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Comparative analysis of jatropha and karanja-based biodiesel properties, performance and exhaust emission characteristics in an unmodified diesel engine

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ABSTRACT: An ever-increasing drift of energy consumption, unequal geographical distribution of natural wealth and the quest for low carbon fuel for a cleaner environment are sparking the production and use of biodiesels in many countries around the globe. In this work, jatropha and karanja biodiesels were produced from the respective crude vegetable oils through transesterification, and the different physical properties of the produced biodiesels have been presented and found to be acceptable according to the ASTM biodiesel specification standard. This paper presents the experimental results of the research carried out to evaluate the BTH, BSFC exhaust emission characteristics of jatropha and karanja blends in a single-cylinder diesel engine at different engine load. Comparative measures of brake thermal efficiency, smoke opacity, HC, CO, and NO_x have been presented and discussed. Engine performance, in terms of higher brake thermal efficiency and lower emissions (HC, CO, NO_x) with jatropha-based biodiesel (JB50) operation, were observed compared to karanja-based biodiesel (KB50).

Key words*:* Comparison, Emission,Jatropha, Karanja, Performance.

INTRODUCTION

Increasing the consumption and price hike of petroleum fuel day to day is problematic for developing countries that are dependent on foreign suppliers and pay huge amounts on import bills. In the last ten years, researchers have given more attention to alternative fuels. Due to the lower availability of petroleum-based fuels in the future, the need for alternative fuels has been raised, and research is in progress for alternative fuels. (Verhelst and Sierens, 2001). Biodiesel is a renewable fuel, with simple production technology, low handling hazards, low pollutant emissions, and can be used in engines without substantial modifications (Demirbas, 2007; Lang et al., 2001). The main source of biodiesels i.e., oil producing plants, can grow easily in a wide range of geographic locations and flexible climatic conditions. Among the edible and nonedible vegetable oils, the nonedible oils such as jatropha, karanja etc. are as economical as biodiesel for their reduced consumption for domestic purposes. Jatropha is a small tree with an oil yield of 1500 kg/ha, and decorticated seeds of jatropha contain around 41-56% oil. Jatropha belongs to the Euphorbiaceae family. The tree has a height of about 6-8 m and a life expectancy of around 50 years. It can survive in abandoned lands and climatic zones with a mean annual rainfall of 250-1200 mm (Atabani et al., 2013; Silitonga et al., 2011; Koh and Ghazi, 2011; Berchmans and Hirata, 2008). Karanja is a forest-based tree, up to 16 m tall. It has a life expectancy of about 70

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years. In parts of India, this tree is also known as Pongamia, and it belongs to the family of Leguminaceae. It has been reported that the oil yield of karanja is 134,000 million tonnes (Raheman and Phadatare, 2009; Stalin and Prabhu, 2007; and Baiju et al., 2009). It has also been established by various researchers that, by using biodiesel the emissions produced from various pollutants like hydrocarbon, particulate matter, carbon monoxide and sulphur dioxide decreases. Countries including China, Austria, Sweden, and Germany have targeted bioenergy use towards 10-20% for their primary energy supply by the year 2020. The Vietnam has set a goal of using bioenergy up to 40.12%. (Zhangming et al., 2001; Trittin, 2004; Worgetter et al., 2006; Alakangas et al., 2005 and Kumar et al., 2003).

Different researchers have tried to produce biodiesel from vegetable oils either by enzymes, acid, or alkali (Nag, 2007). Knothe et al. (1997) have reported an approximate 97.7% conversion to product in a transesterification reaction within 18 minutes by using 1% KOH catalyst at 690°C. Freedman et al., 1984 have discussed the esterification process and reaction of soybean oil and sunflower oils at different temperatures and different molar ratios. Jatropha and karanja plants are abundantly available in India and Bangladesh. Seeds from these plants go to waste annually and can be utilized for biodiesel production, and hence may partly solve the fuel crisis problem (Raheman and Ghadge, 2008). Some problems have been found in the use of edible vegetable oils in CI engines. Problems associated with the use of edible vegetable oils include cornet formation on the injectors, choking and carbon deposits. To reduce these problems, blending, preheating, and ultrasonically assisted methanol transesterification have been used by various investigators (Demirbas, 2005; Carmen et al., 2007; Nwafor, 2003; Barsic and Humke, 1981; Banapurmath et al., 2008; Qi et al., 2010; Kalam and Masjuki, 2004; Lapuerta, 2008; Devan et al., 2009).

