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Analysis of Engine Performance and Exhaust Emission Characteristics of VCR Engine Fuelled with Different Blends of Jatropha Biodiesel

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Abstract
With the concern to global environment issues, researchers are encouraged to find alternate for scarce and rapidly diminishing fossil fuels. From the variety of options, fuels obtained from vegetable oils or animal fats have proven better alternate for petroleum fuels. Having its roots in agriculture, vegetable oils are capable to minimize overall CO addition to the atmosphere. Due to higher viscosity and low volatility compared to petroleum diesel, neat vegetable oils are used in diesel engines; some functional or longevity issues have been highlighted in the literature. In this study, experiments were carried out using fossil diesel and jatropha-diesel blends to evaluate the exhaust emissions and performance characteristics of diesel engine. A single cylinder, four stroke, constant speed, water cooled, variable compression ratio engine was used for the experiments. The measured values were analyzed for various parameters like brake thermal efficiency (BTE), brake power (BP), brake specific fuel consumption (BSFc), brake mean effective pressure (BMEP) and emissions of CO2, CO and Hc. While operating the engine on jatropha-diesel blends, performance and emission parameters were found to be very close to petroleum diesel for lower blend concentrations.

Keywords: *Biodiesel, VCR engine, exhaust emissions*

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INTRODUCTION

The tightening norms on air pollution caused by the wide spread use of petroleum fuels, fading fossil fuels reserves and cultivation based market of India are the motivating forces to advance biodiesel as an alternate to petroleum diesel. Fuels made from renewable natural non-edible resources for use in conventional diesel engines are known as biodiesel.

Biodiesel is eco-friendly fuel similar to petroleum diesel in combustion properties. Biodiesel obtained from vegetable oil is being used in USA and Europe to reduce air pollution and dependence on fossil fuel.

Jatropha (Ratan Jyot) Better Alternate for Diesel Fuel

India, being larger importer of vegetable oils, concerning country's economical aspect, edible oils should be avoided for production of biodiesel. Harvesting of plants like Jatropha curcas, pongamia, neem mahua, castor, linseed etc. can be promoted; and thereby India can become leading producer of such non-edible oils to supplement conventional diesel fuel. Many of these oils produced are yet to be utilized properly. Among these plants, India is keen on jatropha curcas, which can be grown in barren and wastelands. Jatropha seeds contain oil around 30–40%. India is having wasteland around 80–100 million hectares, which can be utilized for Jatropha plantation.

Besides drastic reduction on paying huge amount on importing crude petroleum, promoting use of biodiesel in our country will lead to many benefits like green cover to wasteland, support to agriculture and rural economy and mainly drastic reduction in air pollution. The significant weak points of vegetable oils, as diesel fuels are related to its higher viscosity than the normal diesel fuel.

Use of pure vegetable oils in various short run experiments showed promising results. But the problems may appear if the engine is being run for longer periods. To overcome very high viscosity problem of neat vegetable oils, blending of bio diesel with petroleum diesel is done.

The benefits of bio-diesel over diesel fuel are; minimum sulphur and aromatic content, higher flash point, lubricity, cetane number, biodegradability and non-toxicity. Higher viscosity, higher pour point, lower calorific value and low volatility are the major disadvantages of biodiesel. Also, their oxidation stability is lower; they are hydroscopic and as solvents may cause corrosion of components attacking some plastic materials used for seals, hoses, paints and coatings. Taking in to account all these factors, it is practically accepted that without any modification, blends of petroleum diesel fuel with biodiesels can be used in existing diesel engines. The properties of petroleum diesel and jatropha are given in Table 1.

Variable Compression Ratio Engine

Adopting pertinent VCR technology is a pivotal factor to justify the cost of VCR implementation in future vehicles. All pertinent VCR technologies have to be put side by side to evaluate their respective positive and negative impacts on engine components and operations. The VCR engine is having benefits like higher power density, reduced number of cylinders, sophisticated injection technologies, and complex after treatment. To become highly acceptable in market, the VCR techniques must provide robustness, low NVH level, durability and interfacing with current vehicle design. The compression ratio is a decisive parameter for performance of any engine. The VCR engine is capable of varying compression ratio, adjustable to any fuel and hence provides enormous fuel flexibilities and enhanced performance.

In CI engine, by increasing compression ratio, engine break power can be increased which leads to better mechanical efficiency. Corresponding reduction in clearance volume of cylinders provides increased volumetric efficiency. Also, it results in higher specific fuel consumption (SFC), which affects overall performance of engine. Hence it is important to conduct test to find out over all performance of an engine for different compression ratios. Figure 1 shows VCR engine test setup developed by Apex Innovations Pvt. Ltd., Sangli. It is the bi-fuel mode engine which can be made to run either on petrol or diesel with some changes. Its specifically designed tilting cylinder block facilitates the operator to vary the compression ratio, in either mode, during operation without shutting off engine or without any alteration to geometry of combustion chamber.

Fig. 1: *VCR Engine.*

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The different engine parameters such as brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, brake mean effective pressure, indicated mean effective pressure can be measured at various compression ratio to evaluate engine performance. Being equipped with computerized setup and trial it also provides heat balance sheet for different compression ratios. This set up also facilitates online performance evaluation by virtue of "Labview" based engine performance analysis software package "Engine soft".

Objectives

- To find out most suitable Jatropha biodiesel-diesel blend for maximum engine performance and to minimize the No_x emission from engine.
- To optimize the engine parameter for maximum performance of engine to minimize the No_x emission.

