APPLICATION OF PALMITIC ACID FROM PONGAMIA OIL TO THE VCR ENGINE FOR PERFORMANCE EVALUATION

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Abstract

The goal of the current study is to investigate the potential of three different types of biodiesel, specifically Pongamia oil and palmitic acid (POPA), as pilot fuels for a biodiesel-powered dual fuel diesel engine. According to the findings, POPA-bio diesel produced a maximum brake thermal efficiency of 19.97% in dual fuel mode, compared to 18.4% and 17.4% for POPA-bio diesel at 100% load.According to the emission study, POPA biodiesel's Nox emissions increased under dual fuel mode on average by 25.74% and 32.58% in comparison to B10, B20, and B100 biodiesels. Additionally, the average increase in emissions for POPA-biodiesel was 11.73% and 16.27%, respectively. On the other hand, for POPA-bio diesel, there was an average reduction in NOX emission of 5.8% and 14%, respectively.

Keywords: Pongamia, properties, bulk modulus, preheating, VCR diesel engine, combustion, emissions, Palmitic acid

1. Introduction

The large increase in the number of automobiles and fast depletion of world petroleum reserves have resulted in a great demand for petroleum products [1]. The worlds energy demand in the last two decades has encouraged the world towards searching for the alternative energy sources [2]. The developing country like India is desirable to produce bio-diesel from non-edible oils which can be extensively grown in the waste land of the country [3]. The usage of bio-diesel has reduced the tail pipe emission of carbon monoxide (CO), Hydrocarbons (HC) and particulate matter (PM) [4]. Bio diesel acts as a promising alternative fuel to diesel oil. Vegetable oils are a very promising alternative to diesel oil since they are renewable and have similar properties. Many researchers have studied the use of vegetable oils in diesel engines. Vegetable oils offer almost the same power output with a slightly lower thermal efficiency when used in diesel engines. Reduction of engine emissions is a major research aspect in engine development with the increasing concern on environmental protection and the stringent exhaust gas recirculation. Biodiesel such as Jatropha, Karanja, sunflower, rapeseed are some of the popular biodiesel that are currently considered as substitutes for diesel. These are clean burning, renewable, non-toxic, biodegradable and environmentally friendly transportation fuels that can be used in neat form or blended with petroleum derived in diesel engines. Vegetable oil esters particularly karanja appear to be the best alternative fuel to diesel. Diesel engines have a negative effect on environment since they include high amounts of sulphur and aromatics. CO, SOX, NOX and smoke are produced from fossil fueled diesel engine exhaust emissions [5]. It has been observed that engine parameters such as injection timing, compression ratio have considerable effects on the performance and emissions of diesel engines running on biodiesel blends. Many innovative technologies are developed to tackle these problems. Modification is required in the existing engine designs [6,7]. [8] studied the effects of the engine design parameters such as compression ratio, fuel injection pressure and the performance parameters such as fuel consumption, brake thermal efficiency, emissions of CO, HC, NOx, CO2, and smoke opacity with jatropha methyl ester as fuel. The highest performance is achieved by the engine at 250 bar injection pressure and compression ratio of 18 at which BSFC improves by 10% and BTE improves by 8.9%. With regard to emission aspects increase in compression ratio leads to an increase in emission of HC and exhaust temperature whereas smoke and CO emission reduces. The gaseous fuel i.e. bio diesel is called the primary fuel on which the engine mainly runs. It is seen that in a dual fuel engine, the combustion starts in the same fashion to that of a CI engine. However, in the later part of combustion, the flame propagates in a manner similar to that of an SI engine. A simple diesel engine can be converted into dual fuel diesel engine by connecting a gas mixer at its inlet manifold. Further, a fuel control mechanism needs to be installed to limit the supply of liquid fuel. The power output of the engine is normally controlled by varying the flow of quantity of biogas. It is possible to achieve a substitution of diesel up to 85% by using bio diesel [9].

