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Research Article

OPTIMIZATION OF MAHUA BIOFUEL BLEND AND EGR (EXHAUST GAS RECIRCULATION) FOR CONTROL OF NOX EMISSIONS IN DIESEL ENGINES

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Key words: Environmentally friendly fuel, Catalytic pyrolysis, Red mud biodiese.

Abbreviations BTE: Brake Thermal Efficiency; bTDC: Before Top Dead Center; CO: Carbon Monoxide; EGR: Exhaust Gas Recirculation; EGT: Exhaust Gas Temperature; HC: Hydro Carbon; NOx: Oxides of Nitrogen; SFC: Specific Fuel Consumption

ABSTRACT

Depleting fossil-fuel reserves all over the world and the environmentalimpact caused by them such as pollution and global warming are the driving factors which leads to the search for alternative fuel. Vegetable oils either as raw oil or in the form of methyl or ethyl esters are experimented as a substitute to diesel. This involves little or no engine modification.In this work, performance and emission characteristics of Mahua oil and its blends B10, B20, B30 areevaluated in a direct-injection single-cylinder constant-speed diesel engine at varying injection pressures. It is seen that 20%Mahua oilblendand 200 bar injection pressuregives almost the same brake thermal efficiency with lowerunburned hydrocarbons, carbon monoxide and soot emissions but higher NOx (nitrogen oxides) emissionscompared to diesel fuel. EGR (Exhaust Gas Recirculation) is used to control NOx emissions. Percentageof EGR is varied to determine optimum EGR for 20% Mahua oil blend. The different rates of EGR are evaluated based on Hydrocarbons, NOx and CO emissions.

INTRODUCTION

To meet the growing fuel requirements, petroleum products are imported in huge quantity. To overcome this difficulty, renewable sources of energy such as alternative fuel has come into use. Due to the stringent emission norms like Bharath stage IV, the need for environmentally friendly fuel has become essential. Many investigations have been carried on vegetable oils, non-edible oils, animal fats and waste cooking oils to use them as alternative fuels for diesel engines without much modification in the engine.

Sukumar Puhan et al. investigated methyl, ethyl, butyl esters of Mahua oil and showed that the thermal efficiencies were high for mahua oil methyl ester. The tailpipe emissions such as CO and HC were comparatively less (Vibhanshu, *et al*., 2013). (Sudheer, *et al*., 2013) studied the performance characteristics of 25%, 50%, and 75% blends of transesterified mahua oil with diesel at 200bar injection pressure. The investigation showed a significant increase in brake thermal efficiency and decrease in brake specific fuel consumption for 75% blend with diesel (Sudheer, *et al*., 2013). (Swarup and Bhabani, 2014) investigated the effect of dimethyl carbonate as additive to mahua biodiesel and found that the brake thermal efficiency increases with increase in the amount of additive. Smoke and NOx emissions decreased by increasing the additive percentage. (Nitin, *et al*., 2012) carried out experiments on different rates of cooled Exhaust gas recirculation (EGR) to understand its effect on performance and pollutant emissions. The found that same brake thermal efficiency was produced by different EGR rates and there was a slight penalty in CO, HC emissions. Low rate of EGR was preferred than high rate of EGR due to higher smoke emission. (Ahmed, *et al*., 2017) studied the effect of injection opening pressure for a dual fuel engine with MOME

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and hydrogen. They revealed that 250 bar injection pressure improves brake thermal efficiency by 28% for 20% blend of Mahua biodiesel. (Debalaxmi, *et al.*, 2016) used Mahua Pyrolysis oil as an alternative fuel for light duty diesel engines and suggested that 30% MPO is the optimum blend for CI engines. The smoke opacity for this blend was 75% at full load. This is the least of all blends and is due to the presence of aromatic compounds. (Krushna and Kaustubha, 2014). carried out experiments on thermal and catalytic pyrolysis of Mahua seed oil and found that maximum yield of pyrolytic liquid was obtained at 525°C and calorific value of the oil increased with increasing CaO catalyst. (Sukumar, *et al.*, 2005) during their experimentation produced ethyl ester from Mahua oil by transesterification with ethanol. They finally concluded that this ester fuel reduced CO, HC, NOx and smoke emission by 58%, 63%,12% and 70% respectively. (Senthil, *et al.*, 2016) conducted a study of effect of red mud as a catalyst in the preparation of Mahua oil biodiesel. Red mud biodiesel when blended 100% at brake power 5.2 kW produced 7.5% lower NOx emission compared to KOH biodiesel. It is evident that the type of catalyst used determines the properties of fuel.

