Production of biodiesel from Jatropha curcas and performance along with emission characteristics of an agricultural diesel engine using biodiesel

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Abstract

The objective of the present experimental work is the production of biodiesel and to examine the effects of different blends of biodiesel with diesel on the exhaust emission and performance characteristics of an existing agricultural diesel engine and to select a suitable blend of biodiesel with diesel. The suitability of a blend of biodiesel with diesel is related with the reduction in exhaust emissions and brake specific fuel consumption (BSFC), together with an increase in brake thermal efficiency (BTE). Experimental work started with the production of biodiesel obtained from Jatropha curcas in our own mini biodiesel plant. Biodiesel is blended with diesel at different ratios to obtain different blends, such as B10 (10% biodiesel + 90% diesel by volume), B20, B30, B40, B50, B60, B70, B80, B90 and B100. Experimental results show that BSFC at all loads is less for blends B10 to B50 compared to that of diesel. BTE at all loads is higher for blends up to B60 compared to diesel and after B60 it is more or less the same as diesel. Engine emissions of CO, HC, and also NOx to some extent, are less for all blends from B10 to B100. Among the blends, B10 has lowest BSFC, lowest emission and highest BTE. Higher biodiesel blends can also be used with suitable modifications to arrest some NOx. The present investigation is thus directed to the on-going research towards the search for viable alternative fuels for energy security, environmental problem mitigation and sustainable development.
Keywords: biodiesel, Jatropha curcas, diesel engine, performance and emission.

1 Introduction

For any country to become self sustainable, efficient use of natural resources is very much essential. Nowadays, the internal combustion (IC) engine has become indispensable both in the business and private sectors. The diesel engine dominates in the field due to its ease of operation and higher fuel efficiency. In India the demand for diesel (HSD) is projected to grow by 5.5% per annum. The emission of hazardous gases from the exhausts of heavy duty vehicles have also increased tremendously. This has resulted in environmental degradation, such as air pollution, climatic changes, etc. The primary need today is to create a clean environment. Added to this, the gradual depletion of the world petroleum reserve is causing an energy crisis and generating an intense international interest in developing alternative non-petroleum fuels for diesel alternatives. In recent years, systematic efforts were undertaken by many researchers to determine the best solution among alternative fuels. Thermodynamic tests based on engine performance evaluations have established the feasibility of using a variety of alternative fuels, such as hydrogen, Compressed Natural Gas (CNG), alcohols, bio-gas, producer gas, animal fats (including their derivatives) and a host of vegetable oils. In recent years, vegetable oils have received significant attention both as a possible renewable alternative fuel and as an additive to the petroleum based fuels, as they are renewable, biodegradable, non-toxic, environmentally friendly and have a lower emission profile compared to diesel fuel (Srivastava and Prasad [1]).

Biodiesel exhibits several merits when compared to that of the existing petroleum fuels. Many researchers have shown that particulate matter, unburned hydrocarbons, carbon monoxide and sulphur levels are significantly less in the exhaust gas for biodiesel in comparison to petroleum fuel.

Major problems associated with vegetable oil as a diesel substitute in IC engines have been recognized, such as its high viscosity, low volatility and poly unsaturated character. These problems are due to the large molecular mass and chemical structure of vegetable oils.

The use of non-edible vegetable oils compared to edible oils is very significant in developing countries such as India, because of the tremendous demand for edible oils as food – they are far too expensive to be used as fuel at present. There are many tree species that bear seeds rich in non-edible vegetable oils. Some of the promising tree species are Pongamia pinnata (karanja), Melia azadirachta (neem), Jatropha curcas (Ratanjyot), linseed, castor, rubber, cashew, etc. However, most surprisingly as per their potential, only a maximum of 6% is used. Utilization of this oil/biodiesel as fuel in IC engines is not only reducing petroleum usage, but also improves the rural economy. Therefore, in India the feasibility of producing biodiesel as a diesel substitute can be thought of as significant. Along with the non-utilization of the available potential of the non-edible oil sources, there are large areas of degraded forest lands, unutilized public lands, waste lands, and fallow lands of farmers, which may be exploited easily for systematic plantation to obtain biodiesels. This will also be beneficial for overall economic growth.

