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Original Research Article

Performance of single-cylinder compression ignition engine with indigenous castor oil bio diesel

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Abstract

Neat castor oil poses problems when used in CI engine. Problems are reduced to minimum by subjecting the castor oil to transesterification. Castor oil was converted to bio diesel and blended by 5%, 10%, 15% and 20% in quantity (by volume) with high-speed mineral diesel (HSD) fuel. This fuel was used on a single-cylinder compression-ignition, four-stroke diesel engine. The blended fuel gave lower emissions of CO but resulted in higher values of CO_2 and NO_x. Results showed that engine brake power, thermal efficiency for blended bio diesel fuel were lower than pure mineral diesel, because of lower calorific value of blended fuel. The maximum value of thermal efficiency was observed at 13% substitution of castor oil methyl ester [CME] in diesel. However, higher engine exhaust temperatures were obtained with blended fuel in comparison with that of pure mineral diesel. Chi square ($\chi 2$) statistical test was applied. The value for $\chi 2$ (CME) 0.0524 was observed. The value concluded that there is no effect of fuel type on fuel consumption within the given range. Overall castor oil bio diesel blends fared well in terms of engine performance.

Keywords: Castor Oil Methyl Ester, engine, biodiesel, vegetable oil, performance, emissions.

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1. Introduction

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground based carbon resources. The search for an alternative fuel, which promises a harmonious correlation with sustainable development, energy conservation, and environmental preservation, has become highly pronounced in the present context. For the developing countries of the world, fuels of bio-origin can provide a feasible solution to the crises. The fuels of bio-origin may be alcohol, vegetable oils, biomass, and biogas. Some of these fuels can be used directly while others need to be formulated to bring the relevant properties close to conventional fuels. Given the recent widespread use of diesel fuel in various sectors, this study concentrates on assessing the viability of using castor oil biodiesel blends in the existing diesel engines.

Naveen kumar [1] in his research concluded that petroleum based fuels shall be completed exhausted by the turn of 22nd century. Petroleum fuels tend to produce harmful emission products of combustion that cause major damage to the ecological environment [2]. Such alarming impacts are easily visible within the urban environments. As a result, a new alternative is being sought in order to try and circumvent the damage caused by harmful pollutants into the environment. In this respect, bio diesel has emerged as an ideal candidate for gradually replacing mineral diesel fuel in the near future. Bio diesel has shown tremendous environmental benefits as an alternative fuel [2-6]. Non-edible oil varieties have been investigated in the literature, such as jatropha, polonga, tobacco, rice bran, castor, karanja and soapnut [3-9]. The high viscosity, low volatility and poor cold flow properties of oils, results in severe engine deposits, injector coking and piston ring sticking, preventing them from being used directly in diesel engines [11]. Community scale biodiesel production is a new concept and should be adopted by developing countries like India [12]. Vegetable oils alone can be used only for small engines for a short-term period. For long-term use and for heavy/big engines, blend of diesel and vegetable oils is recommended [13]. It will be expensive and time consuming to incorporate even a minor design alteration in the system hardware of a large number of existing engines operating in the rural agricultural sector of the country. Energetics is presented in the form of an ER defined as the thermal energy of the fuel divided by the fossil-based thermal energy required to transform oil bearing seed into biodiesel [14]. Biodiesel can be used most effectively as a supplement to other energy forms, not as a primary source [15]. Transesterification reaction parameters control the yield of the ester, whilst catalyst removal is required for purification of the ester to make it suitable fuel for diesel engines [16]. Castor oil has became a promising candidate for biodiesel production [17]. The castor bean plant has a greater ability to grow on marginal lands and is high non-edible oil yielding plant and this formed the basis for its selection as a potential candidate for production of biodiesel. In the present work properties of castor oil were formulating closer to the conventional diesel oil and then evaluated in a compression-ignition engine as a potential resource. Chi square ($\chi 2$) statistical test was then applied to test whether the fuel consumption has any significant effect with the fuel type when used in the single cylinder diesel engine. System design approach was taken care of to see that these modified fuels could be utilized in the existing diesel engine without any substantial hardware modifications.