(Shubhangi, *et al.*, 2016) carried out experiments to optimize the transesterification process of Mahua biodiesel using homogeneous and heterogeneous catalyst. It was observed that an optimum yield of 93.8% is produced by nano-CaO heterogeneous catalyst at 65°C reaction temperature. This makes the properties of biodiesel comparable to that of diesel. (Vipul, *et al.*, 2013) conducted performance and emission tests on a single cylinder diesel engine fuelled with different blends of MOME. They concluded that the full load BTE increased by 23% for 20% blend. NOx emissions increased by 23% for the same blend, whereas other blends showed only a marginal increase in NOx emissions (Naveen, *et al.*, 2013).

This paper deals with analysis of varying injection pressures at different load conditions. The injection pressure has impact on the engine performance and emission characteristics. This impact is studied using Mahua oil blends. The use of Mahua biofuel results in less UBHC and CO emissions but an increase in NOx emissions when compared to the emission values of diesel. To reduce the NOx emissions, EGR is used. Experiments are carried out to determine the optimum percentage of Mahua oil blend and percentage of EGR. The fatty acid composition and characteristics of Mahua oil is given in Table 1.

The suitability of a fuel to be used in CI engines is indicated by Cetane number. Ignition delay reduces as the cetane number increases. The branched chain structure of Mahua oil reduces itsCetane number. Higher Cetane number reduces ignition delay. Fuels with longer straight chain hydrocarbons have higher Cetane number. Due to this reason, Mahua oil has Cetane number value less than diesel (Cetane number=46).

Table 1. Composition and characteristics of Mahua oil.

Types of fatty acids	%
Oleic acid	36.0
Palmitic acid	25.5
Stearic acid	22.6
Unsaponfiable matter	1-3
Characteristics	Value
Saponification value	185-195
Refractive index	1.422-1.468
Iodine value	56-70
Calorific value MJ/kWhr	37.862
Cetane Number	34
Density g/cc	0.92

EXPERIMENTAL SETUP AND PROCEDURE

The A single cylinder, 4.4 kW, four-stroke, constant speed, naturally aspirated, air-cooled diesel engine is chosen to analyze the effect of EGR and varying injection pressures on the performance and emissions.An eddy current dynamometer is used to load the engine. The detailed specifications of the test engine are given in Table 2.

The experimental set-up is represented schematically in (Fig. 1). AVL GH12D model piezoelectric pressure transducer and an angle encoder is used to obtain the pressure vs crank angle data. The AVL 364 angle encoder works with a resolution of 0.1_e1_ Crank angle. Heat release rate, cylinder peak pressure and ignition delay period are obtained from the P-θ diagram. HC, CO and NOx emissions are measured using AVL 444 exhaust gas analyzer. The engine speed, exhaust temperature, fuel consumption and exhaust emissions are measured once the steady-state conditions are reached. The experiments are carried out with different blends of Mahua oil and injection pressures of 200 bar and 230 bar. The injection timing is maintained as 23°CA bTDC throughout the test. The accuracy of the results obtained are based on the measurement errors. The accuracy of different measured parameters with instruments used are listed in Table 3.

RESULTS AND DISCUSSION

Performance of Mahua oil blends in diesel engines

The engine was run at constant speed and varying loads from 0 to 100% at two different injection pressures of 200 and 230 bar. The performance parameters such as Brake specific fuel consumption, Brake thermal efficiency and exhaust gas temperature are plotted against the load. (Fig. 2 and 3) shows variation of SFC with load for diesel, Mahua oil and its blends for injection pressures 200 and 230 bar. (Fig. 4 and 5) shows the corresponding variation of BT efficiency with load. It is evident from the results that SFC and BT efficiency are inversely related to each other. Taking diesel as the reference, at any instance say load of 8 kg, SFC of diesel, 10%, 20% and 30% are 0.21, 0.32, 0.38 and 0.40 kg/kW hr. The blends have lower calorific value compared to diesel. This results in increasing values of SFC of blends at any load.