MATERIALS AND METHODS

Materials

Oils of karanja and jatropha were obtained by mechanical pressing of seeds, which were collected from the plantation at Govind Ballabh Pant University of agriculture and technology, Pantnagar, Uttarakhand, India. All of the chemicals needed for the transesterification process were purchased from SRL Laboratories, Dehradun, Uttarakhand, India.

Transesterification process

The transesterification process was carried out in two steps: 1. acid esterification and 2. the base esterification process. The acid esterification process was used to reduce the FFA of the selected oils up to 1-2% as they have more acid than the 4 mg KOH/gm. The first step was carried out at a temperature range of 50-60^{o}C with 200 ml methanol and 0.5% v/v H_2SO_4. A 4 ml sample of methanol was taken from the flask at 15 min intervals and the process carried out until the FFA level reduced. Sulphuric acid and excess alcohol with impurities was removed after pouring the product into a separating funnel. The lower layer was collected from the separating funnel for the base transesterification process.

During the transesterification process, 1% KOH (catalyst) dissolved in 25% v/v methanol was poured into the flask. The mixture was heated at a constant temperature of 70^{o}C and stirred at 700 rpm for 3 h. The mixture was then poured into a separating funnel where two layers formed. The upper layer had methyl esters of vegetable oils and the bottom layer contained glycerol and impurities. The upper layer formed was washed by hot distilled water two to three times so that the catalyst and ethanol could be removed.

Moisture from the biodiesel was removed by drying at 90-100°C under vacuum and passing the layer over anhydrous sodium sulphate. The dehydrated oil was taken for performance and emission measurement.

Test of fuels

The engine research laboratory of the Department of Mechanical Engineering, University of Petroleum & Energy Studies, Dehradun, India was used to carry out the transesterification process, blending and property analysis test of fuels. Three samples were considered for research. These were a) 100% neat diesel fuel (D100), (b) 50% jatropha biodiesel with 50% diesel fuel (JB50), and (c) 50% karanja biodiesel with 50% diesel fuel (KB50). These blended percentages are volume-based proportions.

Equipment for fuel property test

The physical properties of all the test fuels, such as density, viscosity, flash point, and calorific value were evaluated and are presented in Table 2. The calorific value was determined using a bomb calorimeter (Parr instruments), kinematic viscosity using Saybolt's viscometer at ASTM standard temperature of 40°C, flash and fire point using a Cleveland open cup tester.

Experimental set-up

A four-stroke, single cylinder, water-cooled, direct injection diesel engine was selected for the study. The specifications of the engine are shown in Table 1. For engine loading, an eddy current dynamometer is coupled with the engine. The exhaust gas temperature (EGT) is measured with the help of a thermocouple (Type K-Cromel/Alumel) with a range and resolution of 0–1000°C and 0.01°C, respectively. Figure 1 represented the schematic image of the engine test bench and the experimental apparatus used.

The tests have been conducted at a normal injection timing of 24.5° bTDC and injection pressure of 190 bar. To determine the properties, the engine was first fuelled with diesel fuel. Later it was fuelled with blended biodiesels, and each test was repeated at least three times to calculate the mean value.

Table 1. Specifications of the engine

Manufacturer	Kirloskar Oil Engines Limited
Model No	KIRLOSKAR AV1
Engine Type	4-stroke direct injection diesel engine
Number of cylinders	One
Cylinder bore	80 mm
Stroke	110 mm
Displacement	0.553 L
Continuous rated output	1500 rpm
Rated power	3.67 KW
Cooling System	Water cooled
Compression ratio	16.5
Injection timing	24.5 deg. bTDC
Injection pressure	190 bar

