PERFORMANCE AND EMISSION CHARACTERISTICS OF DOUBLE BIODIESEL BLENDS WITH DIESEL

by

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Recent research on biodiesel focused on performance of single biodiesel and its blends with diesel. The present work aims to investigate the possibilities of the application of mixtures of two biodiesel and its blends with diesel as a fuel for diesel engines. The combinations of pongamia pinnata biodiesel, mustard oil biodiesel along with diesel (PMD) and combinations of cotton seed biodiesel, pongamia pinnata biodiesel along with diesel (CPD) are taken for the experimental analysis. Experiments are conducted using a single cylinder direct-injection diesel engine with different loads at rated 3000 rpm. The engine characteristics of the two sets of double biodiesel blends are compared. For the maximum load, the value of specific fuel consumption and thermal efficiency of CPD-1 blend (10:10:80) is close to the diesel values. CPD blends give better engine characteristics than PMD blends. The blends of CPD are suitable alternative fuel for diesel in stationary/agricultural diesel engines.

Key words: *alternate fuel, biodiesel, dual biodiesel, pongamia pinnata, mustard, cotton seed*

Introduction

Millions of people now a day's depend on automobiles, as their main mean of transportation. Petroleum based fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of the world. Therefore, those countries not having these resources are facing a foreign exchange crisis, mainly due to the import of crude oil. Hence, it is necessary to look for the alternate fuels, which can be produced from materials available within the country. There are numerous alternative sources of fuel like vegetable oils, biogas, biomass, alcohols which are all renewable in nature. Among these fuels, vegetable oils appear to have an exceptional importance as they are renewable and widely available, biodegradable and non-toxic, and environmental friendly. In agriculture-based country, like India, the use of vegetable oils has to be identified and initiated in order to prevent environmental degradation and reduce dependence on imported fossil supplies by partially replacing them with renewable and domestic sources. Singaram [1] reported that biodiesel is a significant sustainable energy source and it is used all over world. Biodiesel B20 and less can be used as an alternative fuel without much modifications of diesel engine and almost the same performance of a diesel engine with a petro diesel fuel.

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Vegetable oils can directly be used in diesel engines, as they have calorific value very close to diesel. The high viscosity and low volatility of vegetable oils, however, leads to difficulty in atomizing the fuel. This can be reduced by means of preheating the oil or blending it with diesel or transesterification, *etc*. Senthil *et al*. [2] reported that transesterification of vegetable oil provides a significant reduction in viscosity, compared to other process. Babu *et al*. [3] revealed that NaOH was found to be a better catalyst than KOH in terms of yield in transesterification process. Also the authors reported that the fuel properties of pongamia oil biodiesel were similar to diesel.

Srivastava and Madhumita Verma [4] reported that the maximum thermal efficiency with methyl ester of karanja oil was about 24.87% whereas that of the diesel was 30.59% at maximum power output. Nabi *et al*. [5] revealed that cotton seed biodiesel mixtures showed less CO, particular matter and smoke emissions than those of neat diesel fuel. Jagadish *et al*., [6] concluded that E10B (blend of 10% ethanol, 5% ester, 85% diesel by volume) showed good results with brake thermal efficiency, brake specific fuel consumption and less emission formation.