LITERATURE REVIEW

- Raheman *et al.* undertook a study at IIT Kharakpur, India on behaviour of diesel engine when operated with biodiesel and its blend (B60, B80, B100) at varying loads (L), compression ratio (CR) and ignition timing (IT) [1]. Their experimental results indicated that the brake specific fuel consumption (BSFC) and exhaust gas temperature (EGT) increased where as brake thermal efficiency (BTE) decreased with increase in the proportion of biodiesel in the blend at all compression ratios (18:1–20:1) and injection timings (35–45^0 before TDC).
- Forson *et al.* conducted tests on a single cylinder direct-injection engine operating on diesel fuel, jatropha oil and blends of diesel and jatropha oil in proportions of 97.4, 2.6, 80, 20 and 50%/50% by volume [2]. The tests showed that jatropha oil could be conveniently used as a diesel substitute in a diesel engine. The tests further showed increases in brake thermal efficiency, brake power and reduction of specific fuel consumption for jatropha oil and its blends with diesel generally; but the most significant conclusion from the study is that 97.4%/2.6% jatropha fuel blend produced maximum values of the brake power and brake thermal efficiency as well as minimum values of the specific fuel consumption.
- Venkateswara *et al*. carried out experimental investigations to examine properties, performance and emissions of different blends (B10, B20, B40) of pongamia methyl esters (PME), jatropha methyl esters (JME) and neem methyl esters (NME) in comparison to diesel [3]. Results indicated that B20 have closer performance to diesel and B100 had lower brake thermal efficiency mainly due to its viscosity compared to diesel. However its diesel blends showed reasonable efficiencies, lower smoke, and CO and HC emissions.
- Baitiang *et al*. studied the effect of neat biodiesel (B100) and pure jatropha oil on engine performance, black smoke density, fuel consumption and durability of engines [4]. From the performance test, when comparing BDF and jatropha oil with diesel, the engine performances were slightly different with a small increase of fuel consumption. It is noticeable that black smoke measured from the engines using both biodiesel and jatropha oil can be hugely reduced. It was found that the highest amount of jatropha oil that could be used was a blend between jatropha oil and diesel fuel of 60:40 by volume for practical running time before failure.
- Agarwal *et al.* conducted experiments using various blends of jatropha oil with mineral diesel to study the effect of reduced blend viscosity on emissions and performance of diesel engine [5]. A single cylinder, four stroke, constant speed, water cooled, direct injection diesel engine typically used in agricultural sector was used for the experiments. The acquired data were analyzed for various parameters such as thermal efficiency, brake specific fuel consumption (BSFC) smoke, CO, CO and HC emissions.

While operating the engine on jatropha oil blends, performance and emission parameters were found to be very close to mineral diesel for lower blend concentrations. However, for higher blend concentrations, performance and emissions were observed to be marginally inferior.

Agarwal observed significant improvement in engine performance and emission characteristics for the biodiesel fuelled engine compared to diesel fuelled engine. Improved thermal efficiency of the engine, reduced brake specific fuel consumption and a considerable reduction in the exhaust smoke opacity was observed.

Jatropha as a Fuel for Diesel Engine
Availability of Jatropha
Our country is having rich and massive sources of both edible and non-edible oil seeds. The cost involved in producing methyl or ethyl esters from non-edible oils is much higher than that of diesel fuels. This is because of the relatively higher costs of vegetable oils (about four folds to the cost of diesel in India). This enforces us to find out substitute feed stocks to manufacture biodiesels. Compared to higher priced edible oils, non-edible oils from different sources such as jatropha, honge and neem are easily available in many areas of country at lesser cost.

Among these, jatropha curcas shrubs are widely found in majority of the tropical and sub-tropical areas around the world. The jatropha curcas plant is a drought-resistant, permanent plant living up to 50 years and has the capability to grow on marginal soils. It needs very less irrigation and grows in almost all types of soils. It gives seeds around 0.8 kg per year. It contains oil about 30–40% by weight and the kernel itself ranges from 45 to 60%. Oil from fresh jatropha is a slow drying, odourless and colourless, and tends to become yellowish with age.

Properties of Jatropha
ASTM and IP methods are used to determine the properties of the jatropha oil. The relative chemical and physical properties of the jatropha oil and the diesel fuel are shown in Table 1.

PREPARATION OF JATROPHA BLENDS
In this work, different combinations of blending of jatropha and petroleum diesel have been used. The different blends, J0, J5, J10 and J15 were used. The numerical digits following digit "J" indicates the percentage by volume of jatropha oil in petroleum diesel for particular blend. With help of standard formula, different properties can be calculated for each blend. These calculated properties along with properties of diesel and jatropha are given in Table 2.

Table 1: *Properties of Mineral Diesel Fuel and Jatropha Oil.*

Property	Mineral Diesel	Jatropha Oil
Density (kg/m3)	866.9	917.5
API gravity	31.7	22.7
Cloud point (^{0}C)	3±1	9±1
Pour point (^{0}C)	15	–3
Flash point (^{0}C)	86	99
Fire point (^{0}C)	103±3	274±3
Conradson carbon residue %, w/w)	0.1±0.0	0.8±0.1
Ash content (%, w/w)	0.01±0.0	0.03±0.0
Calorific value (MJ/kg)	45.90	42.048
Carbon (%, w/w)	80.33	76.11
Hydrogen (%, w/w)	12.36	10.52
Nitrogen (%, w/w)	1.76	0
Oxygen (%, w/w)	1.19	11.06

Table 2: *Properties of Diesel and Jatropha Blends.*

Fuel Property	Diesel	Jatropha	J5	JI0	JI5
Density (kg/m3)	866.9	917.5	869.4	871.4	873.4
Calorific value (MJ/kg)	45.90	42.048	45.070	44.807	44.544
Flashpoint (°C)	86	99	88	88.5	89
Kinematic viscosity (cSt)	5.7	36.9	6.12	6.9	7.2
Pour point (°C)	15	–3	15	13	13

Experimental Set Up
This section includes schematic diagram of the engine setup on which the experimentation has been done (Figure 2).

