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Original Research Paper

Emission and Performance Characteristics of A Diesel Engine Operating on Diesel-Bael (*Aegle marmelos*) Biodiesel Blends

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ABSTRACT

The performance, emission and combustion characteristics of a single cylinder direct injection diesel engine fuelled with bael (*Aegle marmelos*) seed oil methyl ester (BOME), diesel and their blends (B20, B40, B60, B80 and B100) have been presented in this paper. BOME was prepared from bael seed oil with methanol by acid and alkali catalysed reaction due to high acid value of oil. The brake specific fuel consumption was higher for biodiesel due to its lower calorific value. Though BOME and its blends recorded lower brake thermal efficiency, they have lower tail pipe emissions as compared to diesel, except for NO_x. Based on this study, bael biodiesel blend B20 (20% biodiesel + 80% diesel, by volume) can be partially substituted for diesel in existing diesel engines without any modification.

INTRODUCTION

With the rapid development of civilization, the use of vehicles and power plants operated by internal combustion engines (ICE) is increasing day by day. The large increase in number of vehicles in recent years has resulted in great demand for petroleum based products. The rapid depletion of petroleum fuels and their ever-increasing cost have led to active search for alternative fuels (Anh & Tan 2008). Vegetable oils provide a viable alternative to petro diesel. The use of vegetable oil in engines is possible but not preferable (Bari et al. 2002). The very high viscosity of raw vegetable oils and the low volatility affect the fuel atomization and spray pattern of fuel, leading to incomplete combustion and severe carbon deposits, injector choking and piston ring sticking. The transesterification is the commonly used process to overcome all the problems. This process changes the properties of the vegetable oil into a diesel like fuel (Chang & Van Gerpen 1997). The biodiesel, derived from vegetable oils, is the most promising alternative diesel fuel due to its following merits: renewable, biodegradable, non-toxic and with higher cetane number than diesel (Lang et al. 2001). Since the biodiesel is derived from plant oils, it produces negligible net green house gas emission (Peterson & Hustrulid 1998). The characteristics of a CI engine fuelled with biodiesel, derived from different vegetable oils, have been analysed (Ekrem Buyukkaya 2010, Usta et al. 2005). The studies showed that esters of vegetable oils can be used in existing diesel engines without any modification. The environmental issues concerned with the exhaust gases emission by the usage of fossil fuels also encourage the usage of biodiesel, which has proved to be ecofriendly far more than fossil fuels (Ekrem Buyukkaya 2010). The advantages of bio-diesels are the minimal sulphur and aromatic content, lubricity, biodegradability and nontoxicity. On the other hand, their main disadvantages are higher viscosity and lower calorific value.

The present study focuses on the extraction of biodiesel from bael (*Aegle marmelos*) seed oil and performance of its diesel blends in a single cylinder direct injection compression ignition engine without any modification.

MATERIALS AND METHODS

Bael fruits were collected in and around Coimbatore. After drying the fruits, seeds were collected by removing outer hard shell. Using expeller, bael oil (25%) was extracted from the seeds.

Fatty acid methyl ester of oil was prepared by acid and alkali catalysed reaction due to high acid value of oil (3.7 mg of KOH/g). Acid catalysed pretreatment was conducted at 55°C with methanol (CH_3OH)/oil at a molar ratio of 6:1 and sulphuric acid (0.5% v/v of conc. H_2SO_4 to oil). Mixture was stirred at a constant speed of 700 rpm for 1 h. The mixture was then poured in a separating funnel for separating lower layer and remaining portion was transesterified using base catalyst.

Base catalysed treatment was conducted at 60°C with methanol (CH_3OH)/oil at a molar ratio of 6:1 and potassium hydroxide (KOH, 13 g for 1 litre of oil). Mixture was stirred at a constant speed of 700 rpm for 1 h. The solution was then poured down to separating beaker and allowed to settle for 8 hours. Glycerin settles at the bottom and methyl ester floats at the top. Methyl ester is separated, heated above 100°C and maintained for 15 min to remove untreated methanol. The impurities were cleaned up by washing with 350 mL of water for 1000 mL of methyl ester. Cleaned biodiesel is methyl ester of non-edible oil (Singh & Singh 2010). Physico-chemical properties of raw bael oil and biodiesel (B100) were compared with that of diesel (Table 1). Most of the fuel properties of bael seed oil methyl ester (BOME) are comparable with that of diesel.

