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# Studies on Production and Characterization of Bio Diesel from Jatropha

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***Abstract*— Our world is getting industrialized and modernized with each passing day which is increasing the vehicles and engines in our daily life and solution is not to reduce them but to use them in a smarter way. However we are having limited resources for petro-fuels. Therefore it is a high time to search for new alternatives in place of petro-fuels. Our research is based on finding such an alternative fuel in the form of Jatropha Oil which is easily available on the earth especially in India. We have compared Jatropha oil with Diesel on a Diesel engine, on different parameters such as CO emission, break thermal efficiency, break specific fuel consumption, smoke density and hydrocarbon emission. We have observed that Jatropha oil is either close to diesel or sometimes performing better than diesel and can be used an alternative to Diesel.**

***Index Terms*— Jatropha Oil, Bio-diesel, Alternative Fuel, CO Emission.**

## I. INTRODUCTION

In the recent times, our world has been facing two main crises, one of fossil fuels and second is of environmental degradation. The unsystematic exploration of fossil fuels and its huge utilization is continuously reducing petroleum reserves worldwide [1]. Now suddenly we are looking forward to alternative fuels, and issues of energy conservation and management, energy efficiency and protecting our environment.

In order to protect the global environment and the concern for long term supplies of conventional fuel [2]. The alternative fuel options should be sustainable as well as environment friendly. Most of the developing countries are using bio-fuels, like Biomass, vegetable oils, alcohol, biogas, synthetic fuels etc. Out of these fuels, some fuels can be used directly as they are, while other fuels are required to have some modifications before to be used as an alternative of conventional coal as a fuel [3][4].

Such an alternative fuel is in large demand in sectors like transport, agriculture, industrial, commercial and domestic uses. If we can get such a liquid fuel from the Vegetable oils, then we can get Environmental benefits out of it with lesser costs [5][6][7].

Some hundred years ago, Mr. Rudolf Diesel was the one who tested vegetable oils as an optional fuel to be used in his engine. Once again recent increase in the prices of petroleum and the uncertainty about the availability of petroleum resources, we are showing interest again to use vegetable oils in diesel engine in place of diesel. The number of past research studies has stated that triglycerides can promise us to be an alternative and better fuel for a diesel engine [8].

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## II. LITERATURE REVIEW

The Jatropha Curcas belongs to Euphorbiaceae family of plants, the seeds of plant provides significant amount of non-edible oil, which is available in arid, semi-arid and tropical regions worldwide. Jatropha is known to a drought resistant tree, which is having a long lifespan with more than fifty years and it grows in marginal lands [9].

The 'Jatropha' word is derived from 'JATROS' which is a Greek word means a doctor. The word 'TROPHE' means food for medicinal uses; therefore Jatropha plant is used for medicinal purposes traditionally. This comes in the category of a hardy shrub which can grow even on poor soils and in low rainfall areas having 250 mm rains a year. Therefore it is being promoted as an ideal plant for small farmers. The seeds of Jatropha plant usually contain oil in the range of 27% to 40%. We can process Jatropha oil for production of a high quality bio-diesel fuel which can be used in any standard diesel engine [10].

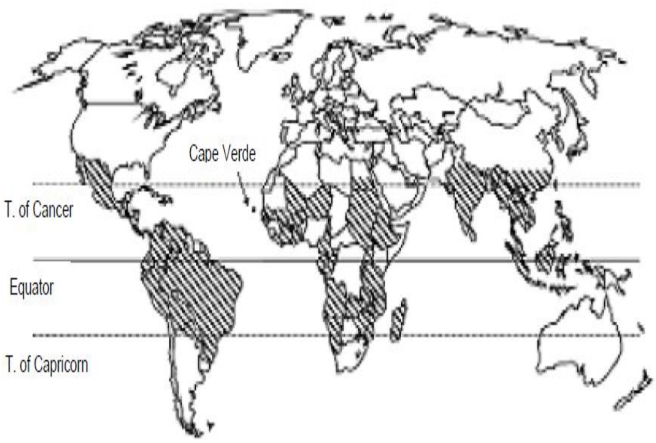


Fig. 1: Suitable climatic conditions for the cultivation of Jatropha Curcas [11]

Following are some of the benefits of Jatropha oil:

- **i.** Jatropha bio-diesel can be used as an alternative option for petro-diesel.
- **ii.** Many properties of Jatropha bio-diesel are similar to diesel fuel.
- **iii.** Jatropha bio-diesel is an oxygenated and eco-friendly fuel.
- **iv.** Jatropha bio-diesel contains less sulphur than diesel.
- **v.** Jatropha bio-diesel can be used in the current diesel engine with a little modification.
- **vi.** Emission of harmful exhaust gases can be reduced by using Jatropha bio-diesel.

| | |
|---|---|
| **Environmental impacts** | 1. Can reduce green house gasses<br>2. Easily biodegradable<br>3. Higher combustion efficiency<br>4. Reduced air pollution<br>5. Carbon neutral |
| **Energy security** | 1. Domestically distributed<br>2. Renewable<br>3. Fuel diversity<br>4. Supply reliability<br>5. Reduction of dependency on petroleum imports<br>6. Lower dependency on fossil fuels |
| **Economic impacts** | 1. Sustainability<br>2. Agricultural development<br>3. Increased farmer income<br>4. Manufacturing jobs may increase in rural areas |

Table 1: Important Benefits of Biofuels [12][13][14]

The production of Jatropha seeds is approximately 0.78 kg per sq. mt. per annum. The content of oil in Jatropha seeds varies from 19% to 41% by its weight. The Freshly extracted Jatropha oil is usually slow drying, without any odour and without any colour but it turns to yellow color after some time [15].

Mr. Forson have used Jatropha oil and blends of diesel in his research on engines with Compression Ignition (CI) and found that at low concentration of Jatropha oil in blends the performance and emission characteristics of engine is quite similar to using petro-diesel [16].

