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Effect of injection timing on a diesel engine fueled with bael biodiesel

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This study presents effect of injection timing on performance, combustion and emission characteristics of Bael (Aegle marmelos) biodiesel and its blend on a single cylinder direct injection diesel engine. Standard injection pressure (220 bar) is maintained throughout the experiment. Injection timings (22°, 23° and 24° bTDC) were considered under steady state conditions of the engine. At injection timing of 22° bTDC, blend B20 (20% biodiesel + 80% diesel, by volume) gave optimum performance. Thus B20 fuel can be effectively used in a diesel engine as an alternative fuel without any modification in the engine.

Keywords: Bael seed biodiesel, Injection timing, Diesel engine

Introduction

Depleting oil reserves, lack of availability of the mineral oil and the problem of environmental pollutions have prompted research worldwide into alternate fuels for internal combustion engines[1]. Vegetable oils, hydrogen and compressed natural gas are used as good alternate fuels for internal combustion engines[2]. Biodiesel from non-edible vegetable oils are preferred as alternate fuels for engine applications to reduce production cost of biodiesel. Fatty acid methyl esters, known as biodiesel, derived from vegetable oil by transesterification, have received the most attention. Biodiesel is an attractive diesel fuel, because of its renewable character and potential for greenhouse gas emission reduction[3]. However, biodiesel presents some problems as compared to diesel fuel. These problems include a little higher NO emission, poor low temperature fuel properties[4]. The use of edible vegetable oils for fuel purposes may cause an increase in the prices of cooking oils. In order to avoid that consequence, it is essential to use non-edible oils for biodiesel production. Bael seed oil is one of the non-edible oil, which can be used for biodiesel production. *Aegle marmelos* or Bael is a slow-growing, medium sized tree, up to 12 to 15 m tall, which belongs to Rutaceae family. It is grown throughout India as well as in Sri Lanka, Pakistan, Bangladesh, Burma, Thailand and most of the Southeast Asian countries. It copes with a wide range of soil conditions (pH range 5-10), is tolerant of water logging and has an unusually wide temperature tolerance (from -7°C to 48°C). The fruits are 5 to 7.5 cm in diameter, oblong pyriform in shape, with a gray or yellow rind. The seeds (fifty or more in a fruit) are embedded in a thick gummy pulp. The seeds yield oil (34.4% on dry weight basis). The seed oil was clear and had a faint odor resembling linseed oil. Leaves, fruits, stem and roots of this tree at all stages of maturity are used as ethno medicines against various human ailments. It is a member of plant species group known as 'Climate Purifiers', which emits greater percentage of oxygen in sunlight as compared to other plants.The performance and emission characteristic of diesel engines depends on various factors like fuel quantity injected, fuel injection timing, fuel injection pressure, shape of combustion chamber, position and size of injection nozzle hole and fuel spray pattern[5]. The injection pressure and timing play a vital role in engine performance and pollutant formation since injection pressure ensures the atomization rate and injection timing attributes to the completeness of combustion[6]. The objective of this paper is to investigate the effect of injection timing (IT) on the performance and emission characteristics of a diesel engine fueled with B20 (20% biodiesel + 80% diesel) and B100 (100% bael seed oil methyl ester).

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Experimental section

Collection of seeds

Fruits of Bael tree were collected. After drying the fruits, seeds were collected after removing outer hard shell. Using expeller, oil was extracted from seeds and filtered by filter paper.

