

Comparative study of performance and emissions of a CI engine using biodiesel of microalgae, macroalgae and rice bran

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Abstract. Biodiesel is an alternative and safe fuel to replace conventional petroleum diesel. With high-lubricity and clean-burning ability the biodiesel can be a better fuel component for use in existing diesel engines without any modifications. The aim of this Research was to study the potential use of Macro algae oil, Micro algae oil, Rice Bran oil methyl ester as a substitute for diesel fuel in diesel engine. B10 and B20 blends of these three types of fuels are prepared by transesterification process. The blends on volume basis were used to test them in a four stroke single cylinder diesel engine to study the performance and emission characteristics of these fuels and compared with neat diesel fuel. Also, the property testing of these biofuels were carried out. The biodiesel blends in this study substantially reduces the emission of unburnt hydro carbons and smoke opacity and increases the emission of NO_x emission in exhaust gases. These biodiesel blends were consumed more by the engine during testing than Diesel and the brake thermal efficiency and volumetric efficiency for the blends was identical with the Diesel.

1. Introduction

Diesel engines are considered as widely used prime movers since hundred years before; these have been used in many areas like generators, automobiles ranging from cars to trucks, ships and locomotives. A diesel engine has high thermal efficiency, less fuel consumptions, reliability and higher durability [1]. The recent uncertainties in petroleum availability and increases in cost of petroleum products made an interest towards vegetable oil derived biofuels for diesel engines [2]. Biodiesel is defined as the fuel which is derived from plant oils such as soybean, rapeseed, Jatropha or animal fats like beef tallow. The most popular method used to produce biodiesel from vegetable oils is the transesterification method [3]. Transesterification is defined as a reaction between the oil and an alcohol with the presence of a catalyst at specified temperature, the reaction produces biodiesel and glycerol. Availability of feedstock, the cost, resulting by products, the government incentives on environment and economical issues are considered to be important factors which decides the competitiveness of any biodiesel to be substitute for the diesel [4]) Biodiesel produced from biomass have already available through commercial markets as blends with diesel up to 20% in many countries [5]. It is always not advisable to use an edible oil source for biodiesel as it affects the food chain. In India more than 50% of the imported oil is used for cooking purpose. In this context the current need is to have an economic and eco friendly biodiesel source. The Non edible oil sources like Jatropha, Pongamia and other non edible oils are treated as potential feed stocks in India. Compared to these non edible oil sources Algae oil and Rice bran oil are considered to be important emerging non edible biodiesel sources due to their low cost and less land area requirement. Algae are photosynthetic



organisms that can grow in any aquatic region with size ranges from micrometers to meters. Macro algae are large (size in inches) multi cellular organisms growing in water bodies. Micro algae are very small (size in micrometers) unicellular organisms normally grow in suspension within a water body [6]. The development of biodiesel from Algae biomass is at emerging stage in stage in India [7]. Paddy, the feedstock for rice bran oil is the leading crop in India and also it has greater potential for producing Rice bran oil. When considering the improved income through rural employment and cleaner environment, Rice bran can be considered as a potential biodiesel resource [8]. A study on Rice bran oil biodiesel revealed that, Rice bran oil biodiesel blends recorded improved brake thermal efficiency and reduced pollutants when compared to Diesel [9]. This study involved in testing the pure Diesel and its two blends by volume from each fuel type; MAME10 (90% Diesel with 10% Micro algae oil biodiesel), MAME20 (80% Diesel with 20% Micro algae oil biodiesel), AME10 (90% Diesel with 10% Macro algae oil biodiesel), AME20 (80% Diesel with 20% Macro algae oil biodiesel), RME10 (90% Diesel with 10% rice bran oil biodiesel), RME20 (80% Diesel with 20% rice bran oil biodiesel). The performance parameters brake thermal efficiency, volumetric efficiency, brake specific fuel consumption and the unburnt hydro carbon, smoke opacity and nitrogen oxide emissions are measured and discussed in comparison with the pure Diesel.