Late Dr. Abdul Kalam, India's Ex-President, always loudly motivated for Jatropha cultivation to produce bio-diesel in India [17]. In one of his speech, he said that India is having about 600,000 km² of wasteland out of which over 300,000 km² is suitable for cultivation of Jatropha plants. Once Jatropha plant is planted and tree is grown this plant is having very long and useful lifespan for many decades. Once grown, in its remaining life, Jatropha plant doesn't require much water as compared to other cash crops.

Dr. Kalam suggested that Jatropha can be cultivated in approx thousand acres of wastelands available in hilly regions of India, which can bring rural prosperity through production of bio-diesel [18]. Dr. APJ Abdul Kalam himself given the green signal to use Green technology using eco-friendly Jatropha bio-fuel.

Dr. Kalam was so much interested that he himself tested the efficiency of bio-fuel for its smell, viscosity level, smoke emissions and performance on his generator and lawn mower at President House of India. He has tested his lawn mower at just a 5% mix of bio-diesel, but the President himself was ready to move forward and experiment with a higher percentage blend on the generator.

Then on the request of Dr. Kalam's, the director of National Botanical Research Institute (NBRI), Mr. P Pushpangadan and Mr. H.M. Behl taken a sample of Jatropha bio-fuel from NBRI to President House and experimented with a 20% mix of bio-diesel. Dr. Kalam was satisfied with the performance of 20% mix then up-scaled the project and tested with a 40% mix of bio-diesel. Even this test went off smoothly as they know about excellent lubricant value of bio-diesel.

## III. MATERIALS AND METHODS

In this chapter, Materials and methods used in our research work has been discussed. In which several experiments, their experimental procedure, their experimental set-up , test set-up and various analytical tools has been used to characterize and to undergo various generator engine performance test of Jatropha biodiesel are described.

We have conducted our research in terms of our subscribed research philosophy, we have employed our selected the research strategy and also we have utilized our set of research instruments to achieve our research goal – to achieve our identified research objective(s) - and also in the quest for solution to our research problem, in order to find an answer to our research questions [19].

The purpose of this section is to:

- To discuss philosophy used in our research in relation to other used research philosophies;
- To illustrate strategy used in our research, including other adopted research methodologies;
- By introducing our developed and utilized instruments used in our research and while chasing our research goals.

**Research Question 1: What are the specific risk factors that impact the success and performance of the research output?**

We have collected the data through different professionals working in the field of bio-diesel production and also through different online published reports by leading bio-diesel research organizations. In order to validate the results and assess them in light of primary data, the further analysis was carried out.

**Research Question 2: What is the impact of demographics and project characteristics on risk dimensions?**

In order to study how these dimensions of risk vary across the personal and project characteristics, we have tested the primary data. This test revealed how these dimensions diverge in case of different levels of designation, experience and age. We have noticed that the risk dimensions deviate among the different team sizes, duration of the project and the total value of the project. The developed countries are globally facing the problem with Air Pollution, so they have already shifting towards using low pollutant substitutes of fuels and bio-diesels. On the other side developing countries have learned a lesson from developed countries and they are also starting using bio-fuels and other green energy solutions.

**Research Question 3: How can the uses of Biodiesel will reduce the dependency of Petroleum products?**

We have studied from the primary data and also through various case studies and published reports of Bio-diesel productions that developed countries are heavily shifting on bio-diesel production and other green energy substitutes. With some variations in the uses pattern like using a good mix of Bio-diesel and conventional diesel we can get better test results on various engine parameters. This is encouraging stats which can reduce the blind tapping of petro products.

**Research Question 4: What are the financial constraints in the production of Bio-Diesel from Jatropha?**

We have researched on the financial feasibility for the production of Bio-diesel via Jatropha Oil. In our research we have found the Jatropha Bio-diesel works best when Jatropha

Oil Methyl Easter (JOME) get blended with pure Diesel in different proportions, like JOME10(10%), JOME20(20%) and so on. Also the rate of production of Diesel from crude petroleum oil is quite less than the production of JOME from crude Jatropha Oil. Still for the limited available petro reserves and for the sake of the environment we can use JOME blended with Diesel and our future fuel. The byproducts in production of JOME, like, 1,3-propanediol, hydrogen, synthesis gas and liquid chemicals, acrolein, tartonic acid and Poly-Glycerol are also in huge demand. This makes our blended JOME financially feasible for its production and use.

### *A. Research Hypothesis*

Following are the hypothesis for testing the relation of the organizational climate dimensions and demographic characteristics with risk dimensions:

**Null Hypothesis (H0):** The preheated Jatropha Oil Methyl Easter blended with pure Diesel cannot work as Bio-fuel by passing various tests on Engine.

**H1:** The preheated Jatropha Oil Methyl Easter blended with pure Diesel will pass all the tests on Engine, and will work as a Bio-fuel.

### *B. Mechanical and chemical oil extraction*

There are two different options for extracting oil from the Jatropha seeds: mechanical extraction and chemical extraction. In both cases the seeds have to be dried prior to extraction, either in an oven or in the sun [20].

Mechanical cold pressing of seeds is the conventional extraction method, due to its simplicity and affordable investment cost already at small scale [21]. For mechanical extraction of oil, we can use an engine-driven press or some manual press. The use of engine-driven press extracts higher percentage of the available oil from the seeds. This percentage is 75-80% as compared to 60-65% for the manual press. We can use either whole oil seeds, kernels or a mix of these two in mechanical press machine [20].

Chemical extraction methods were developed in order to achieve a more complete extraction, where the amount of oil per ton of seed increased. The chemical extraction methods use a solvent. The most common solvent used in extraction of Jatropha oil n-hexane, which extracts 95-99 percent of the oil. Also, the use of n-hexane as a solvent generates large amounts of waste water, requires high energy consumption and causes emissions of volatile organic compounds, and affects human health by forcing operators to work with hazardous and flammable chemicals [21]. Still a significant amount of research input is required for development of alternatives in order to find out supercritical or bio-renewable solvents. We can substitute some solvent based oil extraction with aqueous enzymatic oil extraction to prevent Environmental impacts, but this will also decrease the extraction percentage of oil [20].