2. Castor Plant

2.1 Introduction

Castor seeds contain 40% to 60% of oil by weight and are rich in triglycerides, mainly ricinolein. The seed contains a toxin called ricin, which is also present in lower concentrations throughout the plant. Global castor seed production is around 1 million tons per year. Leading producing countries are India (with over 60% of the global yield), China and Brazil. The top ten castor seed producing countries of world are shown in the table 1. Castor plant plates are shown in figure 1 and 2.

Table 1 Top ten castor oil seed producers—11 June 2008 [10]

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

Fig. 1 Castor plant

Fig. 2 Castor Pod

3. Experimental Procedure & Test Results

3.1 Composition of Castor Oil

Fatty acid composition of castor oil of castor oil is shown in the table 2a. The acid number of castor oil was evaluated by ASTM D-664 to quantify the FFA content in the oil. The acid number was determined as 14 which was very high and indicated FFA content (7%) in the oil. Therefore it was not considered suitable to make biodiesel from this oil through base catalyzed transesterification process. Castor oil was converted into its methyl ester by two stage process i.e. two stage integrated pre-transesterification of free fatty acid and base catalyzed transesterification process. The conditions required and the materials chosen for both the two stages are shown in table 2b.

Table2a. Fatty acid composition of castor oil

Fatty Acid	Values (wt. %)
Linoleic	90.2
Estearic	2.8
Dihidroxiest earic	0.7
Linolenic	0.3
Ricinoleic	4.4
Oleic	0.9
Palmitic	0.5
Licosanoic	0.2

Table 2b Conditions required and the materials chosen

Stage one	I	II
Catalyst type	H_2SO_4	KOH
Catalyst (%wt/wt of oil)	1	2
Methyl alcohol(%wt/wt of oil)	15	20
Temp	67	67
Speed (RPM)	500	500

During the first stage castor oil was reacted with methyl alcohol in the presence of an acid catalyst (sulphric acid) to convert the FFA into fatty esters. 7 kg of oil was taken in the reactor and heated up till 67°C. In a separate flask methanol and H_2SO_4 were taken and properly mixed and then transferred to the reactor containing castor oil. The contents were stirred for 2.5 hours. It was then allowed to cool overnight. Prior to second stage the acid no of the mixture was evaluated and since the acid number was found to be less than 1 the second stage was started. Castor oil having less acid number was taken inside the reactor (fig. 3) and heated at 67 ºC. This temperature is maintained throughout the reaction by the heater and thermostat placed inside the container. The transesterification is carried out in basic medium by KOH which acts as a catalyst. Catalyst is first dissolved in alcohol. Once the oil temperature reached 67 ºC, alcohol solution (containing dissolved catalyst) is added to the reactor and an equilibrium temperature is maintained. Biodiesel reactor is shown in figure 3. During the reaction, vaporization of alcohol takes place. To prevent this condenser is used to condense the alcohol vapor and reflux it back in the reactor. Once the reaction is over the products are taken out through the outlet and placed in the separating funnel. Two phases (having different density) are formed as a result of transesterification in the funnel. Upper layer consists of bio-diesel (CME), alcohol and soap while the lower layer consists of glycerin, excess alcohol, catalyst, impurities, and traces of unreacted oil. CME obtained from the upper layer is blended with diesel on volumetric basis as shown in table 3. The blended fuels are shown in figure 4.

The physio chemical characterization of CME and diesel was carried out in accordance with appropriate ASTM standards and all the properties of methyl ester were found under prescribed limits. Fuel properties of castor oil, castor biodiesel and high speed diesel are listed in table 4.