2. Experimental Setup and Methodology

The required amount of Macro algae biomass was collected from sea shore near Chennai, the micro algae biomass was collected at a fresh water open pond situated at Sathyabama University, Chennai. The collected biomass were cleaned and dried in open sun for 2-3 days. Then dried biomass was pulverized and the powder was crushed again and again with hexane and isopropyl solvent mixture for extracting the lipid in them. Extracted lipid was separated from the biomass and heated for removing the solvent in it. The remaining oil is subjected to transesterification process. Neat refined rice bran oil was procured for the experimental purpose and it was subjected to transesterification process.

Transesterification process is the method used to prepare biodiesel from the oil and it will reduce the viscosity of oil. This work used sodium hydroxide as catalyst for the reaction and methanol as the alcohol. The reaction was held between these two with the three types of oil separately, at 65°C for 3 hours duration and the solution is made to mix well during the reaction. The reaction resulted biodiesel as top layer and glycerol as bottom layer. The top layer was separated after filtering the glycerol by using separator. The prepared biodiesel from the oils were tested for its properties. The properties of the three biodiesel sample were tested by adapting ASTM testing protocols for biodiesel and they are presented in the Table 1.

Table 1. Properties of Biodiesel

Property	Diesel	MAME	AME	RME
Viscosity(cst) at 40 °C	3.9	3.51	4.84	5.045
Cetane Number	49	57	45	46
Calorific Value (kJ/kg)	43200	40362	33300	37081
Flash Point (°C)	58	92	130	124
Fire Point(°C)	64	124	139	147
Specific Gravity	0.804	0.792	0.795	0.8899
Sulfur content	-	-	18	Less than 20 ppm

The Test rig used in this study is a diesel engine of constant speed, four stroke, vertical, air cooled type. The fuel consumption is measured by using a graduated burette for specific time. The normal injection timing and pressure were maintained during the test were 23° BTDC and 200 bar. For

measuring the air consumption rate an orifice meter with U-tube manometer is provided along with an air tank on the suction line. A Smoke meter (AVL415) is provided for measuring FSN of exhaust gases. The test rig is installed with AVL software for obtaining various curves and results during operation. The detailed specification of the test rig was presented in the Table 2. The test was done with conventional Diesel and its two blends (B10 and B20) of each biodiesel. 5 sets of loading was used for testing from 0% to 100%.

Table 2. Engine specifications

Type	Kirlosker, Four stroke, single cylinder,
Rated power	4.4 kW
Rated speed	1500 rpm
Bore dia	87.5 mm
Stroke	110 mm
Compression ratio	17.5:1
Orifice dia	13.4 mm
Coefficient of discharge	0.6
Loading device	Eddy current dynamometer
Make	Benz systems
Dynamometer constant	2000
Supply voltage	240 $\pm$ 10 % AC, 50 Hz, 1 ϕ
Maximum excitation current	6 to 8 Amp

3. Results and Discussion

The performance and emission characteristics of straight diesel and tested biodiesel blends B10 and B20 are discussed in this section.

3.1. Brake thermal efficiency

Brake thermal efficiency gives the amount heat energy that converted to useful work. This parameter purely depends on calorific value of the fuel and the viscosity. The variations in the brake thermal efficiency values against engine loading for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 is presented in the figure 1(a). The Average BTE Values for Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 at all loads are 26.38, 26.19, 26.14, 20.83, 21.6, 23.52 and 24.23% respectively. For all the fuel types the BTE values reaches its maximum value at 75% load and then they started decreasing. The Biodiesel blends followed similar trend of pure diesel. In some stages the micro algae biodiesel blends MAME 20 and MAME 10 recorded slightly high BTE values than diesel, the kinematic viscosity of MAME blends is less than Diesel as indicated by the property test, it improved the fuel atomization and thus leads to better combustion. The BTE value for this fuel type is almost identical with the pure diesel. The other biodiesel blends have low volatility, slightly superior viscosity, and lower heating value it had shown lower brake thermal efficiency than conventional diesel. The macro algae biodiesel blends AME 10, AME 20 recorded less BTE values

than other fuel types. The rice bran biodiesel blends RME 10, RME 20 recorded slightly higher BTE values than AME blends and also the trend of this fuel type is found identical with MAME blends and diesel. At 100% load all the fuel types recorded almost same BTE values.