In some of the older version of diesel motors in generators which are running at a constant speed, we can use Jatropha oil directly as a bio-diesel. It can also be used in newer versions of diesel engines with some minor modifications to their fuel supply system. The Jatropha oil can be mixed with some quantity of petro-diesel before use. The Jatropha oil is having a viscosity which is 20-25 times higher than conventional petro-diesel. So some modification is required in bio-diesel oil to reduce its viscosity and to make it more suitable as an engine fuel [22].

We can use pyrolysis and some methods for micro-emulsification with methanol, ethanol, and butanol types of solvents. Transesterification is the most commonly used method for the conversion of Jatropha oil into bio-diesel, in which one ester gets transformed into another ester. While treating Jatropha oil with methanol, methyl-ester with glycerol gets produced as a by-product. Such produced bio-diesel can be used directly in some diesel engine or as a blend with conventional petro-diesel [20][22].

### *C. Esterification of jatropha oil*

The transesterification process for Jatropha oil adopted a three-stage process. In the first stage, 01 lit. of Jatropha oil gets treated with 4 ml of Toluene and Orthro-phorosphric acid in the first stage. After calculating FFA value, Jatropha oil which is having more than 02% FFA value should be treated with Methanol and Sulphuric acid in the second stage, in the third stage the same mix was treated with Potassium hydroxide and Sulphuric acid [23].

In the second stage about 75 ml per litre of oil can be added to Jatropha oil with 5.5 ml per litre of Sulphuric acid. In the final and third stage we have to add 100 ml per litre of oil to Jatropha oil along with 08 gm per litre of oil of Potassium hydroxide [23].

A reaction temperature of 650C, 500C & 650C was kept for the duration of 01 hr, 02 hr, & 03 hour and stirrer was set to stirring speed of 450 rpm. The same was maintained in all the three stages of transesterification processes respectively. After this the reactant material was placed into a transparent vessel and allowed to cool at room temperature for next 12 hours. Once get settled glycerol can be separated at bottom layer. The upper layers of biodiesel get washed with equal amount of water. In order to remove any access quantity of water, the biodiesel was heated up to 1000 C for next 10 mins. For use, the bio-diesel was cooled down to the normal room temperature that of the room, presenting up to 84% yield from Jatropha oil [24].

Transesterification also known as alcoholysis, is a process of substitution of the radical of an ester by the radical of one alcohol. The reaction of transesterification is shown by the following equation: [25].

$$RCOOR' + R''OH \quad <-> \quad RCOOR'' + R'OH$$

The prepared Jatropha oil methyl ester (JOME) was mixed with diesel in various different proportions from the range of 5%, to 100% with step value of 5% to prepare its blends i.e. JOME5, JOME10, up to JOME90, JOME100.

### *D. Experimental setup*

The reactor used for experiments is a 1000 ml three-necked round bottom flask, placed on a heating mantle of 300 watts capacity, whose temperature could be controlled within ± 20C. The two side necks are having a condenser and another one is used for thermo-well and sample collection. A thermometer was also placed in thermo-well to measure temperature measurement inside the reactor. The central neck was having a paddle blade impeller with a stirrer. The motor was speed regulated to adjust and control speed of the stirrer.

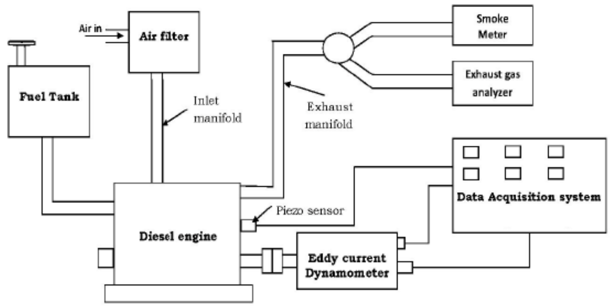


Fig. 2: Block Diagram of our Experimental Setup

Fig. 3: Experimental Setup

We have used a single cylinder which is naturally aspirated, having direct injection compression ignition engine of Kirloskar make in our experiments. Our selected test diesel engine is having 80 mm bore and 110mm stroke. The engine has a rated output of 5HP at a speed of 1500 rpm. We have coupled an eddy current type dynamometer with the test engine to apply engine load using an electrical panel with suitable cooling and lubricating systems. The engine is well mounted on a stationary frame. We have used a Four-stroke single cylinder diesel engine.

### *E. calculation of break thermal efficiency*

We have used a 04 stroke-single cylinder diesel engine in our experiment, which is water cooled and having variable compression ratio. We have used jaw coupling in our engine to couple to an eddy current dynamometer. A standard air tank is fixed within the rig with orifice plates to measure the actual volume of air which is drawn into the cylinder. A differential transducer is provided at the orifice plate in order to facilitate the measurement of air flow rate. Fuel sensor and glass tube are mounted to the fuel tank to measure the fuel consumption by the engine. The thermocouples are provided which are necessary for the measurement of temperature at different locations. A pressure transducer is fitted to the cylinder head. To calculate the speed of the engine we have taken help of a non-contact proximity sensor, while torque is measured using strain gauge based load cell. All the sensors are routed to the computerized data acquisition system for acquiring the readings which is situated in control panel. [26]

### *F. mathematical modeling of bsfc & bte*

We know that the brake specific fuel consumption (BSFC) (g/kWh), the brake thermal efficiency (BTE) and the fuel heating value H,(kJ/kg) can be related as:

$$BSFC = \frac{3.6 \cdot 10^6}{H \cdot BTE}$$

The brake thermal efficiency (BTE) can be calculated using mechanical efficiency (ME) and indicated thermal efficiency (ITE) by multiplying them. The BTE can be calculated by measuring the friction between moving mechanical parts, fluid pumping and operation of auxiliaries:

$$ME = \frac{1}{1 - \frac{FMEP}{BMEP}}$$

Where BMEP or Brake Mean Effective Pressure; FMEP or Friction Mean Effective Pressure both can be calculated in kPa. We can define Brake Mean Effective Pressure as:

$$BMEP = \frac{4 \cdot \pi \cdot T}{D}$$

Where T is the Torque (Nm) of Engine and D is Displacement of Engine ($dm^3$).

