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Performance and Emission Characteristics of Mahua Biodiesel in Four Stroke Single Cylinder Diesel Engine

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Abstract. According to reports, biodiesel derived from non-edible feed, such as Mahua, Jatropha, Pongamia, is a viable option for developing countries, including India. This article presents the results of the survey on performance characteristics and emissions of the diesel engine using Mahua biodiesel. In this research, the mixtures of variable proportions of biodiesel and diesel from Mahua were prepared, analyzed with respect to the performance of diesel fuel and studied using a single-cylinder diesel engine. The thermal efficiency of the brake, the specific fuel consumption of the brake, the temperatures of the exhaust gases, Co, Hc, No and smoke emissions were analyzed. Tests showed a decrease in the thermal efficiencies of the engine brakes as the amount of Mahua biodiesel in the mixture increased. The maximum percentage reduction of the BTE (14.3%) was observed for the B-40 at full load. The temperature of the exhaust gas with the mixtures decreases as the proportion of Mahua in the mixture increases. The emissions of smoke, Co and No of the engine are increased with the mixtures in all the loads. However, the HCH emissions of Mahua from biodiesel were lower than those of diesel.

Keywords: Mahua oil, Biodiesel, Alternate fuel, Diesel engine

Introduction

Recent research shows a renewed interest in biodiesel as a fuel in diesel engines, although the concept of using vegetable oil as fuel for engines is as old as the engine itself. The low cost of diesel has so far attracted the world to use it as fuel in diesel engines until now. But today due to global political turbulence and other reasons, the cost of diesel has increased exponentially. Furthermore, emission standards are more stringent than ever. In this context, many biodiesel has been used by several countries, but only a few and inedible as Jatropha, Pongamia and Mahua can be considered economically viable for some developing nations like India in particular. Mahua biodiesel is one of the most promising biodiesel options among these. Mahua (Madhuca indica) is one of the trees of forest originnon-edible oils with a high production potential of around 60 million tons per year in India (Rajesh and Saravanan, 2016). The core of Mahua fruit contains about 50% of oil, but the oil yield is 34-37% due to a small expulsion. The expelled cake is relevant for the recovery of residual oil. Since Mahua grows mainly in forest areas, and even in uncultivated and uncultivated lands, its cultivation would have no impact on food production, but it would improve the environmental conditions through massive afforestation. Mahua oil is an unused edible vegetable oil, which is available in large quantities in India. Numerous experimental studies on biodiesel as a diesel substitute have been reported in the literature (Hong et al., 2010; Innes, 1981; Mills and Elouali, 2015; Payne et al., 2016; Benbrahim-Tallaa et al., 2012; Leonard, Macchiarulo and Gant, 2014). However, experimental research into the effects of Mahua biodiesel on the diesel engine rarely appears. The main properties of Mahua biodiesel include the calorific value, the gas oil index, the flash point, the point of combustion, the cloud point, the pour point, the specific gravity and the kinematic viscosity. The various physico-chemical properties of Mahua diesel and biodiesel are measured and listed in Table 1 for comparison. It can be seen that the calorific value of Mahua biodiesel is 3% lower than that of diesel. This could be due to the presence of oxygen atoms in the Mahua biodiesel fuel molecule. The specific gravity and kinematic viscosity are respectively 1.66% and 22.36% in the case of Mahua biodiesel compared to diesel. The highest specific gravity of Mahua biodiesel makes the pulverized fuel tight and penetrates deeper. The higher viscosity of Mahua biodiesel could have an impact on combustion characteristics because the high viscosity slightly influences its atomization quality. The higher value of the Mahua diesel biodiesel index is favorable to a low level of engine operating noise and good starting characteristics. Mahua dumping points and biodiesel clouds are not favorable. However, the ignition and fire points of Mahua biodiesel are much higher than those of diesel, which makes Mahua biodiesel safer than diesel due to accidental fuel losses during handling. It can be seen that the properties of Mahua biodiesel fall within the limits of biodiesel specifications in many countries. Many investigators investigated the effects of diesel and diesel mixtures on diesel engine performance and emission characteristics and concluded that partial or complete replacement of diesel with biodiesel is feasible (Bangia et al., 2015; Giles, Carlsten and Koehle, 2012; Gamble, 2012; Miller Jothi, Nagarajan and Renganarayanan, 2008; Kook et al., 2005; Chen et al., 2014; Qi et al., 2011; Saravanan, Nagarajan and Sampath, 2013; McCormick, 2005; Rajesh and Saravanan, 2016). However, the experimental study of the performance and emission characteristics of Mahua biodiesel in the diesel engine has just been reported. Therefore, in this work we try to experimentally study the performance parameters (thermal efficiency of the brakes, specific fuel consumption for the brakes and exhaust gas temperature) and the emission parameters (carbon monoxide, unburnt hydrocarbons, nitrogen oxides and smoke) of Mahua biodiesel and biodiesel Mahua diesel is mixed as fuel in the diesel engine.