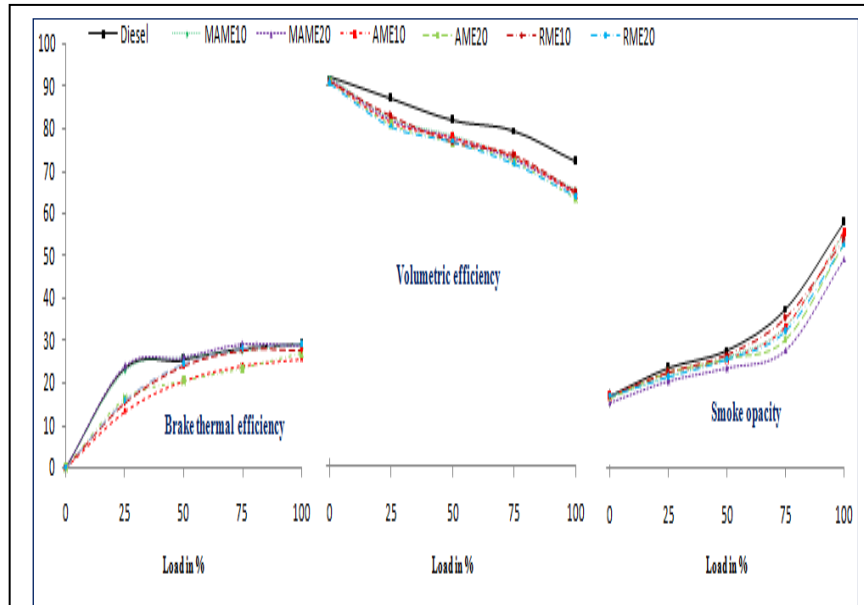


Figure 1. a) Brake thermal efficiency; b) volumetric efficiency; and c) smoke opacity

