Abstract

The major factors responsible for the development of alternate energy resources are environmental regulations and the gradual depletion of fossil fuel reserves. Biofuel is one such example of alternative fuels which is both renewable and environment friendly and thus it can easily be used in diesel engines with minimal modifications. In today's modern paced agriculture based economy biodiesel can be seen as the sustainable transportation fuel, as this alternative fuel is a solution to multiple problems such as gradually increasing environmental concerns and immense decline in the number of petroleum reserves. In our attempt of a sustainable future biodiesel can be taken as a long term solution for such problems.

This research focuses on production of biodiesel from Jatropha oil and experimentally investigates its performance and emission characteristics in a 4 stroke diesel engine using different blending mixtures with diesel. For this purpose biodiesel is produced from Jatropha oil through transesterification process. The blending mixtures of Jatropha biodiesel and diesel are prepared on volume basis through magnetic stirring. These blends are named as JB20D80, JB30D70, JB40D60 and JB50D50. It is observed that JB20D80 reduces the BSFC by 17.89% and increases the BTE by 3.18% in comparison to JB50D50 at maximum loading and approaches the results of diesel.

The properties of the biodiesel produced are compared with the properties of conventional diesel. Along with this the performance and emission characteristics of different blending mixtures obtained is evaluated at constant compression ratio. Experiment reveals that among all the tested biodiesel-diesel blends at various engine loading conditions, optimum results are obtained for JB20D80. All the characteristics of the engine performances have been displayed graphically and their comparison with diesel is also shown.

Introduction

Today India has emerged as one of the prominent players in the global energy market, with third place in the world for primary energy consumption, according to the reports of India Energy Outlook 2021 published by the International Energy Agency (IEA). As the energy demands are continuously increasing, government of India is turning their heads towards alternate energy sources which can fulfill the energy demands of the country or can somewhat lessen the burden of conventional energy resources.

To meet the energy demands of the country, India is adopting different strategies which include increasing the domestic production of gas & oil, boosting the biofuel economy, exploring new sources of energy, shifting to gas based economy and improving the efficiency and productivity of the refinery processes through technology up gradation.

Among all the non-conventional energy resources, biofuel has emerged as one of the major alternate energy sources which promise a greener and more sustainable future. Vegetable oils & animal fats are being utilized for the production of biodiesel. Oil seeds like Neem, Jatropha, Pongamia, Rubber seed, Cotton seed, Peanut, Mahua, and Rapeseed etc. have been used in India for biodiesel production due to their abundant availability. In the present study we will focus on biodiesel production from crude Jatropha oil obtained from the seeds of Jatropha plant. Jatropha comes under the category of second generation biofuel feedstock and thus, it ends the debate of food vs. fuel which was a major problem posed by the feedstocks of first generation biofuels. Jatropha is a small shrub that can grow almost anywhere even in sandy and stony soil. It is a flowering plant which is a member of the spurge family Euphorbiaceae. In India it is known by a variety of names such as Physic nut, Purging nut, Ratanjyot, Jangali Erandi, Kattamanakku, Pepalam, Kadaharalu, Jepal and Kanana Randa. The genus Jatropha is a combination of two Greek words “Jatros” which means “doctor” and “Trophy” which means “food”. Its centre of origin is believed to be Mexico & Central America. It also spans South America, South-East Asia, Africa and India. In Asia Indonesia is the largest producer of Jatropha.

The current research work is based on biodiesel production from crude Jatropha oil and investigates its performance and emission characteristics in a diesel engine using different blending mixtures of biodiesel with diesel experimentally at different loading conditions.

This research work mainly focuses on: i) Production of biodiesel from crude Jatropha oil. ii) Comparison of properties of biodiesel produced from Jatropha oil with conventional diesel. iii) Evaluation of performance and emission characteristics for different blending mixtures (B0, B20, B30, B40 & B50) with diesel in a diesel engine at constant compression ratio. iv) Graphical representation of different performance parameters and emission characteristics at various engine loadings for prepared blends & their comparison with conventional diesel.

Literature Review

Researchers have done a tremendous amount of work in searching the possibility of Jatropha as a biofuel feedstock. Rajak et al. (2020) evaluated the performance and emission for JB20, JB40 and JB60 in a single cylinder diesel engine operating at 1500 rpm with CR 18.5 and at various loads (25, 50, 75 and 100%). It was found that the BTE values for JB20 are slightly lower (0.5-2.06%) and the BSFC values for JB20 are more (3.6-2.2%) compared to diesel fuel. At all engine loads, the NOx emission was lower for Jatropha Curcas blends and also their smoke emission was found to be lower. Dharma et al. (2017) evaluated the performance and exhaust emissions of a single cylinder DI diesel engine fuelled with biodiesel-diesel mixes made from Jatropha Curcas and Celiba Pentandra. The blends are as following: B10, B20, B30, B40 and B50. The engine torque, braking power and BTE values of B10 blend are 34.07 nm, 3.5 KW and 34.1% respectively which was higher when compared to other fuel mixes. For all the J50C50 biodiesel-diesel blends studied in this research, the B10 blend had the lowest CO, NOx and SO values at an engine speed of 1900 rpm. Kavitha et al. (2019) mentioned that three mixes are available: 90% diesel, 7.5% JB, and 2.5% ethanol (D90J7.5E1.25), 95% diesel, 3.75% JB, and 1.25% ethanol (D95J3.75E1.25), and 98% diesel, 1.5% JB, and 0.5% ethanol (D95J3.75E1.25) (D98J1.5E0.5). The brake thermal efficiency values for D90J7.5E2.5 and D95J3.75E1.25 increase by 2.13 and 3.24% respectively at 0.937 KW, when it was compared to diesel. The BSFC value of the blend D90J7.5E2.5 when compared to diesel fell by 2.68% at 0.937 KW. When compared to diesel, D90J7.5E2.5 shows a moderate reduction in NOx emissions, whilst D95J3.75E1.25 shows a slight rise in NOx emissions. Increasing biodiesel mix lowered HC and NOx emissions while reducing biodiesel blend reduced CO emissions. Xu et al. (2017) examined the influence of fuel supply parameters on performance and emission characteristics of a 20% mix of Jatropha Curcas biodiesel (J20) under light load operation of a diesel engine. Rashed et al. (2016) showed that in a diesel engine the performance and emissions of Moringa biodiesel

