International Journal of Automotive and Mechanical Engineering (IJAME)
ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 10, pp. 2155-2169, July-December 2014
©Universiti Malaysia Pahang
DOI: http://dx.doi.org/10.15282/ijame.10.2014.30.0181

STATISTICAL ANALYSIS OF DIESEL ENGINE PERFORMANCE FOR CASTOR AND JATROPHA BIODIESEL-BLENDED FUEL

Devendra Vashist[1,*] **and Mukhtar Ahmad**[2]

[1]Department of Automobile Engineering, Manav Rachna International University, Faridabad, Haryana, India.
*E-mail: vashist_dev2001@yahoo.co.in
[2]Department of Mechanical Engineering, Faculty of Engineering and Technology
Jamia Millia IslamiaNew Delhi, India.

ABSTRACT

Vegetable oils and their methyl/ethyl esters are alternative renewable fuels for compression ignition engines. Asian countries are not self-sufficient in edible oil and are exploring non-edible seed oils, like jatropha and castor as biodiesel raw materials. In the present study jatropha and castor oil were used for the preparation of biodiesel by the transesterification process. Diesel and jatropha oil methyl ester (JOME) blends were used to conduct short-term engine performance tests at varying loads. Similar tests were conducted with castor oil methyl ester (COME). The engine parameters were recorded and compared for the prepared blends. The best engine operating condition based on lower brake specific fuel consumption and higher brake thermal efficiency were identified and compared. The maximum thermal efficiency was observed at 13% substitution of COME in diesel and 18% for JOME in diesel. An analysis of variance test was applied to the observed data for both the fuels. Results indicated for COME, F = 2.397, that there is no significant effect on fuel consumption with the fuel type. There is a significant effect on fuel consumption and thermal efficiency with % of load. For F = 5.69 there is a significant effect on thermal efficiency with the fuel type. Similar trends were observed with JOME blends. These trends indicated that blends in the ratio of 0–20% by volume of biodiesel can be added to neat diesel without any change in the hardware of the engine.

Keywords: Transesterification; Jatropha oil methyl ester; Castor oil methyl ester; Brake thermal efficiency; Engine exhaust temperature; Fuel consumption; F test.

INTRODUCTION

Rudolf Diesel, the inventor of the diesel engine, presented the concept of using biofuels in diesel engine sat the 1911 World's Fair in Paris. R&D activities in this area were not carried out because of the abundant supply of petro-diesel at that time. Only recently was the importance of biofuels realised when it was noticed that petro-diesel resources are depleting fast and additionally that they are polluting the environment [1]. Recently many serious efforts have been made by several researchers to use different sources of energy as fuel in existing diesel engines. The higher viscosity of neat vegetable oil makes it an incompetent fuel for direct use in a diesel engine. The injectors of the engines get choked after a few hours if they are directly run on neat vegetable oil [2]. The viscosity of neat oils can be reduced by blending them with diesel or by the process of transesterification, which produces biodiesel. Worldwide transesterification has been accepted as an effective means of biodiesel production and viscosity reduction of vegetable oil. The transesterification process is influenced by temperatures, catalyst type, the concentration ratio of alcohol to fuel and stirring speed rate [3]. The important compositional difference between biodiesel and diesel fuel is concerned with oxygen content. Biodiesel contains 10–12% oxygen in weight basis and this lowers the energy content. The lower energy content causes reductions in engine torque and power [2, 4-7]. It has been reported that biodiesel containing oxygen reduces exhaust emissions such as HC and CO mainly because of complete combustion. Since biodiesel contains little sulphur compared to diesel fuel, a significant reduction in SO_2 emission was observed by Usta [8].

The price of edible vegetable oils is higher than that of diesel fuel. Therefore, instead of using such oils, waste vegetable oils [9, 10] and non-edible crude vegetable oils [11, 12] have been considered as potential alternative fuels. Different researchers are working on different types of oil to be used as a potential source for biodiesel production, such as jatropha oil [11, 13], castor oil [14], polanga seed oil [4], karanja oil [15], palm oil [16, 17], tobacco oil [8], coffee oil [18], mahua oil [19], rubber seed oil [20], microalgae oil [21], rice bran oil [22], beef tallow [23],waste cooking oil [9], linseed oil [1], soyabeen oil [24], and sunflower oil [25]. To compensate for the shortages of diesel fuel, the adaptation of a selected alternative fuel to suit the diesel engine is considered more economically attractive in the short-term than engine modification to suit the fuel. For this purpose, an alternative liquid fuel that will blend readily with diesel fuel is required. Such an alternative fuel should lend itself to local production in adequate and economic quantities. There should be few modifications to the existing engine. Engine performance and durability should not be affected significantly. In the present investigation, two non-edible oils are taken, i.e. castor seed oil and jatropha seed oil. Biodiesel from both the oils were produced and then studied in a compression ignition engine. A comparison was made between the two sources of oil production and a comparative analysis was made on their usage in the internal combustion engine. Which type of seed will be suitable for a particular region and how blends of both the oils differ from each other when used in existing engines is the basic motivation behind the research in this paper.