The researchers analyzed the diesel engines with single biodiesels of mahua oil [7], jatropha oil [8, 9], honne oil [10] and rice bran oil [11]. However, these works are focused on single biodiesel and its blends with diesel. The objective of this research is to gain a better understanding of mixture of two biodiesels by (1) determining the relationship between diesel engine performance and the percentage of two biodiesel in fuel blends, and (2) determining the relationship between pollutant concentrations in diesel engine exhaust and the percentage of dual biodiesel in fuel blends. The oils and blends are selected on the basis of physical and chemical properties of the oils described in literatures. Most of the researchers used the pongamia pinnata oil and cotton seed oil; few researchers used the mustard oil for conducting the experiments. Therefore two sets of double biodiesel blends namely pongamia pinnata oil-mustard oil (PMD) blended with diesel and cotton seed oil-pongamia pinnata oil (CPD) blended with diesel are selected for current analysis. Both these two sets of double biodiesel blends with diesel are tested in three different combinations. The combinations for the first set is CPD-1 (10% cotton seed oil +10% pongamia pinnata oil +80% diesel); CPD-2 (30% cotton seed oil +30% pongamia pinnata oil +40% diesel); CPD -3 (50 % cotton seed oil +50 % pongamia pinnata oil +0% diesel). The combinations for the second set is PMD -1 (10 % pongamia pinnata +10% mustard oil +80% diesel); PMD-2 (30% pongamia pinnata +30% mustard oil +40% diesel); PMD-3 (50% pongamia pinnata +50% mustard oil +0% diesel). Eventually, the implication of the results of this study was evaluated with the combinations of PMD and CPD.

Methodology

Initially, the three biodiesels were prepared in the laboratory using the seed oils of pongamia pinnata, mustard, and cotton seed by the method of transesterification process using NaOH as the catalyst. The properties like specific gravity, kinematic viscosity, flash point temperature, cetane number, and calorific values for the test fuels (PMD-1, PMD-2, PMD-3, CPD-1, CPD-2, and CPD-3), raw oils and diesel are analyzed using ASTM procedures. The properties are listed in tab. 1. It is observed that the test fuels properties are within the range of biodiesel standards. The equipments like precision hydrometer, Redwood viscometer, Pensky-Marten's closed cup apparatus and digital Bomb calorimeter are used to find out the properties of test fuels.

The performance of test fuels are analyzed in a Kirloskar make single cylinder, four-stroke, direct injection diesel engine. The engine is coupled with an electrical dynamometer. Experiments are conducted with varying loads while engine speed was kept constant. Fuel flow rates are obtained with calibrated burette. The exhaust gas temperatures are measured us-

Table 1. Fuel properties of the biodiesel and its blends

Sl. no.	Fuel	Density [kgm^{-3}]	Calorific value [MJkg^{-1}]	Kinematic viscosity at 40 ºC [mm^{2}s^{-1}]	Flash point [ºC]	Cetane number
	ASTM method	D1298	D420	D 0445	D 0093	D613
1	Pongamia pinnata oil	896	39.40	37	240	39
2	Mustard oil	870	36.58	32	152	40
3	Cotton seed oil	920	39.50	34	235	41
4	Pongamia pinnata biodiesel	871	40.13	5.9	172	48
5	Mustard biodiesel	867	37.53	5.6	140	49
6	Cotton seed biodiesel	890	40.42	5.8	150	52
7	PMD-1	837	44.66	4.4	121	47
8	PMD-2	866	42.45	5.2	138	48
9	PMD-3	871	39.38	6.0	140	49
10	CPD-1	840	45.50	4.5	128	48
11	CPD-2	861	42.89	5.6	130	49
12	CPD-3	880	40.13	5.9	142	50
13	Diesel	830	46.58	4	58	47

ing thermocouple. Parameters like brake specific fuel consumption, brake thermal efficiency, and brake specific energy consumption are analyzed for different load conditions. The emissions from the engine are measured after the engine reached the steady working condition. The AVL make smoke meter is utilized to find the smoke opacity of exhaust gas. The Crypton make exhaust analyzer is used to measure the CO, CO$_2$, HC, and NO$_x$). The experimental set-up is shownin fig. 1 and the tab. 2 shows the test engine specifications.