Table 1: Comparison of properties between Mahua biodiesel and diesel

Characteristics procedure Raw	**Diesel**	**Raw Mahua**	**Esters of Mahua**	**Esters of Mahua 10% Blend**	**Esters of Mahua 20% Blend**	**Esters of Mahua 30% Blend**	**Esters of Mahua 40% Blend**
Specific Gravity	0.82	0.92	0.916	0.83	0.84	0.846	0.856
Flash Point C	53	230	130	61	68	76	84
Fire Point C	58	246	141	67	76	84	92
Kinematic Viscosity at 40 C (mm2/s)	1.83	39	5.8	2.3	2.62	3	3.41
Calorific Value (KJ/kg)	41850	37614	39400	41600	41360	41115	40870

Experimental Method

Test the Engine

This research work was conducted in a Kirloskar diesel TV-1 5.2 kW engine, a cylinder, vertical, four-stroke naturally aspirated, water-cooled, direct injection and the main technical features presented in Table 2. This engine is widely used in agricultural land irrigation applications. The main objective was to study the performance and emission characteristics of Mahua biodiesel as fuel in the diesel engine. To run the desired set of experiments and collect the desired data engine, it is essential to arrange the various instruments mounted in the correct position on the experimental configuration.

Experimental Configuration

Figure 1 shows an experimental configuration used in this work. The motor was loaded Table 2: Test engine specifications. Parameter Specification Engine model Kirloskar TV-1 Engine type DI, naturally aspirated, water-cooled Number of cylinders 1 Diameter (mm) 87.5 Stroke (mm) 110 Displacement (cm3) 661 Compression ratio 17,5 Maximum power (kW) at nominal rpm 5.2 Nominal RPM 1500 Injection pressure (bar) 200 Injection time (◦btdc) 23 Figure 1: Experimental setting. with a stray current dynamometer. The mass flow of suction air was measured with an orifice gauge connected to a pressure gauge.

Table 2: Test engine specifications

Engine details	4 stroke, %constant speed, water cooled, DI
Make model	Kirlosker AV- I
Number of cylinder	One
Rated power	5.2Kw
Speed	1500 rpm
Bore	87.5 mm
Stroke	110mm
Connecting rod length	234mm
Compression ratio	Variable compression ratio (12 to 17.5)
Swept volume	661 cc
Dynamometer	Eddy current, makes SAJ
Dynamometer arm length	195mm
Injection pressure	200 bar
Torque (approximately)	26 Nm

A surge tank was used to dampen the pulsations produced by the engine, to ensure a constant flow of air through the intake manifold. The fuel consumption rate was determined using the glass burette and the stopwatch. The engine speed was measured using a digital tachometer. An AVL 444 gas analyzer was used to measure exhaust gas components such as Co, Hc and No. The smoke density was measured using the AVL 413 fumigant. The exhaust gas temperature was measured with a thermocouple of type k. Before starting measurements, some important points must be considered to obtain meaningful data from the experiments. The engine warmed up before the data was acquired. The temperature of the lubricating oil was checked to confirm that the engine was in sufficiently heated conditions. Environmental conditions must be maintained for different engine operating cycles as pressure and ambient temperature affect the intake air entering the engine cylinder, modifying the air-fuel mixture and the combustion process. All engine tests were performed under constant environmental conditions. During tests with Mahua biodiesel, the engine started with diesel until it overheated. Thus, the fuel was changed to Mahua biodiesel. After finishing the tests with the Mahua biodiesel, the fuel was always changed to diesel and the engine was run until the Mahua biodiesel was purged from the fuel line, injection pump and injector to avoid difficulties initials in the future. Initially, the test engine was run on basic diesel fuel for about 30 minutes to reach a normal working temperature condition after the base data were generated and the corresponding results were obtained. The engine was powered by Mahua diesel and biodiesel blends (B-10, B-20, B-35 and B-40). In every operation, the speed of the motor has been checked and kept constant. All the measures were repeated three times, and the arithmetic mean of these three readings was used for calculation and analysis. The different performance and emission parameters analyzed in the present investigation were brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), carbon monoxide (Co), unburned hydrocarbons (Hc), nitrogen oxide (No).