Biodiesel production

Transesterification

Fatty acid methyl ester (FAME) of oil was prepared by acid and alkali catalyzed reaction due to high acid value of oil (3.7 mg of KOH/gm). Acid catalyzed pretreatment was conducted at 55°C with methanol (CH_3 OH)/oil at a molar ratio of 6:1 and an acid (conc. $H_2 SO_4$) of 5 ml per litre of oil. Mixture was stirred at a constant speed of 700 rpm. After 1 h, contents were poured in a separating funnel for separating lower layer and remaining portion was transesterified using base catalyst. In a beaker, Potassium hydroxide (KOH, 13 g for 1 litre) and methanol (CH_3OH, 200 ml per litre) were thoroughly mixed until it is properly dissolved. The solution obtained was mixed with non-edible oil in three way flask and stirred properly. The solution with non-edible oil was heated to 60°C and continuously stirred at a constant speed of 700 rpm for 60 min. The solution is poured down to separating beaker and is allowed to settle for 5 hours. Glycerin settles at the bottom and methyl ester floats at the top (coarse biodiesel). Methyl ester is separated, heated above 100°C and maintained for 10-15 min to remove untreated methanol. The impurities are cleaned up by washing with 350 ml of water for 1000 ml of coarse biodiesel. Cleaned biodiesel is methyl ester of non-edible oil. For a litre of bael oil, yield of biodiesel was 930 ml.Physico-chemical properties of biodiesel (B100) and raw bael seed oil were compared with that of diesel (Table 1).

Table 1—Properties of Diesel, Bael seed oil and BOME (Bael seed oil methyl ester)

	Diesel	Bael oil	BOME
Density, gm/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/gm	0.54	3.7	0.28
Flash point, ºC	47	----	128
Cetane index	46	----	52.3

Experimental Setup and Procedure

Experiments were conducted on a 4 stroke, water cooled, kirloskar, TV 1 vertical single cylinder direct injection diesel engine developing power output of 5.2 kW at 1500 rpm. The engine is connected with eddy current dynamometer. Engine specifications are given in Table 2. AVL 444 digital gas analyzer was used for measurement of exhaust emission of hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxides (NO). Smoke level was measured using standard AVL 437 smoke meter working on Hatridge principle. The experiment was conducted at manufacturer settings (220 bar and 23° bTDC) for neat diesel (B0). The experiments were conducted at 22°, 23° and 24° bTDC for B20 (20% biodiesel + 80% diesel) and B100 (100% Biodiesel) at injection opening pressure of 220 bar . The experiments were replicated thrice to get reasonable values. All experimental readings were taken under steady state conditions of the engine.

Results and Discussion

Brake Thermal Efficiency (BTE)

As shown in Fig. 1a, BTE of engine increases with load for all fuels may be due to higher gas temperature and pressure inside combustion chamber at higher loads. B20 fuel shows better BTE than B100 fuel, may be due to availability of O_2, which helps in complete combustion of fuel. Drop in BTE with B100 can be attributed to poor fuel combustion due to relatively high viscosity and lower calorific value. IT of 22° bTDC gives higher BTE for B20 and B100 as compared to all other ITs. At rated load, BTE of engine operated with B20 with injection timing of 22° bTDC (29.32%) was higher than B100 (27.49%) and diesel (29.21%) at manufacturer specified IT of 23° bTDC. BTE depends on heating value and specific gravity. Combination of heating value and mass flow rate indicates energy input to engine, which in case of B100 is more compared to B20 and neat diesel[7].

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

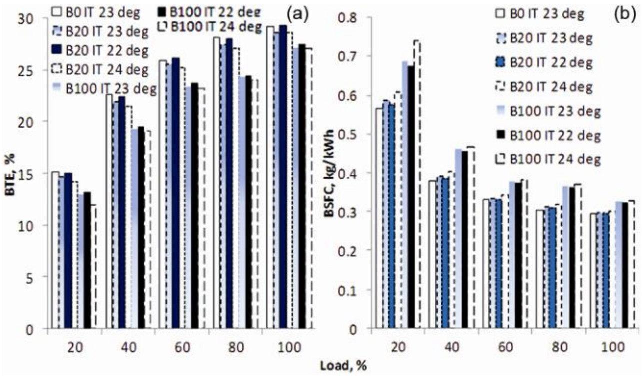

Fig. 1—Variation of: a) brake thermal efficiency; and b) brake specific fuel consumption for B20 & B100

Brake Specific Fuel Consumption (BSFC)

For B20 and B100 fuel, 22° bTDC of IT gives lowest BSFC as compared to all ITs (Fig. 1b). As compared with standard IT (23° bTDC), reduction% in SFC for IT of 22° bTDC at rated load for fuels was found to be: B20, 2.3; and B100, 1%. B20 gave almost same value as that of diesel at 23° bTDC. This is because of more fuel quantity at maximum load, which causes better utilisation of air leading to better combustion. BSFC of B100 has been found more, may be due to lower calorific value and higher density of biodiesel fuel. Similar results were reported by other researchers when tested with methyl ester of Soy bean[8] and Mahua oil[9&10].