Table 2. Test engine specifications

Items	Specifications
Model	Kirloskar engine
Type	Single cylinder
Bore	68 mm
Compression ratio	18:1
Type of cooling	Air cooling
Speed	3000 rpm
BHP	4.5
Stroke	76 mm

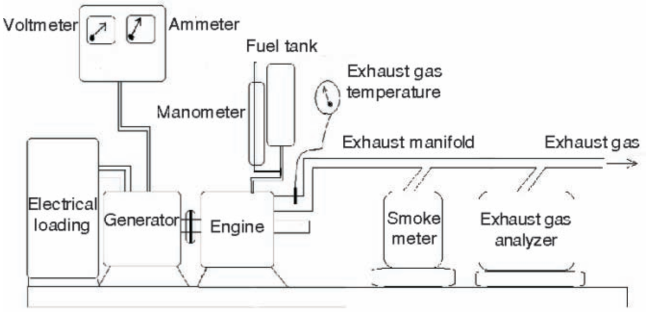

Figure 1. Experimental set-up

Table 3. Error analysis

Sl. no.	Instruments	Error
1	Voltmeter	0.022
2	Ammeter	0.1
3	Exhaust temperature gauge	0.07
4	Stop watch	0.0125
5	Manometer	0.01
6	Burette for fuel measurement	0.01
7	Smoke meter	0.006
8	Digital bomb calorimeter	0.01
9	Thermometer	0.01
10	Smoke opacity	0.01

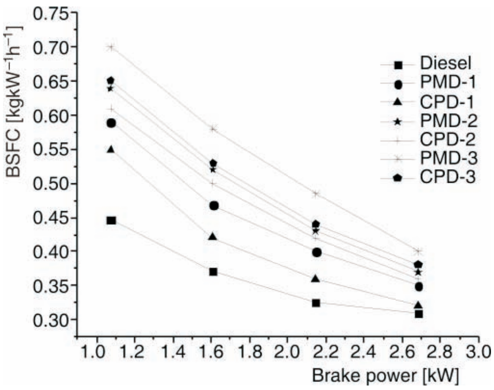

Figure 2. Variations of BSFC with brake power for different dual biodiesel blends

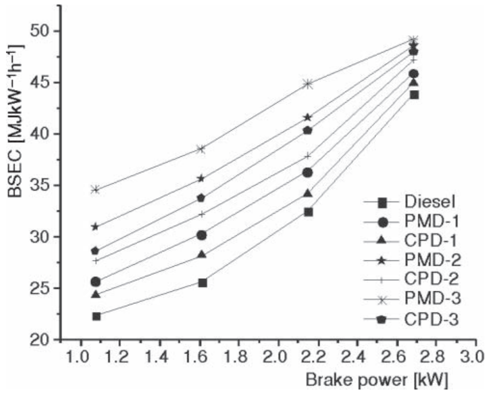

Figure 3. BSEC variations on brake power for different dual biodiesel blends

Error analysis

The percentage error of various instruments that are utilized for this experiment is calculated. Percentage error = minimum scale/minimum value measured. Table 3 listed the percentage of error for various instruments.

Results and discussion

The diesel engine is run with diesel fuel and six different test fuels (PMD-1, PMD-2, PMD-3, CPD-1, CPD-2 and CPD-3). Figures 2-10 shows variation of performance and emission characteristics of various test fuels.

Brake specific fuel consumption

Figure 2 shows the variations in the brake specific fuel consumptions (BSFC) with different loads at a constant engine speed. All the test fuels have higher BSFC than diesel because of a decrease in the calorific value of fuel with an increase in biodiesel percentage in the blends [1]. The specific fuel consumptions (SFC) for the blends of CPD is lower than the blends of PMD and higher than that of diesel. This is due to the lower calorific value of mustard biodiesel than of cotton seed biodiesel as shown in tab. 1. For the maximum load, the value of SFC of PMD-1 is 0.35 kg/kWh, CPD-1 is 0.32 kg/kWh whereas for diesel is 0.31 kg/kWh. Blend CPD-1 has closer SFC value with diesel. The other blends of CPD are higher SFC than diesel. The higher SFC for the dual biodiesel fuel consumption is due to the lower calorific value of the blends.