As the Friction mean effective pressure or FMPE is not inclined on the torque, it makes the mechanical efficiency (ME) to zero when the torque T is zero. The ME increases with torque increase, according to curve containing a derivative which positive but decreasing [27].

Indicated thermal efficiency or ITE can be defined as a function, f(Torque). In quantitative terms ITE remains constant for low to average values of the torque, but with higher values, the fuel supply increases so that it may worse fuel combustion and that's why it reduces ITE.

Thus the brake thermal efficiency

$$BTE = ME \times ITE = f(\omega)$$

is a function of the torque, according to a curve that is well represented by a second order polynomial.

With regard to the influence of rotation speed $\omega(s^{-1})$ on the efficiency

BTE = ME x ITE = f (ω), the FMPE or Friction Mean Effective Pressure is partly proportional to rotation speed and to squared speed itself [28].

Therefore, we can assume that also the function ME = f (ω) is a second order polynomial.

So a particular thermal efficiency ITE and given torque, ITE diminishes with decrease in rotation speed ω because of increased pressure and heat loss inside the combustion chamber, in consequence of the longer duration of each cycle. Therefore we can assume the function ITE = f (ω) and so the function,

BTE = ME x ITE = f (ω), as a polynomial of second order.

Finally, combining the two polynomial equations BTE = ME x ITE = f (T) and,

BTE = ME x ITE = f (ω), we get:

$$BTE=(A_0+A_1T+A_2T^2).(B0+B1.\omega+B_2.\omega^2)$$

Or,

$$BTE=C_0+C_1\omega+C_2\omega^2+C_3T+C_4T\omega+C_5T\omega^2+C_6T^2+C_7T^2\omega+C_8T^2\omega^2$$

With coefficients $C_0$ ... $C_8$ that are easily calculable by the method of multiple regression. These coefficients are specific for each engine and each fuel (JOME0 or JOME100).

### G. *calculation of brake specific fuel consumption*

Brake specific fuel consumption or BSFC is measure of the fuel efficiency of any engine which burns fuel to produce power in form of either rotational or shaft. BSFC is used to compare efficiency of internal combustion engines against a shaft output.

BSFC is rate of fuel consumption by power which can be produced. BSFC helps to find fuel efficiency of various engines for direct comparison.

For the calculation of BSFC, we can use the formula

$$BFSC = r/P$$

in which:

r is the fuel consumption rate in grams per second (g/s)

P is the power produced in watts where $P = \tau\,\omega$

ω is the engine speed in radians per second (rad/s)

τ is the engine torque in newton meters (N•m)

The above values of r, ω and τ can be calculated by the instrumentations used with an engine and applied load to the running engine. The units of BSFC is grams per joule (g/J).

Commonly BSFC is calculated in unit of grams per kilowatt-hour (g/(kW•h)). We can use the conversion factor as following:

BSFC [g/(kW•h)] = BSFC [g/J]×(3.6×106)

We can convert metric to imperial unit as:

BSFC [g/(kW•h)] = BSFC [lb/(hp•h)]×608.277

BSFC [lb/(hp•h)] = BSFC [g/(kW•h)]×0.001644

## IV. RESULTS

| Properties | Obtained values | | Reported values[a] |
|---|---|---|---|
| | Blye & Dyer | Soxlhet | Solvent extract |
| Oil[b] (%) | $47.2 \pm 2.30^{B}$ | $50.1 \pm 2.36^{A}$ | 47.25 |
| Peroxide Value | $0.13 \pm 0.28^{A}$ | $0.22 \pm 0.43^{A}$ | Not Determined |
| Free Fatty Acid (as % oleic acid) | $3.07 \pm 0.20^{A}$ | $2.23 \pm 0.18^{B}$ | 3.5 |
| Iodine Value (wijs) | $98.86 \pm 0.24^{A}$ | $102.41 \pm 1.13^{A}$ | 105.2 |
| Saponification Value | $168 \pm 1.22^{A}$ | $168 \pm 0.82^{A}$ | 198.85 |
| Unsaponifiable matter Content (%) | $0.89 \pm 0.03^{A}$ | $0.95 \pm 0.08^{B}$ | 0.8 |
| Viscosity (mPa.s) at 20/C | $36.29 \pm 0.2^{B}$ | $48.38 \pm 0.26^{B}$ | Not Determined |
| $E_a$ (KJ. molG1) | 13.87 | 13.75 | Not Determined |

[a] Akintayo [29]

[b] Oil = weight of extracted oil x, 100/ Seed's weight

Table 2: Physical and Chemical properties of Jatropha Oil extracted by solvent process

| Fatty Acid Composition | % in Jatropha Oil |
|---|---|
| Oleic 18:1 | 0.23 |
| Linoleic 18:2 | 44.68 |
| Palmitic 16:0 | 0.68 |
| Stearic 18:0 | 32.7 |
| Palmitoliec 16:1 | 7.1 |
| Linolenic 18:3 | 14.22 |
| Arachidic 20:0 | 0.25 |
| Margaric 17:0 | 21.61 |
| Myristic 14:0 | 0.14 |
| Saturated | 45.42 |
| Monounsaturated | 0.13 |
| Polyunsaturated | 33.17 |

Table 3: Fatty Acid Composition in Jatropha Oil

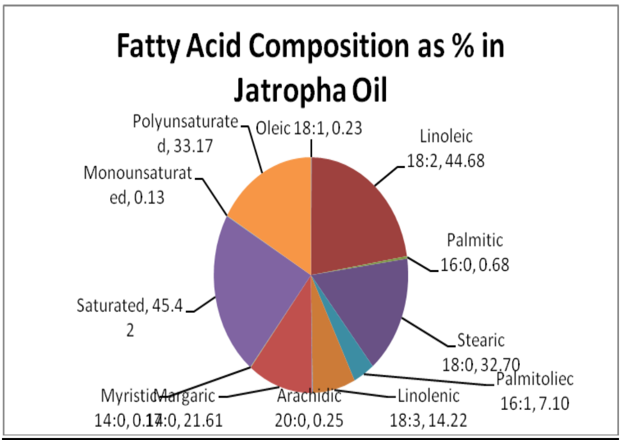


Fig. 4: Fatty Acid Composition (in %) in Jatropha Oil[30]

