Performance and Emission Characteristics of Jatropha Bio-Diesel and Their Blends Operated on CI Engine

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Abstract

The rapid depletion of petroleum fuels and their ever increasing cost have led to an intensive search for alternative fuels. This leads to number of researches on different vegetable oils, but that should not create war against "Food Vs Fuel". Therefore mainly for investigation prefers non-edible oils.

In this present investigation Jatropha, – non edible vegetable oil is selected for test on CI engine and its suitability as an alternative fuel is examined by its performance and exhaust emission on it. Bio-diesel from raw Jatropha oil is prepared and blended with diesel in proportion of J25/75%, J50/50%, J75/25% and J100/0% on the volume basis, then analyzed and compared with diesel.

In performance characteristics, the parameters like brake thermal efficiency, brake specific fuel consumption, mechanical efficiency, volumetric efficiency, air fuel ratio, Indicated mean effective pressure and exhaust emissions such as CO, CO_2, NO, HC and smoke opacity are analyzed.

1. INTRODUCTION

India has developed rapidly during the past decades, reducing the percentage of the population living below the poverty line from 55 percent in 1973 to 21 percent in the late 1990s. However, 250 million Indians still live in poverty and are dependent on continued development to raise their standard of living. In order to fight poverty and enhance livelihoods in developing countries the supply of food and energy must be secured; the population needs food for sustenance, and access to modern energy sources is necessary in order to achieve both economic growth and sufficient social and public services.

India depends on import of fossil fuels to satisfy energy demand, and with population growth and economic development the demand will continue to increase. Fossil fuels are finite energy resources, and as the amount of new supplies found is decreasing, the resources will eventually be exhausted. Furthermore, the use of fossil fuels has a severe impact on climate change. Increased fossil fuel use thus conflicts with the increasing global pressure to reduce environmental impact and mitigate climate change.

In combination with the increasing global demand for renewable energy forms, the need to secure energy supply in developing countries has created a demand for biomass energy, such as biofuels. One of the most common biofuel energy systems is production of biodiesel through transesterification of non-petroleum based oils. Biodiesel can be used in unmodified diesel engines, either alone or blended with conventional petrodiesels. For developing countries, production of biodiesels could represent a way to achieve economic growth by increasing and securing energy supply, but also by creating job opportunities and as a source of income for the farmers involved.

However, the advantages of biofuels come with disadvantages. One of the problems arising from the increasing demand for biodiesel is competition between the production of biodiesel crops and the production of food crops. It is argued that direct competition with food commodities can be avoided through the use of non-edible crops as biodiesel feedstock. Still, if cultivation of biofuel crops leads to higher incomes, farmers will choose to produce biofuels instead of food. This decrease in food production will result in an increase in food prices.

Vegetable Oils

The use of vegetable oils as an alternative fuels has been known for 100yrs when the inventor of the diesel engine Rudolph Diesel first tested peanut oil, in his compression engine.

There are two types of vegetable oils:

1. Edible oils
2. Non-edible oils

The present work focused only on non-edible oils as fuel for engines, as the edible oils are in great demand and far too expensive. Some of the non edible oils are pongamia, jatropha, jojoba, mahua, linseed, castor.

Jatropha

Jatropha crucas in this report referred to only as Jatropha, is a small tree or large bush belonging to the Euphorbiaceae family. See Figure 1for examples of two Jatropha plants. Normally the plant reaches a height of three to five meters but can reach up to eight to ten meters when grown under favourable conditions.

Figure 1- Jatropha tree

The Jatropha seeds are black, measuring on average 18 mm in length, 12 mm in width, and 10 mm in thickness. The seed's shell and inner kernel account for on average 37 and 63 percent of the total weight, respectively. Oil content of the seeds range from 32 to 40 percent; the average is 34 percent. The seed contains toxins, such as phorbol esters, curcin, trypsin inhibitors, lectins, and phytates, which render the seeds, oil, and seed cake non-edible if not detoxified.