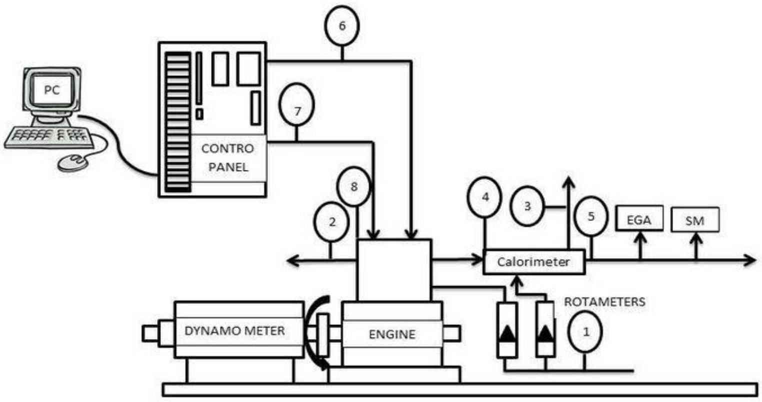

Figure 1. Schematic of experimental set up

1. Water inlet to the calorimeter and engine, 2. Water outlet from the engine gasket, 3.Water outlet from the calorimeter, 4.Exhaust gas inlet to the calorimeter, 5.Exhaust gas outlet from the calorimeter, 6.Atmospheric air temperature, 7.Fuel flow. 8Pressure transducer

Error Analysis

Errors and uncertainties in experiments may result from selection, condition, calibration, environment, observation, reading, and instrument test planning. The analysis of uncertainty is necessary to prove the accuracy of the experiments. The percentage uncertainties of various parameters such as total fuel consumption, braking power, brake specific fuel consumption and brake thermal efficiency have been calculated using the percentage uncertainties of the various instruments used in the experiment. For the typical values of the errors of various parameters shown in Table 3, using the principle of error propagation, the total percentage uncertainty of an experimental test can be calculated as = square root of ((uncertainty of tfc) 2 + (uncertainty of brake power) 2 + (uncertainty of the specific fuel consumption) 2 + (uncertainty of the thermal efficiency of the brake) 2 + (uncertainty of Co) 2 + (uncertainty of Hc) 2 + (uncertainty of No) 2 + (uncertainty of smoke) 2 + (uncertainty of the EGT indicator) 2) = ± 2.1% .

Performance Parameters

Brake Thermal Efficiency (BTE)

From Figure 2 it can be seen that the general trends of the BTE characteristics of biodiesel, diesel and their Mahua blends are almost similar in nature. It is noted that under any load condition, the thermal efficiency of the ordered Mahua biodiesel brake (B-40) and other mixtures (B-10, B-20, B-30) is lower than that of diesel operation. You can see that as the percentage of Mahua biodiesel in the mixture increases, there is a greater decrease in the thermal efficiency of the brakes compared to the diesel mode, ie the diesel operation. This lower BTE of Mahua biodiesel operation is due to the combined effect of higher viscosity, higher density and low calorific power of Mahua biodiesel. The percentage decrease in the thermal efficiency of the brakes for B-10, B-20, B-30 and the clean operation of Mahua biodiesel at full load were 4.48, 7.6, 12.43 and 14.3, respectively. The maximum thermal efficiency of the observed brake was 32.1%, 30.7%, 29.7%, 28.1% and 27.5% in this load for diesel, B-10, B-20, B- 30 and Mahua pure biodiesel, respectively.

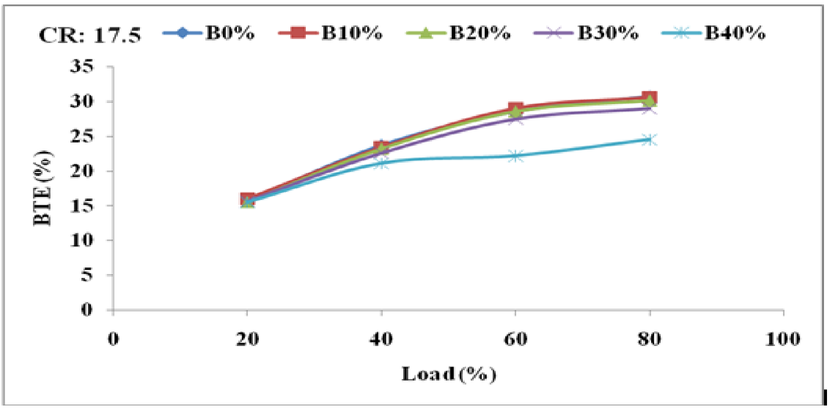

Figure 2. BTE vs. Load (%), CR=17.5

Brake-Specific Fuel Consumption (BSFC)