From the previous works on vegetable oils, it was observed that the use of biodiesel and their blends with diesel to be a viable alternative for CI engines. However, it was observed that it would be required to reduce the viscosity of these by some means such as pre-heating, blending, or transesterification, for using them straight in the conventional VCR engines without any major modifications [10,11]. In addition, pongamia methyl ester is renewable in nature, available in many parts of the world, and appears to be very attractive for use in VCR engines. In this work, pongamiaPalmitic acid was chosen because it is available in India abundantly. It is also relatively inexpensive and almost inedible. With no competing food uses, this characteristic turns attention to Pongamiapinnata, which grow in tropical and subtropical climates across the world. Therefore, pongamiaPalmitic acid becomes a good source of energy.

2. Materials and Methods

2.1 Pongamia Oil

Pongamia, a medium sized glabrous tree, popularly known as karanja is widely available in India. The oil content of karanja seed is about 33 % [4]. Pongamia oil has a yellowish orange color. The feed stock dependent fatty acid compositions (hydrocarbon chains) of pongamia oil vary from ‘C16 to C24’, with the long chain oleic acid (C18:1), linoleic acid (C18:2), palmitic acid (C16:0), stearic acid (C18:0), and behenic acid (C22:0) are the highest [4] as shown in Fig. 1. The amount of fatty acids present in pongamia oil is oleic acid: 49.4%, linoleic acid: 19%, palmitic acid: 10.6%, stearic acid: 6.8%, behenic acid: 5.3%. This pongamia oil contains 29.2% saturated fatty acids (SFA), 51.8% of monounsaturated fatty acids (MUFA) and 19% of polyunsaturated fatty acids.

Figure.1 Photographic view of pongamia fruit

2.2 Transesterification

Transesterification is an effective way to reduce the viscosity and carbon residue of vegetable oils by modifying their structure. Technically, esterified vegetable oil is called biodiesel [12].

The ignition quality of vegetable oils can also be improved by using additives which accelerate combustion to reduce smoke emission. The process of transesterification: triglycerides of vegetable oil (pongamia oil) react with alcohol (methanol/ethanol) in the presence of catalyst say NaOH or KOH and form glycerol and vegetable oil ester. A study was made with specified amount of pongamia oil (1000 mL) and (200 mL) of methyl alcohol and (8 g) of sodium hydroxide taken in a round bottom flask. The mixture was heated to 60 C and held at that temperature with constant speed stirring for 60 min, and then it was allowed to cool for 8 h. The mixture was cooled to room temperature and few drops of hydrochloric acid were added to neutralize it. Two layers were found to be formed; the bottom had glycerol and water and the top layer had the ester. The lower layer glycerin was separated to retain the upper one, which is ester of the pongamia oil. The formed ester was water washed to remove methanol and soap and used for experimentation. The resulting Palmiticacidis a transparent liquid with a pale yellow color. About 830 mL of POPA was produced from 100 mL of raw pongamia oil and the remaining was glycerol. The properties of the diesel, pongamia oil, and its Palmitic acidare given in Table 1. Diesel fuel, pongamia oil, pongamiafatty acid were found to have density values at 830, 912, and 880 kg/m3 , respectively. Kinematic viscosity at 40C was found to be 3.46, 41.06, and 4.25 cSt, respectively.

Table.1 Properties of diesel, pure pongamia oil, and pongamiaPalmitic acidblends

Properties	Diesel fuel	Pongamia oil	100% pongamia methyl ester (B100)	20% ester
Density (kg/m^3)	830	912	880	844.8
Kinematic viscosity at 40°C (cSt)	3.46	41.06	10.12	5.59
Heating value (MJ/kg)	44.66	34	38.3	42.46
Flash point (°C)	50	241	180	76

3. Design of Experimentation

3.1 Experimental Setup

An experimental setup was developed to conduct experiments on the selected compression ignition engine in different single fuel and dual fuel modes to evaluate the emission parameters at different operating conditions. A single cylinder 4-stroke water-cooled direct

16.5:1, developing 3.7 kW at 1500rpm with a dynamometer was used for the present research work as shown in Fig. 2. The specifications of the engine are listed in Table 2. The engine was fitted with a conventional fuel injection system with the three-hole nozzle of 0.2 mm separated at 120 degrees, inclined at an angle of 60 degrees to the cylinder axis. The injection opening pressure recommended by the manufacturer was 180 bar. A provision was made to mount a piezoelectric pressure transducer to measure cylinder pressure. The injection system of the engine was periodically cleaned and calibrated as recommended by the manufacturer.