Brake specific energy consumption

Brake specific energy consumption (BSEC) is used to compare the engine performance of fuels having different calorific values. BSEC is an ideal variable because it is independent of the fuel. Figure 3 represents BSEC for different dual biodiesel blends. The figure shows that the BSEC is higher for all dual biodiesel blends compared to diesel. For the maximum load, BSEC is 46 MJ/kWh in PMD-1, 45 MJ/kWh in CPD-1 where as diesel fuel has 44.02 MJ/kWh. The high specific energy consumption is due to the lower energy content of the ester [12]. From table 1, it is observed that the calorific values of biodiesels are lower than diesel. Hence, the brake specific energy consumption of the dual biodiesel blends increases as compared to that of diesel.

Brake thermal efficiency

The effect of brake power on the brake thermal efficiency for diesel, blends of PMD and blends of CPD is shown in fig. 4. There is a steady increase in efficiency as the brake power increases in the diesel, blends of PMD and blends of CPD operations. The brake thermal efficiency of dual biodiesel is less than that of diesel fuel due to its lower calorific value. Similar findings were also reported by Kannan and Rakkiyanna Gouner [13] while working on seed oils for diesel fuel. The PMD blends have lower brake thermal efficiency than CPD blends. CPD-1 and PMD-1 blends are closer to the diesel values. Oxygen present in the blends perhaps also helped in complete combustion of fuel at no load and also at partial load conditions. At maximum load conditions the change of state from molecule oxygen to atomic oxygen perhaps has lead to a decrease in brake thermal efficiency.

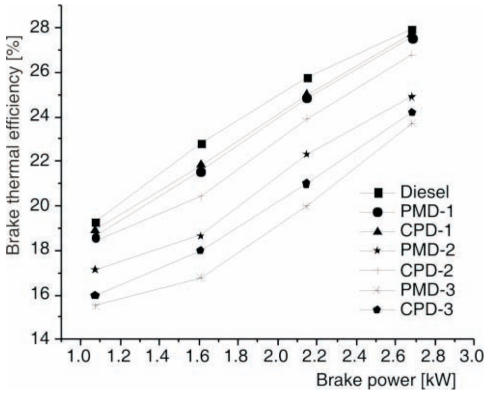

Figure 4. Effect of thermal efficiency on brake power

Exhaust temperature

The exhaust gas temperature provides qualitative information about the progress of combustion in engine. It can be observed that from fig. 5 that the increase of brake power induces the increase exhaust gas temperature. In general, the exhaust gas temperatures are lower for dual biodiesel blends compared to diesel operation which can be attributed to a lower cylinder gas temperature and lower combustion duration.

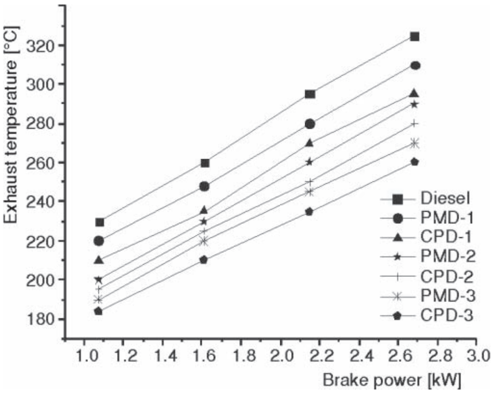

Figure 5. Effect of exhaust temperature on brake power

Carbon monoxide emission

The formation of CO is attributed to the fuel oxidation from combustion. The major contributor to CO formation is insufficient time and oxygen for the oxidation of CO to CO_2. Figure 6 shows the effect of brake power on CO. It can be