Biodiesel

Biodiesel which is derived from triglycerides by transesterification and from the fatty acids by esterification has attracted considerable attention during the past decade as a renewable, biodegradable, eco-friendly and non-toxic fuel. Several processes for biodiesel fuel production have been developed. Biodiesel is recently used as a substitute for petroleum based diesel due to environmental considerations and depletion of vital resources like petroleum and coal. The possible use of renewable resources as fuels and as a major feedstock for the chemical industry is currently gaining growth. Further as petroleum is a fast depleting natural resource, an alternative renewable way to petroleum is a necessity. Now serious efforts are being made on the production and utilization of biodiesel in India. Methyl esters are clean burning fuel with no sulphur emission. Although its heat of combustion is slightly lower than that of the petro-diesel, there is no engine adjustment necessary and there is no loss in efficiency. Methyl esters are non-corrosive and are produced at low pressure and low temperature conditions. Concentrated (about 80 %) glycerine is obtained as a by-product during transesterification process. Bradshaw stated that 4.8:1 molar ratio of methanol to vegetable oil leads to 98% conversion. He noted that ratio greater than 5.25:1 interfered with gravity separation of the glycerol and added useless expense to the separation. Freedman, et al. studied the effect of molar ratio of methanol to oil and effect of changes in concentrations of tri-, di- and monoglyceride on ester yield. Freedman et. al. obtained the results for methanolysis of sunflower oil, in which the molar ratio varied from 6:1 to 1:1 and concluded that 98% conversion to ester was obtained at a molar ratio of 6.1. In the present investigation, biodiesel was prepared from jatropha oil and its properties were analyzed to acertain its suitability as biodiesel.

Jatropha oil

The Jatropha oil can be used directly as a liquid fuel in older diesel motors, in generators and pumps running at a constant speed, or in newer engines with small modifications in the fuel system. The Jatropha oil can also be mixed with fossil diesel before use in the engine, which combines the properties of the fossil fuel with the lower environmental impact of the vegetable oil. However, Jatropha oil has a viscosity that is 20-25 times higher than the viscosity of conventional diesel, which causes problems when using the unmodified oil or blends with a high percentage of Jatropha oil in an engine. Thus, there is a need for modification of the oil to reduce viscosity and make it more suitable as an engine fuel. Methods for this are pyrolysis and micro-emulsification with solvents like methanol, ethanol, and butanol, but the most common method is to convert the Jatropha oil into biodiesel through transesterification. This method transforms an ester into another ester; in this case a reaction between Jatropha oil and methanol is used to produce a methyl-ester (biodiesel) with glycerol as a by-product. The biodiesel can be used directly in a diesel engine or in a blend with conventional diesel.

2. PROCEDURE FOR PREPARATION OF BIODIESEL FROM VEGETABLE OIL

Biodiesel preparation contains mainly following processes

1. Extraction of raw oil
2. Finding FFA value of that oil
3. Esterification of raw oil
4. Separation of glycerol from biodiesel
5. Washing of biodiesel

Extraction of raw oil

We can extract crude oil from jatropha seeds by using a equipment called expeller.

Finding FFA value of that oil

For this we have to do titration, the process is described below

1. Fill the burette with 0.01N of NaOH solution.
2. Take 1ml of oil sample in conical flask.
3. Now add 10ml of isopropyl alcohol to that sample oil.
4. Add 2-3 drops of phenolphthalein indicator to sample oil
5. Now titrate against NaOH solution.
6. Note down the readings of burette.
7. That reading itself indicates FFA value of that oil.

Esterification of raw oil

1. Now take 1 litre of oil sample.
2. That oil is heated upto 55°C to 60°C temperature but do not exceed 70°C.
3. Now take 200ml of methanol or ethanol in that add 4.5grams of KOH.
4. Shake that mixture well till KOH dissolves completely and the solution becomes potassium methoxide solution.
5. Now add that solution to 1 liter oil sample with constant stirring of raw oil. Stir upto 10-15 minutes.
6. Leave that solution to settle down up 8-10 hours.
7. It will form two distinct layers.
8. The upper layer is called bio-diesel and lower dark, thick layer is called glycerol which is used to make soap.

Separation of glycerol from bio-diesel

Remove the lower layer slowly without disturbing upper layer i.e glycerol settles at the bottom.

Washing of bio-diesel

This step is optional because it depends on colour of the bio-diesel obtained but sometimes it is necessary because the separated bio-diesel contain some methanol, to remove that methanol washing is necessary because methanol is soluble in water. After separating the impurity, pure form of bio-diesel is obtained and this can be used as fuel in automobiles.

