PERFORMANCE ANALYSIS OF A DIESEL ENGINE FUELED WITH PUNNAI OIL METHYL ESTER AND ITS DIESEL BLENDS

C. Bibin[1], K. Kishore[2], K. Baskar[2], J. Akshay Sharma[2]
1, Assistant professor, 2 U.G Students ,Department of Mechanical Engineering,
RMK College of Engineering and Technology, Chennai

ABSTRACT
The major objective of the present study was to analyze the performance characteristics of 10% to 40% (by volume) blending of punnai oil methyl ester (PME) with diesel as fuels in the diesel engine at various loads. Performance parameters such as brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), indicated power (IP), exhaust gas temperature (EGT) at various engine loads were determined for each fuel operation. From steady state experimental results, it was found that PME and its diesel blends show slightly higher BSFC, less BTE, higher EGT. Engine IP was more for the blends up to B30 compared to diesel fuel operation, but it significantly reduced in case of the blend B40.
Keywords: Biodiesel, Punnai oil, Diesel engine

1. INTRODUCTION

Rapid depletion of petroleum reserves and the increasing concern for the environment has forced the scientific community to develop ecofriendly alternative fuels, especially, to the diesel oil for its partial or full replacement. Vegetable oil obtained from non-edible sources is considered promising alternate fuel for diesel engine compared to their edible counterpart due to the food vs. fuel controversy. Biodiesel derived from non-edible plant species such as Jatropha curcas (Ratanjot), Pongamia pinnata(karanja), Azadirachta indica (Neem), Madhuca indica (Mahua), Hevea brasiliensis (Rubber seeds) are receiving significant attention as possible renewable alternate fuels in India. Biodiesel is a clean burning, renewable alternate fuel that has minimum sulfur and aromatic content. Sulfur is a pollutant directly and no significant air pollution reduction strategy can work without getting sulfur out of fuels. Reduction in sulfur content is the most notable restriction in the recent years, which has direct economic consequence on the investment made by the oil companies and finally on the fuel price. Biodiesel has definitely the advantages from this point of view. However it has higher viscosity and lower heating value. High viscosity of fuel leads to poor atomization of the fuel spray and incomplete combustion resulting in gradual coking of the injector tips, oil ring sticking and thickening and gelling of the engine lubricant oil. Biodiesel is less suitable for low temperature application as its cloud and pour points are higher than diesel. At low temperature, fuel forms wax crystals, which can clog fuel lines and filters in a vehicle’s fuel system. Probably for these reasons, the 5-20% (by volume) blending with standard diesel has been considered as suitable at present for using in existing diesel engines without any modifications. But the most suitable biodiesel blending that gives optimum performance in an unmodified diesel engine depends upon the type of biodiesel and the engine configurations.

Many researchers have experimentally evaluated the performance of conventional diesel engines fuelled with bio-diesel and its blends. P. K. Devan et.al, evaluated the performance of a single cylinder, four stroke engine fuelled with diesel and various blends of diesel and biodiesel. They observed that brake specific fuel consumption (BSFC) increased with the increasing proportion of biodiesel in the fuel blends and the engine brake thermal efficiency (BTE) was lower with the blends as fuels. M. Srinivasa Rao et.al, used biodiesel and its blend in a single cylinder diesel engine and observed that the blends containing 20–40% of biodiesel in the blend yielded an engine performance closely matching that of diesel oil. A. Murugesan et.al. used methyl ester and its blends in a single cylinder, four-stroke, direct injection (DI) diesel engine for obtaining comparative measures of torque, power and BSFC. They found that the torque produced in case of B20 and B40 were 0.1–13% higher but for B60 to B100, it reduced by 4–23% from that of diesel. At an average speed of 2525 rpm (±2%), the BSFC for B20 and B40 was 0.8–7.4% lower than diesel and in case of B60–B100, the BSFC was 11–48% higher than diesel. The BTE were also higher for B20 and B40.

In the present investigation, biodiesel was prepared from Punnai oil using a two-step acid base catalyzed trans-esterification process in a laboratory scale. The properties of the various blends were determined. An experimental study was conducted to evaluate and compare the different blending in a standard, fully instrumented, four stroke, DI, Kirloskar 'TAF1' Diesel engine. The series of tests were conducted using the fuels at various loads. The performance parameters such as BTE, BSFC, indicated power (IP) and the various losses are measured and analyzed.