JATROPHA CURCAS

Jatropha curcas is a plant belonging to the Euphorbiaceae family that produces a significant amount of oil from its seeds. This is a non-edible oil-bearing plant widespread in arid, semi-arid, and tropical regions of the world. Jatropha is a drought-resistant perennial tree that grows in marginal lands and can live for over 50 years [26]. The oil content in jatropha seed is reported to be in the range of30 to 50% by weight of the seed and ranges from 45 to 60% by weight of the kernel itself [26]. The jatropha tree has several beneficial properties: its stem can be used as a natural tooth paste and brush; latex from the stem can be used as a natural pesticide and for wound healing; and its leaf can be used as feed for silkworms, among other uses. It is a fast-growing tree and easily propagated. Jatropha usually grows below 1400m above sea level and requires a minimum rainfall of 250 mm, with an optimum rainfall of 900–1200 mm [2]. This plant is not even browsed by animals for its leaves. Figure 1 shows jatropha seed, fruit and plant at the Manav Rachna International University campus.

Figure 1. Jatropha seed, fruit and plant.

CASTOR PLANT (RICINUS COMMUNIS)

The castor oil plant, Ricinuscommunis, is a species of flowering plant in the spurge family, Euphorbiaceae. Castor is indigenous to the south-eastern Mediterranean Basin, Eastern Africa, and India. Castor seed is the source of castor oil, which has a wide variety of uses. The seeds contain between 40 and 60% oil that is rich in triglycerides, mainly ricinolein. The seed contains ricin, a toxin, which is also present in lower concentrations throughout the plant. It is a fast-growing, suckering perennial shrub which can reach the size of a small tree (around 12m/39ft). Figure 2 shows the castor plant and pod at the university campus.

Figure 2. Castor plant and Pod.

The glossy leaves are 15–45 cm long, long-stalked, alternate and palmate with 5–12 deep lobes with coarsely toothed segments. The fruit is a spiny, greenish (to reddish purple) capsule containing large, oval, shiny, bean-like, highly poisonous seeds with variable brownish mottling. In areas with a suitable climate, castor establishes itself easily as an apparently “native” plant and can often be found on wasteland. If sown early, under glass, and kept at a temperature of around 20 °C until planted out, the castor oil plant can reach a height of 2–3 m in a year. The toxicity of raw castor beans is due to the presence of ricin, a poisonous substance. The toxin provides the castor oil plant with some degree of natural protection from insect pests, such as aphids. In fact, ricin has been investigated for its potential use as an insecticide. The castor oil plant is also the source for undecylenic acid, a natural fungicide. Global castor seed production is around 1 million tons per year. Leading producing areas are India (with over 60% of the global yield), China and Brazil, and it is widely grown as a crop in Ethiopia. Table 1 shows the top ten producers of castor oil.

Table 1. Top ten castor oil seed producers.

Country	Production (Tonnes)
India	830000
People’s Republic of China	210000
Brazil	91510
Ethiopia	15000
Paraguay	12000
Thailand	11052
Vietnam	5000
South Africa	4900
Philippines	4500
Angola	3500
World	**1209756**

COMPARISON BETWEEN THE JATROPHA & CASTOR PLANT

A comparison of the castor and jatropha plant has been made, which is shown in the Table 2. From the table it is indicated that both the two plants require different conditions for their growth. Both of them are toxic plants and do not compete with crops for production. Both the plants are also not grazed by the animals.

ESTERIFICATION OF CASTOR AND JATROPHA SEED OIL

Castor and jatropha oil were converted into biodiesel by a two- and three-stage transesterification reaction, respectively. For castor oil the two-stage transesterification was adopted since the free fatty acid (FFA) value was less than 2% after the first stage of transesterification process, while for jatropha oil the three-stage process was adopted. One litre of both the oils was treated with 4 ml of toluene and orthrophosphoric acid in the first stage. FFA value was then calculated: jatropha oil, which had more than a 2% FFA value, was then treated with methanol and sulphuric acid in the second stage, while in the third stage it was treated with potassium hydroxide and sulphuric acid; castor oil, which had a lower FFA (less than 2%) value, was only treated with methanol and sulphuric acid for the completion of the transesterification process. In the second stage 75 ml/litre of oil and 5.5ml/litre of oil of sulphuric acid was added to jatropha oil while in the third stage 100ml/litre of oil and 8gm/litre of oil of potassium hydroxide was added to jatropha and castor oil. A reaction temperature of 65°C, 50°C & 65°C during 1hr, 3hrs, and3hrs, respectively, and a stirring speed of 450 rpm were maintained in the first, second and third stages of transesterification, respectively. Thereafter the reactant material was poured into a transparent vessel and allowed to cool at room temperature for 12h. It was allowed to settle for the separation of glycerol as the bottom layer. The upper layer of biodiesel was put into another transparent vessel for washing with an equal amount of water. The biodiesel was heated up to 100°C for 10 min to remove excess water. Then the biodiesel was cooled down to room temperature before use, presenting an 84% yield from jatropha oil and a 90% yield from castor oil.

Table 2. Comparison of the castor and jatropha plant.