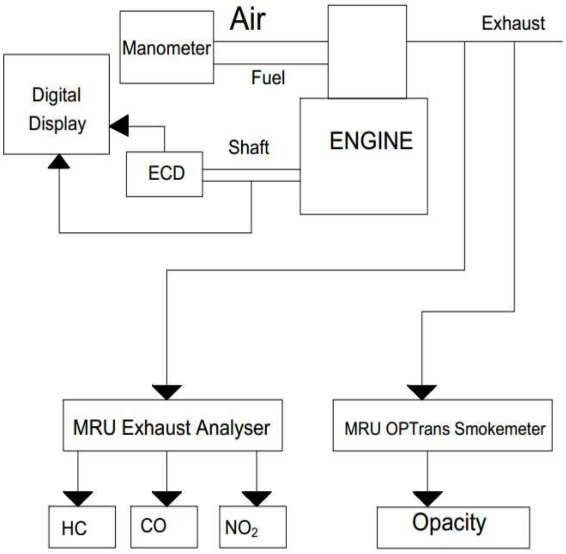

Fig. 1. Schematic image of engine test bench with experimental apparatus

Exhaust gas analyser

To determine the exhaust emission, AVL exhaust gas analyser was used. The range and resolution of the equipment are: i) NO_X, 0-5000 ppm and 1 ppm, respectively; ii) CO, 0–5 vol% and 0.01%, respectively; iii) CO_2, 0–10 vol% and 0.l% respectively.

Uncertainty analysis

Uncertainty was calculated through the analysis of the instrument's accuracy and precision, along with the repeatability of the measurement. All experiments were performed several times and data were collected at least three times. Average values were used for graph plotting.

RESULTS AND DISCUSSION

Comparison of properties of fuels used

Table 2 shows the properties of fuels of transesterified non-edible oils and diesel. The kinematic viscosities of biodiesel of karanja and jatropha at 40°C are more than diesel fuel. The result shows that the cetane number and the calorific value of the two biodiesels are less than diesel fuel. In comparison of the two vegetable oils, jatropha shows better results in specific gravity, viscosity, and cetane number. The difference in properties for different vegetable oils is due to the variation in fatty acid composition and other associated compounds such as colouring matters, odorant compounds, etc.

Table 2. Properties of diesel and blends of jatropha and karanja

Properties	D100	JB 50	KB 50	EN14104-2003	ASTM D 6751-02
Density (Kg/m^3)	834.2	851.2	863	860-900	-
Viscosity at 40°C (mm^2/s)	3.72	4.23	4.39	3.5-5.0	1.9-6.0
Cloud point (°C)	4	7	9	-	-
Pour point (°C)	-6	-3	-4	-	-
Flash point (°C)	78	152	147	>120	>130
Cetane number	48	51	53	-	-
Calorific value (MJ/Kg)	44.5	41.63	39.63	-	-

The measured properties of the neat diesel fuel and blends of jatropha and karanja are presented in Table 2. Each property was measured three times, and mean values were presented with the ASTM and EN standard values of biodiesel properties for comparison.

The density of JB50 and KB50 were found to be higher than D100. However, the density of JB50 was found to be lower than KB50. Kinematic viscosity levels of the jatropha and karanja biodiesel satisfied ASTM D6751-02 and EN 14104-2003 standards and were found to be close to neat diesel fuel.

The calorific values of the JB50 and KB50 presented in Table 2 were slightly lower than the neat diesel fuel. The flash point values of the selected biodiesels were within ASTM and EN standards. The flash point values were higher than the diesel fuel, which provides an advantage in terms of transport and handling.

The pour points of JB50 and KB50 were found to be -3°C and -4°C, which favours their use in cloudy climates. The cloud points of the tested fuels were within the ASTM limit for biodiesel standards. The cloud points were 7°C and 9°C for JB50, KB50 respectively. Its concern in tropical and hot countries in Asia is limited.

Comparison of the effect of loads on the performance parameters

Brake thermal efficiency

Brake thermal efficiency (BTE) refers to the combustion quality of the engine. Figure 2 represents the variation for the tested fuels with engine load. It was found that the trend of variation for BTE of the JB50 and KB50 blends represent the same trend as expected for D100. The BTE was found to be lower for the tested blends of JB50 and KB50 compared to D100. BTE for KB50 is lower compared to JB50. This reduction in efficiency is due to the poor atomization and combustion quality as a result of the low volatility, higher viscosity, and higher density of the karanja-based biodiesel blend. Among the biodiesels tested, the maximum BTE was recorded with JB50 and is 28.4% at 80% engine load compared to 30.3% for D100.