Fig.3 Biodiesel reactor

Table3. Blend Ratio's prepared

Sr. No.	Nomenclature	CME Diesel blend CME %	Diesel %
01	D100	00	100
02	CME5	05	95
03	CME10	10	90
04	CME15	15	85
04	CME20	20	80

Fig.4 Fuel Samples

Table4. Fuel properties

Parameters	High speed diesel	Castor oil	Castor biodiesel 5%	Castor biodiesel 10%	Castor biodiesel 15%	Castor biodiesel 20%	Castor biodiesel 100%	Test method
Density at 25 °C, kg/m^3	810	950	815	820	825	830	905	ASTM D 4052
Kinematic viscosity, mm^2/sec.	3.05	230	-	-	-	-	12.5	ASTM D 445
Flash point, °C	53	305	55	57	58	61	115	ASTM D 93
Fire point, °C	56	320	57	60	62	65	121	
Calorific value, kj/kg	44580		44291	44000	43713	43424	38800	
Cetane Index	46	43					50	ASTM D 976

3.2 Engine test

A Four-stroke single cylinder diesel engine with mechanical rope brake loading was used for the study. The engine is used for agricultural and commercial purposes. It is a single cylinder, four stroke, vertical, water-cooled engine having a bore and stroke of 80 and 110 mm respectively. The compression ratio was 16.5 at rated speed of 1500rpm. It has a provision of loading through rope brake dynamometer. The inlet valve opens at 4.5^o before top dead center (BTDC) and closes at 35.5^o after bottom dead center (ATDC) the exhaust valve opens 35.5^o before bottom dead center (BBDC) and closes 4.5^o after top dead center (ATDC). The fuel injection pressure was maintained at 200 bar throughout the experiment .The engine was tested with Diesel, B5, B10, B15 and B20 at 25%, 50%, 75% and 100% load at a constant speed of 1500 rpm. The engine has run smoothly through the whole study and no major problem was reported. The experimental set up is shown in figure 5 and 6.

Fig.5 Single Cylinder Diesel Engine

Fig.6 Rope Brake Dynamometer

3.3 Exhaust Gas Analyzer

The exhaust gas composition was measured using exhaust gas analyzer. It measures NO_x, CO_2, CO, HC and O_2 in the exhaust gases. The basic principle for measurement of these emissions is a non-diffractive infrared radiation (NDIR) and an electrochemical method for oxygen measurement. Measurement range and resolution for different gases by the exhaust gas analyzer used are given in table 5.

Table 5. Exhaust gas analyzer specifications

Exhaust gas	Measurement range	Resolution
NO_x	0-40000 vol. ppm	1 vol. ppm
CO	0-10 vol.%	0.01 vol. %
CO_2	0-20 vol %	0.1vol. %
HC	0-20000 ppm	1 ppm
O_2	0-22 vol %	0.01 vol.%

3.3.1 Engine test conditions

1. The engine was started without any load. The speed was noted as 1500 rpm.
2. Before starting of the test, the engine was kept running running for 30 minutes to get stabilized and there after stabilization period of 10 minutes was allowed for subsequent tests. At first the tests were conducted using neat diesel as fuel by varying the load from 0% (idle load) to 100% and engine speed was kept constant.
3. The selected load on the engine was applied. The engine was kept running under the desired load condition for 10 minutes.
4. At each operating condition of load, time for consumption of 10cc of fuel was noted along with difference in U tube manometer, air inlet temperature, exhaust temperature and reading of the exhaust emissions (CO, CO_2, NO_x, HC, O_2) were recorded.
5. The same procedure was repeated for testing the prepared fuel blends. After completion of the tests on one of the fuel blends, the remaining test fuel from the fuel tank was drained off fully to avoid any mixing of the prepared fuel. Then the

next prepared fuel blend was filled into the fuel tank and the engine was run for 15 minutes duration for its stabilization and combustion of remaining fuel in the pipeline as well as in the injection systems.