3. EXPERIMENTS CONDUCTED TO DETERMINE THE PROPERTIES OF JATROPA OIL

1. Viscosity
2. Density
3. Flashpoint
4. Fire point
5. Calorific Value (CV)

Procedure to determine the viscosity

The viscosity of the vegetable oil is determined by using bolt viscometer. The apparatus is cleaned thoroughly. The ball valve is placed in the position thus closing the orifice. The sample is poured into the cup upto gauge point. The standard 50ml flask is kept under the orifice of the cup. The sample is heated to the required temperature, which is noted from the thermometer immersed in the oil. After heating to the desired temperature the ball valve is lifted off. The oil drains into the flask placed beneath. The time taken to collect the oil up to the mark is measured using stop watch.

The kinematic viscosity of the sample is determined using the formula. Kinematic viscosity = A*S - B/S in centistokes.

Where S = Say bolt seconds to collect the 50ml sample.
A and B are constants, A = 0.02240 and B = 1.84.

Figure 3-Say Bolt Viscometer

Procedure to measure density

The density of oil is determined by using Hygrometer apparatus. The apparatus consists of a measuring cylinder in which the oil sample whose density is to be determined is filled upto certain level. Then the hygrometer is dipped inside the measuring cylinder containing the oil. The level of liquid shown by the graduations on the hygrometer determines the density of the oil.

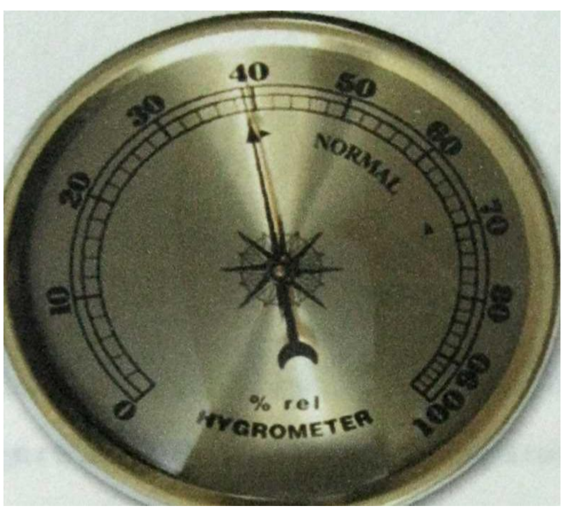

Figure 4-Hygrometer

Procedure to measure flash point and fire point

The flash and fire point is determined by the Pensky-Marten apparatus. A metal cup is generally made of brass which is provided with a stirrer for maintaining uniform temperature of oil and a shutter to close the cup. There is provision to heat the oil cup in a water bath. This apparatus measures the flash points above 50°C.

The given oil is filled in the metal cup to the standard mark and shutter is closed. The oil is stirred slowly at a rate of 2rps to maintain uniform temperature. Then the water is heated slowly to rise the oil temperature by about 5°C per minute. At every 10°C rise of temperature of oil, flame is introduced for a moment by opening the shutter. The temperature at which a distinct flash appears inside the cup is recorded as the flash point and the temperature at which a distinct fire appears inside the cup is recorded as the fire point respectively under closed conditions

Figure 5-Pensky-Marten apparatus

Procedure to determine calorific value

The calorific value of jatropha oil is determined using the bomb calorimeter apparatus. The calorific value can be defined as the amount of heat liberated when a unit mass or volume of the fuel is burnt completely in air or oxygen.

Calorific value of a fuel is the thermal energy per unit quantity of fuel is burnt completely and the products of combustion are cooled back to the initial temperature of the combustable mixture it measures the energy content in a fuel This is an important property of the bio-diesels that determine the sutiability of the material as alternative to the diesel fuels. The heating value of the prepared bio-diesel was determined with the help of bomb calorimeter. In known amount of fuel was burnt in a bomb and the temperature difference was noted down.

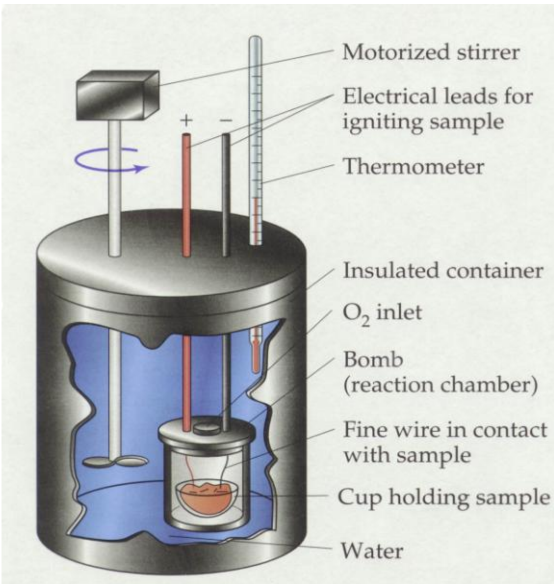

Figure 6-Bomb Calorimeter

4. PERFORMANCE PARAMETERS

Engine performance is an indication of the degree of success of the engine performs its assigned task, i.e. the conversion of the chemical energy contained in the fuel into the useful mechanical work. The performance of an engine is evaluated on the basis of the following