Experiments were conducted on a single cylinder, four stroke, water cooled diesel engine coupled with an eddy current dynamometer. Fig. 1 shows the schematic diagram of the experimental set-up. The technical specifications of the engine are given in Table 2. AVL 444 digital gas analyser was used for measurement of exhaust emission of hydrocarbons (HC), nitrogen oxides (NO_x) and carbon monoxide (CO). Smoke level was measured using standard AVL 437 smoke meter. The experiments were conducted for B0 (diesel), B20 (20% biodiesel + 80% diesel, by volume), B40, B60, B80 and B100 (Biodiesel). Experiments were conducted at idle 20, 40, 60, 80 and 100% load at a constant speed of 1500 rpm. All experimental readings were taken under steady state conditions of the engine.

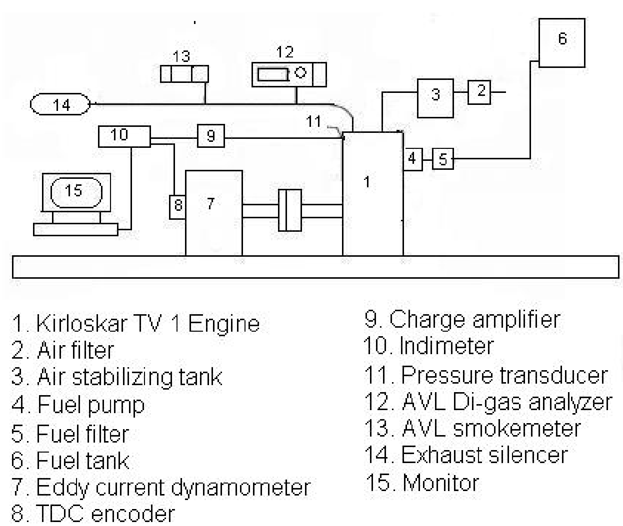

Fig. 1. Experimental setup.

Table 1: Properties of diesel, bael seed oil and BOME (Bael seed oil methyl ester).

	Diesel	Bael oil	BOME
Density, g/cc	0.856	0.87	0.876
Kinematic viscosity at 40ºC, cSt	2.246	36.22	4.81
Gross calorific value, MJ/kg	43.68	43.26	40.52
Acidity, mg of KOH/g	0.54	3.7	0.28
Flash point, ºC	47	-	128
Cetane index	46	-	52.3

Table 2: Specifications of diesel engine.

Make	Kirloskar
Model	TV 1
Type	Vertical single cylinder
Bore & Stroke	87.5 X 110 mm
Compression ratio	17.5: 1
Rated power	5.2 kW
Rated speed	1500 RPM
Injection timing	23° bTDC
Injection pressure	220 bar

RESULTS AND DISCUSSION

BSFC (Fig. 2) was found more for all biodiesel fuels compared to diesel for all loads, due to lower calorific value and higher density. The BSFC was found to increase with the increasing proportion of biodiesel in the fuel blends. The percentage increase in BSFC for B20, B40, B60, B80 and B100 is 2.72, 4.95, 7.16, 9.76 and 11.34% respectively as compared with diesel at rated load. Similar trends of BSFC with increasing load in different biodiesel blends were also reported by other researchers (Raheman & Ghadge 2007, Usta et al. 2005) while testing biodiesels obtained from mahua oil and hazelnut soapstock/waste sunflower oil mixture.

The Brake Thermal Efficiency (BTE) of engine increases with load for all fuels (Fig. 3) just as ordinary fossil diesel engine, due to higher gas temperature and pressure inside combustion chamber at higher loads. The brake thermal efficiency values for BOME and its blends are slightly lower than that of diesel fuel due to lower calorific value. It is also due to relatively lower injector operation pressure resulting in poor fuel atomization. The percentage decrease in BTE for B20, B40, B60, B80 and B100 is 1.92, 3.8, 4.86, 6.21 and 6.89% respectively as compared with diesel at rated load.