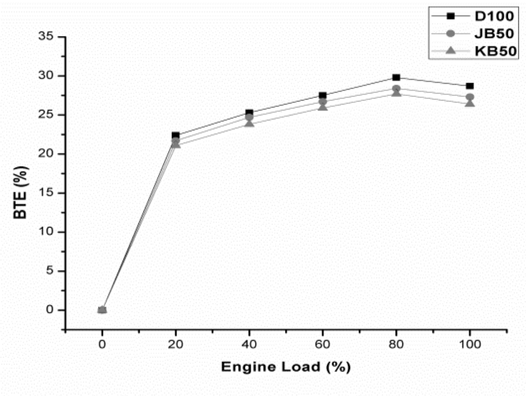

Fig. 2. Effect of engine load on BTE

Brake specific fuel consumption

Figure 3 shows the variation of BSFC values of the tested fuels with engine load. Test blends of JB50 and KB50 exhibited slightly higher BSFCs compared to D100. This reduction was due to their low density and calorific value. Out of the tested fuels, KB50 shows the lowest BSFC due to its lower calorific value and density.

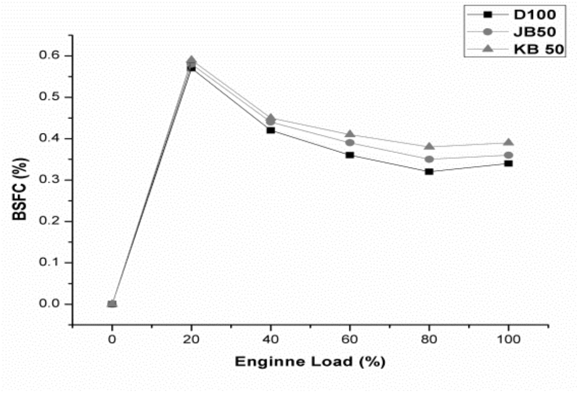

Fig. 3. Effect of engine load on brake specific fuel consumption

Comparison of the effect of loads on the emission characteristics

Hydrocarbon emission

Variation of HC emission for all the tested fuels against load is presented in Figure 4. All fuels exhibit higher emissions at higher engine load. This is due to the fact that less oxygen is available for reaction during the injection of fuel at a higher engine load. Of the biodiesels tested, HC emission values were 62 and 54 ppm for JB50 and KB50, respectively, compared to 42.3 ppm with D100 at 80% load.

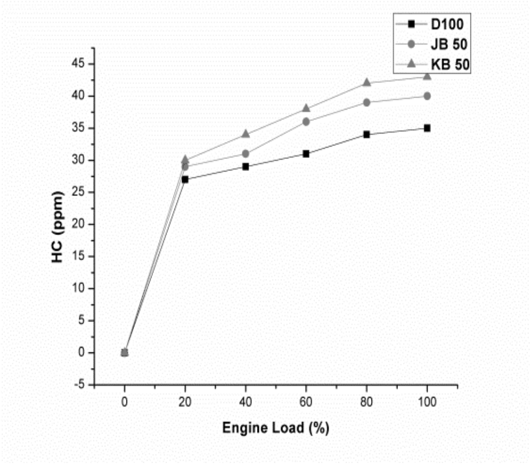

Fig. 4. Effect of engine load on hydrocarbon emission

Carbon monoxide emission

CO emission indicates incomplete combustion of fuel inside the engine cylinder, which occurs when the flame front approaches the fissure volume and a relatively cool cylinder liner. Hence, the flame temperature is cooled down and results in incomplete combustion. Figure 5 represents the variation of effect of engine load on the carbon monoxide emission of the tested blends. Similar trends were also observed during the emission of carbon monoxide in the exhaust. Carbon monoxide values were 0.418% and 0.153% for JB50 and KB50 respectively, compared to 0.1138% with base diesel at 80% load.

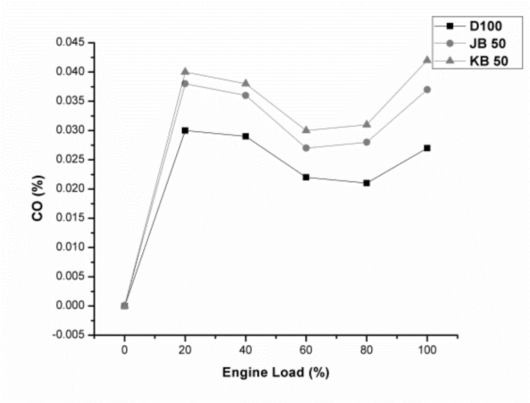

Fig. 5. Effect of engine load on carbon monoxide emission

NO emission

NO emission is high due to a high combustion temperature and equivalent ratio. The effect of engine load on NO emission is shown in Figure 6. Lower NO emissions were observed for JB50 and KB50 compared D100. During the premixed combustion phase, heat release rates of biodiesels were lower, which would lead to a lower peak temperature. NO emission values were 935 and 952 ppm for JB50 and KB50, respectively, compared to 972 ppm with D100 at 80% load.