1. Specific Fuel Consumption.
2. Brake Mean Effective Pressure.
3. Specific Power Output.
4. Specific Weight.
5. Exhaust Smoke and Other Emissions.

For the evaluation of an engine performance few more parameters are chosen and the effect of various operating conditions, design concepts and modifications on these parameters are studied. The basic performance parameters are the following.

Indicated thermal efficiency (η_t):

Indicated thermal efficiency is the ratio of energy in the indicated horsepower to the fuel energy. The fuel consumption is inversely proportional to horsepower.

Mechanical efficiency (η_m):

Mechanical efficiency is the ratio of brake horse power (delivered power) to the indicated horsepower (power provided to the piston).

Brake thermal efficiency (η_{th}):

Brake thermal efficiency is the ratio of energy in the brake horse power to the fuel energy. The brake thermal efficiency equals the product of the indicated thermal efficiency and the mechanical efficiency.

Volumetric efficiency (η_v):

The engine output is limited by the maximum amount of air that can be taken in during the suction stroke, because only a certain amount of fuel can be burned effectively with a given quantity of air. Volumetric efficiency is an indication of the 'breathing' ability of the engine and is defined as the ratio of the air actually induced at ambient conditions to the swept volume of the engine. The volumetric efficiency can be calculated considering mass or volume of air. However, it is preferable to mass basis.

Specific fuel consumption (SFC):

The fuel consumption characteristics of an engine is generally expressed in terms of fuel consumption in grams per horsepower-hour. Brake specific fuel consumption and indicated specific fuel consumption, abbreviated BSFC and ISFC, are the fuel consumption on the basis of BHP and IHP, respectively.

Fuel-air (F/A) or air-fuel (A/F) ratio:

The relative proportions of the fuel and air in the engine are very important from standpoint of combustion and efficiency of the engine. This is expressed either as the ratio of the mass of the fuel to that of the air or vice versa. In SI engines the fuel-air ratio practically remains constant over a wide range of operation. In CI engines at a given revolution the airflow does not vary with load; it is the fuel flow that varies with load. Therefore the term fuel-air ration is generally used instead of air-fuel ratio. In the CI engine the fuel-air ratio varies directly with the load on the engine.

5. EXPERIMENTAL SETUP AND PLAN

The setup consists of single cylinder, four strokes, diesel engine connected to eddy-current dynamometer for variable loading. It is provided with necessary equipment and instruments for combustion pressure, fuel injection pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for Pθ-PV diagrams and fuel injection pressure- crank angle diagram. Windows based Engine Performance Analysis software package is fully configurable. Pθ-PV diagram and performance curves are obtained at various operating points. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurements with computer. The set has stand-alone type independent panel box consisting of air box, fuel tank, manometer, fuel measuring unit, differential pressure transmitters for air and fuel flow measurement, process indicator and engine indicator. The setup enables study of engine for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance.

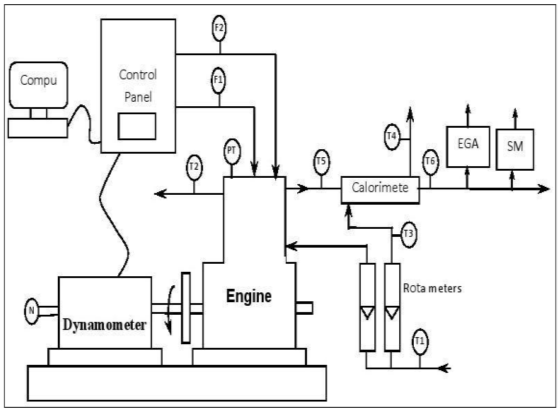

Figure 7- Schematic diagram of experimental setup

Table 1-Engine specification

Manufacturer	Kirloskar Oil Engines Ltd., India
Model	TV–SR II, naturally aspirated
Engine	Single cylinder, DI, Four Stroke
Bore / stroke	87.5mm/110mm
Compression ratio	16.5, 17.5 and 18 (Variable)
Speed Rated power	1500 r/min, constant 5.2 kW
Injection pressure	240 bar/23° deg BTDC
Type of sensor	Piezo electric
Response time	4 micro seconds
Crank angle sensor	1-degree crank angle
Resolution of 1 degree	360 °encoder with a resolution of 10