Experimental Procedure
The current study is conducted to investigate the performance and emission characteristics of diesel and jatropha blends, in a stationary single cylinder, four stroke, bi-fuel VCR engine (computerized) running on diesel mode. With some changes, either mode can be selected to make engine run on diesel or petrol mode.

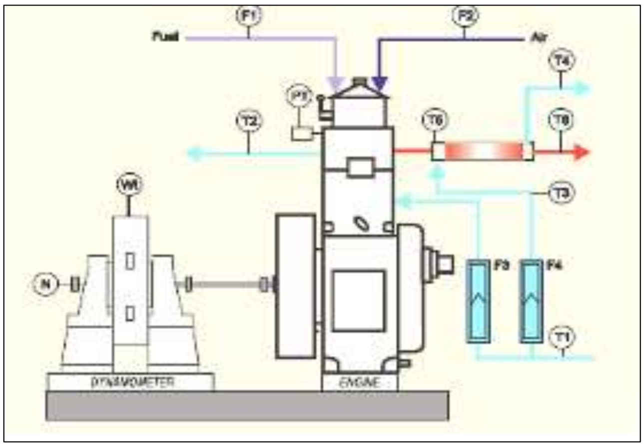

Fig. 2: *Schematic Arrangement of Experimental Set Up.*

Its specifically designed tilting cylinder block facilitates the operator to vary the compression ratio, in either mode, during operation without shutting off engine or without any alteration to geometry of combustion chamber. The compression ratio is alterable when the engine is operating. To measure the ignition timings using stroboscopic light method precisely, the flywheel is calibrated in degrees. A screw adjustment is provided so that the ignition timing, whose setting is indicated by a calibrated pointer, can be adjusted while the engine is running. To apply load on engine, eddy current dynamometer is used, whose power absorption unit consist of a well balanced star wheel rotor mounted on precision bearings, which rotates in the stator.

Fuel flow measurement and fuel consumption unit consists of fine beam infra red sensors, conditioning card, and a calibrated pipette of 50 cc. The reaction torque is sensed by using various weighing mechanisms such as spring balance or load cell with digital indicator etc. The main shaft of the dynamometer is having arrangement for fitting flange coupling at both ends. The control of extension unit is mounted on a separate panel. The digital signals are directly interfaced to computer interface card. To measure air flow, computerized measuring set-up consisting an air tank and orifice meter are provided. Also, computerized water flow measurement set-up is there. The exhaust gas calorimeter system is also having interface with computer measuring water carried away by exhaust gases. Thermocouples are fitted to measure all the temperatures required for heat balance sheet. A computer is equipped with a software “Engine soft”, to analyze the data.

The exhaust gas analyzer is used to measure the concentration of pollutants CO, CO_2 and HC present in the exhaust gas of a diesel engine. The engine was made to run on diesel first and then on blends of jatropha. The various fuel blends and petroleum diesel were subjected to performance and emission tests on the engine. The data of performance were then analyzed to evaluate parameters like thermal efficiency, brake power, brake-specific fuel consumption and brake mean effective pressure.

The petroleum diesel was made to undergo test at compression ratio 14 and at varying loads. At constant compression ratio of 14 and varying the load in the range of 3, 6, 9 and 12 kg, all the performance parameters were automatically recorded by the computer which is interfaced with the engine.

For on line performance evaluation, Labview based engine performance analysis software package “Engine soft” is provided. The compression ratio was then changed to 16, 18, 20 and the performance parameters were recorded for each load considered. The same procedure was repeated for the various blends considered for the tests, (J5, J10, J15), and the performance parameters were recorded.

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RESULTS AND DISCUSSION

For each blend of J0, J5, J10 and J15 at four different loads (3, 6, 9 and 12 kg) and at constant speed, the tests were performed. Four different values of compression ratios (14, 16, 18 and 20) were considered for the tests. The following results were obtained from the tests.