(20%) were examined and compared to palm, Jatropha Curcas and diesel fuel. When compared to diesel the average value of BP for biodiesel-diesel blends was slightly lower by (6.92-8.75) % than diesel, whereas BSFC values were higher by (5.42-8.39) %. Biodiesel blends significantly decreased CO (22.93-32.65) and HC (11.84-30.26%) emissions, but somewhat increased NO (6.91-18.56%) emissions when compared to diesel fuel. Sahoo et al. (2009) showed that biodiesel (B20, B50 and B100) were compared to diesel in terms of performance and emissions. For a full load, the use of JB20 and JB50 showed 0.09-2.64% and 0.05-3.8% improvement in power respectively. The change in BSEC values for JB20, JB50, and JB100 blends were 2.86, 6.0, and 12.37% respectively at rated speed respectively. The smoke emissions for JB20, JB50 and JB100 blends at full load and rated speed reduced by 28.57%, 40.9% and 64.28% respectively. Ong et al. (2014) showed that JB10, JB20, JB30 and JB50 engine performance and emissions were tested in a diesel engine at full load. The BSFC value for JB10 was 261 g/KWh and 290 g/KWh at 1900 rpm which was reported the lowest while the highest BSFC was recorded as 401 g/KWh for JB50 at 2400 rpm. In comparison to other tested biodiesels the BTE values for JCB were higher. JB10 had the lowest NOx of 86.10 ppm at 1900 rpm and the highest NOx of 120.36 ppm at 2400 rpm. They reported a decreased HC emission for JB10 compared to diesel. Chauhan et al. (2010) showed that preheated Jatropha Curcas oil's performance and emissions in a medium capacity diesel engine were evaluated. Preheated Jatropha Curcas oil can be used a suitable diesel replacement in a diesel engine. Considering the BTE, BSEC, and gaseous emissions 80 degree Celsius was determined to be the best fuel input temperature. The BTE values of warmed Jatropha Curcas oil were greater than that of unheated Jatropha Curcas oil. Jatropha oil has a greater BSEC than diesel. It was observed that the CO emissions for unheated Jatropha Curcas oil were more than diesel fuel or warmed Jatropha Curcas oil. HC emissions are lower with oil at 100 degree Celsius than with diesel. Elango and Senthilkumar (2011) reported the performance and emission characteristics of a diesel engine running on various Jatropha Curcas oil/diesel mixtures (10-50%). It was found that the BSFC of B20 is somewhat greater than diesel, although other mixes are closer to diesel. For the same power output, B20 obtained a maximum BTE of 29.4% while diesel reached 30.9%. The exhaust gas temperature were greater because the engine was air-cooled, which increased NOx emissions. Blends of up to 20% lowered CO2 emissions significantly while just slightly lowering BTE. Agarwal and Agarwal (2007) showed the effect of raising the fuel temperature to reduce the viscosity of Jatropha Curcas oil on the engine's combustion and emission characteristics. When comparing diesel with heated Jatropha Curcas oil, the BSFC and EGT for unheated Jatropha oil were shown to be greater. Unheated Jatropha Curcas oil has a lower BTE than heated Jatropha Curcas oil and diesel. When the quantity of Jatropha Curcas oil in the blends increased it was observed that the emission characteristics increased in comparison to diesel. For warmed Jatropha Curcas oil CO2, CO, HC, emission and smoke opacity were found to be comparable to diesel. Forson et al. (2004) reported in a single cylinder DI diesel engine, the performance of Jatropha Curcas oil and diesel mixtures. Diesel, Jatropha Curcas oil and diesel/Jatropha Curcas oil blends of 97.4%/2.6%, 80/20% and 50/50 by volume were used in the tests. The breaking power, thermal efficiency and specific fuel consumption were attained using a 97.4% diesel/ 2.6% Jatropha blend. CO readings are lower at higher loads (higher than 4 Nm) for fuels with less than 2.6% oil by volume. Senthil Kumar et al. (2003) presented the experimental results of a single cylinder DI diesel running at 1500 rpm utilizing plain Jatropha Curcas oil and its esters (100% JB) as fuel. When compared to diesel, Jatropha Curcas oil had a somewhat lower BTE. The maximum values for brake thermal efficiency are 27.4,29 and 30.2% with Jatropha Curcas oil (JB) and diesel. Sahoo et al. (2009); Fattah et al. (2014) examined that in certain circumstances, blended biodiesel outperforms regular diesel fuel in terms of BP. Chauhan et al. (2010); Kathirvelu et al. (2017) shows that using jatropha biodiesel reduces BTE. Thapa et al. (2018) mentioned that BP drops as the amount of biodiesel in the fuel blend increases on the other hand Madiwale et al. (2018) mentioned that BP diminishes when the amount of Jatropha biodiesel in the fuel mix grows. Chauhan et al. (2012) examined that as we increase the amount of Jatropha biodiesel in the diesel–biodiesel blend it lessens the HC emissions. Reksowardojo et al. (2007) mentioned in his report that as we increase the percentage of biodiesel it reduces the HC emissions by 14.91 to 27.53 percent when compared to diesel fuel. Senthilkumar and Sankaranarayanan (2016) examined in his report that at full load conditions the HC emissions were lower than other load conditions. Abed et al. (2019) mentioned in his report that in most of the cases, the NOx emissions from Jatropha biodiesel are greater in comparison to diesel. At full load conditions CO emissions from Jatropha biodiesel-diesel blends are usually reduced by 10–40% when compared to that of diesel (Huang et al. 2010; Singh A. et al. 2021). Sundareasan et al. (2007) examined that the rise in CO emissions is noticed when the load percentage increases. (Chauhan et al. 2012; Pandhare and Padalkar 2013) examined that as the biodiesel content in the blend increases smoke opacity decreases, while it rises when the load increases for Jatropha biodiesel and its blends.