Variable load tests are conducted for 0, 1, 2, 3, 4, and 5 KW at a constant rated speed of 1500 rpm. With fuel injection pressure 180 bar and cooling water exit temperature of 60°C. All observations recorded were replicated to get a reasonable value

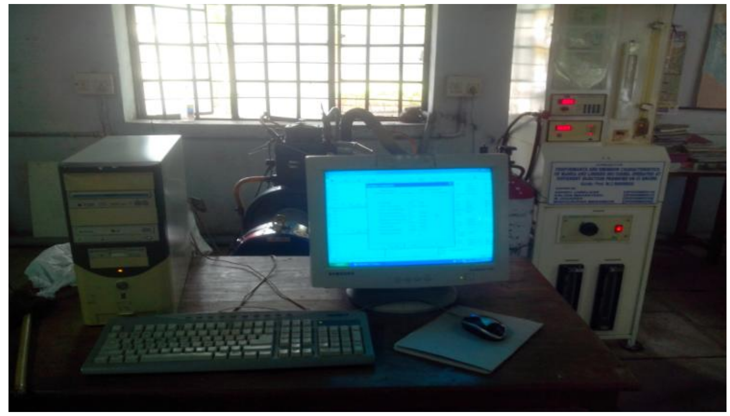

Figure 8-Engine setup

Figure 9- Modular diagnostic system

6. RESULTS AND DISCUSSION

Experiments are conducted on jatropha biodiesel to determine the following

1. The physical properties like viscosity, calorific value, fire point, flash point and density of different biodiesel blends and pure diesel.
2. The performance characteristics of a 4 stroke diesel CI engine such as brake thermal efficiency, brake specific fuel consumption, mechanical efficiency, volumetric efficiency, air fuel ratio, Indicated mean effective pressure.
3. The emission characteristics such as carbon-monoxide, carbon-dioxide, oxides of nitrogen (NO), HC and smoke.

Physical properties of bio-diesel blends and pure diesel

The physical properties such as viscosity, calorific value, fire point, flash point and density of different biodiesel blends and pure diesel are determined and the obtained values are tabulated in table 2

Table 2-Physical properties of bio-diesel blends and pure diesel

Properties	Units	Diesel	J 100%	J 75%	J 50%	J 25%
Density at 15°C	Kg/m3	832	890	880	870	860
Kinematic viscosity at 40°C	cSt	3.12	5.3	4.75	4.21	3.67
Calorific value	kJ/kg	44000	340770	41583	42395	43207
Flash point	°C	56	175	145	115	85.75
Fire point	°C	65	185	155	125	95.75

7. PERFORMANCE CHARACTERISTICS

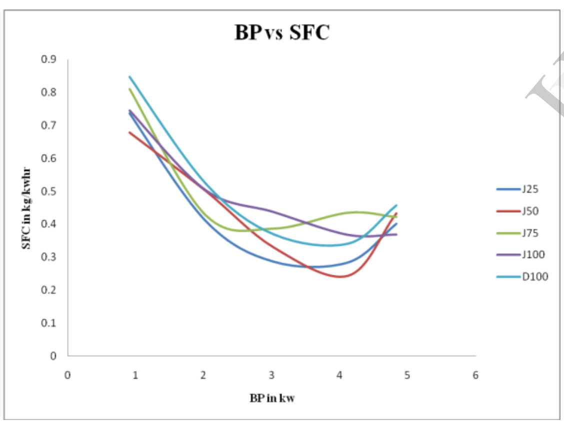

Figure 10-Brake power vs Specific fuel consumption

The variation of Specific fuel consuption with Brake power for diesel and different biodiesel blends are shown in figure 10. Specific fuel consuption of bio-diesel blends and diesel are decreasing at higher loads, Specific fuel consuptionis for diesel is slightly higher than biodiesel blends at lower loads and almost same for higher loads as evident from graph