6. The experiments were conducted for each blend and three replications were made on each setting of independent variables. The results of engine performance and emission characteristics were compared with that of neat diesel.

3.4 Engine performance

Engine performance was measured using 100% HSD, B5, B10, B15 and B20 only. This blend ratio was selected because it is practically viable to have this ratio because of low availability of biodiesel and also it is in line with the intention of the Government of India to blend up to 10% biodiesel with mineral diesel for the automobile sector. When the engine reached the stabilized working condition, brake power, engine torque, and exhaust temperature were measured and analyzed.

3.4.1 Engine exhaust temperature

Variation of exhaust gas temperatures at full load and at constant rpm of 1500 for five different fuel types (i.e HSD (high speed diesel), castor B5, B10, B15, B20) are shown in figure 7. The exhaust gas temperature measurements showed that for diesel fuel the temperature is less as compared to biodiesel blended fuel mixtures. This is basically due to a lower burning temperature developed in the combustion chamber when using mineral diesel as fuel as compared to biodiesel blends this is in agreement with earlier research in this field [5]. The possible cause of higher temperature of exhaust may be that the fuel is pumped to the cylinders on volumetric basis, therefore higher density of the blends provides larger mass flow rate for the same fuel volume. CME contains some amount of oxygen that takes part in combustion and this may be a possible reason for more complete combustion. The oxygen molecule present in biodiesel molecular structure may be readily available for oxygen [1].

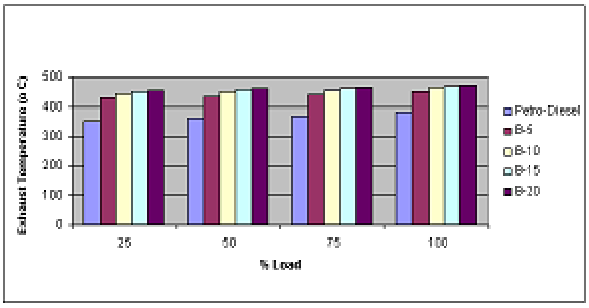

Fig. 7 Engine exhaust temperature for different load using five fuel types

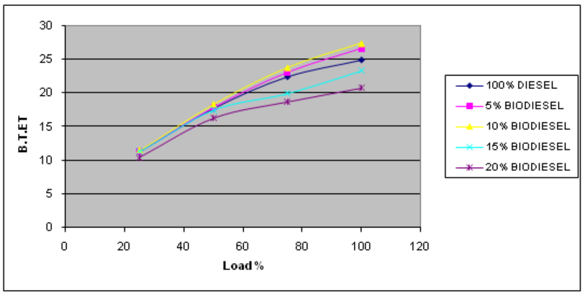

Fig. 8 Brake Thermal Efficiency vs Load

3.4.2 Brake Thermal Efficiency

Dependence of brake thermal efficiency on load for all selected fuel blends is shown in figure 8. It was noticed that for all the fuels, brake thermal efficiency has the tendency to increase with increase in the applied load. This means that the combustion of the blends was completed more efficiently than the combustion of the diesel fuel [5]. Another reason for the same is that there remains the same value of frictional losses but increase in power developed. The figure shows a slight improvement in BTE with biodiesel addition up till 10% substitution level. The molecules of biodiesel contain some amount of oxygen, which takes part in the combustion process. 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 lower percentage substitution of biodiesel in diesel and this effect being offset at higher substitution due to lower calorific value of biodiesel. The maximum thermal efficiency has been observed at 13% substitution of CME in diesel. The lower brake thermal efficiency obtained for B20 could be due to the reduction in calorific value and increase in fuel consumption as compared to lower concentration of biodiesel diesel in the blend. The above results are in agreement with the results reported by other researchers [1], [4], and [7]. It has been observed that BTE at full load for diesel and B20 are 24.92% and 20.8 % respectively suggesting that BTE for B20 is comparable with diesel.