Test Fuel Preparation

The crude Jatropha oil is purchased from Harvi Trading Company of Udaipur, Rajasthan. Diesel is procured from local oil station (Nayara Petrol Pump) of Gorakhpur, India. Fig. 1 shows the experimental setup for preparation of diesel through transesterification.

Figure 1: Experimental setup for biodiesel production

i) Alcohol-Catalyst Mixing ii) Transesterification iii) Separation

At first the catalyst, NaOH (1% wt) is added into methanol (40 ml) in a beaker and is magnetic stirred for about 60 minutes at 500-600 rpm. Crude Jatropha oil (200 ml) is taken in a beaker and heated through electric heater at 60℃ for 30 minutes. After that the alcohol-catalyst mixture is added into the heated Jatropha oil for the transesterification process. This solution is then heated at (60-65) ℃ and stirred magnetically for around three hours. Then the mixture was allowed to settle down for 24 hrs. in a separating funnel. After 24 hrs. a dark coloured liquid settled down at the bottom of the funnel and a pale coloured liquid was floating at the top. The pale coloured liquid was then separated from the glycerol carefully. The crude biodiesel thus obtained is washed with water and dried at 100°C to evaporate the water particles in it. The glycerol which settled down at the bottom is used in the pharmaceutical industries for the manufacture of ointments, creams and lotions. It is also used in the production of cosmetic products, soaps and in food industry.

Figure 2 represents the flow chart for biodiesel production from crude Jatropha oil.