| Temperature | Heat Flow Endo Up (mW) | |
|---|---|---|
| | Soxlhet | Blye and Dyer |
| -60 | 21.10 | 22.74 |
| -55 | 22.15 | 23.98 |
| -50 | 23.28 | 25.16 |
| -45 | 23.74 | 26.05 |
| -40 | 24.97 | 27.84 |
| -35 | 26.23 | 29.09 |
| -30 | 27.57 | 30.63 |
| -25 | 31.91 | 35.45 |
| -20 | 35.17 | 39.93 |
| -15 | 39.94 | 44.32 |
| -10 | 35.22 | 40.48 |
| -05 | 31.49 | 36.76 |
| 0 | 31.52 | 37.52 |
| 05 | 35.34 | 36.93 |
| 10 | 39.78 | 41.17 |
| 15 | 34.93 | 38.03 |
| 20 | 36.71 | 40.45 |
| 25 | 35.64 | 42.87 |
| 30 | 39.45 | 47.12 |
| 35 | 44.39 | 52.29 |
| 40 | 50.23 | 58.38 |
| 45 | 56.47 | 64.72 |
| 50 | 61.83 | 69.91 |
| 55 | 68.91 | 78.11 |
| 60 | 76.49 | 84.31 |

Table 4: Heating profiles of Jotropha Biodiesel extracted by Blye and Dyer & Soxlhet methods

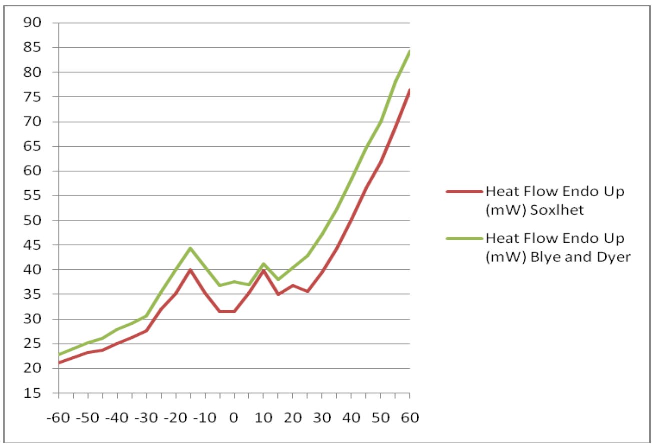


Fig. 5: Heating profiles of Jotropha oil extracted by Blye and Dyer & Soxlhet methods

| Thermogram | 2.5° C /min | | 5° C /min | |
|---|---|---|---|---|
| | Blye & Dyer | Soxlhet | Blye & Dyer | Soxlhet |
| **Peak 1 [°C]** | 25.44 | 31.10 | 26.11 | 31.54 |
| **$\Delta H_f$ [J/g]** | +13.76 | 5.36 | 12.64 | 5.91 |
| **Peak 2 [°C]** | 10.49 | 7.03 | 7.70 | 10.11 |
| **$\Delta H_f$ [J/g]** | +2.73 | +49.56 | 0.87 | +0.42 |
| **Peak 3 [°C]** | 0.70 | 1.82 | 0.83 | 1.54 |
| **$\Delta H_f$ [J/g]** | +0.22 | 0.15 | 0.35 | 0.50 |

Table 5: Melting behavior of Jatropha Curcas seed oil using different scan rates

| Temperature ( in $^0$C) | Jatropha Oil Viscosity | |
|---|---|---|
| | Blye Dyer | Soxlhet |
| 5 | 56.6 | 72.4 |
| 10 | 49.2 | 63.4 |
| 15 | 42.9 | 56.3 |
| 20 | 37.4 | 49.7 |
| 25 | 32.1 | 36.8 |
| 30 | 30.7 | 33.9 |
| 35 | 27.2 | 29.5 |
| 40 | 24.8 | 26.9 |
| 45 | 23.2 | 25.1 |
| 50 | 21.1 | 22.9 |

Table 6: Effect of temperature on viscosity of Jatropha Oil

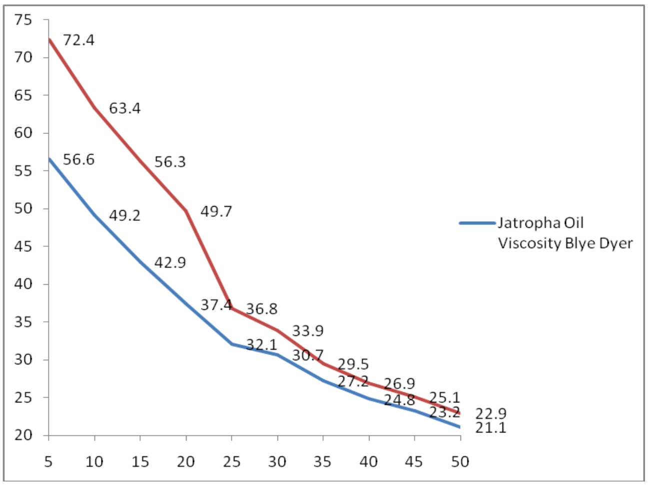


Fig. 6: Effect of temperature on viscosity of Jatropha Oil

| S. No. | Types of oil blends | Sp. gravity | Calorific value (MJ/kg) | Flash point (°C) | Fire point (°C) |
|---|---|---|---|---|---|
| 1 | 100% JOME | 0.904 | 39.92 | 106 | 202 |
| 2 | 90% JOME+10% Diesel | 0.890 | 41.26 | 95 | 167 |
| 3 | 80% JOME+20% Diesel | 0.882 | 41.82 | 93 | 152 |
| 4 | 70% JOME+30% Diesel | 0.875 | 42.24 | 90 | 144 |
| 5 | 60% JOME+40% Diesel | 0.866 | 42.79 | 96 | 132 |
| 6 | 50% JOME+50% Diesel | 0.858 | 42.97 | 104 | 129 |
| 7 | 40% JOME+60% Diesel | 0.850 | 43.31 | 91 | 124 |
| 8 | 30% JOME+70% Diesel | 0.842 | 43.85 | 86 | 115 |
| 9 | 20% JOME+80% Diesel | 0.838 | 44.42 | 83 | 102 |
| 10 | 10% JOME+90% Diesel | 0.834 | 45.67 | 80 | 91 |
| 11 | 100% Diesel | 0.828 | 46.78 | 76 | 84 |
| 12 | Preheated JOME at 100$^0$C | 0.863 | 42.85 | 95 | 133 |
| 13 | Preheated JOME at 110$^0$C | 0.854 | 43.16 | 94 | 130 |
| 14 | Preheated JOME at 120$^0$C | 0.842 | 44.23 | 92 | 129 |