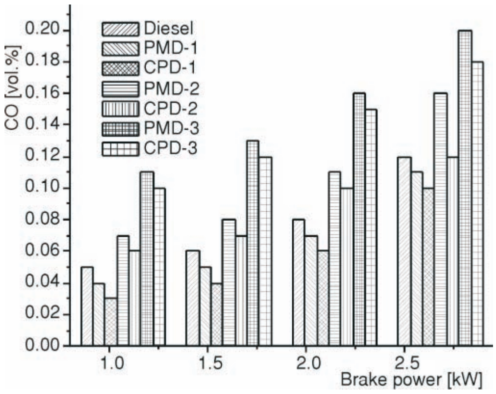

Figure 6. Effect of brake power on CO

noticed that CO emissions increases with increasing engine load, due to the increase in the peak combustion temperature and the associated increase in the rate of dissociation reaction. The overall test result indicates that PMD-1 and CPD-1 gives low CO emissions compared with diesel and other dual biodiesel blends. Since PMD-1 and CPD-1 blends run lean mixture, the levels of CO are relatively low. The other PMD and CPD blends give higher CO emissions than pure diesel. Carbon is formed during low air-to-fuel ratio such as acceleration and high loads.

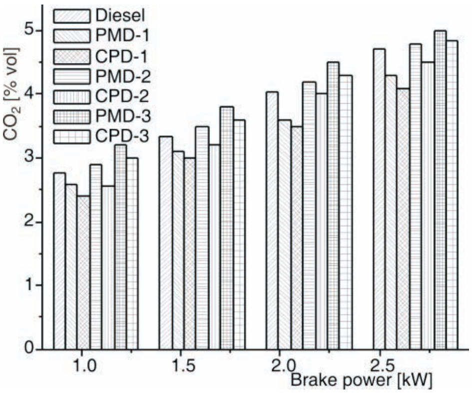

Figure 7. Brake power effect on CO_2

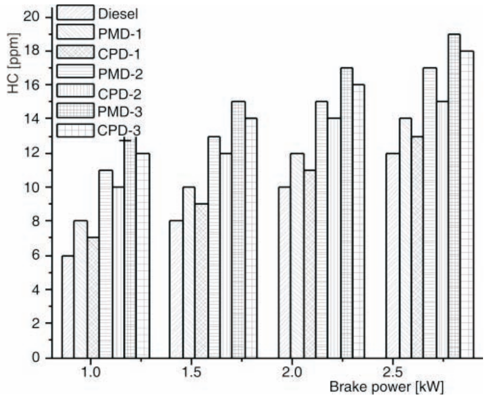

Figure 8. Effect of brake power on HC

Carbon dioxide emission

Figure 7 depicts the CO_2 emission of various fuels used. It is inferred that CO_2 emission increased with increase in load for all blends due to the increase of the BSFC as shown in fig. 2. All the PMD blends and CPD blends emit less amount of CO_2 in comparison with diesel, because of the fact that biodiesel in general is a low carbon fuel and has lower elemental carbon to hydrogen ratio than diesel fuel.

Hydro carbon emission

Unburnt HC emission is the direct result of incomplete combustion. It can be observed from fig. 8, HC emissions of PMD blends and CPD blends are slightly higher than diesel fuel due to incomplete and unstable combustion of the tested fuels. The PMD blends and CPD blends generally exhibit lower HC emission at lower engine loads and higher HC emission at higher engine loads. This is because of relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at a high engine load. At near stoichiometric fuel-air mixtures, HC emissions are higher and lean fuel mixtures have substantially low HC emission. For the maximum load, the HC emission is 14 ppm in PMD-1, 13 ppm in CPD-1, whereas diesel gives 12 ppm. From the results, CPD-1 gives lesser HC than other blends and nearer to diesel.

Nitrogen oxides

The variation of NO_x emission for different dual biodiesel blends is indicated in fig. 9. Oxides of nitrogen in the engine exhaust are a combination of NO and NO_2. Nitrogen and oxygen react at relatively high temperatures. Therefore, high temperatures and availability of oxygen are the two main reasons for the formation of NO_x. When the proper amount of oxygen is available, the higher the peak combustion temperature the more is the NO_x formed. The NO_x emission for all the fuels tested followed an increasing trend with respect to brake power. NO_x emission of the CPD-1 is lower than diesel at lower and intermediate level loads and it increases at maximum load.