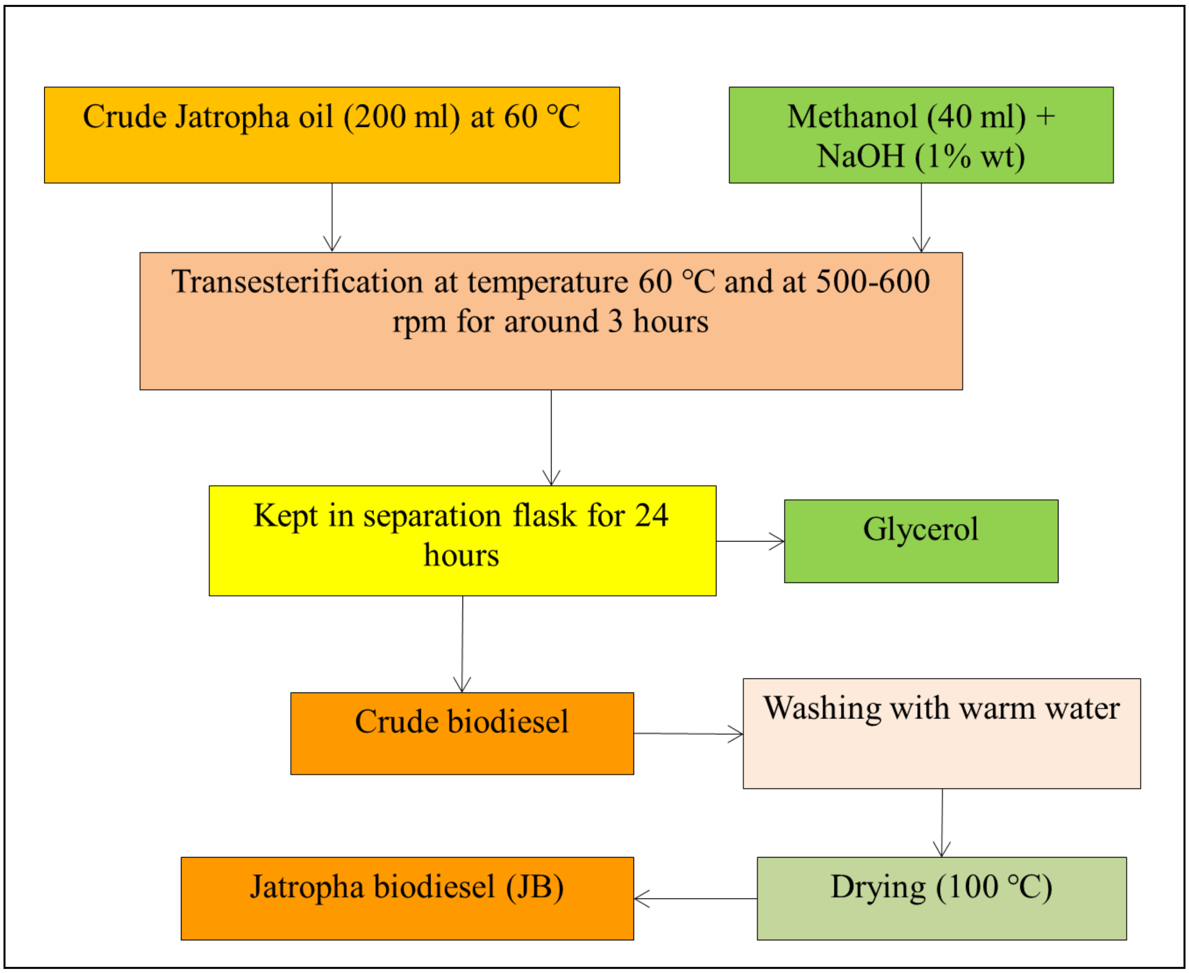

Figure 2: Flowchart for Jatropha biodiesel production

The biodiesel yield can be calculated as,

$$\text{Biodiesel yield (\%)} = \frac{\text{Total weight of methylesters}}{\text{Total weight of oil in sample}} \times 100$$

$= \frac{148}{200} \times 100$

$= 74\%$

Four samples of Jatropha biodiesel (JB) and diesel are prepared on the basis of volume concentration through magnetic stirring to ensure the homogeneity of blends. The prepared blends are named as JB20D80 (JB 20% and diesel 80%), JB30D70 (JB 30% and diesel 70%), JB40D60 (JB 40% and diesel 60%) and JB50D50 (JB 50% and diesel 50%).

Properties (Unit)	**Diesel**	**Jatropha Biodiesel**	**JB20D80**	**JB30D70**	**JB40D60**	**JB50D50**
Density (Kg/m^3)	830	880	838	845	849	856
Kinematic Viscosity (mm^2/s)	2.76	4.12	2.68	3.03	3.44	3.9
Calorific Value (KJ/Kg)	42970	39520	41334	41253	39594	39577
Flash point (℃)	61	168	72	77	77	79
Fire point (℃)	65	174	76	83	83	87

Table 1: Properties of diesel and prepared blends of biodiesel & diesel

Performance Analysis

The performance analysis of biodiesel produced from Jatropha oil in different blending mixtures with diesel is performed on a 10 HP rated single cylinder Kirloskar diesel engine coupled with hydraulic dynamometer. The testing is carried out at Internal Combustion (IC) engine lab of Mechanical Engineering Department of Madan Mohan Malaviya University of Technology, Gorakhpur, and Uttar Pradesh, India. The specification of the engine is given in the table as shown below.

Figure 3: The Engine Setup

PARTICULARS	DESCRIPTION
Engine type	Vertical, single cylinder, water-cooled, four stroke cycle, compression ignition diesel engine
Number of cylinders	1
Bore	120 mm
Stroke	139.7 mm
Cubic capacity	1580 cm^3
Compression ratio	17.5:1
Rated output	7.4 KW or 10 HP
Rated speed	1500 rpm
Fuel tank capacity	4 L
Engine weight (dry)	150-200 kg
Rotation while looking at the flywheel	Clockwise
Starting	Hand start
Type of fuel injection	Direct injection