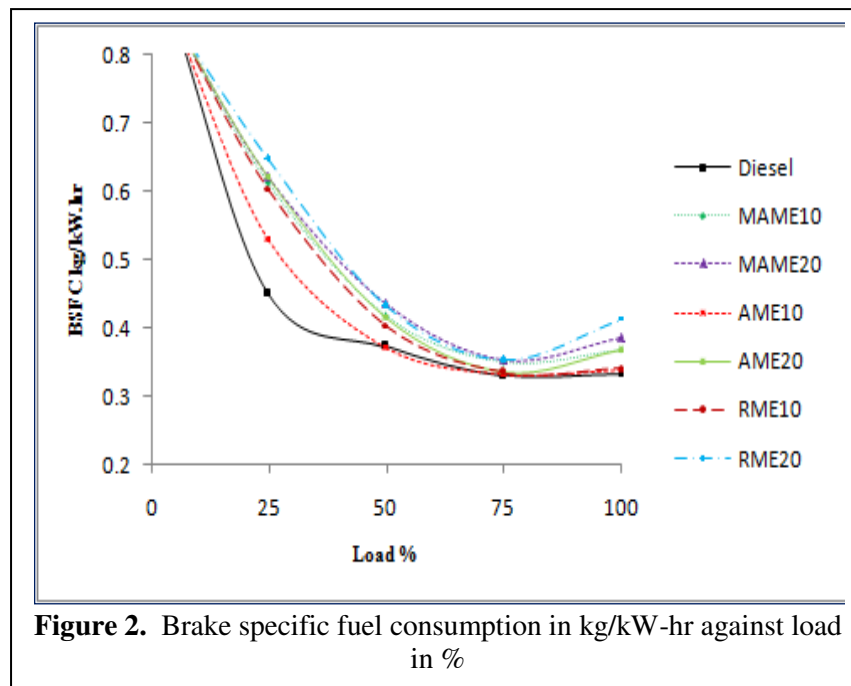


Figure 2. Brake specific fuel consumption in kg/kW-hr against load in %

3.2. Volumetric efficiency

Volumetric efficiency indicates the breathing ability of any air borne engine. It relates the actual and theoretical amount of mixture sucked to engine. The variations in the volumetric efficiency values against engine loading for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 is presented in the figure 1(b). The Average Volumetric Efficiency Values for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 at all loads are 82.31, 78.14, 77.62, 77.57, 76.83, 77.93 and 76.69% respectively. The Volumetric Efficiency for all the fuel types decreases with increase in load. The minimum volumetric efficiency value for diesel is 71.83% at 100% load the same for MAME10, MAME20, AME10, AME20, RME10 and RME20 at 100% load are 65.58, 65.07, 64.28, 63.5, 64.97 and 64 % respectively. The maximum Volumetric Efficiency for diesel is 92% occurred at 0% load the same for MAME10, MAME20, AME10, AME20, RME10 and RME20 at 0% load are 91.85, 91.34, 90.87, 90.9, 91.25 and 90.55% respectively. Due to its higher heating value, Diesel has got higher Volumetric Efficiency values than the other fuel types. All the fuel types other than diesel have almost same Volumetric Efficiency values. The difference between their Volumetric Efficiency values is less than 1%.

3.3. Smoke Opacity

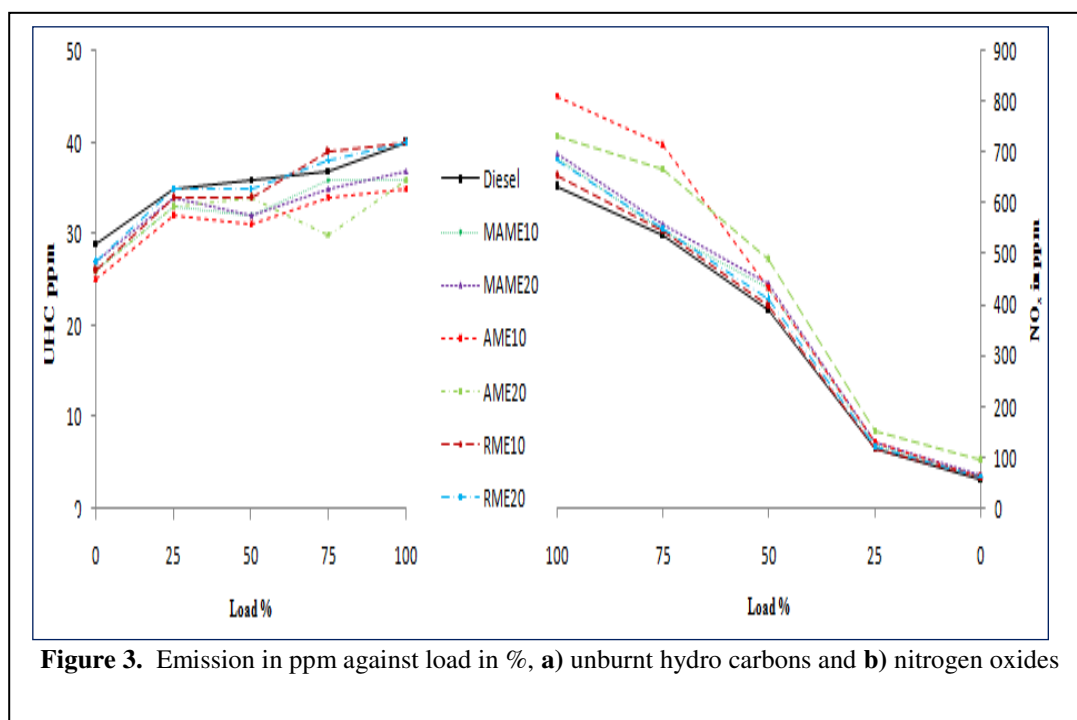


Figure 3. Emission in ppm against load in %, a) unburnt hydro carbons and b) nitrogen oxides

Smoke in the engine emission indicates how completely the combustion was held. These variations in percentage against engine loading for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 are presented in the figure 1(C). The Average Smoke Opacity Values for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 at all loads are 30.6, 28.62, 25.5, 28.8, 25.29 and 27.8 % respectively. The smoke opacity for all the fuel types increases with increase in engine load. At 0% load the smoke opacity values for all the fuel types are almost same and those were less than 17%. When the load increases the smoke opacity starts increase and reached to a maximum at 100% load. The average maximum smoke opacity values for all the fuel types is 50.25%. The biodiesel blend MAME 20 has recorded lesser smoke opacity values than the other fuel types at all loads. The RME biodiesel blends show higher smoke opacity values among the six blends

but it is still lesser than diesel. Due to the high oxygen content in the biodiesel which helped for complete combustion the blends could record less smoke opacity values than Diesel.