This is due to the maximum NO_x is formed at air-fuel ratios between 14:1 and 16:1. Air-fuel ratio is the important factor which significantly affects NO_x emissions. At lean and rich air-fuel mixtures the NO_x concentration is comparatively low. At maximum load, amount of NO_x produced for PMD-1, PMD-2, PMD-3, CPD-1, CPD-2, and CPD-3 are 180 ppm, 200 ppm, 220 ppm, 170 ppm, 192 ppm, and 200 ppm respectively whereas diesel produced only 150 ppm.

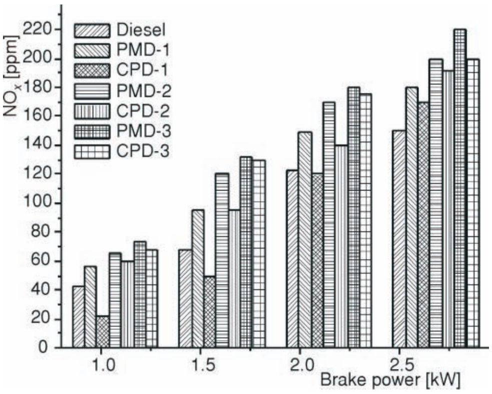

Figure 9. Variations of brake power on NO_x

Smoke opacity

Smoke originates early in the combustion cycle in a localized volume of rich fuel- air mixture. Any volume in which fuel is burned at relative fuel-air ratio greater than 1.5 and at pressures developed in diesel engines produces soot. The amount of soot formed depends upon local fuel-air ratio and type of fuel. If this soot, once formed finds sufficient oxygen it will burn completely. If soot is not burned in combustion cycle, it will pass through exhaust, and if in sufficient quantity, it will become visible. The size of the soot particles affects the appearance of smoke. The soot particles which are chain-line clumps of carbon, agglomerate into bigger particles which have an objectionable darkening effect on diesel exhaust. Black smoke largely depends upon air-fuel ratio and increases rapidly as the load is increased and the available air is depleted. The variation of smoke opacity for different dual biodiesel blends as a function of brake power is presented in fig. 10. It can be noticed that the smoke emissions are higher for both PMD and CPD blends compared to the diesel fuel due to heavier molecules of biodiesel [13] and poor mixture formation tendency [14]. Due to heavier molecular structure of CPD and PMD, atomization becomes poor which leads to sluggish combustion, leading to higher smoke emission.

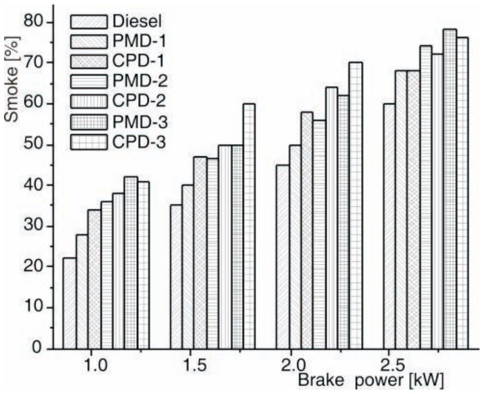

Figure 10. Effect of brake power on smoke opacity

Conclusions

The use of biodiesel as an alternate fuel is a promising solution. The current work focus on an experimental investigation conducted on a single cylinder direct injection Diesel engine, which has been operated with two sets of double biodiesel blends. Engine performance and exhaust emissions have been obtained and compared for two sets of double biodiesel blends and diesel. The results showed that CPD blends have better engine performance and emission characteristics than PMD blends.

The SFC of blend CPD-1 is 0.32 kg/kWh where as for diesel is 0.31 kg/kWh. CPD blends having lower exhaust temperature in all loads than PMD and diesel. The CPD blends produced low CO_2 emissions than PMD blends. The PMD-1, CPD-1, and CPD-2 produced low

CO_2 emissions than diesel. The PMD-1 and CPD-1 produced low CO emissions than diesel. CPD blends are promising alternate substitute for stationary and agricultural diesel engines.

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