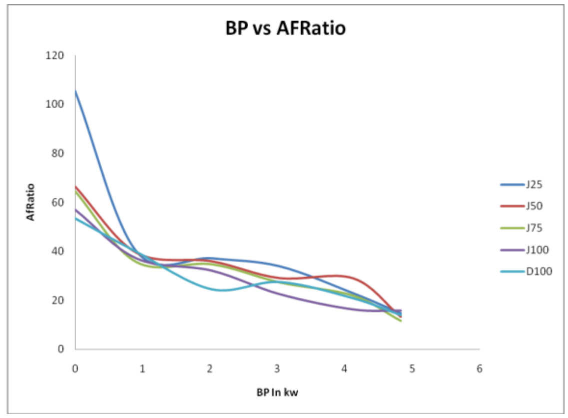

Figure 11-Brake power vs Air-Fuel ratio

The variation AF ratio with Brake power for diesel, and different biodiesel blends are shown in figure 11. The AF ratio of blends and pure bio-diesel is slightly higher than diesel for certain lower loads, but for higher loads, the AF ratio remains almost constant as evident from the graph. For J25 the AF ratio is maximum at lower load this may be due to absence of sufficient air during combustion.

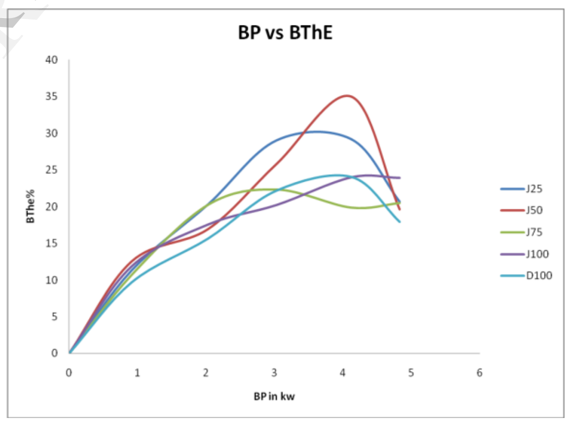

Figure 12-Brake power vs Brake thermal efficiency

The variation of Brake thermal efficiency with Brake power for diesel and different blendings of biodiesel oils are shown in figure 12. It is observed that the brake thermal efficiency is low at lower loads and increases at higher loads. For a blend of J25, J50, the Brake thermal efficiency is high at 80% load when compared with other blends of fuel. Increase in thermal efficiency is due to high percentage of oxygen presence in the biodiesel, the extra oxygen leads to causes better combustion inside the combustion chamber At full load condition the Brake thermal efficiency of diesel and bio-diesel blends are almost same as evident from the graph

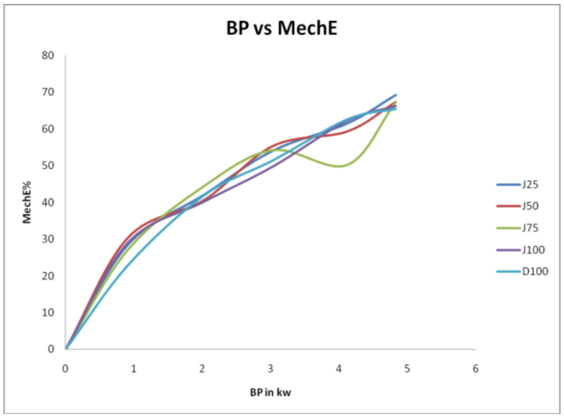

Figure 13-Brake power vs Mechaniacal efficiency

The variation of mechaniacal efficiency with Brake power for diesel and different blendings of biodiesel oils are shown in figure 13. Mechanical efficiency increases as the load increases for both diesel and biodiesel blends, Mechanical efficiency of biodiesel blends are high compared to diesel and it is high for a blend J25 compared to other biodiesel blends.

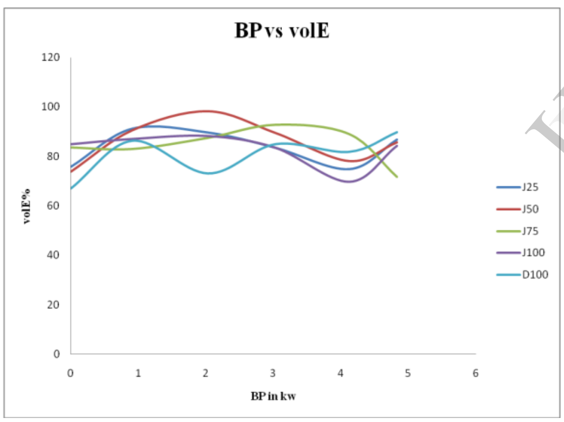

Figure 14-Brake power vs volumetric efficiency

The variation of volumetric efficiency with Brake power for diesel and different blendings of biodiesel oils are shown in figure 14. Volumetric efficiency of biodiesel blends is comparatively higher than the diesel as evident from graph. At full load condition the volumetric efficiency for biodiesel blends and diesel are almost same.