Properties	Jatropha	Castor
Land requirement	1. Low fertility marginal, degraded, fallow waste and other lands. 2. Arid and semi-arid and even on alkaline soils [12].	1. Alkaline or acid soils, as long as the subsoil is permeable and there is good drainage. 2. Arid and semi-arid 3. Seed will not set if soil moisture is inadequate. 4. Castor beans should not be planted in an area that is subject to erosion.
Rainfall	It can be grown in areas of low rainfall (200mm/year)	It requires only moderate rainfall (approx. 600mm/year) and can withstand long periods of drought, but will thrive under higher rainfall.
Where plantation can be done	It is ideal to replant on marginal lands to prevent desertification and erosion.	It is ideal to replant on marginal lands to prevent desertification and erosion.
Effect on cattle	It attracts no insects and is not browsed by cattle or sheep. Propagation by seed/cutting is easy.	Raw castor beans are toxic due to the presence of ricin and are not browsed by cattle or sheep.
Production per hectare	Jatropha seeds (0.4–12.5 tons/ha/year) can be easily plucked.	Each hectare of castor oil bean plants planted in arid and semi-arid regions produces 350–650 kg of oil.
CO_2 absorption	High carbon dioxide absorption level	The estimated carbon dioxide absorption level of castor bean plants is 34.6 tonnes per hectare, with two growing cycles per year.
Competitionwith food crops	The jatrophaplant does not compete with food crops, as it can be grown on marginal lands, which are not competingwith food production lands.	Castor bean does not compete with food crops, as castor bean can be grown on marginal lands, which are not competingwith food production lands.
Temperature	Average annual temperature well above 20 °C [26].	Castor beans grow best where temperatures remain fairly high throughout the growing season of 140 to 180 days. The seed may fail to set, however, if the temperature stays above 100 °F for an extended period.
Oil content	Seeds contain non-edible oil 35 % and oil yield per hectare	The seeds contain between 40 % and 60 % oil by weight.

Transesterification, which is also called alcoholysis, is a process of substitution of the radical of an ester with the radical of one alcohol. It is the same process as hydrolysis, except for the fact that alcoholis used instead of water. The transesterification reaction is represented by the general Eq. (1).

$$RCOOR^{'} + R^{''}OH \leftrightarrow RCOOR^{''} + R^{'}OH \qquad (1)$$

Important properties of transesterified oils were evaluated for comparison with diesel available in the local market. These are given in Table 3.

Table 3. Chemical properties of jatropha and castor oil.

Parameters	Jatropha oil	Castor oil	Jatropha biodiesel 100%	Castor biodiesel 100%	High speed diesel
Density at 25°C (kg/m^3)	960	950	875	905	810
Kinematic viscosity mm^2/sec	240	230	13	12.5	3.05
Flash point (°C)	340	305	140	115	53
Fire point (°C)	350	320	150	121	56

The density of the fuel was found using mass and volume measurement apparatus, the kinematic viscosity of the oil was determined with the help of a Redwood Viscometer and the flash point was obtained from Pensky-Martens apparatus (Plate 3)as per the standard test procedure of the Bureau of Indian Standards (IS: 1448–1970).The prepared jatropha oil methyl ester and castor oil methyl ester was mixed with diesel in four different proportions, i.e. 5%, 10%,15% and 20%, to prepare its blends, i.e. JOME5, JOME10, JOME15, JOME20, COME5, COME10, COME15,and COME20. Figure3 shows the prepared sample blends of JOME and COME.


(a) (b) (c)

Figure 3. (a) Panksy martin flash point apparatus; (b) JOME samples; (c) COME samples.

EXPERIMENTAL METHODOLOGY

A four-stroke single-cylinder diesel engine (Figure 4) with mechanical rope brake loading was used for this study. The specifications of the engine are shown in Table 4. The inlet valve opens at 4.5° before top dead centre and closes at 35.5° after bottom dead centre, the exhaust valve opens 35.5° before bottom dead centre and closes 4.5° after top dead centre. The engine was tested with pure diesel and prepared blends of jatropha and castor biodiesel at 25%, 50%, 75%, and 100% loading at a speed of 1500 rpm only. The engine was started with standard diesel fuel and warmed up. The warm up period ends when the cooling water temperature is stabilised. Then fuel consumption, brake power, brake-specific fuel consumption, brake thermal efficiency and exhaust gas temperature were measured with different blends of jatropha and castor methyl ester.

Table 4. Engine specification.

Description	Value and unit
BHP	5
Speed	1500 RPM
Number of cylinders	ONE
Compression Ratio	16.5:1
Bore	80 mm
Stroke	110 mm
Orifice Diameter	20mm
Type of Ignition	Compression Ignition
Method of loading	Rope Brake
Method of Starting	Crank Start

(a) (b)