2 Jatropha – assortment and decisive factor

The basic composition of any vegetable oil is triglyceride (fatty esters of glycerol). Structurally, a triglyceride is a reaction product of one molecule of glycerol ($C_3H_8O_3$), with three molecules of fatty acids to yield three molecules of water and one molecule of triglyceride. The carbon chain length and number of unsaturated bonds varies in fatty acids. Various acids present in vegetable oil are Myristic(14:0), Palmitic(16:0), Stearic(18:0), Arachidic(20:0), Behenic(22:0), Linoceric(24:0), Oleic(18:1), Erucle(22:1), Linoleic(18:2) and Linoleinic(18:3) (Barnwal and Sharma [2]).

There are a number of varieties of Jatropha, such as Jatropha integerrima, Jatropha podagrica, Jatropha multifida, Jatropha tanjorensis, Jatropha glandulifera, Jatropha gossypifolia and Jatropha curcas. Best among these is Jatropha curcas. Mass spectroscopy and elemental analysis supported a C_{20} $H_{24}O_3$ formula for Jatropha curcas. The ideal diesel fuel molecule is a structural non-branched hydrocarbon molecule ($C_{16}H_{34}$), whereas Jatropha oil molecules are cyclic with branched hydrocarbon molecules (fig.1).

As Jatropha oil contains a substantial amount of oxygen in its structure, it is expected to have a lower heating value than diesel fuel. The heat value also decreases with unsaturation as a result of fewer hydrogen atoms and decreases with increasing saponification number. This unsaturation causes vegetable oils to be more reactive than diesel fuel. The proportion and location of double bonds present in Jatropha also affects the cetane number.

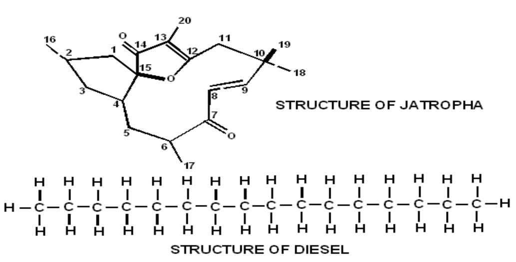

Figure 1: Molecular structure of Jatropha and diesel oil.

3 Preparation of laboratory samples

Biodiesel is basically monoalkyl esters of long-chain fatty acids derived from renewable feedstocks, such as vegetable oil or animal fats, for use in compression ignition engines, etc. (Barnwal and Sharma [2]). Many standardized procedures are available for the production of biodiesel. The commonly used methods for bio-fuel are blending, micro-emulsification, cracking and transesterification. In the current study, the transesterification process was adopted for the production of biodiesel in the authors' indigenous laboratory.

Transesterification, otherwise known as alcoholysis, is the reaction of fat or vegetable oil with an alcohol to form esters and glycerine. A catalyst is used to improve the reaction rate and yield. At first the catalyst sodium hydroxide (NaOH) is dissolved into anhydrous methanol in the catalyst pre-mix tank in proper proportions and then stirred. When the catalyst is fully dissolved into the methanol, the catalyst premix is mixed with the requisite amount of heated untreated vegetable oil (Jatropha). The mixtures are maintained at a temperature a little below 65°C and stirred vigorously for around three hours. After completion of stirring, the mixture is allowed to settle down for 24 hours. The layer of glycerol (heavier phase), which settled at the bottom, is carefully taken out and the upper layer is the ester of Jatropha oil, which is tapped separately. The washing of the transesterified vegetable oils are done for the removal of additional ester followed by evaporation for the removal of water particles and alcohol. The preparation process of biodiesel is elaborated by Barnwal and Sharma [2] and Otera [3]. The derived biodiesel is then mixed or blended with diesel in various proportions (like B10, B20,…,B60, etc.) for engine operations. The block diagram of the experimental setup is shown in fig. 2.

3.1 Measurements of fuel properties

The progress in the performance of the IC engines over the past century has resulted from the pleasing erudition of the engine design and fuel properties. The replacement of existing fuels with new fuels requires understanding of the critical fuel properties in order to ensure that the new fuels can be used. Some key fuel properties of Jatropha oil, determined by standard methods, and the comparison with the standard diesel fuel are given in table 1. The results obtained are in reasonable agreement with reported values (Raheman and Phadatare [4], Clark and Lyons [5] & Ramadhas *et al.* [6]).