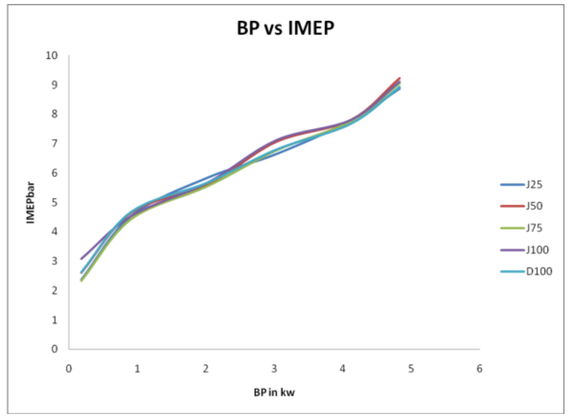

Figure 15-Brake power vs Indicated mean effective pressure

The variation of Indicated mean effective pressure with Brake power for diesel and different blendings of biodiesel oils are shown in figure 15. Brake Indicated mean effective pressure is increasing as the load increases and it is almost same at lower and higher loads as evident from graph.

8. EMISSION CHARACTERISTICS

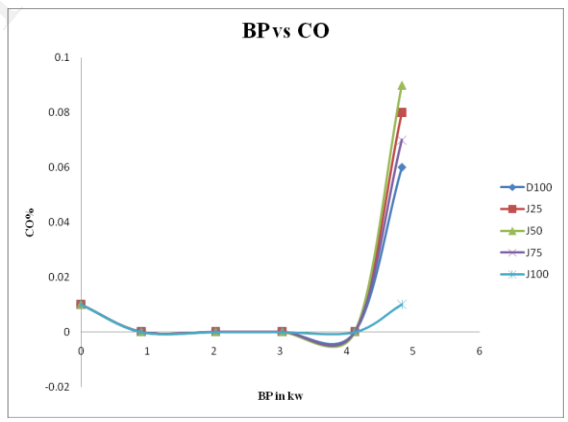

Figure 16-Brake power vs carbonmonoxide

The variation of carbonmonoxide with Brake power for diesel and different biodiesel blends are shown in figure 16. CO emission is same at lower loads for both bio-diesel blends and diesel and at full load CO emission is slightly high for biodiesel blends than diesel, this increasing trend of CO emission is may be due to increase in volumetric fuel consumption and knock with the engine power output.

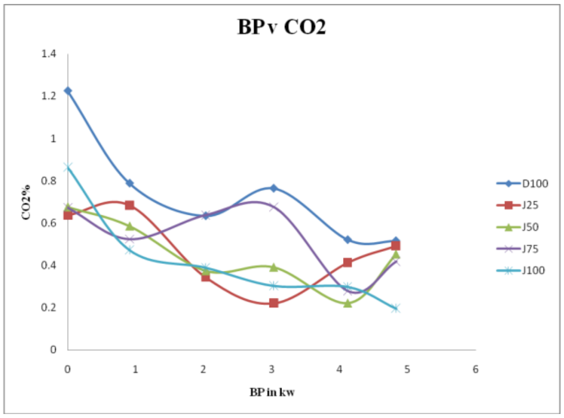

Figure 17-Brake power vs carbondioxide

The variation of carbondioxide with Brake power for diesel and different blendings of biodiesel oils are shown in figure 17. CO_2 emission for biodiesel blends and diesel is decreasing as the load increases and it is observed that, the CO2 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..