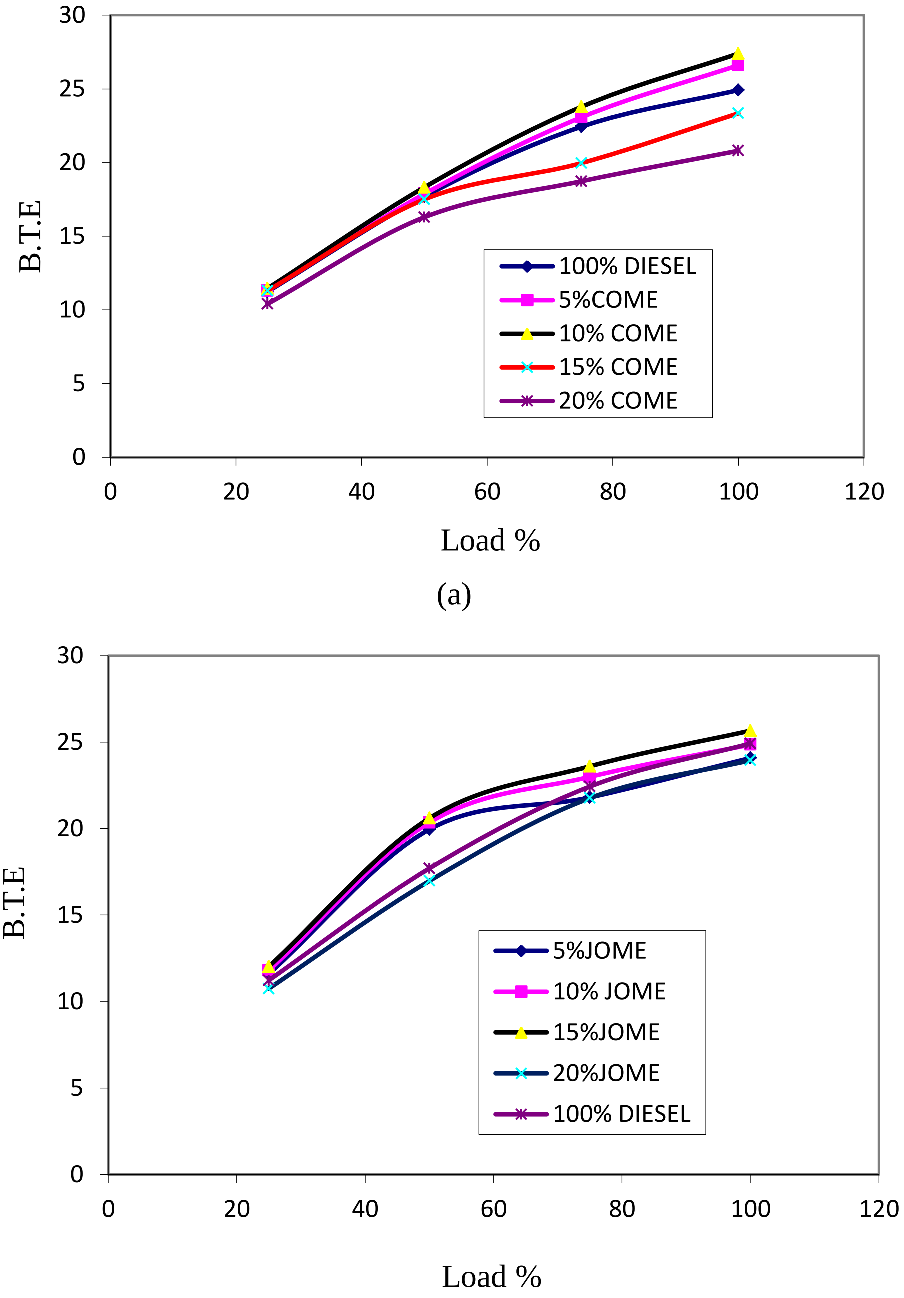
Figure 4. (a) Single cylinder diesel engine, (b) Rope brake dynamometer.

RESULTS AND DISCUSSION

Effect of Loading on Brake Thermal Efficiency

Figure 5a and5b depict brake thermal efficiency versus load for diesel COME and diesel JOME fuel blends, respectively. It was noticed that for all the fuels blends, brake thermal efficiency had the tendency to increase with an increase in the applied load. This is due to the reduction in heat loss and increase in power developed with an increase in load [2]. The figure shows a slight improvement in brake thermal efficiency with biodiesel addition up until the13% substitution level for COME and18% for JOME. The molecules of biodiesel contain some amount of oxygen, which takes part in the combustion process [1, 2, 4, 8]. It was observed that after a certain limit with respect to biodiesel blend the thermal efficiency trend is reverted and it starts decreasing as a function of the concentration of biodiesel in the blend. This may be due to improved combustion with a lower percentage substitution of biodiesel in diesel and this effect being offset in a higher substitution due to lower calorific value [1]. The maximum thermal efficiency has been observed at 13% substitution of COME in diesel and 18%

for JOME. The lower brake thermal efficiency obtained for COME20 & JOME20 could be due to the reduction in calorific value and an increase in fuel consumption compared with lower concentration biodiesel diesel blends. It has been observed that brake thermal efficiency at full load for COME20isbetween 24.92 and 20.8% for JOME20, and dieselis23.95% and 20.8%, respectively, suggesting that brake thermal efficiency for the biodiesel20 blend is comparable with diesel.