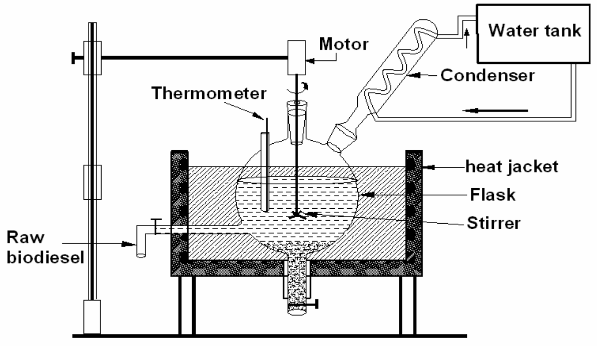

Figure 2: Block diagram of experimental setup.

Table 1: Comparative study of fuel properties of diesel and biodiesel.

Properties	Jatropha oil		Diesel
	Raw	Derived biodiesel	
Viscosity(cSt) at 30^0C	53.79	7.2	2.5
Calorific value (kJ/kg)	39570	42640	43500
Flash point (^{0}C)	261	248	52
Fire point (^{0}C)	302	295	63
Cloud point (^{0}C)	7	6	5
Pour point (^{0}C)	4	4	4
Specific gravity (at 30^0C)	0.902	0.876	0.835
Cetane Number	36	57.1	51

3.2 Performance and emission testing

To study engine performance and emission, the experiments were done in a Kirloskar vertical single cylinder, direct injected compression ignition diesel engine (engine model – avi). The power output of the engine is 5hp at 1500rpm, having a compression ratio of 16.5:1. The emission, as well as engine performance, was studied at different engine loads (25, 50, 75 and 100%).

4 Results and discussion

4.1 Physical and chemical properties

As shown in table 1, the viscosity and specific gravity of the biodiesel obtained are very high compared to suitability for the IC engine. Major problems encountered with biodiesel used in IC engines are its low volatility and high viscosity due to the long chain structure. The common problems faced are excessive pumping power, improper combustion and poor atomization of fuel particles. It is evident that dilution or blending of biodiesel with other fuels, such as diesel, would bring the viscosity and density close to the specification range. Therefore, biodiesels obtained from Jatropha were blended with diesel oil in varying proportions to achieve the required viscosity and density close to that of a diesel fuel.

4.2 Effect of dilution

The biodiesel was mixed with diesel oil in proportions in steps of 10% i.e. B10, B20, B30…. B100, and the dilution of biodiesel results in a homogeneous mixture for all level of mixing. The physical and chemical properties of all blends were determined. The results show, as given in fig. 3, that blends up to 50% biodiesel have viscosity and density equivalent to the specified range for IC engine fuel. Therefore, it can be suggested that up to 50% blend (B50) biodiesel may be used to run the compression ignition (CI) engine.

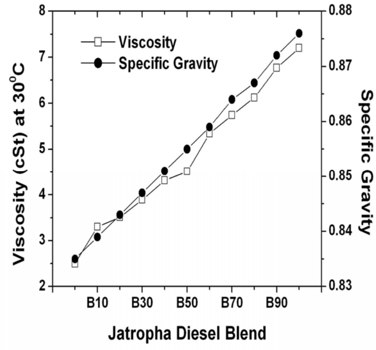

Figure 3: Variation of specific gravity and viscosity for different blends.

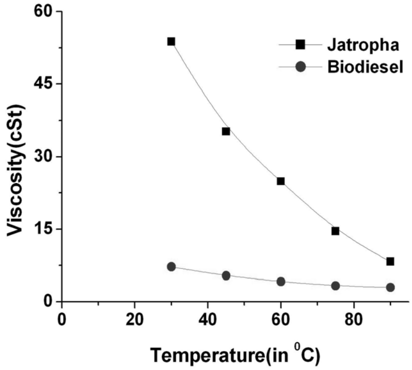

Figure 4: Viscosity at different temperature.

A comparative study of viscosity and specific gravity dependencies of Jatropha oil (raw and derived) is made at different temperatures. The results show, as in fig. 4, that the viscosity reduces at a higher temperature and comes close to that of diesel fuel. Therefore, it can also be suggested that a higher percentage of blend is possible if preheating is done on the fuel in use.