(Fig. 6 and 7) shows the variation of exhaust gas temperature with loads respectively. The exhaust gas temperature increases as the percentage of blend increases. This is due to the high viscous nature of the oil. Mahua oil has longer chain fatty acids which results in late burning in the combustion chamber. This in turn affects the atomization and dispersion of the fuel leading to higher temperature of exhaust gas.

It is evident that injection pressure of 200 bar and 20% blend is an optimum condition which gives 43% BT efficiency at full load conditions. The SFC of Mahua oil is only slightly varying from that of diesel. Cost of 20% Mahua oil is Rs. 80 per litre at full load, whereas cost of diesel is Rs. 60/litre. The cost of Mahua oil would decrease on mass production, whereas there will be an increase in cost of diesel with time. Thus, 20% Mahua oil blend seems to be beneficial from all aspects except NOx emissions.

Table 2. Specifications of the engine.

Make	Kirloskar Engine
Model	TV1
No. of stokes	4
No. of cylinders	1
Bore and stroke	87.5 mm and 110 mm
Compression ratio	17.5:1
Rated speed	1500 rpm
Rated output	4.4 kW at 1500 rpm
Fuel injection timing	23°CA bTDC
Aspiration	Natural
Swept volume	661 cc

Reduction of NOx using EGR

An effective method to reduce NOx emissions is the Exhaust gas recirculation (EGR) method. Due to the recirculation of exhaust gases, the oxygen content available for combustion is lowered and results in lower peak combustion temperature. Hot EGR or cooled EGR can be used. In this investigation, cooled EGR is used. A control valve at the intake manifold helps in regulating the exhaust gas flow rate. The concentration of CO_2 at inlet and exhaust manifolds is used to calculate the flow rate of EGR, using the formula.

$$EGR(\%) = \frac{(\%CO_2(Intake))}{(\%CO_2(Exhaust))} \times 100$$

A fire gas analyzer is used to measure the CO_2 concentration at the exhaust. The effects on Brake thermal efficiency, NOx, CO and HC emissions alone are focused. (Fig. 8 and 9) shows the variation of SFC and BT efficiency with percentage of rated load for diesel and 20% Mahua oil at 10%, 20% and 30% EGR rates. There exists a decrease in Brake thermal efficiency when the EGR rates are increased. This is due to deficit in oxygen content in the combustion chamber.

Table 3. List of instruments with the range and accuracy.

Instruments	Range	Accuracy
EGT (K type)	0-1000	± 1
Gas analyzer CO	0-15%	± 0.06%
HC	0-20000 ppm	± 0.14 ppm
NOx	0-2000 ppm	± 5 ppm
Pressure pick up	0-250 bar	± 0.1

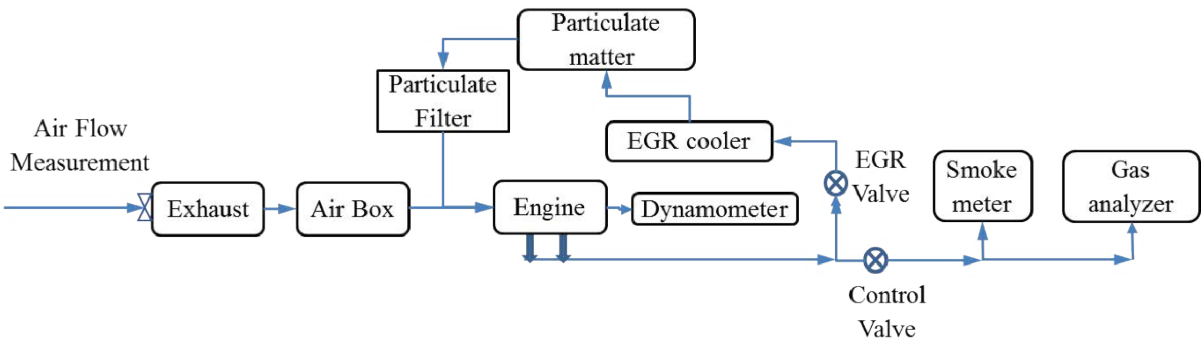

Fig. 1 Experimental set up.