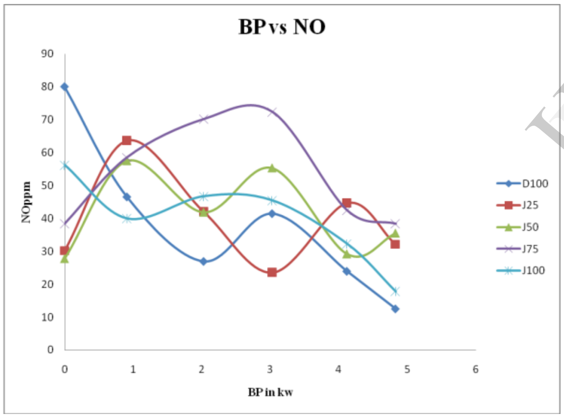

Figure 18-Brake power vs oxides of nitrogen(NO)

The variation of oxides of nitrogen with Brake power for diesel and different blendings of biodiesel oils are shown in figure 18. NO is higher for blends of biodiesel compared to diesel, the increase in NO emissions for blends of biodiesel is due to presence of mono unsaturated and poly unsaturated fatty acids present in the jatropa biodiesel and jatropa biodiesel has considerable higher viscosity which results into longer combustion duration and demonstrates significant energy release during the last phase of burning. From graph at lower load NO emissions for diesel is higher compared to blends of biodiesel this due to late burning of blends of jatropa biodiesel during expansion.

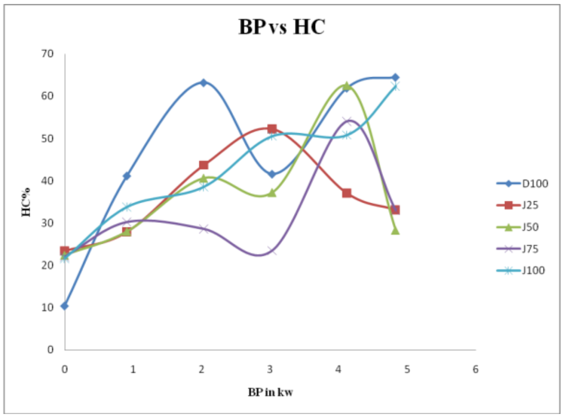

Figure 19-Brake power vs HC

The variation of HC with Brake power for diesel and different blendings of biodiesel oils are shown in figure 19. HC emissions showing increasing trend first and then decreasing trend with power output. The HC emissions of the biodiesel blends are less than that of diesel fuel. The reason for lower HC emissions is attributed to the higher cetane number (52) and inherent presence of oxygen in the molecular structure of the Jatropha biodiesel. HC emission for diesel is less than other bio-diesel blends this may be due to proper combustion of diesel at 0kw which results in low HC emission.

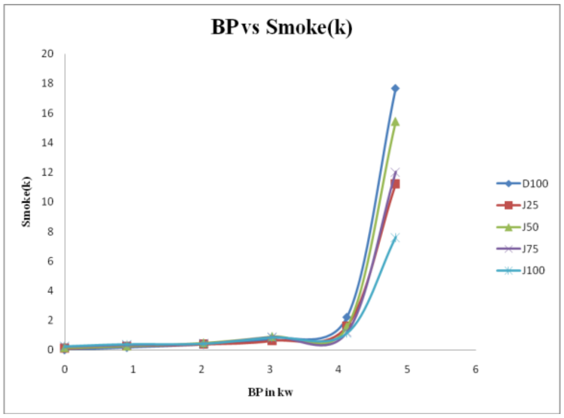

Figure 20-Brake power vs Smoke (K)

The variation of emission of Smoke (K) with Brake power for diesel and different blendings of biodiesel oils are shown in figure 20. Emission of Smoke(K) of bio-diesel blends and diesel is same at lower load but diesel emission is higher at higher load as evident from graph.

9. CONCLUSION

The performance characteristics, brake thermal efficiency, brake specific fuel consumption, Mechanical efficiency, volumetric efficiency air-fuel ratio, Indicated mean effective pressure and emission characteristics, carbon monoxide, carbon-dioxide, oxides of nitrogen(NO), HC and smoke of a single cylinder vertical direct injection Kirloskar engine using Jatropha biodiesel with its blends as fuels were experimentally investigated. The following conclusions are made based on the experimental results.

1. The brake thermal efficiency should be high for a good engine. Jatropha bio-diesel blends has higher brake thermal efficiency than diesel. J50 having brake thermal efficiency higher than other blends.
2. Since a good and efficient engine requires a fuel with low specific fuel consumption. J50 having low specific fuel consumption than other blends.
3. Mechanical efficiency should be high for a good engine. J25 and J50 high mechanical efficiency than other blends.
4. CO emission is slightly higher than diesel. J50 and J75 blends emits 0.02 and 0.01% more than diesel.
5. CO_2 emissions are lower for biodiesel blends than diesel.
6. Smoke emissions are decreasing for biodiesel blends as the load increases. J25 emits low smoke(k) compared to other biodiesel blends.

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