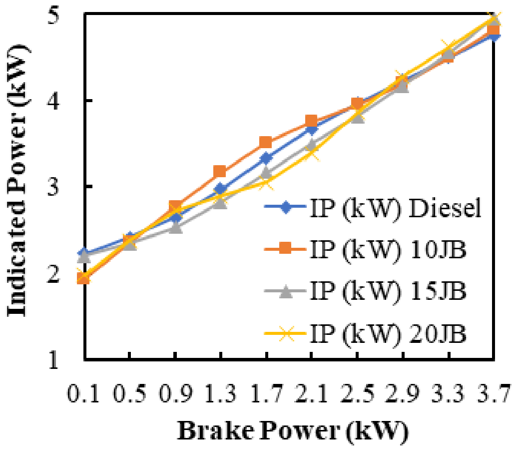

Figure 6: Variation Indicated Power with Brake Power

### 3.4.2. Biodiesel Blends and Engine Torque:

The variation of Engine torque for blends of biodiesel and pure diesel at 12 kg load and 1500 rpm is shown in Fig. 7. Graph illustrates that the output torque decreases with increasing blend ratio. JB20 shows 2.4 % lower torque compared to pure diesel. The decrease in output torque is due to lower heat content of biodiesel compared to diesel.

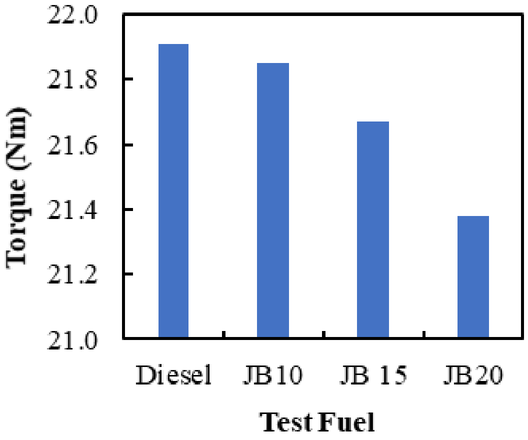

Figure 7: Variation of Engine Torque with test Fuels

### 3.4.3. Brake Thermal Efficiency:

The variation of brake thermal efficiency with respect to brake power is shown in Fig. 8. From experimental results it is observed that, brake power increases with brake thermal efficiency both for diesel and Jatropha biodiesel blends. Brake thermal efficiency of Jatropha blends was lower than that diesel at higher load, however, at lower load thermal efficiency of blends are very close to diesel. The possible reason for lower BTE is due to lower calorific value and increase in fuel consumption of Jatropha biodiesel as compared to diesel fuel. Oxygen present in the biodiesel improves the combustion characteristics but higher viscosity and poor volatility of biodiesel led to their poor atomization and combustion characteristics. Therefore, thermal efficiency of blends was found to lower compared to diesel which is confirmed by previous study conducted by S.P Adhikari, Lochan Kendra Devokta and Ishor Joshi [14], [15].

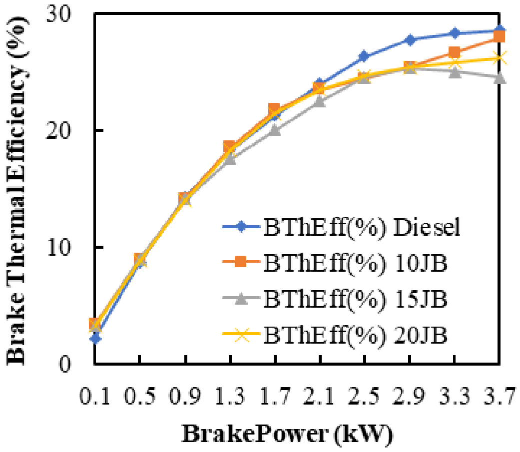

Figure 8: Variation of Brake thermal efficiency with Brake Power

### 3.4.4. Brake Specific Fuel Consumption:

BSFC of Jatropha biodiesel blends and diesel are decreasing at higher loads. Higher BSFC are observed for higher proportion of Jatropha biodiesel blends compared to diesel fuel. Since the biodiesel have low calorific value and higher densities than diesel which requires larger mass fuel flows for the same energy output from the engine leading to increase in BSFC for biodiesel blends as indicated in Fig. 9.