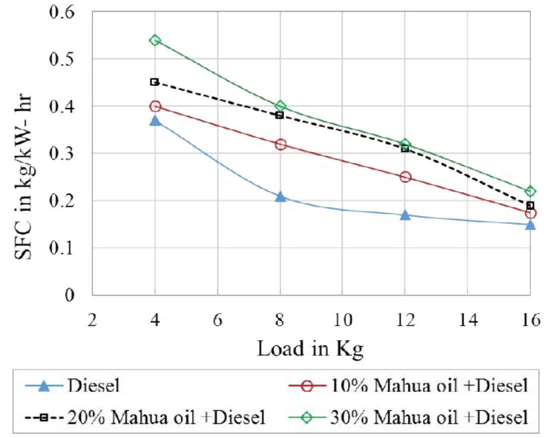

Fig. 2 SFC for injection pressure 200 bar.

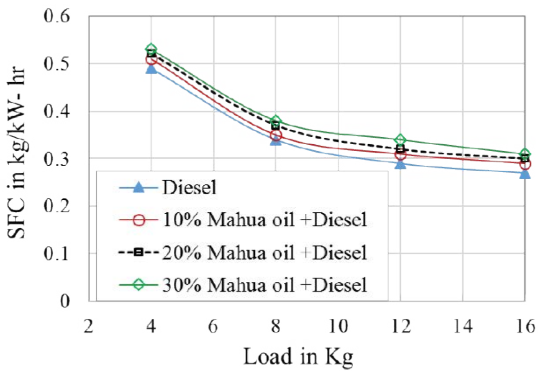

Fig. 3 SFC for injection pressure 230 bar.

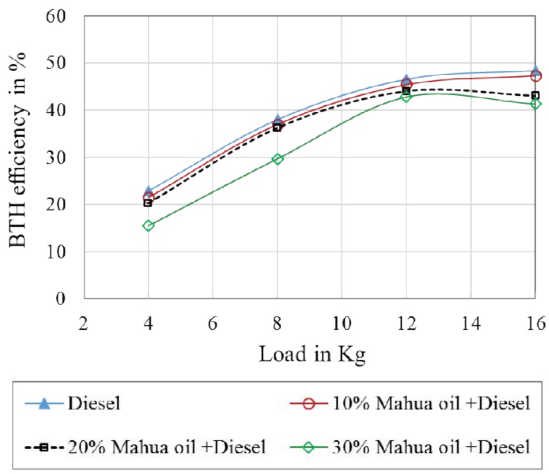

Fig. 4 Brake thermal efficiency for injection pressure 200 bar.

The variations of NOx emissions with engine load for diesel and 20% Mahua oil with 10%, 20% and 30% EGR flow rates are shown in (Fig. 10). The graph depicts the proportional decrease in NOx emissions with increasing EGR flow rate. This is attributed to lower temperature in the combustion chamber. The reduction in NOx is higher at higher loads. The fact is the drastic reduction of O_2 at high loads. (Fig. 11 and 12) shows CO and HC emissions vs engine load for all rates of EGR. HC and CO emissions are marginally higher than those without EGR. Incomplete combustion occurs due to rich air fuel mixture at various locations inside the combustion chamber. This results in slightly higher HC and CO emissions. For the 20% Mahua oil at 200 bar injection pressure, it is observed that optimum NOx emission

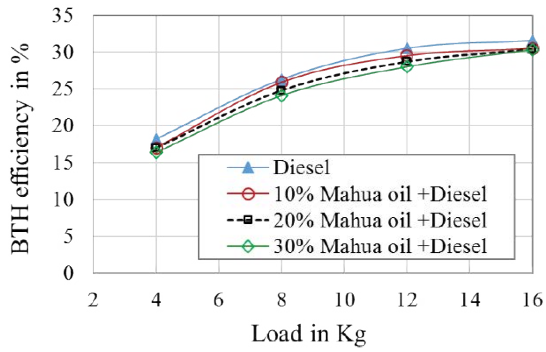

Fig. 5 Brake thermal efficiency for injection pressure 230 bar.