It is observed that the exhaust gas temperature (EGT) increases with load because more fuel is burnt at higher loads to meet the power requirement (Fig. 4). There is an increasing trend of EGT as increase in blend ratio of biodiesel with diesel, could be due to increased heat losses of higher blends, which is also evident from their lower BTEs as compared

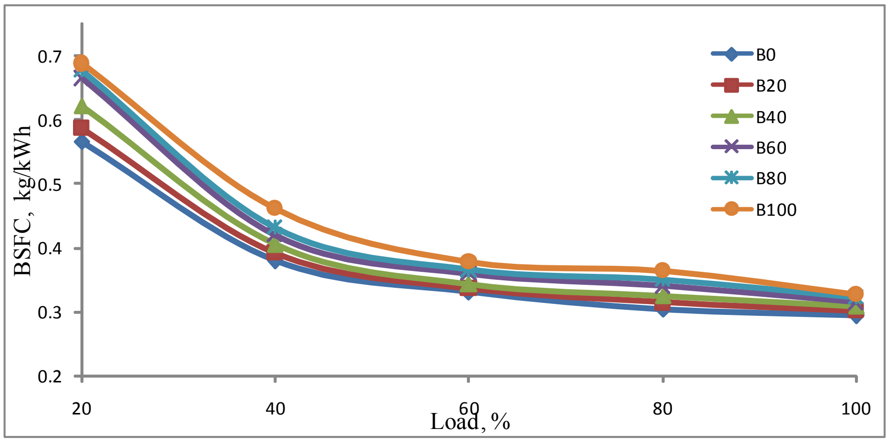

Fig. 2: Variation of brake specific fuel consumption (BSFC) with load.

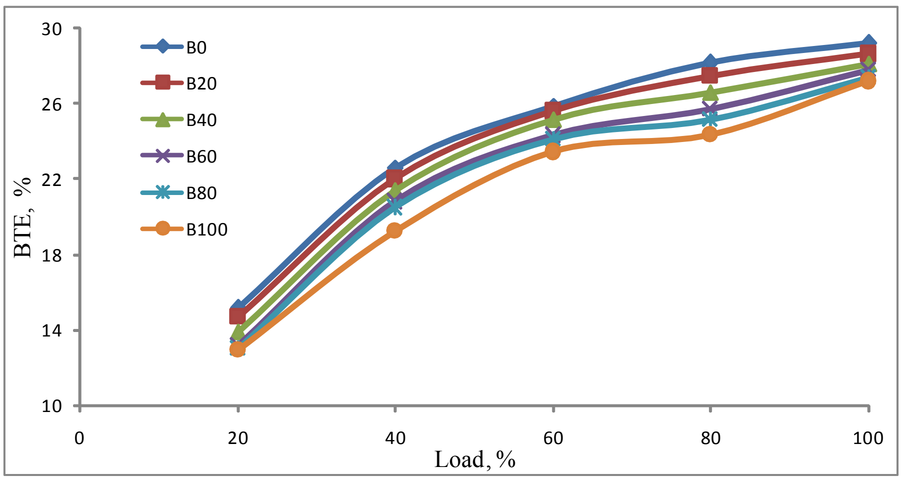

Fig. 3: Variation of brake thermal efficiency (BTE) with load.

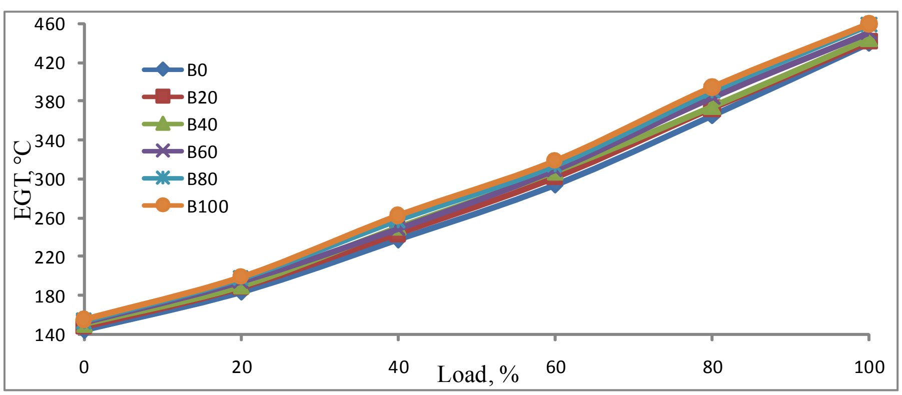

Fig. 4: Variation of exhaust gas temperature (EGT) with load.