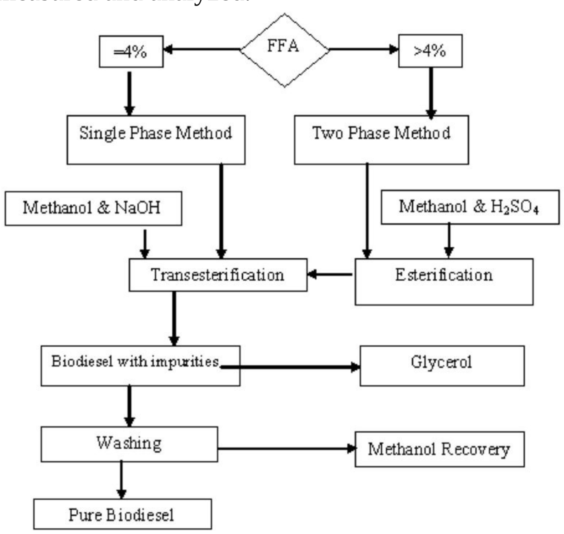

Fig. 1: Schematic presentation of biodiesel production.

2. PROPERTIES OF DIESEL AND VARIOUS BLENDS OF BIODIESEL

Biodiesel obtained from punnai oil was mixed with diesel and **t**he properties of diesel and various blends were evaluated. These are summarized in Table 1 below.

Table 1. Properties of diesel and various blends of biodiesel

Property	**Diesel**	**B10**	**B20**	**B30**	**B40**
Density at 15°C (g/cc)	0.846	0.850	0.855	0.859	0.866
Kinematic viscosity at 40°C (cSt)	2.34	2.64	2.84	3.07	3.28
Higher heating value (kJ/kg)	45553.0	45489.9	45418.1	45348.9	45247.4
Cetane Index	46.60	46.34	46.50	46.34	45.39
Flash point (°C)	46.0	47.0	49.0	53.0	55.0
Pour point (°C)	3.0	-3.0	0.0	3.0	6.0
Sulpher content (ppm)	489.0	440.0	390.0	302.0	274.0

3. EXPERIMENTAL SET-UP

The experimental set up is a single-cylinder, four-stroke, naturally aspirated, DI diesel engine with specifications given in Table 2. Necessary instruments for combustion pressure, fuel pressure and crank-angle measurements are provided in the set up. One piezo sensor mounted in the engine cylinder head senses the in cylinder pressure and the pressure signals from this are fed to a charge amplifier. A high precision crank angle encoder is used to give signals for top dead centre (TDC) and the crank angle. The signals from the charge amplifier and the crank angle encoder are supplied to a data acquisition system which is interfaced to a computer through engine indicator for obtaining pressure crank angle (p-θ) diagram. There are provisions made in set up also for interfacing airflow, fuel flow, temperatures and load measurement. A differential pressure transducer is used to measure air flow rate. The engine is coupled with an eddy current dynamometer for controlling the engine torque through computer. Thermocouples are used to measure different temperatures, such as exhaust temperature, coolant temperature, and inlet air temperature. Two rotameters are provided for engine cooling water and calorimeter water flow measurement. A Labview based engine performance analysis software package is provided for on line performance evaluation. A gas analyzer was used to measure the concentration of gaseous emissions. The gas analyzer calibrates automatically every time they are started and display the quantity of exhaust gases.

Table 2. Engine Specifications.

Make and Model	Kirloskar TAF 1
Number of cylinder	1
Stroke	Four stroke
Ignition	Compression ignition
Bore	87.5 mm
Stroke	110mm
Compression Ratio	17.5:1
Speed (Constant)	1500 rpm
Rated Power	4.4 kW
Fuel injection timing	23^0 bTDC
Type of dynamometer	Eddy current dynamometer
Injection pressure	200 bar

3.1 Experimental procedure

The engine was first made to run at a fixed compression ratio by supplying the diesel fuel to the engine and then the various blends of diesel and biodiesel one by one. The load was varied from no load to over load in five steps in case of all the fuels investigated. For each fuel three test run were performed under identical conditions to check for the repeatability of all results. The repeatability of the results was found to be within an acceptable limit. At each load, the engine speed was measured by the crank angle encoder; cylinder pressure was measured by the piezo electric sensor mounted in the cylinder head. The fuel flow and the air flow were measured by the flow transducers. The signals that were obtained from various sensors were fed to the engine indicator for storing the data and interfacing with computer. The stored data were analyzed by using the analysis software package.