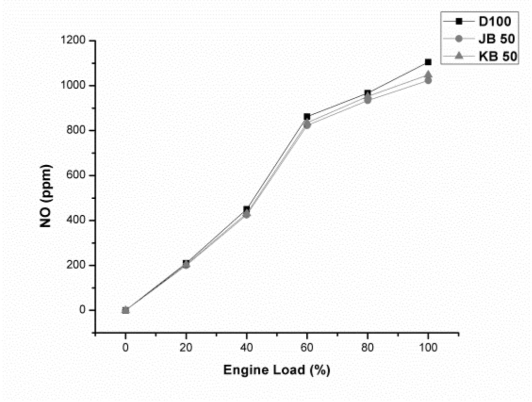

Fig. 6. Effect of engine load on nitrous oxide emission

Uncertainty analysis of NO emission is presented in Table 3. In a similar way, an uncertainty analysis of other performance and emission data was performed.

Table 3. Uncertainty level of NO emission for JB50

Three tests			Max-min value		Analyzer accuracy		Average	%Uncertainty	
Test 1	Test 2	Test 3	Max	Min	+1 ppm	-1 ppm	ppm	+	-
ppm	ppm	ppm	ppm	ppm					
199	199	200	200	199	201	198	199	0.51	-0.51
422	425	427	427	422	428	421	424	0.71	-0.71
834	831	834	834	831	835	830	832	0.24	-0.24
918	918	921	921	918	922	917	919	0.21	-0.21
956	958	956	958	956	959	955	957	0.21	-0.21
983	983	985	985	983	986	982	984	0.21	-0.21

Smoke opacity

Figure 7 represents the effect of engine load on smoke opacity for D100, JB50 and KB50. The smoke opacity for KB50 is 78.0 HSU, which is higher in comparison with other fuels. This is due to a heavier molecular structure and higher viscosity, which leads to higher smoke emission. As for JB50, it is 74 HSE. Smoke opacity is observed to be higher for biodiesel tested compared to D100. At 80% load, smoke opacity values were 68, 71 for JB50 and KB50 respectively, compared to 55 HSU with D100.

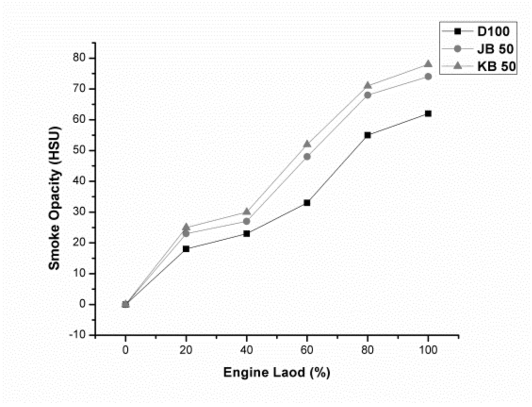

Fig. 7. Effect of engine load on smoke opacity

CONCLUSION

The study conducted here provides a systematic comparison between JB50 and KB50 and D100 operations. The JB50 and KB50 were tested to establish the effect of engine load variation on the performance and emission of the engine using D100 as the primary fuel. The study also draws a comparison between JB50 and KB50. The vital findings were summarized as follows:

- The brake thermal efficiency of JB50 and KB50 was found to be lower than D100 due to poor atomization as a result of higher and lower density.
- The HC and CO emissions with KB50 and KB50 were found to be slightly more than the D100 operation.
- Test blends of JB50 and KB50 result in slightly higher smoke emissions than D100, and this is attributed to incomplete combustion due to their higher viscosity and lower volatility.
- NO emissions of JB50 and KB50 were found to be slightly lower than for D100. Both blends tested result in a slightly reduced thermal efficiency and increased smoke, HC and CO levels. The existing engine could be operated on the blends without any engine modification.

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