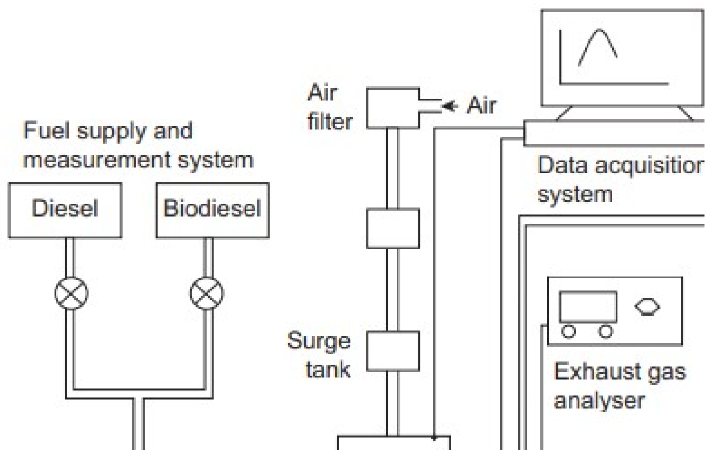

Figure.2 Schematic of the experimental setup of VCR ENGINE

Table.2 Specifications of the test engine

Type	Four-strok diesel eng
Engine	Kirloskar-.
Type of cooling	Water cool
Bore	80 mm
Stroke	110 mm
Displacement volume	553 cc

4. RESULT AND DISCUSSION

In this section, the details of experiments conducted in various modes of operation are presented. All readings were taken only after the engine attained stable operation. The gas analyzers were switched on before starting the experiments to stabilize them before starting the measurements. All the instruments were periodically calibrated. The engine output was varied from no load to full load in steps of 25%, 50%, 75%, and 100% in the normal operation of the engine. At each load, the fuel flow rate; air flow rate; exhaust gas temperature; emissions of carbon monoxide, hydrocarbon, and oxides of nitrogen, and smoke readings were recorded. Experiments were carried out initially using diesel fuel POPA and its diesel blend with the base engine to generate the baseline data. A separate fuel tank was used for the biodiesel. The engine was started with diesel and then switched to 20% POPA (B20) for the experimental investigation. All the experiments were conducted at the rated speed of 1500 rpm and the standard injection timing. NOx, and smoke emissions were recorded. The procedure was repeated for the tests with other blends.

4.1 TESTS WITH PONGAMIA PALMITIC ACIDBLENDS WITH DIESEL

The experiments were conducted with diesel fuel and POPA for baseline data. From the results obtained, the combustion, performance, and emission parameters were measured and are discussed in this section. The results were also compared with the baseline diesel fuel.

4.1.1 Peak cylinder pressure

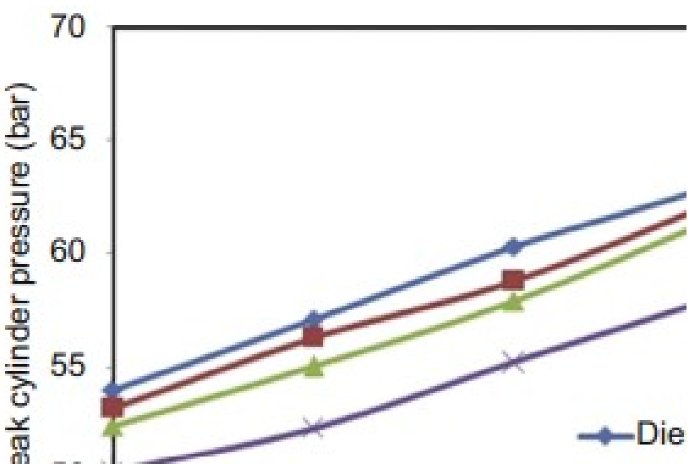

Figure. 3 Variation of peak cylinder pressure with brake power.