4. RESULTS AND DISCUSSION

4.1 Brake Thermal Efficiency

The effect of BP (load) on BTE for diesel, B10, B20, B30 and B40 is shown in Fig. 2. It is seen that there is a steady increase in efficiency with load in all the fuel operations. This is due to the fact that with the increase in load both the BP and fuel flow rate to the engine increase and there is reduction in heat loss. However the rate at which BP increases is higher than the rate of increase of fuel flow rate. It is also observed that the thermal efficiencies are closer to each other. However there is a slight decrease in the BTE of the blends at all the BPs and the BTE of the engine was the lowest for the blend B40. The BTE of the engine with diesel, B10, B20, B30 and B40 as fuels at full load are 25.63%, 24.86%, 24.34%, 24.09% and 22.32% respectively. It was also observed that the rate of fuel consumption was more with the blends and it was the maximum for the blend B40. Higher fuel consumption in case of the biodiesel blends may be due to higher injection line pressure and reduced fuel loss due to higher viscosity and density associated with these fuel blends. It essentially means that if it is attempted to produce a specified power output from the engine fuelling the engine diesel as well as the biodiesel blends then the fuel consumption rate becomes higher with the biodiesel blends. The fuel consumption rate at full load for diesel, B10, B20, B30 and B40 are 1.15 kg/hr, 1.187 kg/hr, 1.214 kg/hr, 1.228 kg/hr and 1.328 kg/hr respectively. As it was seen in Table 1 that the calorific value of the blends were lower than that of diesel and also it decreased gradually with increase in the percent of biodiesel in the blend. Again the densities of the blends were more compared to that of diesel. Since the BTE of an engine is defined as the ratio of BP to the fuel energy input which is the product of calorific value of the fuel and its flow rate, therefore it depends on the fuel flow rate and it's calorific value while the BP being the same for all the fuels at particular load. It was observed that the rate at which fuel flow rate increased with the blends was more compared to the rate of decrease in the calorific value of the blends with increasing proportion of biodiesel in the blends. Hence the BTE of the engine decreased in case of the biodiesel blends as its fuels.

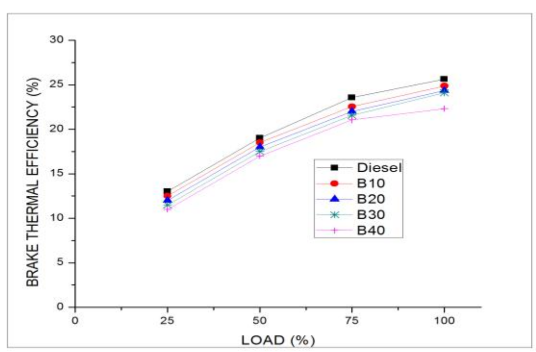

Fig. 2: Variation of brake thermal efficiency with brake power for different fuels

4.2 Brake Specific Fuel consumption

The BSFC of the engine with the biodiesel blends viz. B10, B20, B30 and B40 as fuels are compared with its diesel fuel operation at various loads and it is shown in fig. 3. All the fuels showed similar trend as that of diesel in the entire range of load i.e. for diesel as well as all the blends tested, BSFC of the engine decreased with increase in load. The BSFC decreases with BP because increase in BP with load is higher as compared to fuel consumption. But the BSFC of the blends are found to be higher compared to that of diesel at all the loads. This was due to higher fuel consumption of the engine during its operation with the biodiesel blends, e.g. the BSFC values with diesel, B10, B20, B30 and B40 at full load were found to be 0.3285 kg/kWhr, 0.3391 kg/kWhr, 0.3468 kg/kWhr, 0.3508 kg/kWhr and 0.3794 kg/kWhr respectively. BSFC, the parameter which characterizes the fuel consumption characteristics of an engine is the ratio of fuel flow rate to the brake power output. As in case of engine operation at a particular load, the BP remains the same for all its fuel operations and the fuel consumption being more in case of the biodiesel blends, therefore the BSFC is more for the fuel blends and this explanation holds good for the entire range of load. Higher fuel consumption rate in case of the biodiesel blends is already explained.