3.4.3 Mechanical Efficiency

Figure 9 shows the chart between mechanical efficiency and load for five different fuels. The chart is comparable with that of diesel. With increasing amount of biodiesel, the frictional horsepower losses in the engine follow a declining trend. Long duration non-engine tests with CME biodiesel blends needs to be conducted in order to evaluate the coefficient of friction, specific wear rates etc.

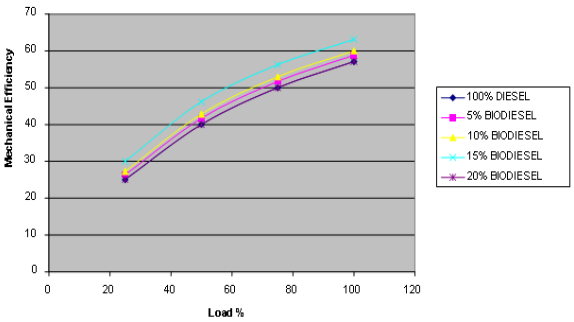

Fig. 9 Mechanical efficiency vs Load

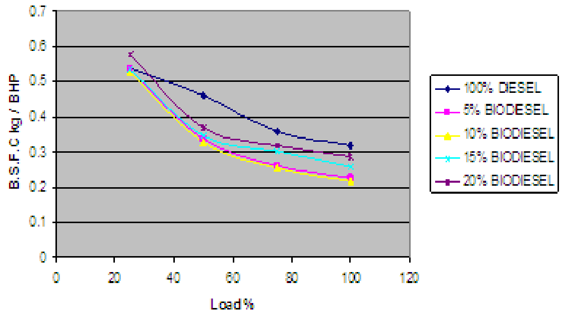

Fig. 10 Brake specific fuel consumption (kg/hr-B.H.P) vs Load %

3.4.4 Fuel Consumption vs Load

The dependence of brake specific fuel consumption on load is shown in figure 10. More amount of blended fuel is consumed when the percentage of biodiesel is increased beyond 13 % this is because diesel has more calorific value as compared to that of biodiesel blended fuel.

4. Engine emissions

Because of high viscosity and less availability of raw material castor biodiesel with maximum blend ratio of 20% by volume (B 20) was used in the engine tests. The emissions of CO_2, CO, and NO_x, against fuel type are shown in Figs. 11 to 13, with exception to the increases in carbon dioxide and oxides of nitrogen emissions with more biodiesel blended in the fuel mixtures, CO pollution parameter was found to decrease. Results were similar to those reported by other research workers [7].

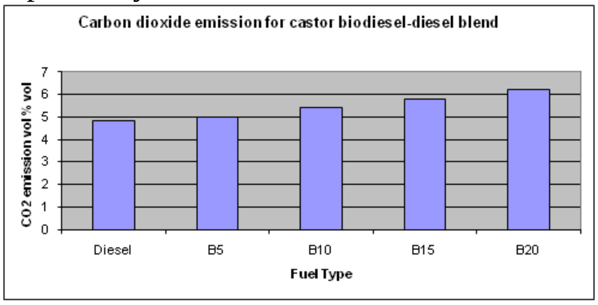

Fig. 11 CO_2 Emission

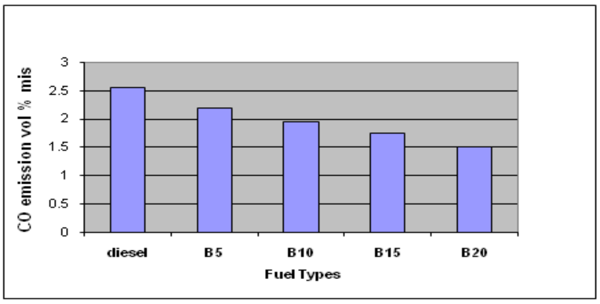

Fig. 12 CO Emission

High value of CO_2 (fig. 11) is due to the presence of more carbon atoms as well as higher oxygen content in biodiesel fuel. CME contains some amount of oxygen that takes part in combustion and this may be a possible reason for more complete combustion. The oxygen molecule present in biodiesel molecular structure may be readily available for oxygen [1].