Fig. 3 shows the variation of peak cylinder pressure with brake power for diesel and biodiesel blends. The peak cylinder pressure in the diesel engine also depends on the viscosity of the fuel. During the ignition delay, the droplets have sufficient time to spread in the fresh air.

Most of the fuel admitted would have evaporated and formed a combustible mixture with air, which results in complete combustion. The peak pressure decreases for 100% POPA, which has high viscosity that results in increased physical delay. The peak pressure for diesel, B10, B20, and B100 varies from 54 to 67.7 bar, 53.2 to 66.9 bar, 52.4 to 66.2 bar, 50.3 to 62 bar, respectively. It can be observed that the peak pressure for the 100% Palmiticacidwas lower compared to that of other blends and diesel fuel. This could be due to the high viscosity and low volatility of the biodiesel, which increases the ignition delay period during the premixed combustion phase.

4.1.2 Combustion duration

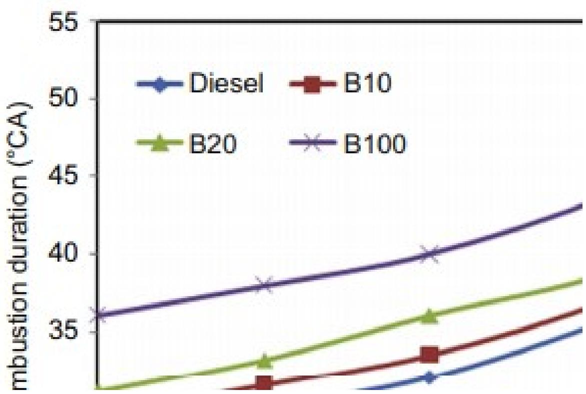

Figure.4 Variation of combustion duration with brake power

Fig. 4 illustrates the variation of the combustion duration with brake power for diesel and the biodiesel blends. The duration from the start of combustion (SOC) to the end of combustion (EOC) is taken as the combustion duration (CD). For all cases, combustion duration increases with the increase in load. The combustion duration for diesel, B10, B20, and B100 were 41, 42.6, 44, and 50CA, respectively, at the rated power output. It could be seen that the combustion duration was higher for B100 which may be due to the high viscosity and density of the vegetable oil. This may also be due to more quantity of biofuels injected than diesel fuel.