TABLE 2: Engine Specifications

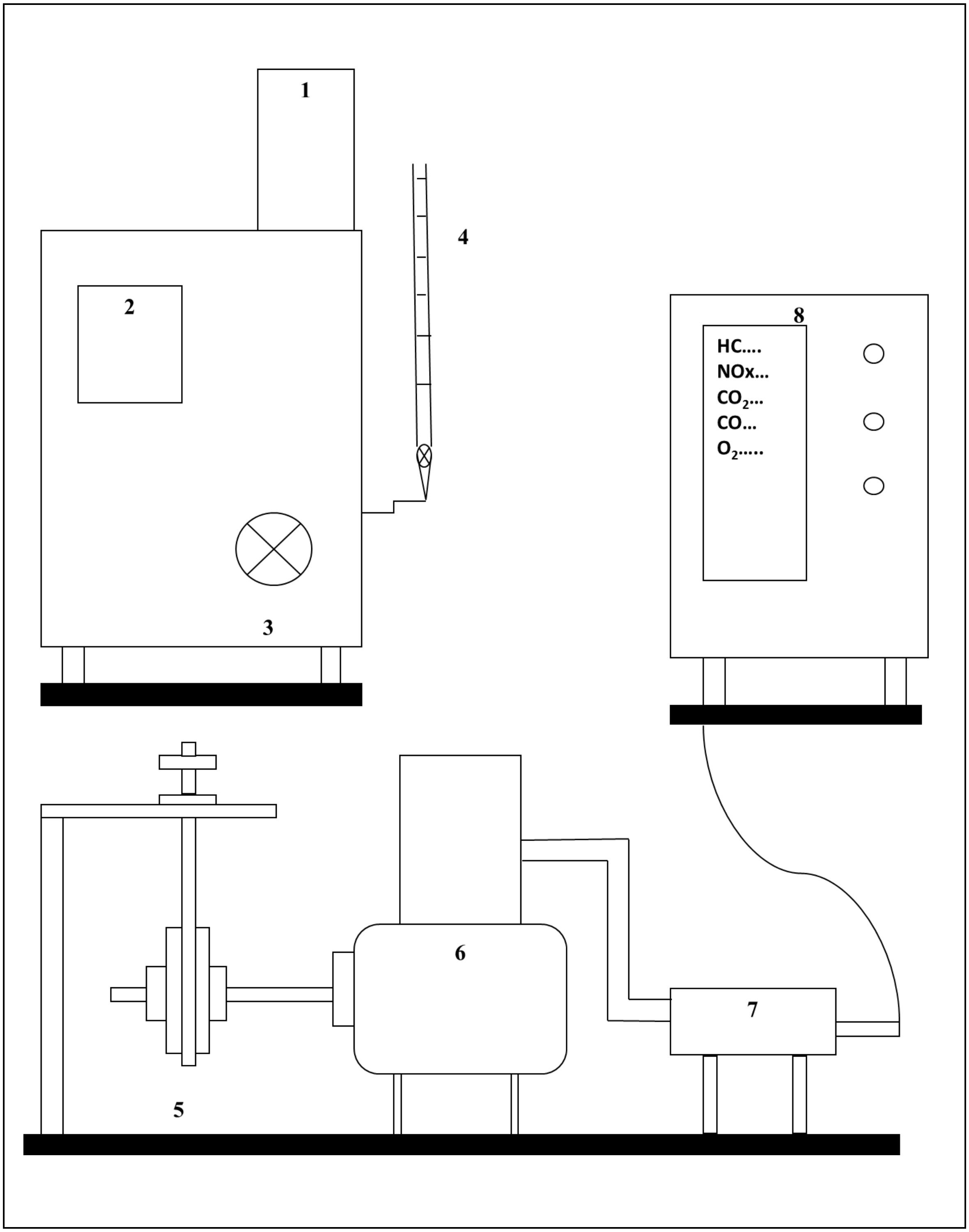

Figure 4: Block Diagram for Engine Setup

Here,

1. Fuel Tank
2. Temperature Indicator
3. Manual Valve
4. Burette
5. Dynamo
6. 4 Stroke Diesel Engine
7. Exhaust
8. Exhaust Gas Analyzer

Method:

For obtaining the base line data of the engine first the experiment is performed with diesel and then with blends of diesel and biodiesel. Biodiesel and diesel oil will be mixed in the following proportion by volume to obtain blends:

100% diesel- JB0D100

80% diesel + 20% biodiesel – JB20D80

70% diesel + 30% biodiesel – JB30D70

60% diesel + 40% biodiesel – JB40D60

50% diesel + 50% biodiesel – JB50D50

All the tests were performed at constant maximum speed of 1500 rpm with variable loads of 1-4 kg. Loads were varied with the help of a hydraulic dynamometer. Initially the dynamometer was set on 0 kg and then the time taken by the engine to consume 10 ml of fuel from burette was noted down. Further, loads were increased up to 4 kg by increasing lever of the hydraulic dynamometer and volume flow rate for each load for different blending mixtures was calculated. During this experiment, the exhaust gas temperature and exhaust emissions from gas analyzer will also be noted. Similarly, experiments will be performed for all blending mixtures. All the experiments will be performed three times and average value will be reported.

Results & Discussions:

This experimental study investigates the emission and performance characteristics of Jatropha biodiesel blended with diesel in different mixing ratios at various engine loading conditions.

Performance Parameters:

Performance parameters like BSFC, BTE & EGT are investigated for the prepared blends at various engine loadings and the results are compared with conventional diesel.

Brake Specific Fuel Consumption:

The variations in brake specific fuel consumption for diesel and various blends of biodiesel-diesel are shown in figure 5. BSFC refers to the amount of fuel consumed per unit brake power produced. It is experimentally investigated that the BSFC decreases with increasing load. It is observed that in the initial phase there is a drastic decrease in BSFC. The blends as well as the pure diesel follow the same trend. Its value should be as low as possible for efficient performance of the engine. The maximum value of BSFC is obtained for JB50D50 and minimum value is obtained for JB20D80 due to their lower and higher heating value. It is found that JB20D80 lowers BSFC by 17.89% in comparison to JB50D50.

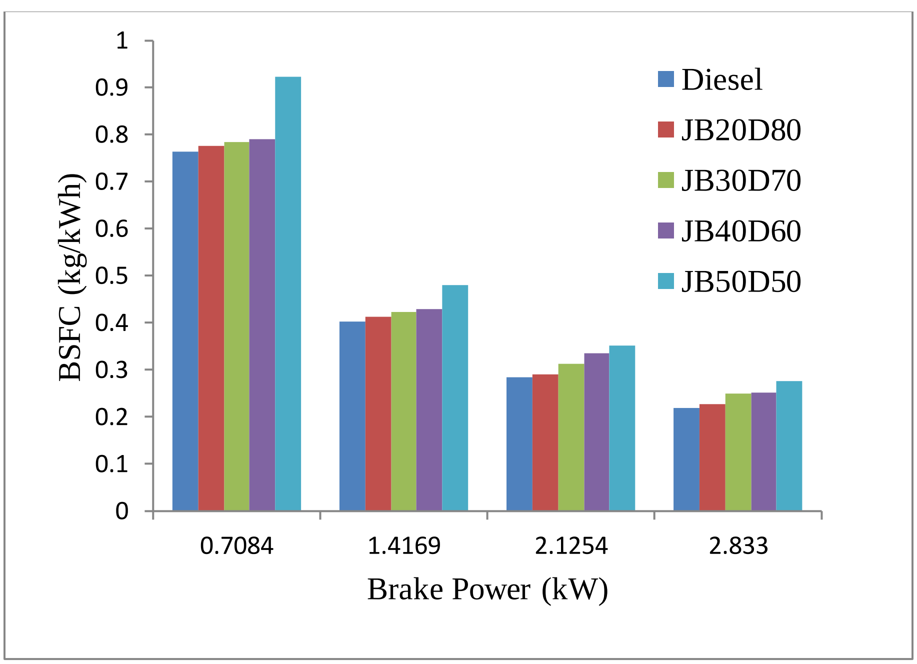

Figure 5: Variation of BSFC vs BP

Exhaust Gas Temperature:

The variations in exhaust gas temperature for diesel and various blends of biodiesel-diesel are shown in figure 6. It is experimentally investigated that the exhaust gas temperature increases with increase in load. It is also shown that as the percentage of biodiesel increases in the blend the exhaust temperature also increases. The maximum value of EGT is obtained for JB50D50 and minimum value is obtained for JB20D80 corresponding to their heating values.