4.3 Effect of engine performance

At different engine loads for different blends, the BTEs are as plotted in fig. 5. It is observed that the values are quite compatible with standard diesel fuel. As is suggested for B50 blend, the maximum BTE was found to be 36.9%. However, at part load, an increase of 1.86% (at 50% load) and 1.37% (at 75% load) efficiencies proves to be a better option than diesel fuel on which most of the engines run.

As the density of esterified fuel is higher, it leads to greater discharge of fuel for the same displacement of the plunger in the fuel injection pump, as a result of

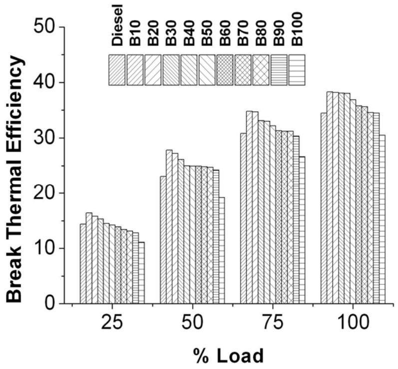

Figure 5: Variation of thermal efficiency for different biodiesel–diesel blends.

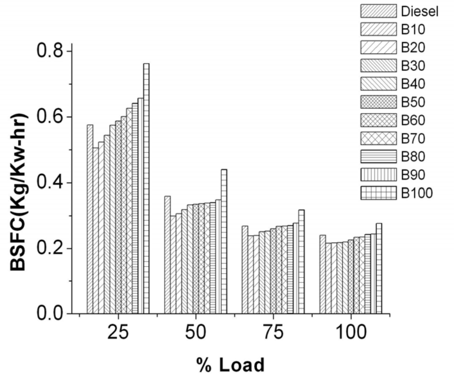

Figure 6: Variation of BSFC for different biodiesel–diesel blends.

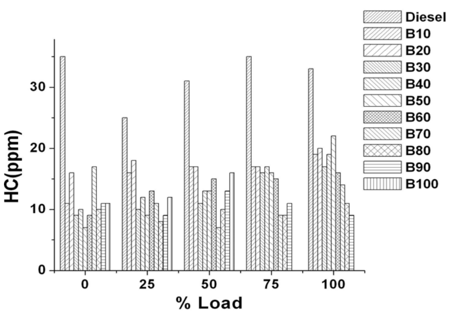

Figure 7: Variation of HC for different biodiesel–diesel blends.

which a higher Break Specific Fuel Consumption (BSFC) value of the biodiesel–diesel blend than that of diesel may be expected. However, from fig. 6, almost the reverse trend is observed in BSFC values against different percentage loads and blend variations. A change in combustion time due to a higher cetane number may be a reason for this reduction of BSFC.

4.4 Effect of engine emission

The variations of unburnt hydrocarbons (HC) at different engine loads are plotted in fig.7. It is observed that the levels of unburnt hydrocarbons for the different biodiesel–diesel blends are lower than diesel fuel. Transesterification of Jatropha converts the complex structure of glycerides to the simple structure of glycerols, which ensures the completeness of combustion. The shorter ignition delay associated with a higher cetane number could also reduce the over mixed fuel, which is the primary source of unburnt hydrocarbons. From figs. 8 and 9 it

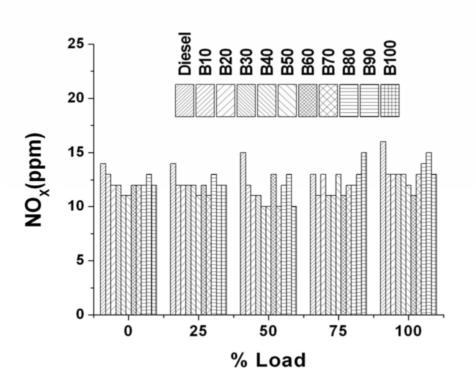

Figure 8: Variation of NO_X for different biodiesel–diesel blends.