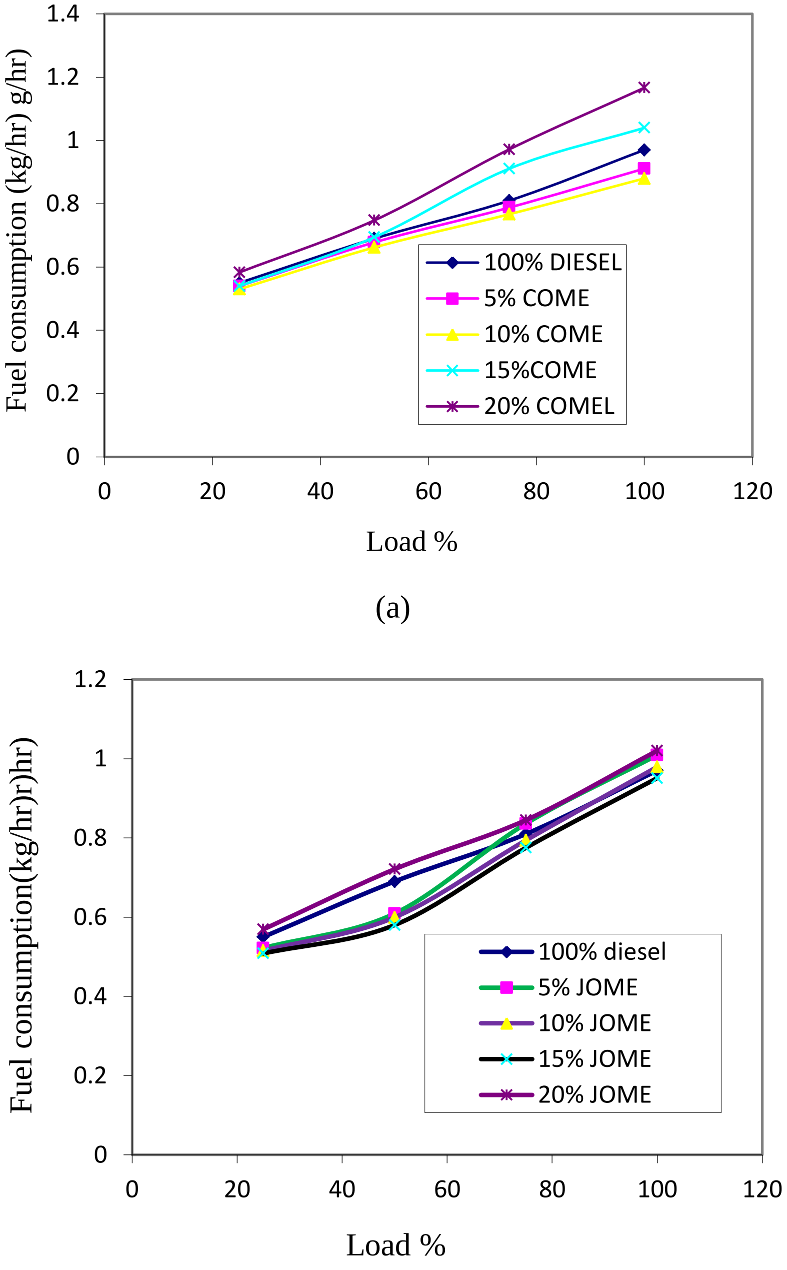
(a)

(b)

Figure 5. Brake thermal efficiency versus load for (a) COME and (b) JOME blends.

Effect of Load on Brake-specific Fuel Consumption

Figure 6a and6b show the effect of load on brake-specific fuel consumption. More fuel is consumed with the increase in the load for all the blends. The optimum fuel blend is determined by taking the average of the results. It can be seen that more fuel is consumed when the percentage of biodiesel is increased beyond 13% and 18% for COME and JOME blends, respectively. This is because diesel has more calorific value compared with that of biodiesel [1, 2, 4, 8]. Therefore, COME13 and JOME18 are the recommended fuel blend when all the test fuels are compared with respect to BSFC against load over the entire range of engine operations.



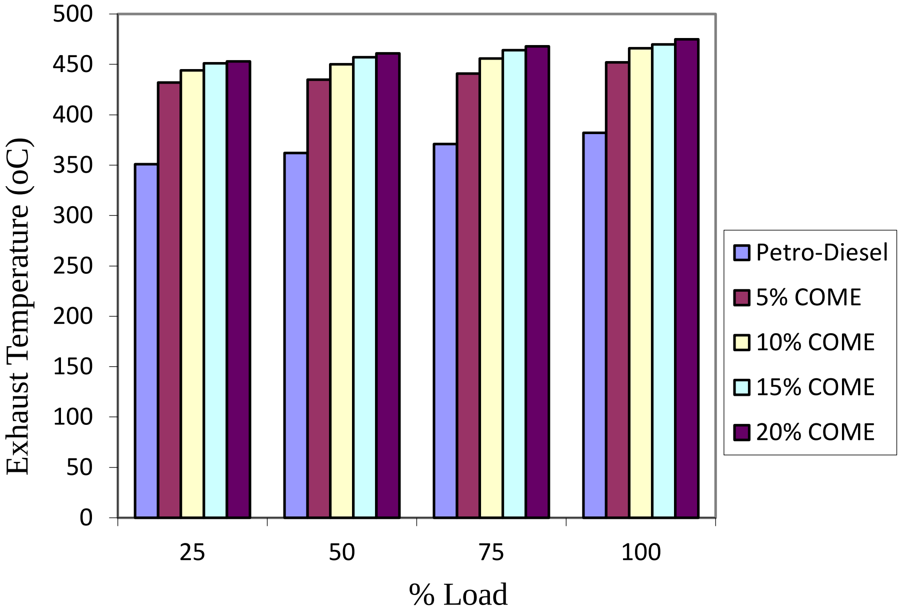
(a)

(b)