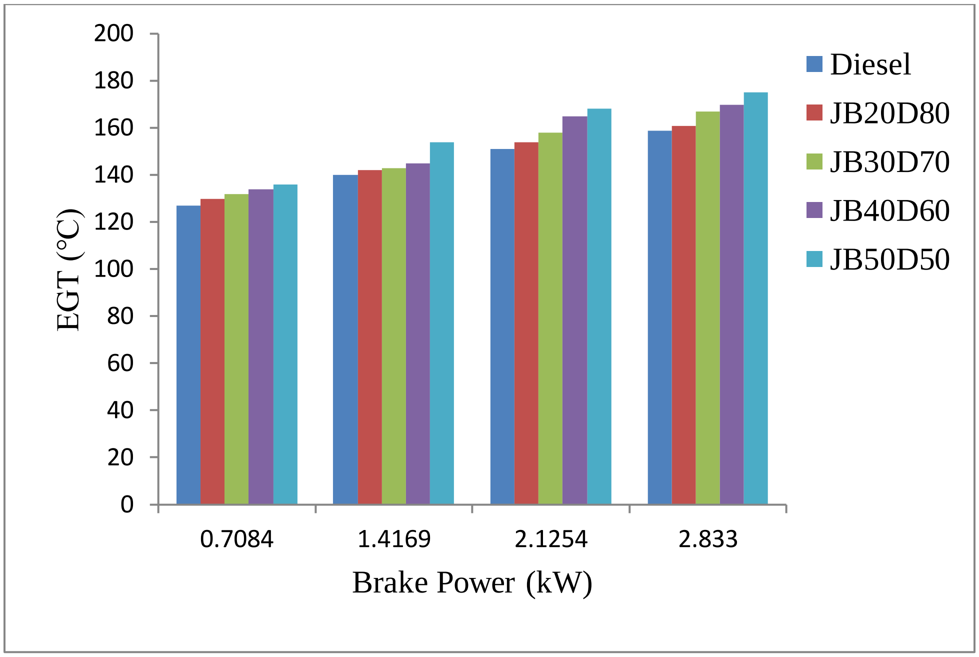

Figure 6: Variation of EGT vs BP.

Brake Thermal Efficiency:

The variations in brake thermal efficiency for diesel and various blends of biodiesel-diesel are shown in figure 7. It is experimentally investigated that as the load increases the BTE values for diesel and blends also increases, but further as we increase the load it increases with a decreasing rate. It can be observed from the graph that diesel and biodiesel-diesel blends follow similar trend but BTE decreases with increase of biodiesel percentages in the blends. BTE value is maximum for JB20D80 and minimum for JB50D50 due to their higher and lower heating values respectively while diesel has the highest heating value. It is found that JB20D80 increases BTE by 3.18% in comparison to JB50D50.

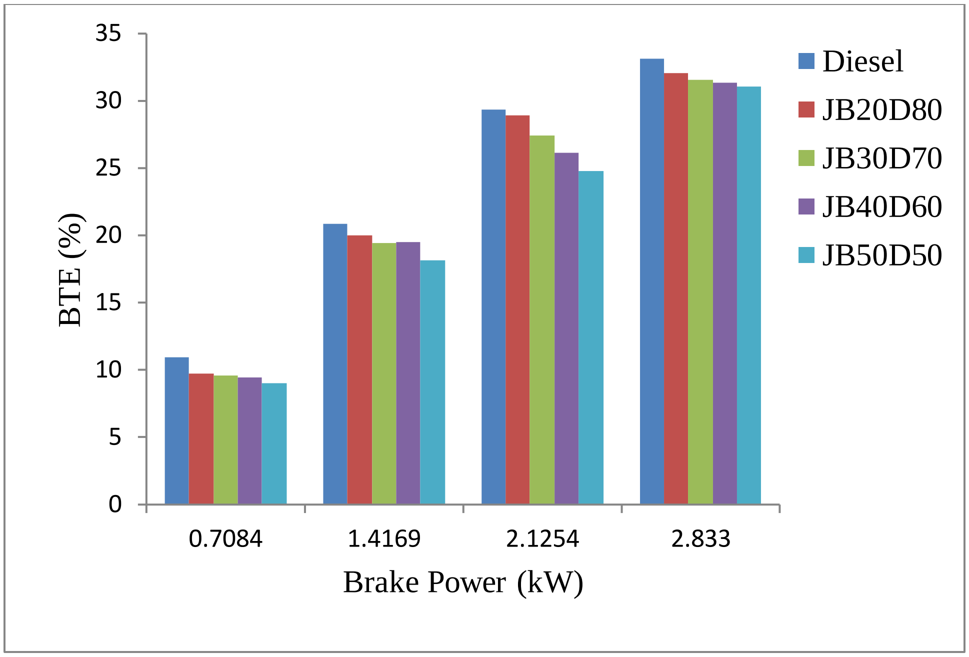

Figure 7: Variation of BTE vs BP

Exhaust Emissions:

The exhaust emissions are recorded with the help of gas analyzer which was attached to the engine exhaust through a probe and the data was recorded. The various emission parameters which are recorded are as follows: HC, NOx, CO_2 & CO.