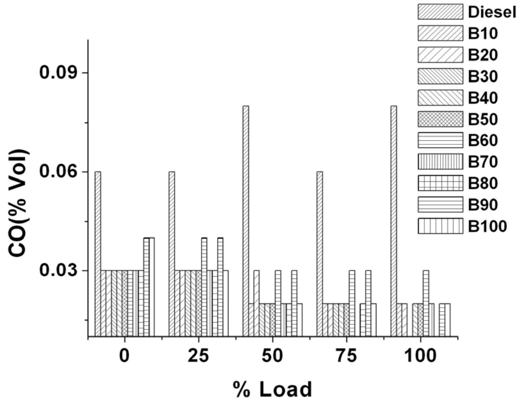

Figure 9: Variation of CO for different biodiesel–diesel blends.

is observed that blends of biodiesel–diesel are good from a pollution point of view. The amount of NOx produced is less to some extent and the CO produced is much less than diesel fuel. This may be due to complete combustion of the biodiesel being an oxygenated fuel. Similar trends of observations on CO and NOx production were also reported while running diesel engines with esterified karanja, rapeseed, sunflower and soyabean oil, such as Raheman and Phadatare [4], Clark and Lyons [5] and Alfuso *et al.* [7].

A comparison between Jatropha derived biodiesel and that of karanja on various parameters is given in table 2.

Table 2: Comparison between Jatropha and karanja derived biodiesel.

	Karanja derived by Raheman *et al.* [4]	Jatropha derived (present investigation)
01. Fuel Properties	**B100**	**B100**
Viscosity(cSt) at 30^0C	9.60	7.20
Calorific value (MJ/kg)	36.12	42.64
02. Engine Performance		
Brake thermal efficiency (% [maximum]	26.19	36.91
BSFC (kg/kW-hr) [max.]	0.52	0.59
03. Engine emission		
NOx (ppm)	9 - 12	10 - 13
CO (% volume)	< 0.02	0.02 - 0.03

It is clear that the calorific value and maximum BTE for Jatropha derived biodiesel is higher than that of karanja. The engine emission parameters and BSFC are of comparable magnitude for both the fuels.

5 Conclusion

The effect of the delay period, heat release rates and pressure rise are definitely better selection criterion for biodiesel, but this work is primarily concentrated on the performance and emission characteristics of the engine, which are also very important parameters. The physical and chemical properties of biodiesel obtained suggest that it cannot be used directly due to higher viscosity and density. Low volatility will cause poor atomization of biodiesel, resulting in incomplete combustion and carbon deposits, and subsequently jamming of the injector nozzle. A higher cloud point may result in cold starting problems during winter. Hence, it can be concluded that a 50% blend (B50) of biodiesel–diesel will partially replace the fuel in CI engines on a short term basis. The engine works smoothly on methyl ester of Jatropha and a diesel blend with comparable performance to diesel operation. With transesterification, the emission concentration of CO, NO_X, and HC have decreased in the exhaust. As the viscosity reduces with temperature, the preheating of the biodiesel blend and multi fuel injection will definitely cause the use of a higher percentage of blends without alteration of much performance in comparison to a diesel engine.

References

[1] Srivastava, A. & Prasad, R., Triglycerides-based diesel fuels. *Renewable & Sustainable Energy Reviews*, **4,** pp. 111-113, 2000.
[2] Barnwal, B. K. & Sharma, M. P., Prospects of biodiesel production from vegetable oils in India. *Renewable & Sustainable Energy Reviews, **9**,* pp. 363-378, 2005.
[3] Otera, J., Transesterification. *Chem. Rev*., **93(4)**, pp.1449-1470, 1993.
[4] Raheman, H. & Phadatare, A. G., Diesel engine emissions and performance from blends of karanja methyl ester and diesel. *Biomass and Bioenergy*, **27**, pp. 393-397, 2004.
[5] Clark, N. N. & Lyons, D.W., Class 8 truck emission testing: effects of test cycles and data on biodiesel operation. *Transactions of ASAE*, **42(5),** pp. 1211-1219, 1999.
[6] Ramadhas, A. S., Jayaraj, S. & Muraleedharan, C., Use of vegetable oils as I.C. engine fuels – A review. *Renewable Energy*, **29,** pp. 727-742, 2004.
[7] Alfuso, S., Auriemma, M., Police, G. & Prati, M.V., The effect of methyl-ester of rapeseed oil on combustion and emissions of DI diesel engines. *SAE paper 93-2801*, 1993.