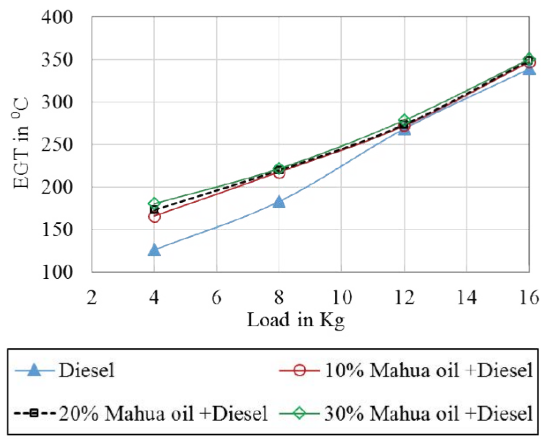

Fig. 6 Exhaust gas temperature for injection pressure 200 bar.

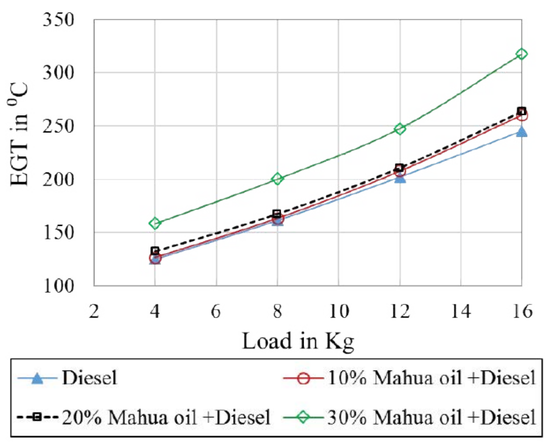

Fig. 7 Exhaust gas temperature for injection pressure 230 bar.

and brake thermal efficiency are achieved at 20% EGR flow rate.

H_2O and CO_2 in the exhaust gases when re-circulated, dilutes the intake charge. EGR increases the SFC at all rated loads when compared to the blend without EGR. The variations of NOx emissions with engine load for diesel and 20% Mahua oil with 10%, 20% and 30% EGR flow rates are shown in Fig.10. The graph depicts the proportional decrease in NOx emissions with increasing EGR flow rate. This is attributed to lower temperature in the combustion chamber. The reduction in NOx is higher at higher loads. The fact is the drastic reduction of O_2 at high loads. (Fig. 11 and 12) shows CO and HC emissions vs engine load for all rates of EGR. HC and CO emissions are marginally higher than those without EGR. Incomplete combustion occurs due to rich air fuel mixture at various locations inside the combustion chamber. This results in slightly higher HC and CO emissions. For the 20% Mahua oil at 200 bar injection pressure, it is observed that optimum NOx emission

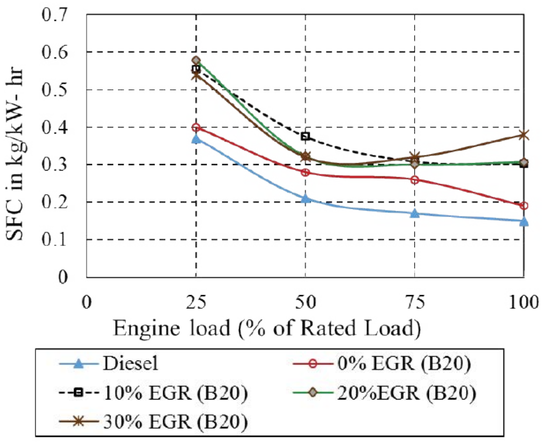

Fig. 8 SFC for various EGR rates.