Table 7: Effect of blending Jatropha Oil Methyl Easter(JOME) with Diesel

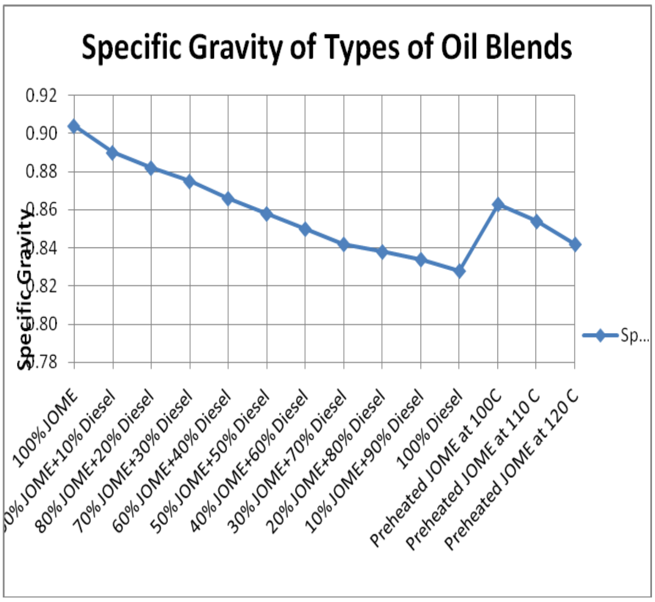


Fig. 7: Specific gravity of various Oil blends

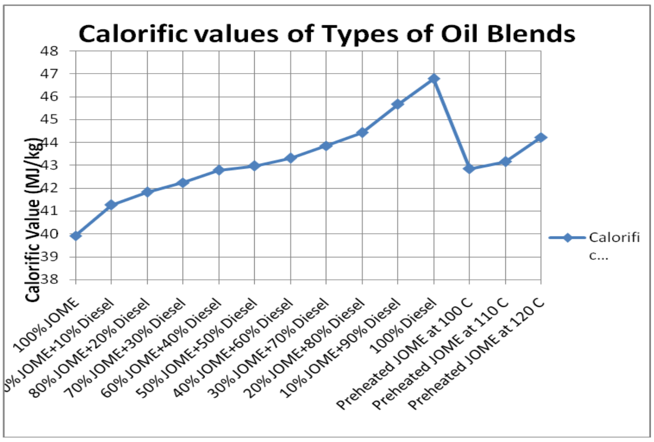


Fig. 8: Blended JOME Vs. Calorific Values

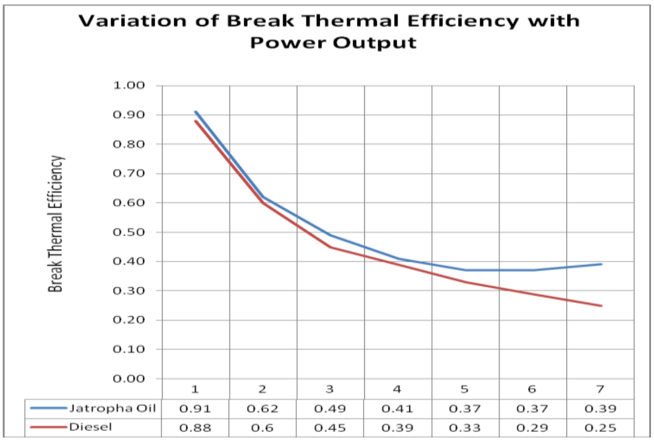


Fig. 12: Brake Thermal Efficiency Chart

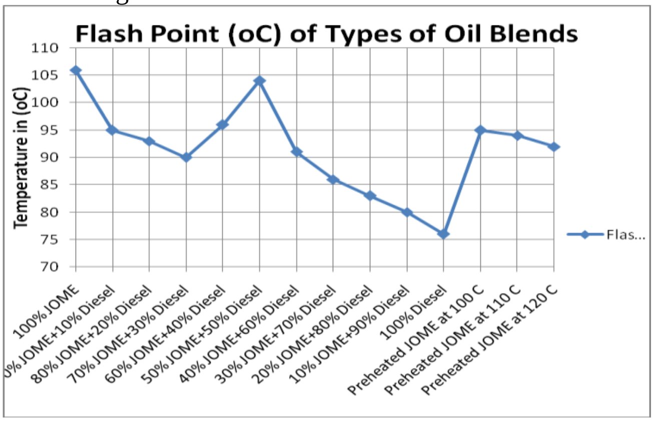


Fig. 9: Blended JOME Vs. Flash Point

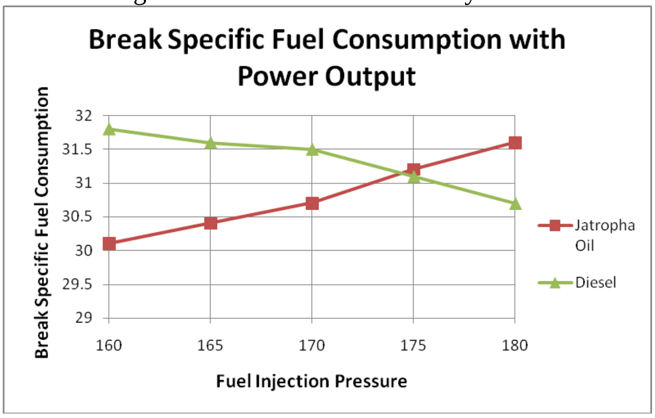


Fig. 13: Brake Thermal Fuel Consumption with Power Output