with diesel (Raheman & Ghadge 2007). It may also be attributed to larger fuel particles due to poor atomization, which prolongs the diffusion combustion time. The mean EGTs of B20, B40, B60, B80 & B100 were 1.74%, 3.06%, 4.45%, 6.31% and 7.45% higher than the mean EGT of diesel, respectively.

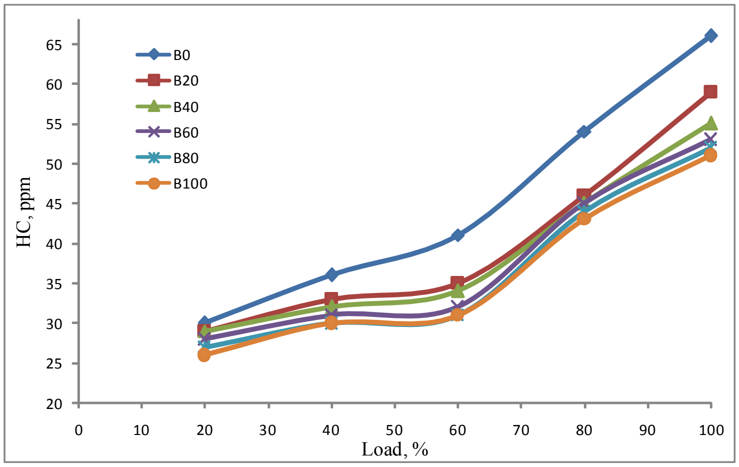

Fig. 5: Variation of HC emissions with load.

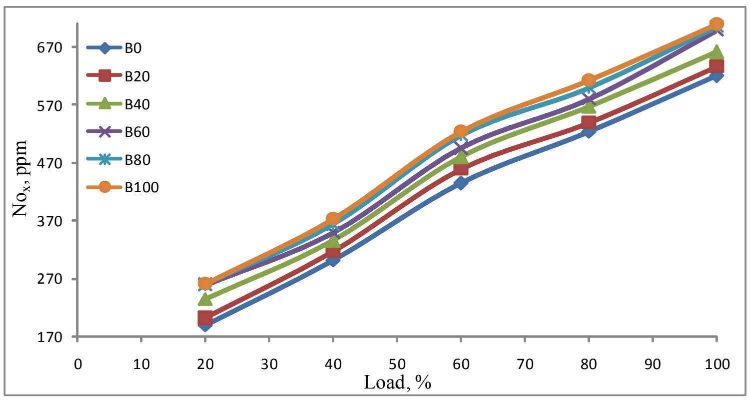

Fig. 6: Variation of NO_x emissions with load.

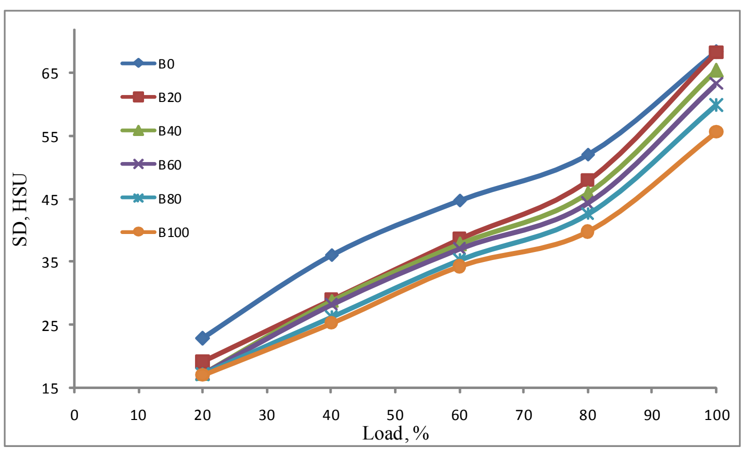

Fig. 7: Variation of smoke density (SD) with load.