3.4. Brake specific fuel consumption

Brake specific fuel consumption is the amount of fuel consumed to produce one unit power at unit time. It mainly depends upon the fuel property heating value. The variations of BSFC in kg/kW-hr against engine loading for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 are presented in the figure 2. The Average BSFC Values for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 at all loads are 0.37, 0.44, 0.45, 0.39, 0.43, 0.42 and 0.46 kg/kW –hr respectively. Compare to the biodiesel blends diesel shows less BSFC values at all the loads due to its high heating value and low density. The BSFC values for all the fuel types decreases with increase in the load. At higher loads the difference in BSFC values between diesel and its blends with three biodiesel types are lesser. The differences between the BSFC values of all the fuel types are greater at lower loads. When comparing between biodiesel blends MAME Blends were consumed more by the engine than the other blends. The AME 10 and RME 10 were very close to diesel. The BSFC values of MAME 10 and MAME 20 blends were almost identical. The BSFC values range from 0.33 kg/kW–hr, 0.64 kg/kW–hr for all the fuel types tested at all loads.

3.5. Un-burnt hydro carbon(UHC) Emissions

The unburnt hydro carbon emission measures the combustion ability of any fuel. The variations of UHC in ppm against engine loading for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 are presented in the figure 3(a). The average UHC emission values for Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 at all loads are 35.4, 32.6, 33, 31.4, 31.8, 34.6 and 35 ppm respectively. These emissions increases as increase in engine load for all the fuel types. As no carbon content in the AME and MAME blends they emitted less UHC emissions than the RME blends. The UHC emissions for RME blends are approximately identical with that of pure diesel. The increase in UHC emission when increasing the engine load is of very small amount. The UHC emissions range from 25ppm to 40 ppm for all the types of fuels at all loads. The lower UHC emissions of the biodiesel blends indicates they had better and complete combustion than the Pure Diesel.

3.6. Nitrogen oxide(NO_x) emissions

The nitrogen oxide emission of any fuel is greatly affected by the oxygen content in the fuel, Cylinder temperature and the fuel retention time during combustion. The variations of NO_x emission in ppm against engine loading for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 are presented in the figure 3(b). The average NO_x emission values for the fuels Diesel, MAME10, MAME20, AME10, AME20, RME10 and RME20 at all loads are 346, 371, 379, 430, 428, 355 and 367 ppm respectively. Oxygen content in the plant oil derived biodiesel blends are more. When biodiesel is used in the engine, more fuel is sucked and it needs more time to burn it completely, also the complete combustion increases the cylinder temperature. Because of these reasons the NO_x emissions for the biodiesel blends are high when compared to pure diesel. The least NO_x value was found to be 55 ppm emitted by diesel at 0% load. The highest NO_x value is 812 ppm emitted by the AME 10 blend at 100% load. The average values of RME blends are very close to the diesel values. At lower loads all the fuel types emitted almost same NO_x emissions especially at 0% load and 25% load, because at lower engine load cylinder temperature will not be that much higher. The Diesel, RME and MAME blends followed identical trend at all loads.

4. Conclusion

The performance and emission characteristics of the micro algae, macro algae and rice bran oil biodiesel blends in the tested engine prove that the carbon emissions of the biodiesel blends are less

compared to Diesel except NOX emission. The engine consumed more fuel when the biodiesel blends are used. The volumetric efficiency values of the blends were slightly lesser than Diesel. The performance test revealed that the biodiesel blends exhibited complete and improved combustion. This study reveals that these types of biodiesel blends can be a better alternate to the pure diesel fuel to be used in a CI Engine without any modification.

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