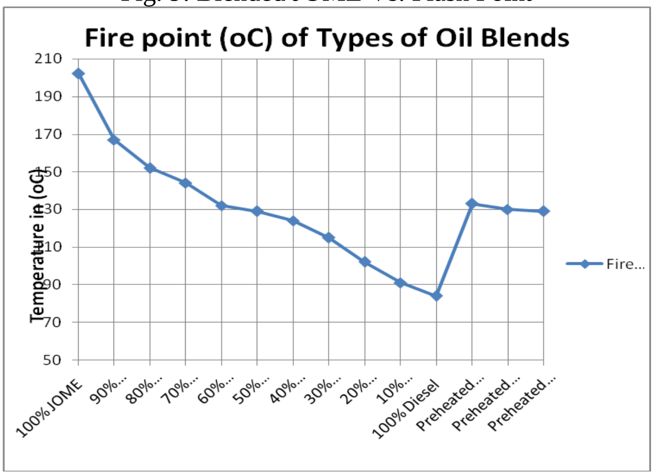


Fig. 10: Blended JOME Vs. Fire Point

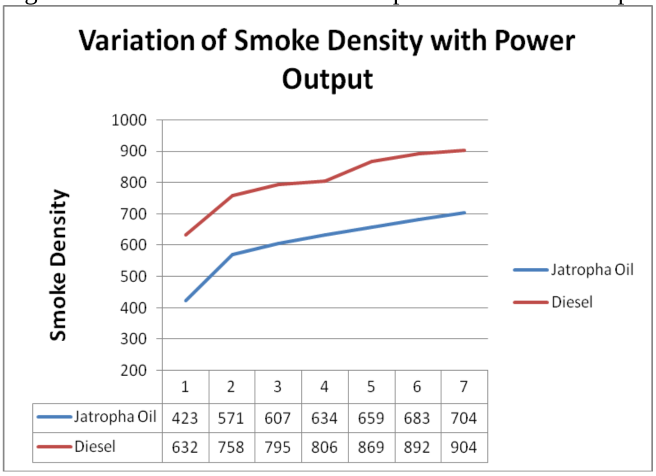


Fig. 14: Variation of Smoke Density with Power Output

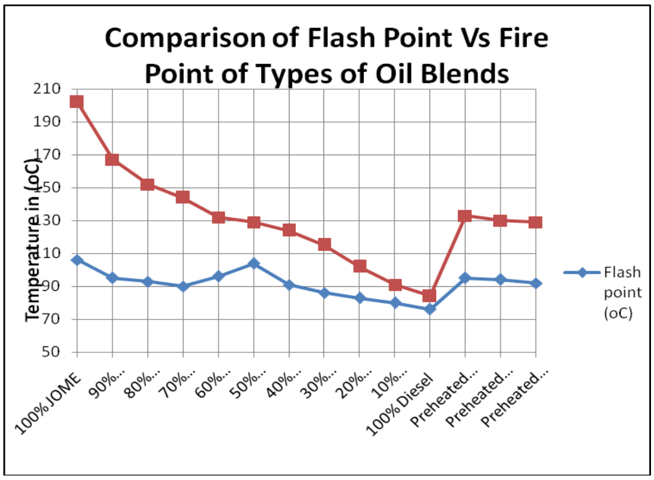


Fig. 11: Flash point Vs. Fire Point

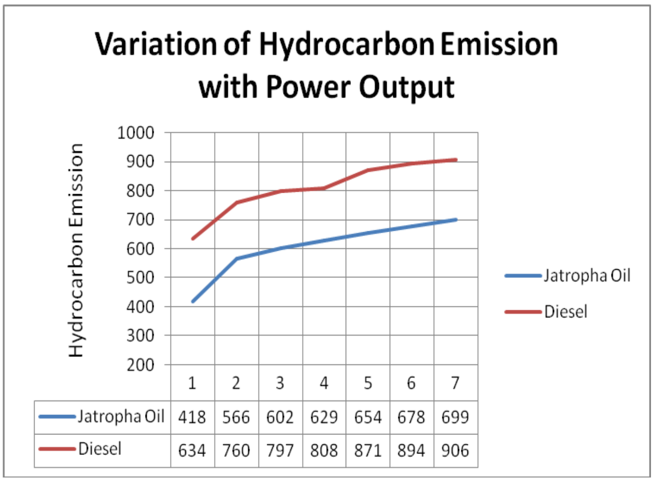


Fig. 15: Variation of HC Emission with Power Output

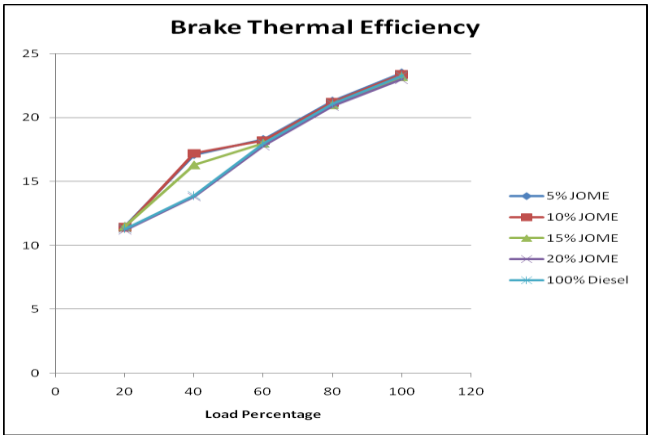


Fig. 16: BTE Vs. Load for JOME.

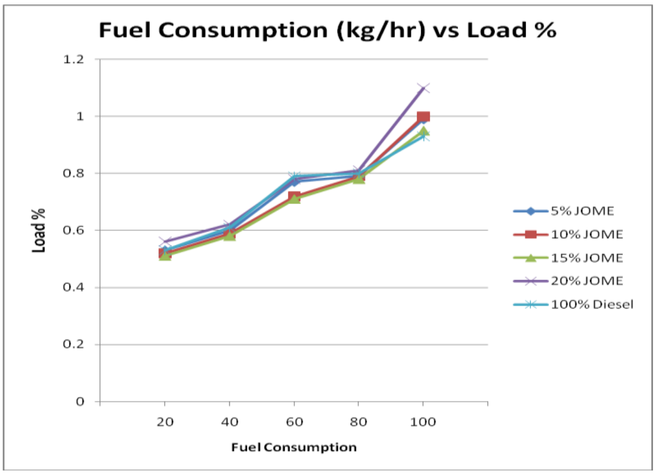


Fig. 17: Fuel Consumption Vs. Load for JOME.