The BSFC of diesel is observed, at low load, to be about 1.59 kg/kWh while that of JB10, JB15 and JB20 is 1.90 kg/kWh, 1.96 kg/kWh and 1.79 kg/kWh, respectively. When engine operates on high load, the combustion is improved due to higher in-cylinder temperature after successive working of engine at this load that would improve fuel atomization and evaporation processes and partially improve fuel air mixing process.

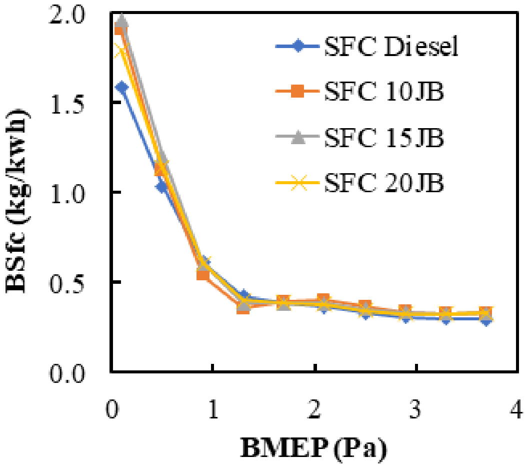

Figure 9: Variation of Brake Specific Fuel Consumption with Brake Mean Effective Pressure

Due to this reason with the rise in load, the power increases in high extend than that of the fuel consumption. So, the BSFC is nearly similar of all the tested fuel for all loading conditions.

### 3.4.5. Air-Fuel Ratio (A/F ratio):

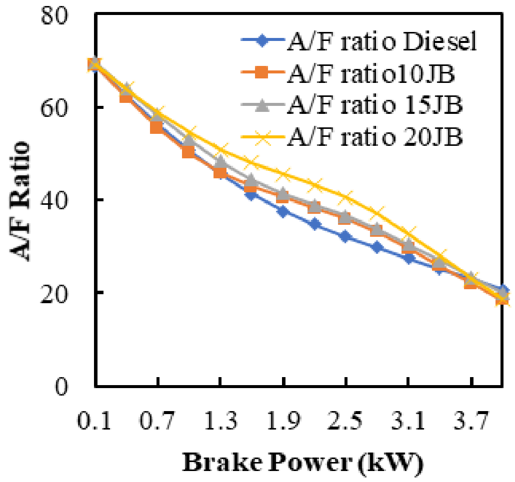

Figure 10: Variation of Air Fuel Ratio Consumption with Brake Power

The effects of engine load on air- fuel ratios for biodiesel blends were investigated in Fig. 10. Air-fuel ratios decreased with the increase in engine loads due to the increase in fuel consumption at higher loads. It means that the richer fuel is required at higher brake powers than at lower brake powers. Diesel has a lower A/F ratio as compared to Biodiesel blends. 20JB has a higher A/F ratio among all tested fuels.

This may be attributed due to higher volumetric efficiency of biodiesel

### 3.4.6. Mechanical Efficiency:

The ME increases with load for both diesel and biodiesel blends is shown in Fig. 11. With increasing load, friction losses decreases and ME increases. As we increase the load, the friction plays a smaller role in overall efficiency due to the fact that the piston moves faster to retain the same rpm at high load. This gives higher mechanical efficiency at higher loads. Fuel with high mechanical efficiency is generally desirable. So, at higher loads, Jatropha biodiesel blends have higher ME than diesel fuel. At maximum load, ME for diesel, JB10, JB15 and JB20 were 77.33 %, 78.62 %, 91.8 % and 86.1 %, respectively, which shows maximum ME was for JB15.