Engine Emissions

Hydrocarbon (HC) Emissions

IT (22° bTDC) gives lowest hydrocarbon as compared to all other injection timings for all biodiesel blends (Fig. 2a). As compared with IT (23° bTDC), reduction% of HC for IT of 22° bTDC for fuels at rated load was found to be: B20, 6.8; and B100, 5.8 %. B20 gives more reduction% of hydrocarbon at full load. This may be due to the viscosity and surface tension affects the penetration rate, maximum penetration and droplet size of the fuel, which in turn affecting the mixing of fuel and air[7]. Higher Cetane number of the fuel also plays a vital role in ignition process[7].

Carbon monoxide (CO)

IT (22° bTDC) gives lowest CO as compared to all other ITs for all blends of fuel (Fig. 2b). As compared with standard IT (23° bTDC), %reduction in CO for IT of 22° bTDC for fuels was found as follows: B20, 6.9; and B100, 9%. CO emission increases sharply after 80% of the rated load due to incomplete

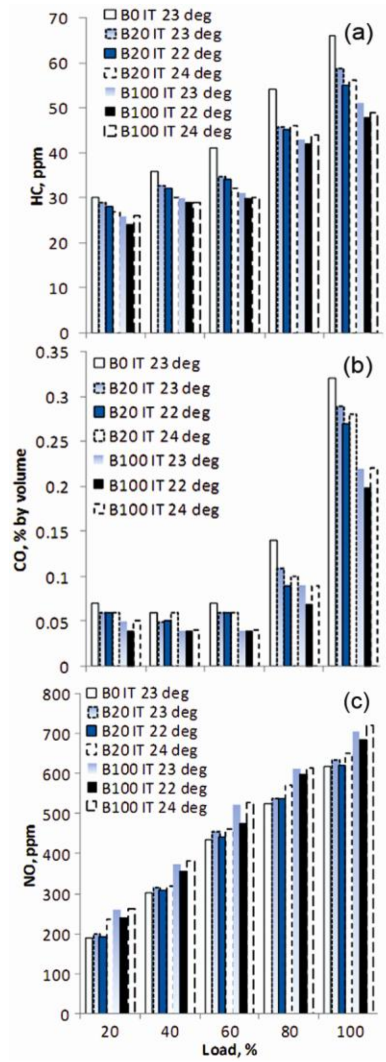

Fig. 2—Variation of: a)HC emissions;b) CO emission for B20 & B100; and c)Variation of NO emission for B20 & B100

combustion as more fuel is injected at higher loads with shorter residence time. The emission of CO were lower for IT of 22° bTDC, may be due to higher cetane number and good mixing quality of air fuel mixture.

Oxides of Nitrogen (NO)

IT (22° bTDC) gives lowest NO as compared to all other ITs for all blends (Fig. 2c). As compared with standard IT (23° bTDC), reduction% in NO for IT of 22° bTDC for fuels at rated load were found to be: B20, 2.3; and B100, 2.9%. NO emission of B20 at IT 22° bTDC is higher than diesel at 23° bTDC by 0.32%. Vegetable based fuel contains a small amount of oxygen, which contributes towards NO production[11]. The amount of NO produced is a function of the maximum temperature in the cylinder, oxygen concentrations, and residence time[12]. The improvement of NO reduction from standard timing to retardation timing is attributed to the lowering of temperature throughout the combustion chamber and shortening of ignition delay as timing is retarded.

Conclusions

Use of Bael biodiesel in the engine indicates that injection timing of 22°bTDC gives better performance, combustion and emission when compared with standard injection timing of 23°bTDC. B20 provides best results in terms of higher BTE, lower BSFC and low emissions of CO, HC and NO. Hence B20 can be effectively used as an alternative biodiesel with IT of 22° bTDC in tested engine.

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