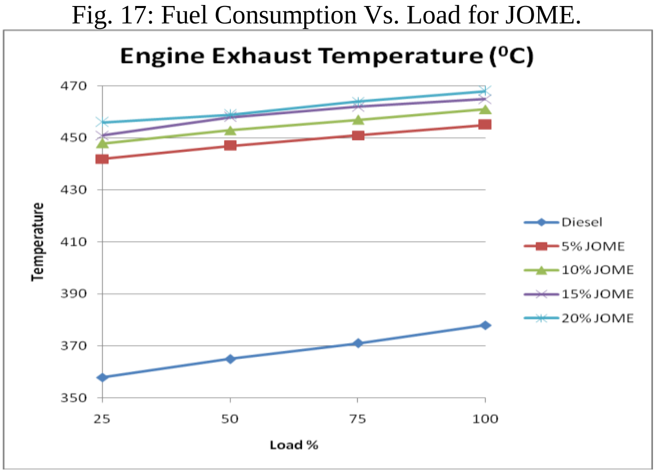


Fig. 18: Engine Exhaust Temprature for different Loads for JOME Blends

## V. CONCLUSIONS & FUTURE SCOPE

Based on the experimental results of our research work, we can discuss following conclusions:

1. The brake thermal efficiency of our test engine majorly depends on the fuel's heating value and viscosity. The Jatropha bio-diesel is having brake thermal efficiency almost nearer to that of diesel fuel.
2. If there is a higher combustion rate of fuel, the temperature starts increasing inside the engine and also in the exhaust.
3. The break specific Fuel Consumption of Jatropha oil is quite close to diesel up to 3KWA load.
4. The Hydrocarbon emissions in Jatropha oil are less than diesel fuel.
5. The CO emission is also quite less as compare to Diesel as it depends on the temperature inside the combustion chamber of the engine.

Because of the environmental benefits, the production of bio-diesel is increasing exponentially, even when the cost of producing bio-diesel is more than as compare to petro based fuels. If we start using a solid heterogeneous catalyst in the production of bio-diesel, we can reduce the production costs. Then bio-diesel will become financially viable as compare to petro-fuels. For the same purpose we require significant research efforts to search for the better catalysts in our esterification process for bio-diesel production.

The ex-President of India, Late Dr. APJ Abdul Kalam, always promotes for the Jatropha cultivation for the production and use of bio-diesel. In one of his speech, Dr. Kalam said that in India, the availability of wasteland is about 600,000 sq. km out of which about 300,000 sq. km are most suitable for cultivation of Jatropha plants. The Jatropha plants are having a long lifespan of more than thirty years. Once the plantation of Jatropha is done, and tree survived, it requires quite little water in the tune of 250 mm of rainfall a year, as compared to similar crops and trees


Fig. 19: Dr. A.P.J. Abdul Kalam on Jatropha Cultivation

## VI. IMPLEMENTATION OF BIO-DIESEL IN INDIA BY INDIAN RAILWAYS

The Indian Railways are already using the Jatropha Bio-diesel blended with Petro-diesel fuel in different various ratios, to power Diesel engines of Indian Railways with the great amount of success. Presently the Petro-diesel locomotives that are running from Thanjavur to Nagore stations and also from Tiruchirapalli to Lalgudi stations, from Dindigul and Karur stations in Tamil Nadu state are running on a blend of Jatropha bio-diesel and diesel oil [31].

**Andhra Pradesh**

The government of Andhra Pradesh has gone for an agreement with Reliance Industries for cultivation and plantation of Jatropha trees. Reliance industries have selected 200 acres of land at Kakinada, Andhra Pradesh for the plantation of Jatropha trees in order to produce high quality Jatropha bio-diesel fuel [32].

**Kerala**

Kerala is also in the planning mode for massive Jatropha planting drive [33].

**Chhattisgarh**

The government of Chhattisgarh has taken an initiative to plant 160 million Jatropha saplings in year 2006, with an aim to become a self-reliant state for using bio-fuel by the year 2015 [34]. Chhattisgarh state also planned to earn Rs. 40 billion annually just by selling Jatropha seeds after year 2010. The central government of India has provided Rs. 135 million to Government of Chhattisgarh in year 2013 for developing nursery for Jatropha curcas plants.

In the month of May 2005, then Chief Minister Mr. Raman Singh started using Jatropha bio-diesel for his official government vehicle. Chhattisgarh government have planned to use Jatropha bio-fuel in all the vehicles owned state government using diesel and petrol. The Chhattisgarh Bio-fuel Development Authority have also accepted that seeds of Jatropha curcas plant is a rich source of bio-diesel [35]. The Chhattisgarh government also tied up with a Panchratan company of public sector 'Indian Oil' to produce bio-diesel and maintain Jatropha plantation in Chhatisgarh. This company Indian oil CREDA Biofuels Ltd. is established in year 2009 which has covered all districts of Chhatisgarh for the plantation of Jatropha curcas.

**Karnataka**

Farmers of Karnataka state are planting Jatropha in semi-arid regions of the state [36]. Since year 2002, Labland Biodiesel which is a Mysore based company is playing a leading role in Research and Development activities for Jatropha curcas-based Biodiesel [37].

**Tamil Nadu**

Tamil Nadu has also started aggressive promotion for the plantation of Jatropha plants to help farmers overcome the losses due to irregular rains in past few years. The government of Karnataka are into a contract with following four entrepreneurs: M/s Mohan Breweries and Distilleries Ltd, M/s Dharani Sugars and Chemicals Ltd, M/s Shiva Distilleries Ltd & M/s. Riverway Agro Products Pvt. Ltd.

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