It is evident that there is an increase in HC emissions for all the test fuels as the load increases (Fig. 5). This trend is due to the presence of fuel-rich mixtures at higher loads. However, HC emission is lower for biodiesel blends. The availability of oxygen (%) in fuel may lead to better combustion and reduce HC emissions in exhaust (Qi et al. 2009). The percentage decrease in HC emissions for B20, B40, B60, B80 and B100 is 10.61, 16.67, 19.7, 21.21 and 22.73% respectively as compared with diesel at rated load.

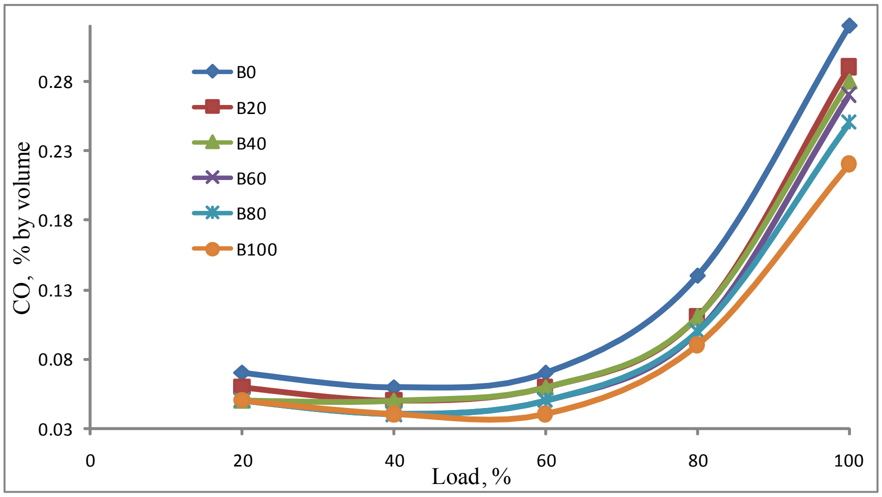

Fig. 8: Variation of CO emissions with load.

NO_x formation highly depends on availability of oxygen and the highest local temperature inside the cylinder. NO_x emission for all fuels increases with load (Fig. 6). As load is increased, the overall fuel-air ratio increased which resulted in an increase in the gas temperature in the combustion chamber, and hence NO_x formation, which is sensitive to temperature increases. NO_x emission for biodiesel blends is higher than diesel due to higher oxygen content. NO_x emission for biodiesel blends was found to increase with the increasing proportion of biodiesel in the fuel blends. The percentage increase in NO_x emissions for B20, B40, B60, B80 and B100 is 2.75, 6.62, 12.76, 13.73 and 14.38% respectively as compared with diesel at rated load.

Smoke opacity is increased with load for all fuels (Fig. 7), might be due to the decreased air-fuel ratio at higher loads when larger quantities of fuel are injected into the combustion chamber, much of which goes unburnt into the exhaust. It is also due to poor atomization. Smoke emission for biodiesel blends is lower than diesel due to higher oxygen content, which causes combustion more complete, and further promote the oxidation of soot. Smoke emission for biodiesel blends was found to decrease with the increasing proportion of biodiesel in the fuel blends. Compared with diesel fuel operation at maximum load, reductions (%) in smoke opacity were: B20, 0.15; B40, 4.39; B60, 7.46; B80, 12.43; and B100, 18.57%. As the oxygen content increases, larger fractions of the fuel carbon are converted to CO in the rich premixed region, rather than soot formation (Ekrem Buyukkaya 2010).

It is observed that the CO initially decreased with load and later increased sharply up to full load. This trend was observed for all the fuels tested. CO emission is lower for biodiesel blends for all loads (Fig. 8). CO emission increases sharply after 80% of the rated load for all fuels due to incomplete combustion as more fuel is injected at higher loads with shorter residence time. Initially, at no load condition, cylinder temperatures might be too low, which is responsible for lower CO emissions. The percentage decrease in CO emissions for B20, B40, B60, B80 and B100 is 9.38, 12.5, 15.63, 21.88 and 31.25% respectively as compared with diesel at rated load.