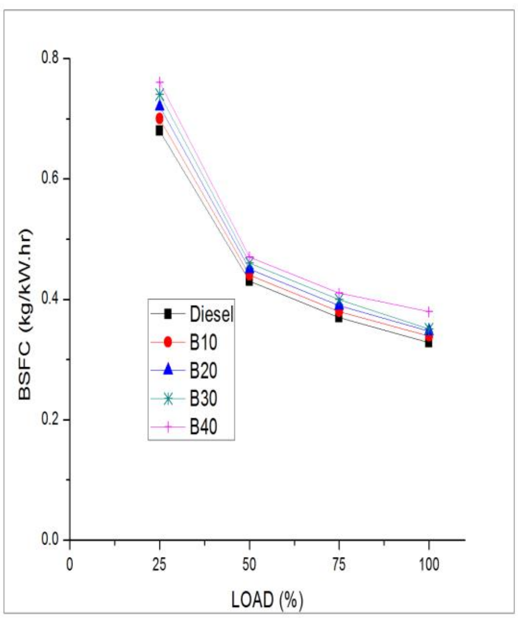

Fig. 3: Variation of specific fuel consumption with brake power for different fuels

4.3 Indicated power

The variation of IP with load for all the fuels tested is presented in fig. 4. It is observed that the IP of the engine operated with the blends up to B30 is slightly more than the IP produced when run with diesel. However, for the blend B40 the IP produced by the engine was less compared to that of diesel over the entire range of load. At full load, the IP produced by the engine with diesel, B10, B20, B30 and B40 as fuels were found to be 5.6 kW, 5.76 kW, 5.80 kW, 5.92 kW, and 5.42 kW respectively. It was observed that the loop work i.e. the work done during the gas exchange process and the compression work decreased in case of the blends B10, B20 and B30. Also there was an increase in the combustion and expansion work associated with these blends. Hence the net work done during the cycle was more with these blends and this ultimately resulted in higher IP. Lower IP of the engine with B40 as fuel was due to increase in the compression and loop works and reduction in the combustion and expansion work. The loop works corresponding to fuel operation with B10, B20, B30 and B40 are 20.121 joules, 18.319 joules, 14.642 joules and 42.966 joules respectively compared to a loop work of 24.156 joule corresponding to diesel fuel operation at full load. Similarly the combustion and expansion works for diesel, B10, B20, B30 and B40 are 724.13 joules, 728.18 joules, 719.64 joules, 743.05 joules and 692.86 joules respectively. It is seen that there was a significant increase of about 77.9% in the loop work in case of the fuel blend B40 and the combustion and expansion work was also significantly less as opposed to the combustion and expansion works corresponding to the other fuel blends in which it was more than corresponding to that of diesel.

The work required during the compression process at full load with diesel and the various blends of biodiesel and diesel as fuels are found as 309.8 joules, 300.51 joules, 286.15 joules, 294.92 joules and 311.35 joules respectively. As can be seen from these values that compared to compression work required during diesel fuel operation, it was less for the blends up to B30 and slightly being in case of the blend B40.