Effect of Various Blends on Engine Performance

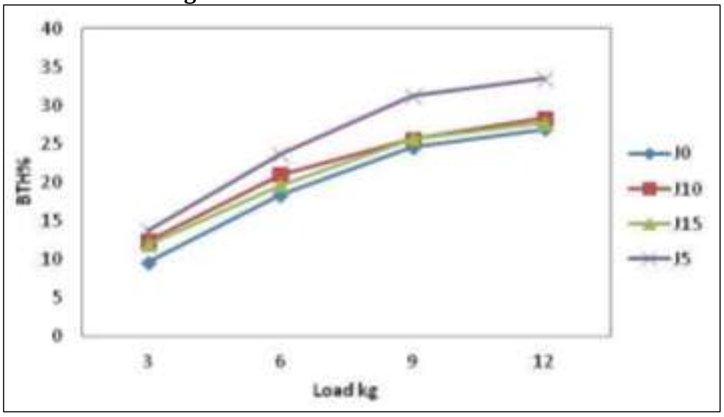

Fig. 3: *Variation of Brake Thermal Efficiency % with Load at CR of 14.*

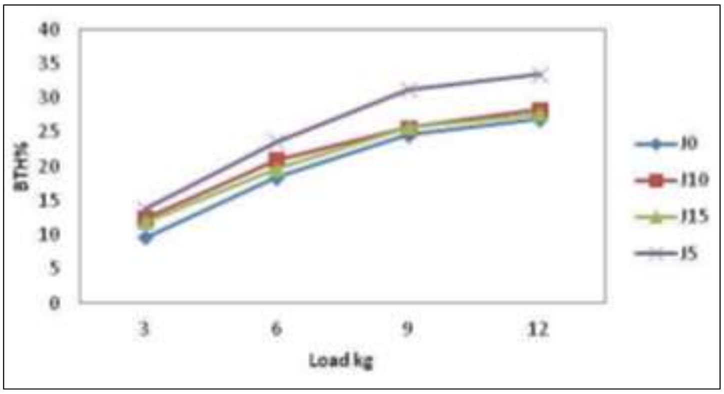

Fig. 4: *Variation of Brake Thermal Efficiency % with Load at CR of 16.*

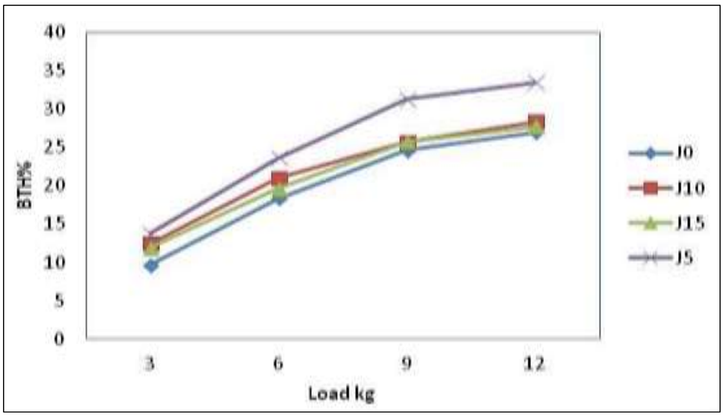

Fig. 5: *Variation of Brake Thermal Efficiency % with Load at CR of 18.*

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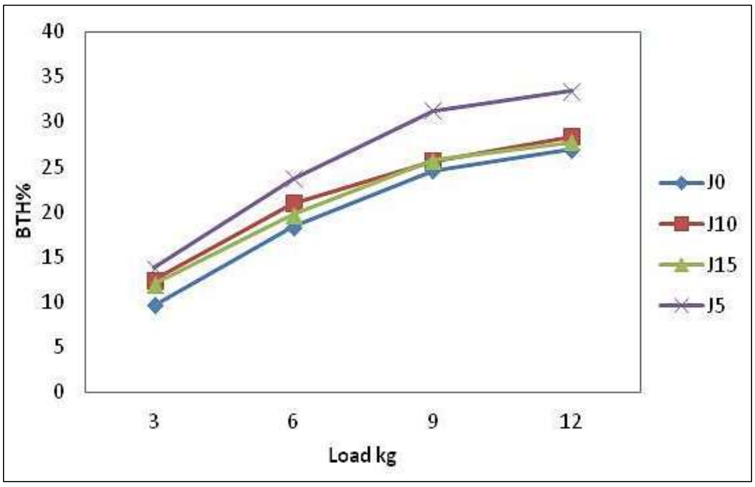

Fig. 6: *Variation of Brake Thermal Efficiency % with Load at CR of 20.*

As shown in Figures 3–6, the brake thermal efficiency increases with higher concentration of biodiesel in the blends. However the brake thermal efficiency of J5 is higher than pure diesel and all other blends. This may be due to increased amount of oxygen in J5, which have resulted in improved combustion.

As the ignition delay tends to reduce with increase in compression ratio, since higher compression ratio increases the temperature, improvement in brake thermal efficiency can be noticed from the above figures.

At higher temperature, combustion characteristics show improvement, may be owing to the fact that biodiesel blends have lower volatility compared to diesel. The J5 was found to be the best compared to diesel and all other blends at all compression ratios. It can be seen from Figures 3–6 that the brake thermal efficiency improved with the increase in the load. This is due to increased temperatures inside the cylinder as load increases, more fuel burning and less amount of heat loss. The J05 was found to be the best compared to diesel and all other blends at all loads.

As indicated in Figures 7–10, for lower concentrations of biodiesels in the blends (J5, J10, and J15) the brake power is nearly close to that of petroleum diesel. The J5 blend was found to be the best compared to petroleum diesel and all other blends. This may be due to extra amount of oxygen in J5, which might have resulted in improved combustion.

Figures 7–10 show that the brake power improved with the increasing compression ratio. Increase in the compression ratio increases the temperature in the cylinder and reduces the ignition delay. The biodiesel blends have lower volatility compared to diesel, so, at higher temperature, their combustion characteristics improve. The J5 was found to be the best compared to diesel and all other blends at all compression ratios. The brake power improved with the increase in the load.