Data of 100 cycles were averaged to analyse cylinder pressure. Fig. 9 shows the variation of cylinder pressure for diesel, BOME and its blends at full load condition. The difference in peak pressure is very small and may be influenced by lower heat value of biodiesel. From this figure, it is clear that diesel gives maximum peak pressure of 69.988 bar as compared with other blends of fuel. However, the combustion process of the test fuels is similar, consisting of a phase of premixed combustion following by a phase of diffusion combustion. Combustion starts earlier for biodiesel than for diesel. This is owing to a short ignition delay and advanced injection timing for biodiesel (because of a higher bulk modulus and higher density of biodiesel). It is observed that the peak pressures of 69.988, 69.977, 69.961, 69.624, 68.89 and 67.414 bar were recorded for standard diesel, B20, B40, B60, B80 and B100, respectively.

Fig. 10 shows the variation of heat release rate at full load for diesel, BOME and its blends. Because of the vaporization of the fuel accumulated during ignition delay, at the beginning a negative heat release was observed and, after combustion was initiated, this became positive. It can be observed that the peak heat release rates of biodiesel blends are lower than that of diesel due to the less delay period. On the other hand, increased accumulation of fuel during the relatively longer delay period resulted in higher rate of heat

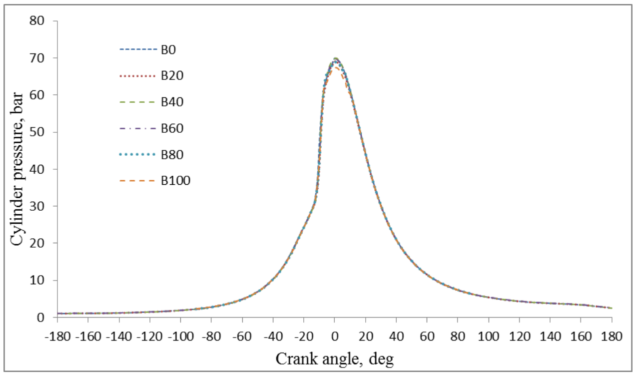

Fig. 9: Variation of cylinder pressure with respect to crank angle at rated load.

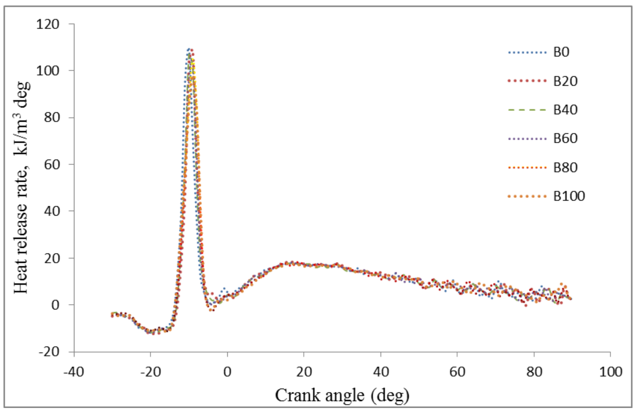

Fig. 10: Variation of heat release rate with respect to crank angle at rated load.

release while running with diesel. The ignition delay slightly decreased with the use of biodiesels. It is known that the fuels with higher cetane number makes auto-ignition easily and gives short ignition delay. So, primary reason for the decrease in the ignition delay is cetane number of the biodiesel which is higher than that of petro diesel. The maximum heat release rate of standard diesel, B20, B40, B60, B80 and B100 is 109.565, 108.632, 106.897, 104.901, 104.883 and 98.206 kJ/m^3deg, respectively.

CONCLUSIONS

The performance, emission and combustion characteristics of a single cylinder diesel engine fuelled with BOME and its blends were investigated. From this study, it is concluded that bael seed oil methyl ester (BOME) can be directly used in diesel engines without any modification. Brake specific fuel consumption (BSFC) increased with increase in proportion of biodiesel in blends. BOME and its blends produce lesser emissions than diesel, except NO_x and have satisfactory combustion and performance characteristics.

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