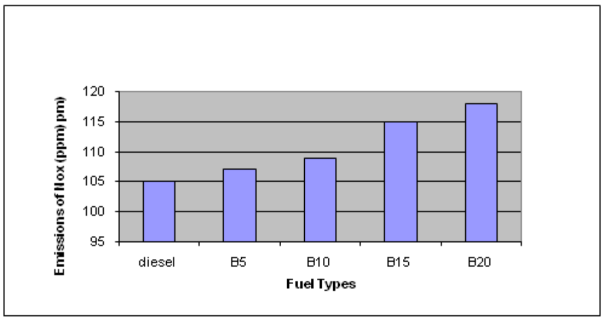

Fig. 13 NO_x Emission

Figure 12 shows the trends for CO, which suggests less formation of CO and complete combustion of fuel due to in built oxygen in the biodiesel. There are mainly three factors affecting NO_x emission; oxygen concentration, combustion temperature and time.

The higher temperatures of combustion chamber and the presence of fuel oxygen with CME caused higher NO_x emissions, especially at full load. Also, it is known [5] that the external oxygen supplied with air is less effective than the fuel-borne oxygen in the production of NO_x. Since the burning temperature is higher, because of this, tendency for the formation of NO_x will be higher in the blended fuels as compared to that of diesel. Figure 13 shows this tendency.

8. Chi square (χ^2) test for any significant effect on use of fuel type

Chi square (χ^2) test was applied for different blends of castor biodiesel blend at 100% load to check that if fuel consumption has any significant effect with the fuel type for the given fuels. The test was applied for the data given in the table 6.

Table 6 Fuel Type vs Fuel Consumption

Fuel type	Fuel consumption (Kg/Hr)
Diesel	0.97
CME 5	0.911
CME 10	0.88
CME 15	1.04
CME 20	1.166

The formulae applied is given by the equation 1 given below

$$\chi^2 = \sum \frac{(O-E)^2}{E} \qquad \text{(Eq 1)}$$

Where

O = Observed frequency

E = Expected or theoretical frequency

The values obtained for chi square on putting in the formulae is given as under

χ^2 (CME) = 0.0524

For four degrees of freedom $\chi^2_{0.05}$ = 9.49 (from the χ^2 table) the calculated value is much less than the table value. The assumed null hypothesis is accepted hence we can conclude that there is no significant effect of fuel type on fuel consumption within the given range for COME blends and diesel when used in the single cylinder diesel engine.

5. Conclusions

Following conclusions may be drawn from the study reported in this paper.

1. Blended biodiesel fuel gives less emission than mineral diesel, except for carbon dioxide and NO_x. Higher CO_2 is released due to higher oxygen and carbon contents of biodiesel, thus signifying complete combustion of the fuel in compression-ignition engines. Higher NO_x releases are due to higher temperatures of combustion than mineral diesel fuel and more amount of oxygen available in the combustion chamber.
2. The brake specific fuel consumption is lowest for blend ratio of 13. After this ratio (blend ratio more than 13) brake specific fuel consumption starts increasing. This is mainly because of a lower calorific value of bio diesel in comparison to diesel.
3. Engine exhaust temperatures of blended biodiesel fuel mixtures are higher than that of pure mineral diesel, mainly due to the presence of oxygen content in biodiesel (proper combustion taking place with biodiesel blends).
4. Statistically the obtained parameters were checked with the help of the chi square test

which indicated that for the given range there is no significant effect of fuel type on fuel consumption.

Overall, castor oil bio diesel was found to give an engine performance which is comparable to that of diesel .This result is very positive because castor oil is not only non-edible but the castor bean plant can easily grow on marginal lands, thus making it a very valuable raw material for biodiesel production in India.

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