4.1.3 Brake thermal efficiency

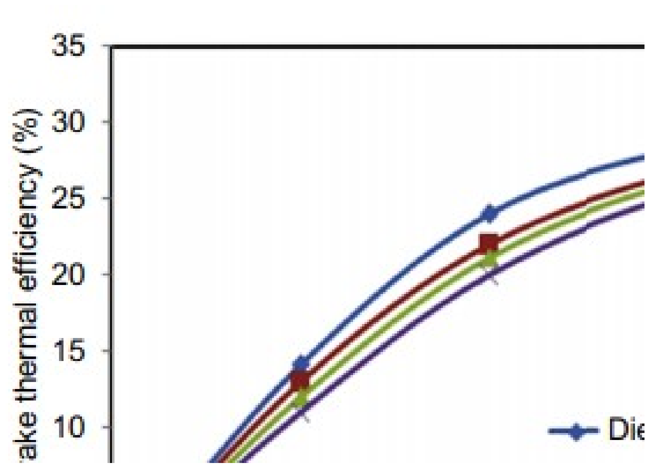

Figure.5 Variation of brake thermal efficiency with brake power

The variation of brake thermal efficiency (BTE) with brake power for different fuel blends are shown in Fig. 5. In all the cases the BTE decreases with the increase in the percentage of biodiesel content in the blends. For all the cases, BTE increases with increase in load. This is due to the reduction in heat loss at higher load and increase in brake power with the increase in load. At lower loads, the biodiesel has shown lesser BTE with an increase in blend ratios because of the high viscosity biodiesel causing an inferior air-fuel mixture by forming larger fuel droplets during atomization. The maximum efficiency obtained for diesel, B10, B20, and B100 were 30%, 29.2%, 28%, and 26% at the rated power output, respectively. The full load condition with B10 and B20 blends give a closer value of BTE with diesel. The increase in BTE for B10 and B20 might be due to better atomization and vaporization for fuel particles and the calorific value of B10 and B20 blend is almost equal to that of diesel, resulting in higher BTE compared to that of B100 biodiesel blends. The decrease in BTE for B100 may be due to low viscosity and low volatility of fuel leading to poor atomization, and hence low BTE. This result was closer to the observations made by the researchers. The higher viscosity combined with the poor volatility behavior of biodiesel caused by intermolecular friction produces a nonhomogeneous mixture during the atomization and hence incomplete combustion and the decrease in BTE are the results of high blend ratio of biodiesel. The lesser heat content of POPA and the unsaturated condition of pongamia are other reasons for giving a reduced thermal efficiency compared to diesel.

4.1.4 Nitrogen oxide emission

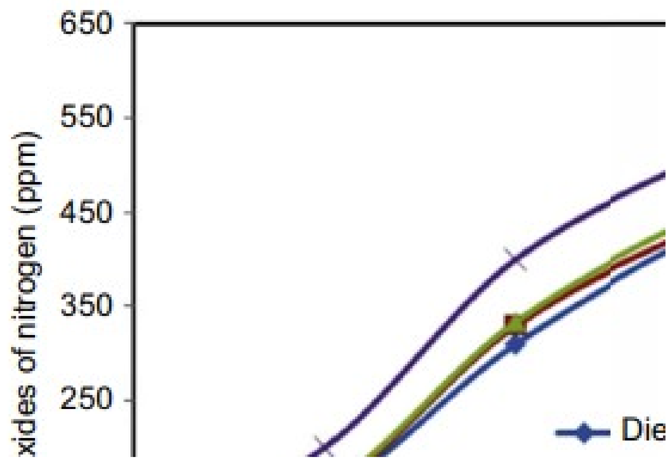

Figure.6 Variation of nitrogen oxide with brake power.

The variation of nitrogen oxide emissions with brake power for biodiesel blends are presented in Fig. 6. The NOx emission increases with an increase in the load for all fuels. The formation of nitrogen oxides has been significantly influenced by the cylinder gas temperature and the availability of oxygen during combustion. The NOx for B20 was 524 ppm and for B100 it was 615 ppm, whereas for diesel it was 510 ppm at the rated power output conditions. It was observed that the increase in NOx emission for biodiesel may be due to more oxygen atoms present in the biodiesel. The higher temperature in the combustion chamber during combustion is also a factor for higher NOx emission.

4.1.5 Smoke emission

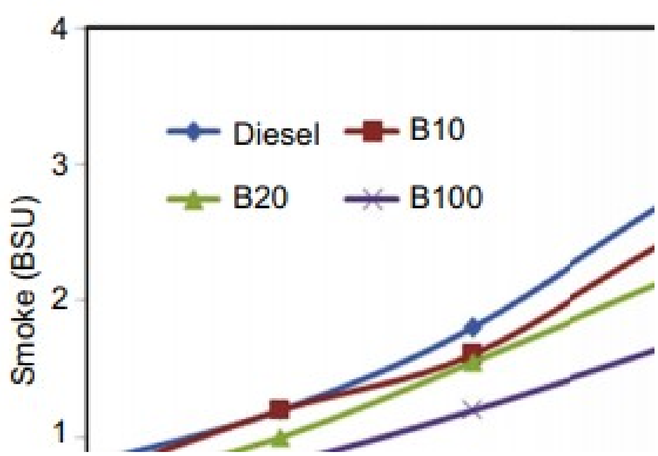

Figure.7 Variation of smoke with brake power.

exhaust of the CI engines contains solid carbon particles that are generated in the fuel-rich zones within the cylinder during combustion. These are seen as exhaust smoke and cause an undesirable odorous pollution. The smoke emission increases with an increase in the load for all fuels. The smoke density for diesel was 3.5 BSU at the rated power output, whereas for B10, B20, and B100 it was 3.1, 2.8 and 2.2 BSU at the rated power output, respectively. The reduction in smoke for biodiesel blends may be due to more oxygen atom present in the biodiesel, resulting in better combustion of biodiesel.