Hydrocarbon Emissions:

The variations in hydrocarbon emission for diesel and various blends of biodiesel-diesel are shown in figure 8. Incomplete combustion leads to the emission of hydrocarbon. It is experimentally investigated that that it increases with increase in load and is the highest for diesel. It is shown that as the amount of biodiesel in the blends increases the hydrocarbon emissions decreases. Its value is highest for JB20D80 and lowest for JB50D50. HC emissions were found to be reduced by 3.27% for JB20D80 and 14.75% for JB50D50 in comparison to diesel fuel.

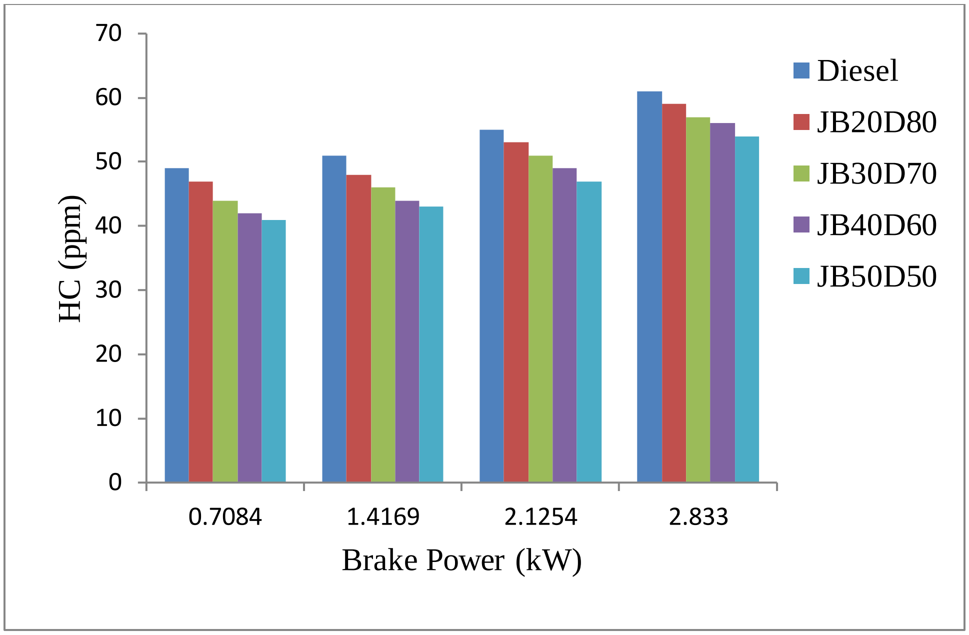

Figure 8: Variation of hydrocarbon emissions vs BP

NOx Emissions:

The variations in nitrogen oxides emission for diesel and various blends of biodiesel-diesel are shown in figure 9. The NOx emission increases with increase in load for each blend as well as for the diesel. As the amount of biodiesel in the blend increases the NOx emission also increases. The maximum value for NOx emission is obtained for JB50D50 and minimum value is obtained for JB20D80 while diesel has lowest NOx emission due to its highest heating value. It is found that NOx emission reduced by 15.34% for JB20D80 in comparison to JB50D50. Higher values of NOx for JB biodiesel may be due to presence of excess oxygen content.

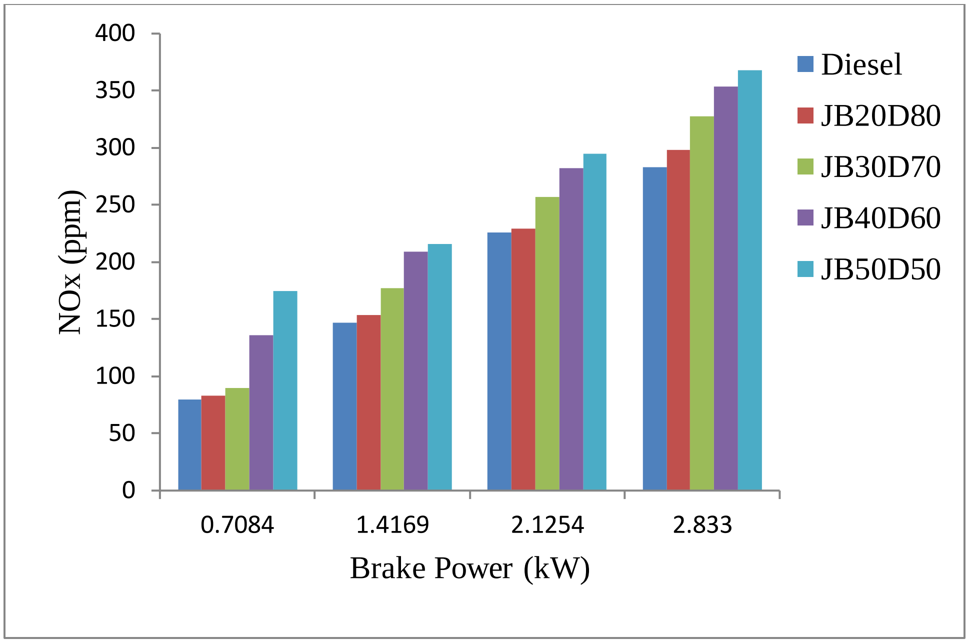

Figure 9: Variation of NOx emissions vs BP

Carbon Dioxide Emissions:

The variations in carbon dioxide emission for diesel and various blends of biodiesel-diesel are shown in figure 10. It is experimentally investigated that the CO_2 emissions increases with increase in load for all blends as well as for the amount of biodiesel in the blend. Its value is maximum for JB50D50 and minimum for JB20D80. Diesel has the lowest CO_2 due to its high heating value and density. It is found that CO_2 emissions for JB20D80 reduced by 15.23% in comparison to JB50D50.