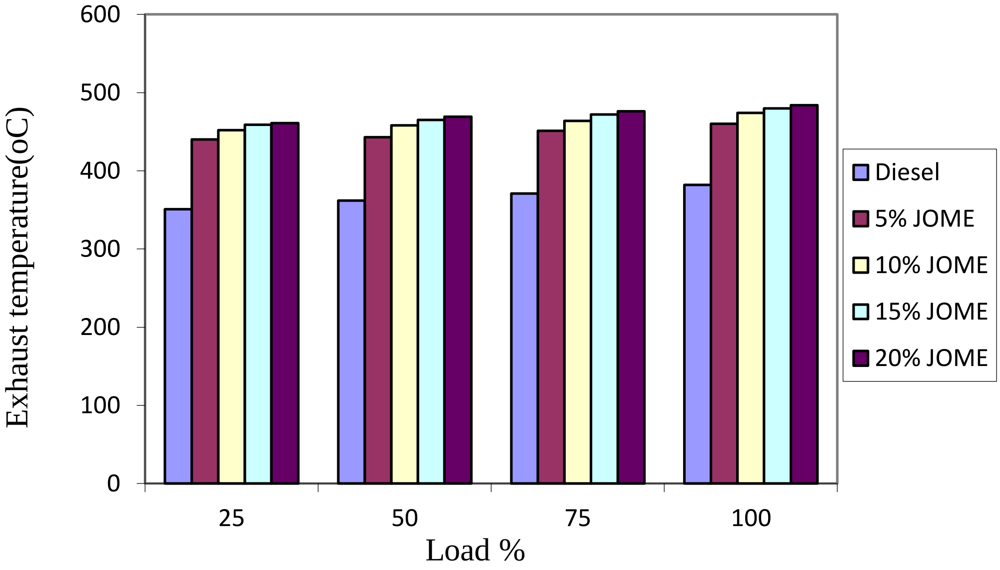
Figure 6. Fuel consumption versus load for (a) COME and (b) JOME blends.

Effect of Loading on Engine Exhaust Temperature

The engine exhaust gas temperature measurements for castor and jatropha biodiesel blends are shown in Figure 7a and 7b. The figure shows that for mineral diesel fuel the temperature is less compared with biodiesel-blended fuel mixtures. This is basically due to the lower burning temperature which is developed in the combustion chamber when using mineral diesel as fuel. Biodiesel, which has a higher oxygen content (as well as a higher flash point) tends to burn at higher temperatures than mineral diesel fuel [1, 2, 4, 8]. In methyl esters heat release always takes place in advance compared with diesel and injection also starts earlier in the case of biodiesel as a fuel and average cylinder gas temperature was observed to be higher in the case of biodiesel as a fuel [1].



(a)



(b)

Figure 7. Engine exhaust temperature for different load using five fuel types.

TWO WAY ANOVA (ANALYSIS OF VARIANCE) OR F TEST

Statistical ANOVA Test (Fuel Consumption with % of Load)

Two way ANOVA tests were conducted on five fuel types for the observed data shown in Table 5.After the application of the ANOVA test, Table 6 was formed. For $\nu_{4,12}$, table value of $F_{0.05}$ =3.26, which is more than the calculated value (2.397), the null hypothesis holds true, hence there is no significant effect on fuel consumption with the fuel type. For $\nu_{3,12}$, table value of $F_{0.05}$ =3.49, which is less than the calculated value (25.38), the null hypothesis is rejected, hence there is a significant effect on fuel consumption with % of load. Similarly, results were obtained for the JOME blends shown in Table 5. For $\nu_{4,12}$table value of $F_{0.05}$, = 3.26, which is more than the calculated value (1.67), the null hypothesis holds true, hence there is no significant effect on fuel consumption with the fuel type. For $\nu_{3,12}$table value of $F_{0.05}$, =3.49, which is less than the calculated value (78.92), the null hypothesis is rejected, hence there is a significant effect on fuel consumption with % of load [1, 2, 4, 8].

Table 5. Observed data for COME and JOME blends.

Load/ fuel type	Diesel	COME 5 / JOME 5	COME 10 / JOME 10	COME 15/ JOME 15	COME 20 / JOME 20
25%	0.55	0.54 / 0.522	0.53 / 0.515	0.54 / 0.508	0.583 / 0.569
50%	0.69	0.678 / 0.609	0.662 / 0.599	0.694 / 0.58	0.747 / 0.721
75%	0.81	0.788 / 0.836	0.767 / 0.793	0.911 / 0.775	0.972 / 0.845
100%	0.97	0.911 / 1.009	0.88 / 0.979	1.04 / 0.951	1.166 /1.02

Table 6. ANOVA table for COME and JOME blends.