4.2 Overall Comparison Of The Experimental Data Of POPA And Diesel Blends With Various Nozzle Opening Pressures, Tio2 Coated Piston, And Dee Fuel Additives

From the above investigations, it could be observed that 20% POPA (B20) with TiO2 coated piston gave better performance and reduction in exhaust emissions compared to 20% POPA with various nozzle opening pressures and 10% oxygenated fuel additive DEE due to better vaporization of B20 air fuel mixture by more heat retainment of TiO2 coated piston resulting in complete combustion of biodiesel-diesel blends (Table 3)

Table.3 Overall comparison base diesel, B10, B20, and B100 with 220 and 180 bar injection pressures, B20 with TiO2 coated piston, and also B20 with 10% DEE as fuel additives

	Diesel Base	B100 Base	B20 Base	B10 Base	B20-220 I
Peak cylinder pressure (bar)	67.7	62	66.2	66.9	69
Maximum rate of pressure rise (bar/°CA)	4.9	4	4.65	4.8	5.2
Peak heat release rate (J/°CA)	60	48	51	55	61
Ignition delay (°CA)	14.94	13.54	14.44	14.67	14.22
Combustion duration (°CA)	41	50	44	42.5	43.2
Brake thermal efficiency (%)	30	26	28	29.2	28.4
Brake-specific energy consumption (kJ/kWh)	11994.28	13836.74	12831.16	12331.29	12668.14

Comparison of diesel with POPA blends (B20) with Palmitic Acid(10% DEE) as an additive

• The peak pressure increased, and the ignition delay decreased for B20-DEE10 as compared to that of the diesel with the base engine.

• The BTE for B20-DEE10 decreased compared with diesel fuel engine and slightly increased compared with B20 fuel engine.

• The NOx emissions were almost equal for B20-DEE10 fuel compared to that of diesel fuel at the rated power output, while the smoke emissions decreased compared to that of diesel with the base engine and increased compared with B20 fuel engine.

Finally, it can be concluded that the 20% PongamiaPalmiticacidblend with TiO2 coated piston engine operation gives a better performance with considerable reduction in exhaust emissions and with improved combustion properties. This could be due to more heat retainment in the ceramic coated piston compared to that of the other two techniques. The NOx emissions for 10% DEE with B20 blend are almost equal to that of diesel fuel with the base engine.

5. Conclusion

In the present work, different methods were studied and analyzed in order to improve the performance of vegetable oil Palmiticacidfueled compression ignition (CI) engine and was compared with the base diesel fuel.

From the experimental results, the following conclusions were drawn:

1. The peak cylinder pressures decreased for the biodiesel blends compared with the diesel engine. The ignition delay was found decreased for the biodiesel blends compared with the base engine.
2. The maximum rate of pressure rise decreased for biodiesel blends as compared to the diesel fuel for all loads.
3. The BTE obtained for B10 and B20 was closer to that of diesel fuel.
4. The NOx emissions were found increased by about 2.5% for B20 and for B10 and B100 it was 1.9% and 17.0%, respectively, at the rated power output compared to the diesel fuel.
5. The smoke emissions were seen to have been decreased by about 20.0% for B20 at the rated power output compared to diesel. For B10 and B100 it was about 11.42% and 37.14%, respectively, compared to diesel fuel.

be used directly as VCR engine fuel. Overall it was concluded that up to 20% blend can be used to run the stationary VCR engine without any modifications.

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