This is due to increased temperatures inside the cylinder as load increases; there is more fuel burning, and less amount of heat loss. The J5 was found to be the best compared to diesel and all other blends at all loads, as seen from the figure. Figures 4.9–4.12 show that for lower blends (J5, J10 and J15) the brake specific fuel consumption is lower than mineral diesel. The oxygen present in the biodiesel might have helped in improved combustion of the blend. The J05 blend was found to be the best compared to diesel and all other blends. This may be due to extra amount of oxygen in J05 blend, which might have resulted in improved combustion.

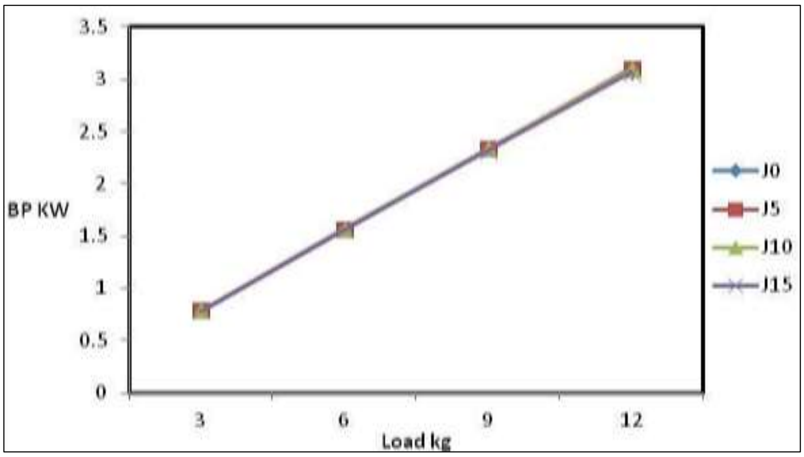

Fig. 7: *Variation of Brake Power with Load at CR of 14.*

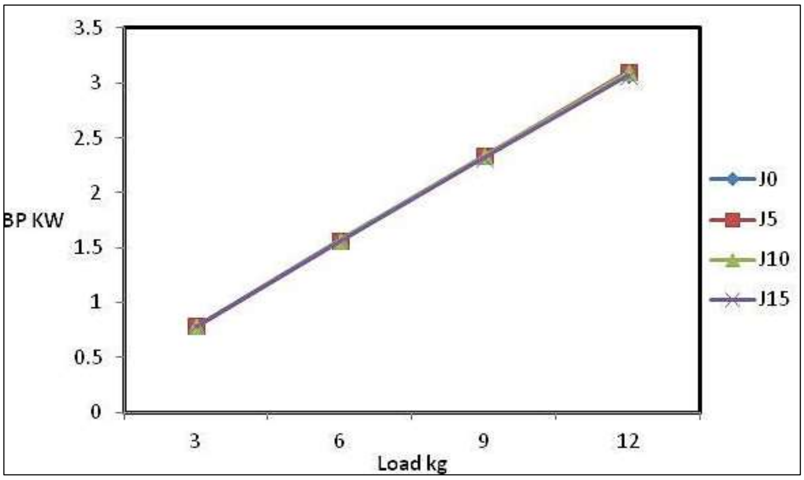

Fig. 8: *Variation of Brake Power with Load at CR of 16.*

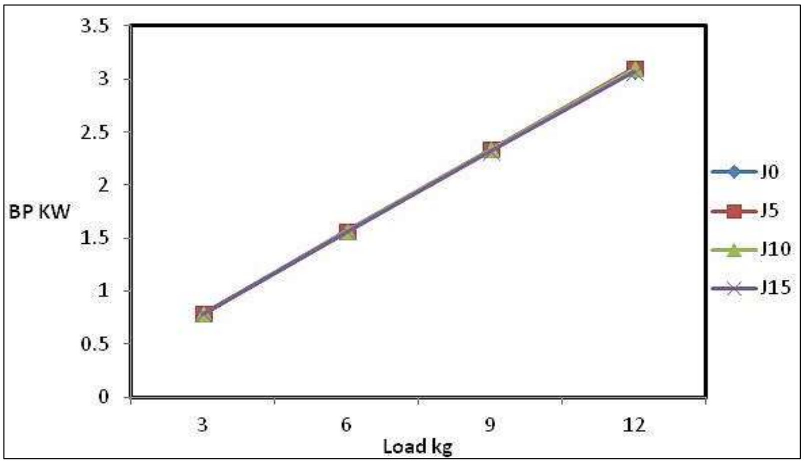

Fig. 9: *Variation of Brake Power with Load at CR of 18.*

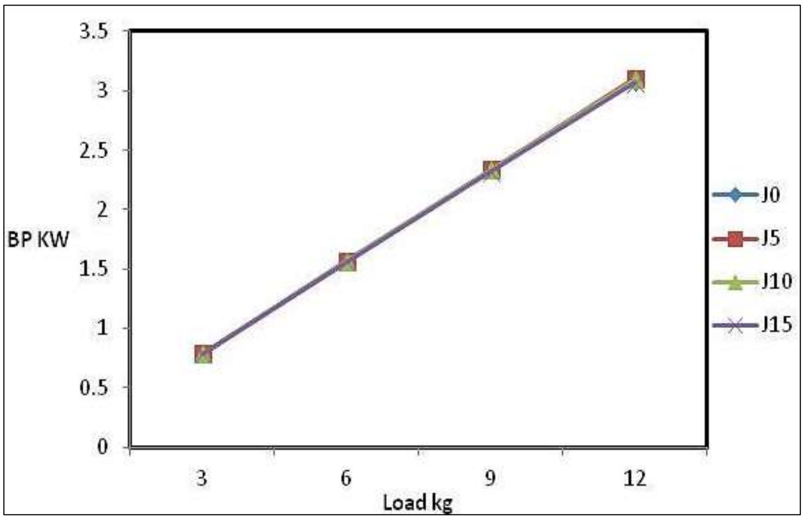

Fig. 10: *Variation of Brake Power with Load at CR of 20.*

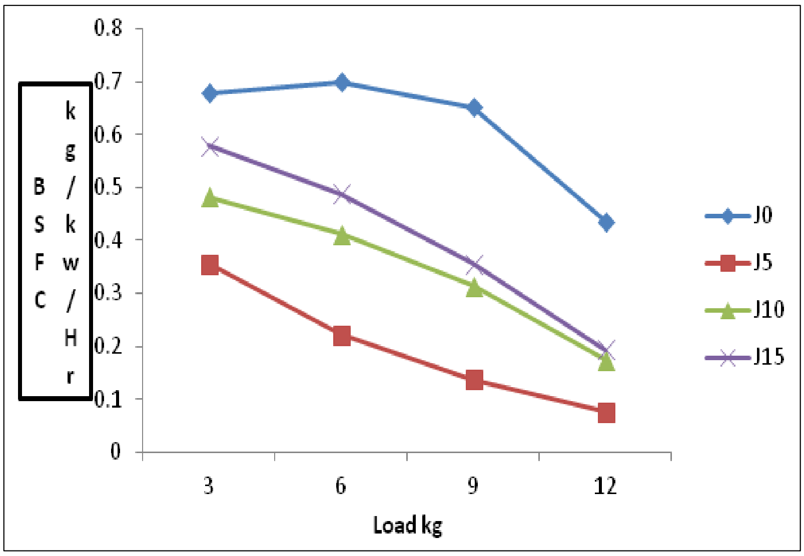

Fig. 11: *Variation of Brake Specific Fuel Consumption with Load at CR of 14.*

Figures 11–14 show that the brake specific fuel consumption decreases with increasing compression ratio. The results show that increasing the compression ratio in blends has more benefits than with pure diesel. Due to their low volatility and high viscosity, biodiesels might be performing relatively better at higher compression ratio. The J5 blend was found to be better compared to diesel and all other blends at all compression ratios. Figures 11–14 show that the brake specific fuel consumption was observed to decrease with increase in load for all blends and pure diesel at any combination of compression ratio. The reason for this is that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to less portion of the heat losses at higher loads. The J5 blend was found to be the best compared to diesel and all other blends at all load.