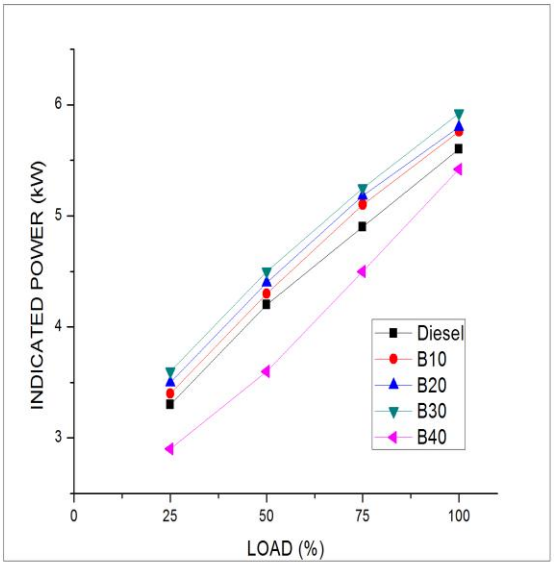

Fig. 4: Variation of Indicated power with brake power for different fuels

4.4 Exhaust gas temperature

EGT is one the important parameter in engine study as it represents the temperature of the fuel mixture after it combusted in the cylinder. EGT is a direct indication of loading given to an engine and in case, the EGT exceeds the permissible limit it results in severe smoke escaping out the engine. There is a direct proportionality between temperature in the combustion chamber and the nitrogen oxides emission. Since, EGT indicates the temperature that prevails in the combustion chamber, therefore an increase in EGT means more nitrogen oxide emission. Biodiesel fueled engines emit more NOx as compared to that of diesel fueled engines. The variation of EGT with load for the tested fuels is compared and presented in Figure 4. It was found that the EGT increased with increase in engine loading for all the fuels. With increasing load, the amount of fuel injected to the engine's combustion chamber increases and as a result, more amount of heat is released due to burning of relatively more amount of fuel. This is the reason that EGT is more at higher load. In general, the EGT was found to increase by small values with the increasing concentration of PME in the blends at all the loads. At full engine load, the EGT with diesel, B10, B20, B30 and B40 were 333.28, 337.15, 343.6, 344.87 and 340.06°C respectively. This increase in EGT in case of the biodiesel blends could be due to higher amount of fuel injected as it was seen that fuel consumption of the engine was more for these blends. Increased EGT in case of the PME blends may also be due to higher amount of heat release in late combustion phase which was observed in the heat release analysis. Slightly lower EGT for B40 compared to B20 and B40 at full load can be due to incomplete combustion of this particular fuel blend. P. K. Devan also observed higher EGT in case of blends of methyl ester with diesel. Higher EGT with the biodiesel blends was explained to be due to increased heat losses associated with them and the same reasoning was also given for lower BTE with respect to the blends. However Avinash Kumar Agarwal observed lower EGT up to B20 with biodiesel and the EGT was more for the other fuel blends and pure biodiesel. N. Kapilan et.al. on the other hand, observed slightly lower EGT (with little variation) in case of various blends and pure biodiesel at all the loads.

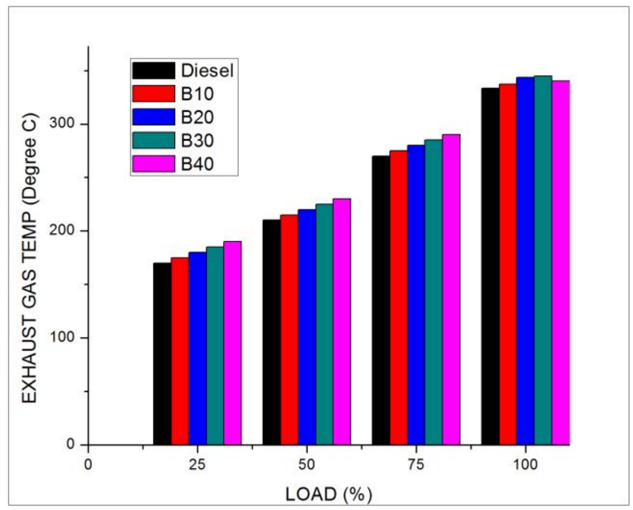

Fig. 4: Exhaust Gas Temperature Variation with Load for various tested fuels

5. CONCLUSION

A comparison of physical and fuel properties of different PME blends with diesel fuel indicates that the blends are quite similar in nature to diesel fuel with viscosities being slightly higher and calorific values being lower for the blends. The BTE of the engine operated with the blends was found to be lower than that with diesel. The BSFC was found to be more in the case of PME blends compared to that with diesel at all loads. IP produced by the engine was higher when run on the PME blends up to B30 compared to its diesel operation over the entire range of load. However, it showed lower engine IP with B40 as fuel to the engine. This was the reason that the IP and BTE of the engine were lower at various engine loads when operated with the blend

B40. The viscosity was more for the blends and due to higher viscosity and particularly for this blend; the fuel did not atomize properly leading to poor combustion, which ultimately resulted in lower BTE. Use of fuel injection pump employing higher injection pressure could be a solution to this problem relating to use of higher level of biodiesel blending. Based on the study it can be recommended that PME blending up to 30% can be used in an unmodified Kirloskar diesel engine without any significant loss in performance.

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