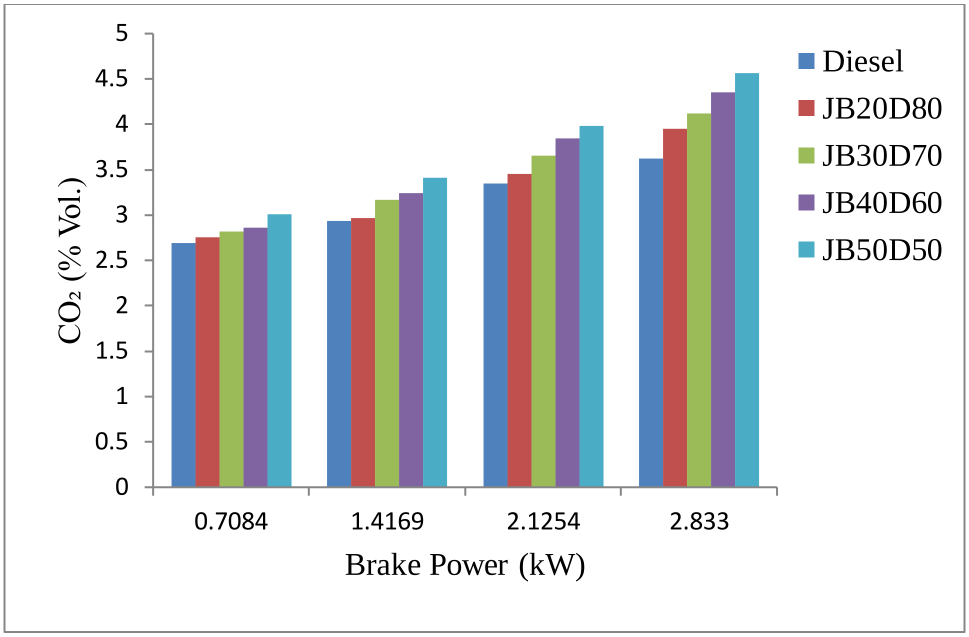

Figure 10: Variation of carbon dioxide emissions vs BP

Carbon Monoxide Emission:

The variations in carbon monoxide emission for diesel and various blends of biodiesel-diesel are shown in figure 11. It is experimentally investigated that as the load increases CO emissions also increases. It is found to decrease with higher percentage of biodiesel in the blended fuels. The highest value for CO emissions is obtained for diesel whereas the lowest value is obtained for JB50D50.

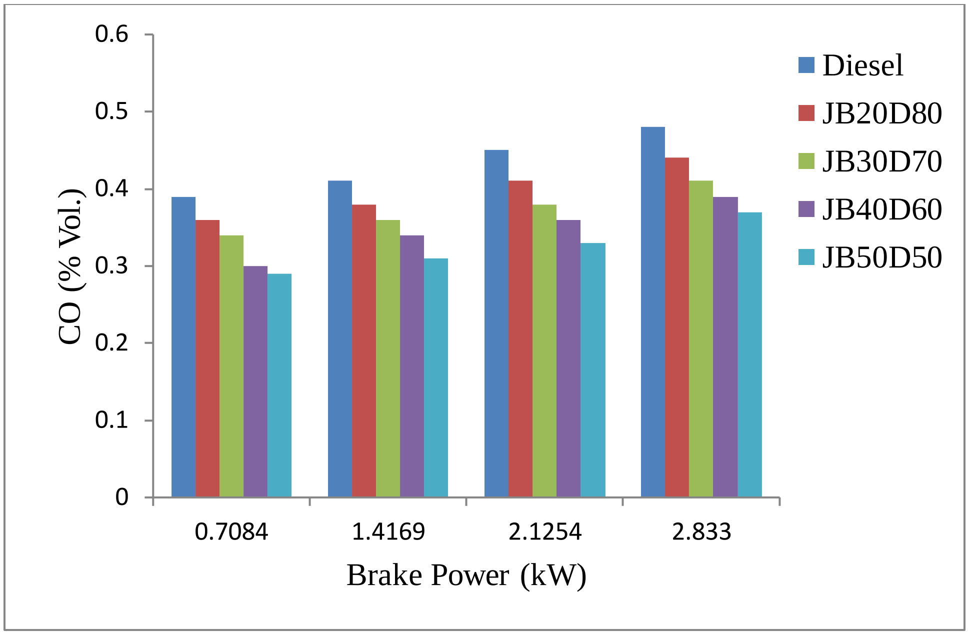

Figure 11: Variation of CO vs BP

Conclusion

In the current research work the performance & emission characteristics of Jatropha biodiesel are experimentally investigated using different blending mixtures with diesel.

Based on the obtained results of prepared fuel blends at full load following conclusions can be drawn:

i) BSFC value of JB20D80 was found to be 17.89% lower than JB50D50 and the results are approaching the values of diesel fuel.

ii) BTE value for JB20D80 increased by 3.18% in comparison to JB50D50.

iii) NOx emissions were reduced by 15.34% for JB20D80 in comparison to JB50D50. The NOx emissions increased with increasing engine load, due to a higher combustion temperature.

iv) CO_2 emissions reduced by 15.23% for JB20D80 in comparison to JB50D50 which leads to reduction in global warming and thus saves the environment.

v) HC emissions reduced by 3.27% and CO emissions reduced by 8.33% in comparison to diesel fuel which leads to reduction in greenhouse gases.

The present investigation concludes that from performance and emission parameters, B20 can be used as alternative fuel blend for the partial replacement of conventional diesel fuel.

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