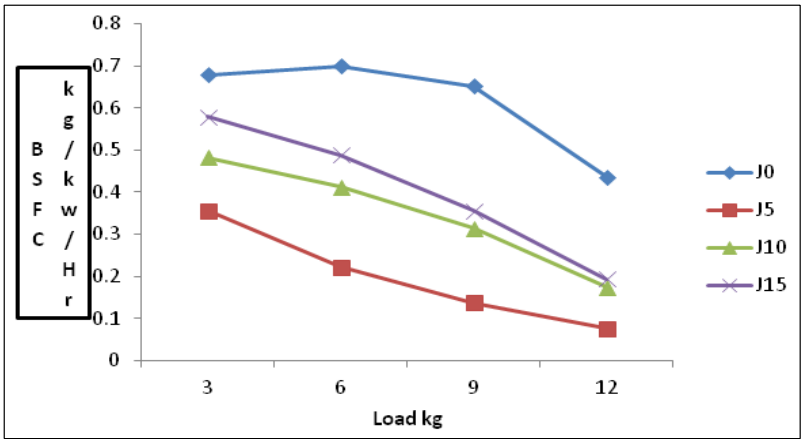

Fig. 12: *Variation of Brake Specific Fuel Consumption with Load at CR of 16.*

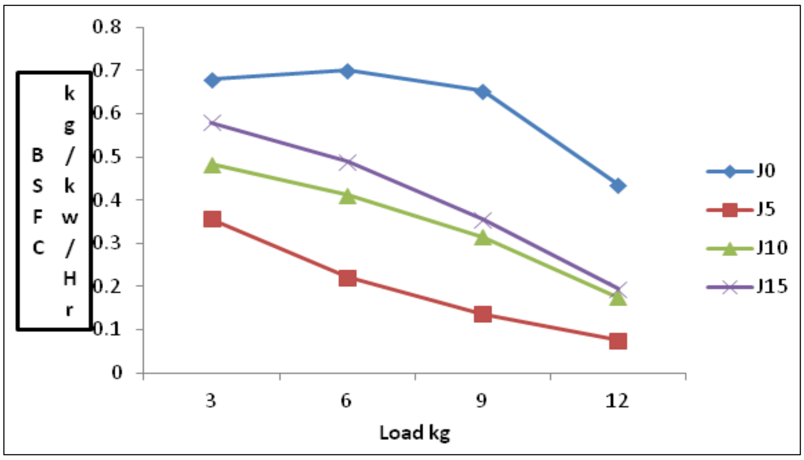

Fig. 13: *Variation of Brake Specific Fuel Consumption with Load at CR of 18.*

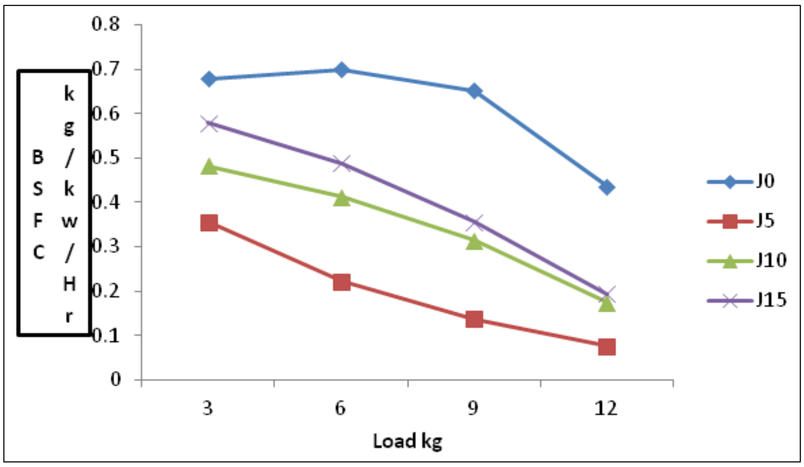

Fig. 14: *Variation of Brake Specific Fuel Consumption with Load at CR of 20.*

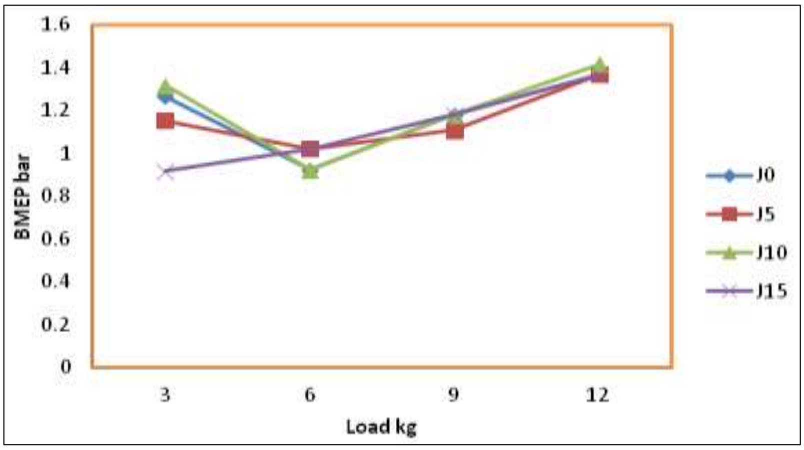

Fig. 15: *Variation of Brake Mean Effective Pressure with Load at CR of 14.*

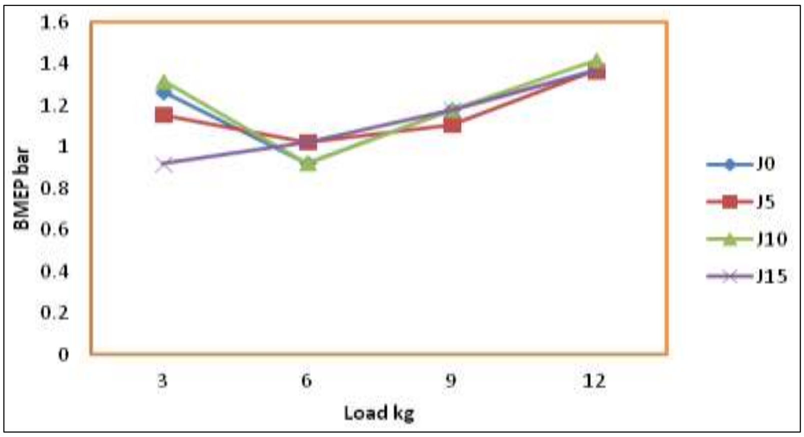

Fig. 16: *Variation of Brake Mean Effective Pressure with Load at CR of 16.*

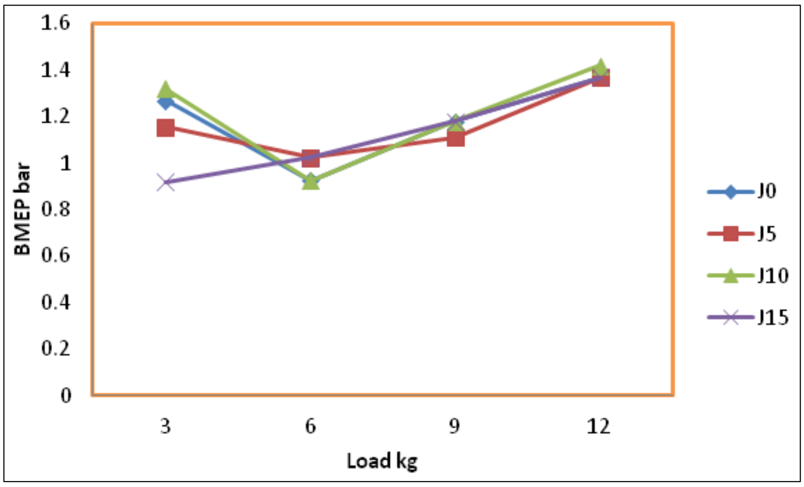

Fig. 17: *Variation of Brake Mean Effective Pressure with Load at CR of 18.*

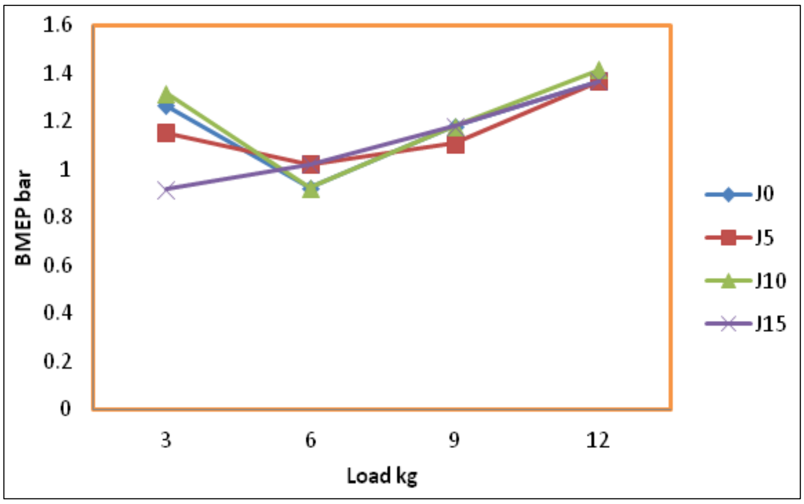

Fig. 18: *Variation of Brake Mean Effective Pressure with Load at CR of 20.*

Figures 15–18 show that the brake mean effective pressure is a function of blend, load and compression ratio. The brake mean effective pressure increases with the increase of concentration of biodiesel in the blend. The best values are achieved for J5 blend. The brake mean effective pressure also increases with increasing values of load and compression ratio. The best values are achieved for J5 blend at all loads and compression ratios.

Effect of Various Blends on Exhaust Emission