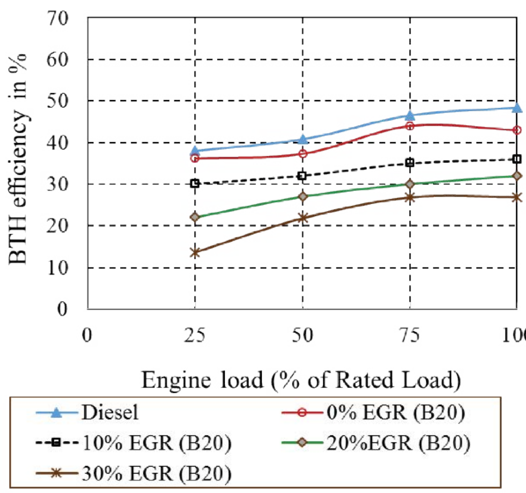

Fig. 9 Brake thermal efficiency for various EGR rates.

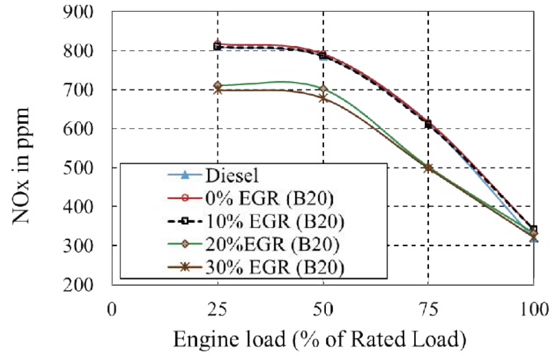

Fig. 10 NOx for various EGR rates.

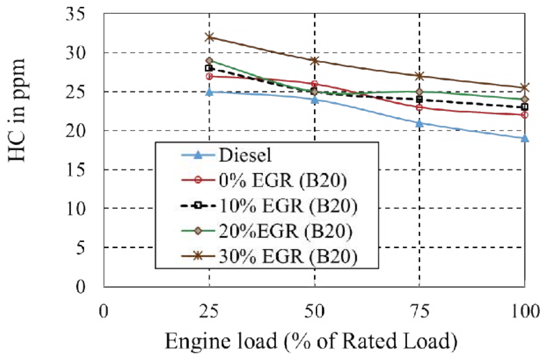

Fig. 11 HC for various EGR rates.

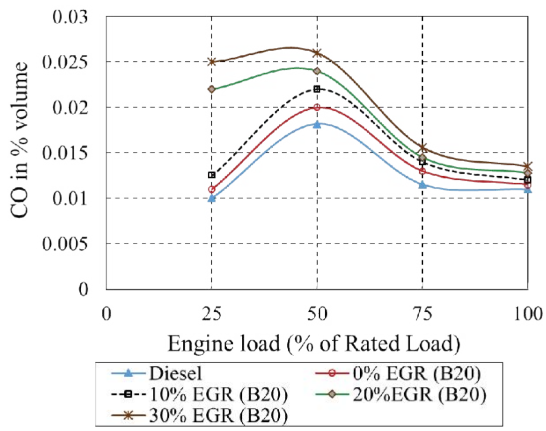

Fig. 12 CO for various EGR rates.

and brake thermal efficiency are achieved at 20% EGR flow rate.

CONCLUSIONS

Experimental studies were carried out to determine combustion, performance and emission characteristics of Mahua oil blends with and without EGR under different values of injection pressure. The results of the present work are summarized as follows:

1. Mahua oil and its blends can be used directly without any major engine modification.

2. The brake thermal efficiency decreases with a corresponding increase in the percentage of Mahua oil blend.

3. Injection pressure of 200 bar and 20% Mahua oil blend is found to be optimum condition considering the SFC and BT efficiency.

4. NOx emissions are higher for Mahua oil and its blends. As the percentage of blend increases, the NOx emission rates are also higher. Three EGR flow rates are used to reduce the NOx emissions. 20% EGR flow rate is found to be optimum for the 20% Mahua oil blend and 200 bar injection pressure considering the emission of NOx and BT efficiency.

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