Source of variation	Sum of squares (COME / JOME)	Degrees of freedom	Mean square (COME / JOME)	Variation ratio or F	F Table value (COME / JOME)
Between fuel type	0.06272 / 0.0167	4	0.01568 / 0.004175	F_{COME}=0.01568/0.00654 = 2.397 F_{JOME} =0.004175 / 0.0025 = 1.67	3.26 / 3.26
Between load %	0.5 / 0.59	3	0.166 / 0.197	F_{COME}= 0.166/0.00654 = 25.38F_{JOME}= 0.1973 / 0.0025 = 78.92	3.49 / 3.29
Residual	0.0785 / 0.03	12	0.00654 / 0.0025		
Total	0.641 / 0.636	19			

Statistical ANOVA Test (Thermal Efficiency with % of Load)

Two-way ANOVA tests were conducted on five fuel types for the observed data shown in Table 7. After application of ANOVA test, Table 8 was formed. For $\nu_{4,12}$, table value of $F_{0.05}$ =3.26, which is less than the calculated value (5.75), the null hypothesis is rejected, hence there is a significant effect on thermal efficiency with the fuel type. For $\nu_{3,12}$, table value of $F_{0.05}$ =3.49, which is less than the calculated value (120.38), the null hypothesis is rejected, hence there is a significant effect on thermal efficiency with the % of load. Similarly for JOME blends Table 7 shows the observed data. For $\nu_{4,12}$, table value of $F_{0.05}$ =3.26, which is less than the calculated value (5.69), the null hypothesis is rejected, hence there is a significant effect on thermal efficiency with the fuel type. For $\nu_{3,12}$, table value of $F_{0.05}$ =3.49, which is less than the calculated value (354.766), the null hypothesis is rejected, hence there is a significant effect on thermal efficiency with the % of load.

Table 7. Observed data for COME and JOME blends.

Load/ fuel type	Diesel	COME 5 / JOME 5	COME 10 / JOME 10	COME 15 / JOME 15	COME 20 / JOME 20
25%	11.23	11.3 / 11.6	11.45 / 11.8	11.3 / 12.02	10.4 / 10.75
50%	17.7	17.87 / 19.95	18.32 / 20.35	17.5 / 20.6	16.29 / 16.97
75%	22.43	23.07 / 21.8	23.78 / 23.6	19.96 / 23.6	18.73 / 21.76
100%	24.9	26.604 / 24.08	27.4 / 25.66	23.34 / 25.66	20.8 / 23.95

Table 8. ANOVA table for COME and JOME blends.

Source of variation	Sum of squares (COME / JOME)	Degrees of freedom	Mean square	Variation ratio or F	F Table value
Between fuel type	32.44 / 10.75	4	8.11 / 2.689	F_{COME}=8.11/1.41 = 5.75 F_{JOME}= 2.689 / 0.4720 = 5.69	3.26 / 3.26
Between load %	509.22 / 502.35	3	169.74 / 167.45	F_{COME} = 169.74/1.41 = 120.38 F_{JOME} = 167.45 / 0.4720 = 354.766	3.49 / 3.49
Residual	17.036 / 5.6651	12	1.41 / 0.472		
Total		19			

Economics Related to Biodiesel Production

Due to a substantial increase in the market price of diesel in recent years, the cost of biodiesel is coming closer to that of petroleum diesel. If this situation were to prevail for a somewhat longer duration, it may motivate oil producers to divert oil production to biodiesel production. In an attempt to study the possible role of various parameters, a formula has been devised, as shown in Eq. (2):

$$E \le \frac{[(A/B)-C]}{D} \qquad (2)$$

where *A* is the unit price of petroleum diesel; *B* is the ratio of calorific value of petroleum diesel to the calorific value of biodiesel or biodiesel equivalent of petroleum diesel. As the calorific value of biodiesel is less compared with the calorific value of petroleum diesel, the calorific value of biodiesel of jatropha oil = 37 MJ/Kg and calorific value of petroleum diesel= 42 MJ/Kg, so the value of B = 42/37 =1.135; *C* is the processing cost per litre of biodiesel from oils; *D* is the amount of oil required per litre of biodiesel (varies from 1.1 to1.2); and *E* is the maximum possible market price of oil to be used as feedstock for biodiesel production. Table 9 represents the variation of the maximum possible price of oil (as feedback for biodiesel production) with the price of petroleum diesel.

Table 9. Variation of the maximum possible price of oil.

S. No	Unit petroleum diesel price A (Rs/Litre)	Maximum allowable unit price of oil E (Rs/Litre)
1	20	9.26
2	30	16.60
3	40	23.95
4	50	31.29
5	100	68

Considering B = 1.135, C = 6.5, D = 1.2.

CONCLUSIONS

Jatropha oil methyl ester and castor oil methyl ester were prepared and mixed with diesel in four different proportions, i.e. 5%, 10%,15%, and 20%. With these blends short-term engine performance tests at varying loads were conducted. The engine parameters were recorded and compared. The best engine operating condition based on lower brake specific fuel consumption and higher brake thermal efficiency were identified. The maximum thermal efficiency was observed at 13% substitution of COME in diesel and 18% for JOME in diesel. Statistically the obtained parameters were checked with the help of the F test, which indicated that there is no significant effect on fuel consumption with the fuel type, there is a significant effect on fuel consumption with % of load, there is a significant effect on thermal efficiency with the fuel type, and there is a significant effect on thermal efficiency with the % of load. These trends indicated that blends in the ratio of 0–20% by volume of biodiesel can be added to neat diesel since the results are similar in nature to those obtained with neat diesel. A formula has been devised that takes into account the different factors which will motivate oil producers to divert oil production towards biodiesel production. Based on the formula, oil producers will have an idea of what point it will be beneficial to divert the oil production towards biodiesel production. Based on the obtained results it is recommended that:

i) 13% COME by volume has to be added to neat diesel to get better results with the engine.
ii) Following the same pattern,18% JOME by volume has to be added to neat diesel as fuel to get better results.
iii) The formula $E \leq [(A/B) - C]/D$ can be used as a parameter by oil producers to evaluate whether to divert oil production towards biodiesel production.