The effect of neat mineral diesel and various blends such as J5, J10 and J15 on engine exhaust emission is shown in Figures 19–21.

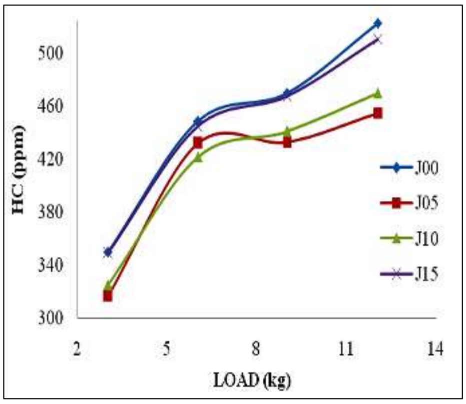

Fig. 19: *Variation of HC Emission with Load at CR of 18.*

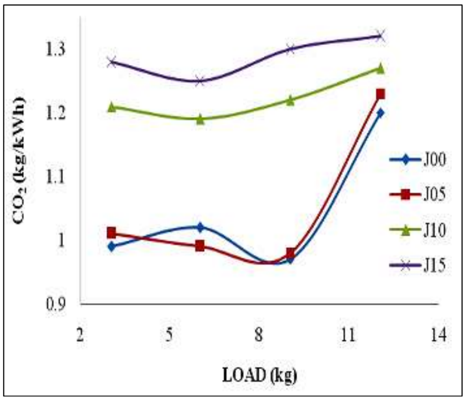

Fig. 20: *Variation of CO_2 Emission with Load at CR of 18.*

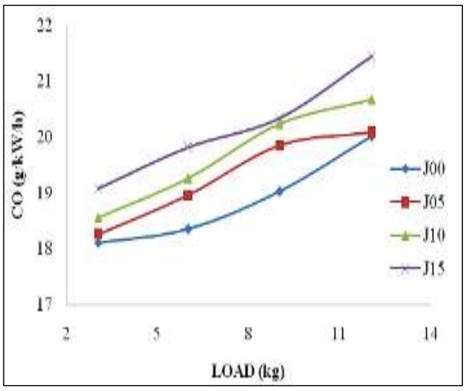

Fig. 21: *Variation of CO Emission with Load at CR of 18.*

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Figures 19–21 show that HC emissions of all biodiesel blends were found to be very close to diesel at compression-18 and at various loads. The emissions were also observed to increase with the load. CO emissions of all biodiesel blends were observed to be higher than diesel fuel at compression ratio 18. The emissions were also observed to increase with the load. CO emissions of all biodiesel blends were observed to be higher than diesel fuel at compression ratio 18. The emissions were also observed to increase with the load.

CONCLUSION

The main objective of the present investigation was to evaluate the suitable jatropha-diesel blend in terms of engine performance and emissions. The performance and emissions tests were conducted with diesel, and blends of jatropha oil at different loads and at constant speed (1500 rpm). From the experimental results obtained, jatropha oil blends are found to be a promising alternative fuel for compression ignition engines.

- The performance parameters such as brake thermal efficiency, brake power, brake mean effective pressure for all jatropha blends was found to be higher as compared to diesel.
- The brake thermal efficiency increased by 14.67%, brake power increased by 1.19% and brake mean effective pressure increased by 11.54% as compared to diesel at the compression ratio 18 and at load 12 kg for the blend J5. For the blend J10, the percentage increase in brake thermal efficiency, brake power and brake mean effective pressure is 8.83, 1.17, 9.67 respectively as compared to diesel. For the blend J15, the percentage increase in brake thermal efficiency, brake power and brake mean effective pressure is 9.59, 0.88, 8.92 respectively as compared to diesel.
- The brake specific fuel consumption decreases up to 15.62% for various blends of jatropha.
- CO_2 emissions increase in the range of 2.05 to 3.93% in comparison with pure diesel.
- CO Emissions increase in the range of 0.34 to 3.77% in comparison with pure diesel.
- J5 blend was found to be the suitable blend as compared to the blends J10 and J15.

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Comment [AG1]: Only 5 ref have been cited

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