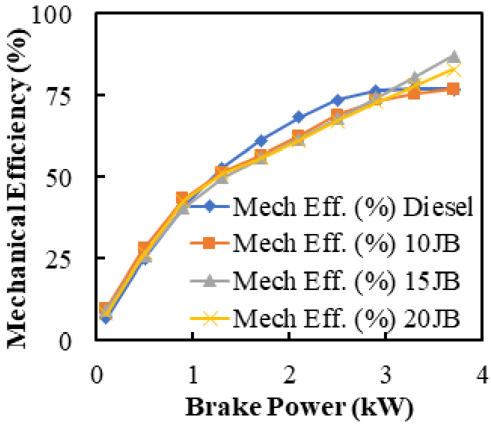

Figure 11: Variation of Mechanical Efficiency with Brake Power

### 3.4.7. Exhaust Gas Temperature:

The effect of exhaust gas temperature (EGT) on diesel and Jatropha biodiesel blends is shown in Fig. 12. To indicate the cylinder combustion temperature, EGT is one of important parameter. It is also good parameter for emission analysis especially for NOX. The results showed that the EGT increased with increase in load in all cases. The test results also show that EGR of diesel has 7% lower compared to blends fuels as shown in figure. The exhaust gas temperature is affected by the change in ignition delay. Higher ignition delay results in delayed combustion and higher exhaust gas temperature [16]. Ignition delay has direct impact on heat release rate and indirect impact on engine noise and exhaust gas emission formation. The ignition delay period is divided into into physical and chemical delay [17]. The physical delay depends on the fuel's property and composition while in chemical delay fuel reaction begins slowly and then accelerates until self-ignition takes place. The chemical delay decreases as cylinder temperature decreases [18]. Biodiesel have slightly lower cetene number which may exhibit longer delay periods and a slower burning rate, hence resulting in late combustion in the expansion stroke and higher exhaust gas temperature [19].

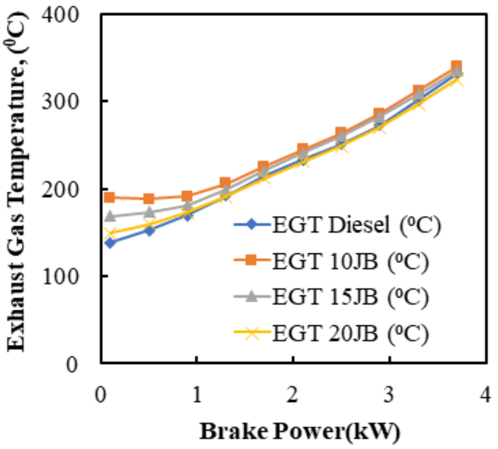

Figure 12: Variation of Exhaust Gas Temperature with Brake Power

### 3.5. Emission Characteristics:

#### 3.5.1. Smoke Opacity:

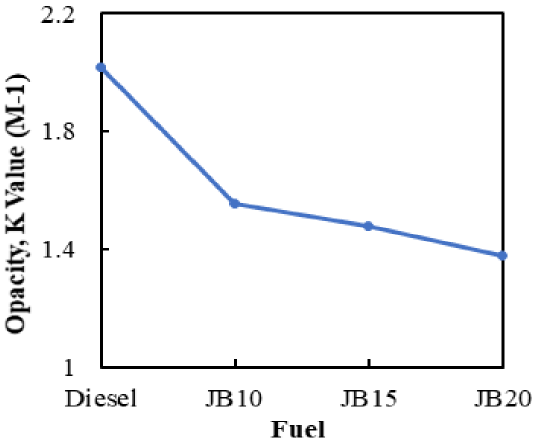

Figure 13: Variation of Smoke opacity for various Jatropha biodiesel blends

One of main problem in diesel engine is smoke opacity. Fig 13 shows the variation of smoke opacity of diesel fuel and jatropha biodiesel blends. It is observed that smoke density is reduced with the increasing the biodiesel percentage compared to pure diesel. Lower smoke emissions are the indication of complete combustion of the fuel as additional oxygen is available on biodiesel fuel itself. The smoke opacity is reduced in the range from 23.26 % to 31.68 % for Jatropha biodiesel blends than diesel fuel at full throttling condition.

## 4. Conclusions:

In this paper, a procedure for biodiesel production from Jatropha seed oil was presented and the effects of biodiesel blends to diesel fuel on the performance and emission of a diesel engine were investigated and analysed. The experimental results can be concluded as:

- Due to higher Free Fatty Acid concentration on Jatropha seed oil two step transesterification process was selected for maximum yield of biodiesel.
- The physio thermal properties of biodiesel were compared with ASTM standard and are found within limits. JB20 has lower cetene number and calorific value but density and viscosity were higher than that of diesel. The engine operates smoothly, did not show any starting problem and no audible knock while running with Jatropha biodiesel blends.
- IP was found to be quite similar for all test fuel for low and high loading condition.
- BSFC and EGT were found to be higher for Jatropha biodiesel blends compared to diesel.
- BTE and ME of blends were comparable to diesel specially at low load but at high load, BTE and ME increase for diesel than biodiesel blends.
- Smoke density is found to be reduced while running engine with biodiesel blends as compared to diesel

Therefore, from this experiment, it can be concluded that engine performance given by biodiesel blends was comparable with diesel. Moreover, biodiesel blends gave lesser emission in comparison to conventional diesel. Thus, this experimental investigation reveals that biodiesel produced from Jatropa oil can be successfully used in diesel engine without any modifications.

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