ACKNOWLEDGMENTS

Authors would like to thanks Manav Rachna International University for providing laboratory facilities and funding for carrying out the engine tests in the Internal Combustion Engine Laboratory of the University.

REFERENCES

[1] Agarwal AK, Das L. Biodiesel development and characterization for use as a fuel in compression ignition engines. Journal of Engineering for Gas Turbines and Power. 2000;123:440-7.

[2] Agarwal AK. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in Energy and Combustion Science. 2007;33:233-71.

[3] Ma F, Hanna MA. Biodiesel production: a review. Bioresource Technology. 1999;70:1-15.

[4] Sahoo P, Das L, Babu M, Naik S. Biodiesel development from high acid value polanga seed oil and performance evaluation in a CI engine. Fuel. 2007;86:448-54.

[5] Kamil M, Rahman MM, Bakar RA. Performance evaluation of external mixture formation strategy in hydrogen fueled engine. Journal of Mechanical Engineering and Sciences. 2011;1:87-98.

[6] Kamil M, Rahman MM, Bakar RA. Integrated simulation model for composition and properties of gases in hydrogen fueled engine. International Journal of Automotive and Mechanical Engineering. 2013;8:1242-155.

[7] Kamil M, Rahman MM, Bakar RA. An integrated model for predicting engine friction losses in internal combustion engines. International Journal of Automotive and Mechanical Engineering. 2014;9:1695-708.

[8] Usta N. Use of tobacco seed oil methyl ester in a turbocharged indirect injection diesel engine. Biomass and Bioenergy. 2005;28:77-86.

[9] Sudhir C, Sharma N, Mohanan P. Potential of waste cooking oils as biodiesel feedstock. Emirates Journal for Engineering Research. 2007;12:69-75.

[10] Yu C, Bari S, Ameen A. A comparison of combustion characteristics of waste cooking oil with diesel as fuel in a direct injection diesel engine. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. 2002;216:237-43.

[11] Kumar Tiwari A, Kumar A, Raheman H. Biodiesel production from jatropha oil (Jatropha curcas) with high free fatty acids: An optimized process. Biomass and Bioenergy. 2007;31:569-75.

[12] Pramanik K. Properties and use of Jatropha curcas oil and diesel fuel blends in compression ignition engine. Renewable Energy. 2003;28:239-48.

[13] Nayak C, Pattanaik BP, Nayak SK. Effect of preheated jatropha oil and jatropha oil methyl ester with producer gas on diesel engine performance. International Journal of Automotive and Mechanical Engineering. 2014;9:1709-22.

[14] Chakrabarti MH, Ali M. Performance of compression ignition engine with indigenous castor oil biodiesel in Pakistan. NED University Journal of Research. 2009;6:10-9.

[15] Naik M, Meher L, Naik S, Das L. Production of biodiesel from high free fatty acid Karanja (Pongamia pinnata) oil. Biomass and Bioenergy. 2008;32:354-7.

[16] Bari S, Yu C, Lim T. Performance deterioration and durability issues while running a diesel engine with crude palm oil. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. 2002;216:785-92.

[17] Mat Yasin MH, Mamat R, Sharma KV, Yusop AF. Influence of palm methyl ester (PME) as an alternative fuel in multicylinder diesel engine. Journal of Mechanical Engineering and Sciences. 2012;3:331-9.
[18] Oliveira LS, Franca AS, Camargos RR, Ferraz VP. Coffee oil as a potential feedstock for biodiesel production. Bioresource Technology. 2008;99:3244-50.
[19] Ghadge SV, Raheman H. Biodiesel production from mahua (Madhuca indica) oil having high free fatty acids. Biomass and Bioenergy. 2005;28:601-5.
[20] Ramadhas AS, Jayaraj S, Muraleedharan C. Biodiesel production from high FFA rubber seed oil. Fuel. 2005;84:335-40.
[21] Chisti Y. Biodiesel from microalgae. Biotechnology Advances. 2007;25:294-306.
[22] Sinha S, Agarwal AK, Garg S. Biodiesel development from rice bran oil: Transesterification process optimization and fuel characterization. Energy Conversion and Management. 2008;49:1248-57.
[23] Nelson RG, Schrock MD. Energetic and economic feasibility associated with the production, processing, and conversion of beef tallow to a substitute diesel fuel. Biomass and Bioenergy. 2006;30:584-91.
[24] Chiu C-W, Schumacher LG, Suppes GJ. Impact of cold flow improvers on soybean biodiesel blend. Biomass and Bioenergy. 2004;27:485-91.
[25] Ghai S, Das L, Babu MG. Emissions and performance study with sunflower methyl ester as diesel engine fuel. ARPN Journal of Engineering and Applied Sciences. 2008;3(5):75-80.
[26] Chhetri AB, Tango MS, Budge SM, Watts KC, Islam MR. Non-edible plant oils as new sources for biodiesel production. International Journal of Molecular Sciences. 2008;9:169-80.