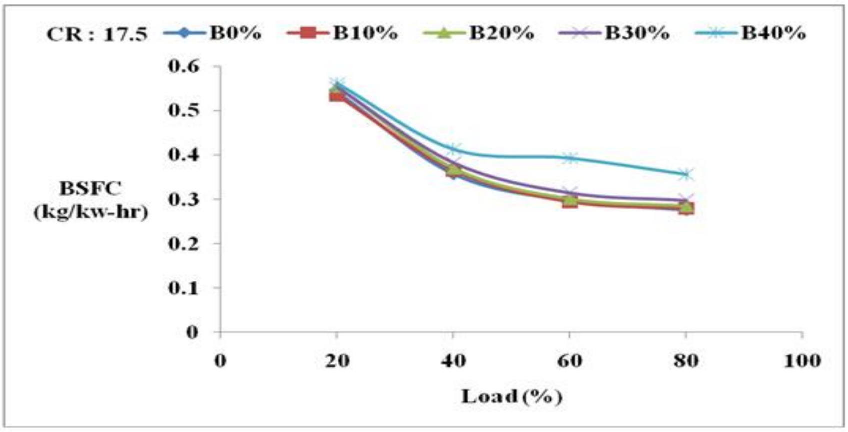

Figure 3. BSFC vs. Load (%), CR=17.5

Figure 3 shows the comparison of the effect of the load on the specific fuel consumption of the brake between diesel biodiesel and Mahua for different mixing conditions. It is noted that the specific fuel consumption of the brake decreases when the load is increased for all Mahua diesel and biodiesel operations and their mixtures. However, the rate of decrease in the specific fuel consumption of the brake is greater during loads up to 50% lower than higher loads (50 to 100%). It can also be noted that the specific fuel consumption of the brake increases when the proportion of Mahua biodiesel in the mixture increases for a given load, but the increase in the specific fuel consumption of the brake for operation B-40 (Mahua pure biodiesel) is much more than other diesel blends and operations under higher load conditions.

Exhaust Gas Temperature

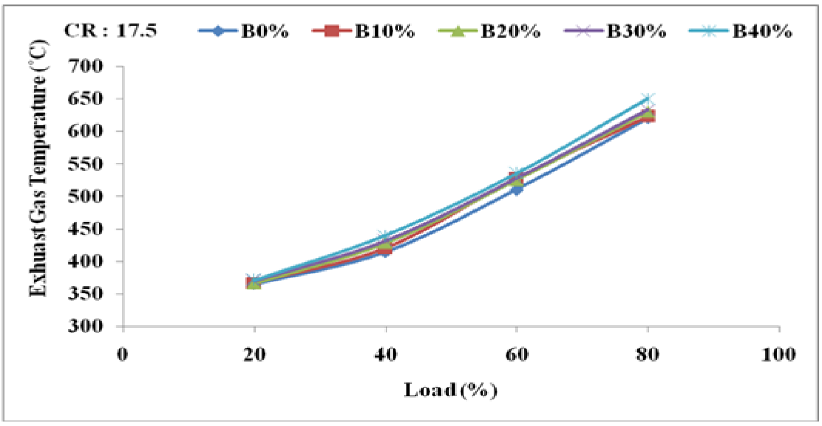

Figure 4. EGT vs. Load (%), CR=17.5

The relationship between exhaust gas temperature (EGT) and the load for different fuel and diesel mixtures is shown in Figure 4. Results showed that with increasing load, EGT is increased in all biodiesel blends and Mahua diesel. But EGT showed a decreasing trend from B-10 to B-40 to a particular load. The minimum 20% EGT load was found at 179 ° C in B-10 and followed by 176 ° C in B20, 175 ° C in B-30, 173 ° C in B-40 and the lowest EGT is (173 ◦C) for B40. Similarly, it was found that the EGT in the case of B-10 and B-40 was, respectively, 2% and 1% lower than the reference diesel fuel in a 20% load condition. The increase of EGT with the increase in load can be attributed to the increase in cylinder pressure due to better combustion of the fuel following a better atomization in heating conditions. The increase in EGT with the increase in Mahua biodiesel percentage may be due to delayed combustion. This could also be due to the slower combustion characteristics of Mahua biodiesel. 0 0.05 0.1 0.15 0.2 0.25 0.3 Load (%) 0 20 40 60 80 100 Diesel B-10 B-20 B-30 B-40 Co (% vol.) Figure 4: Comparison of Co emissions between diesel and Mahua biodiesel and mixtures.

Total Fuel Consumption

It was noted from the figure that the total fuel consumption of Mahua oil biodiesel was marginally higher than the clean diesel operation for the normal compression ratio. With an 80% load, the total fuel consumption of the engine when running on a clean diesel engine is 1,132 kg / h, while it is 1,146 kg / h, 1,177 kg / h, 1,201 kg / h and 1,450 kg / h when the engine runs on diesel with 10% of Mahua biodiesel, 20% of Mahua biodiesel, 30% of Mahua-biodisel oil and 40% of Mahua-biodisel oil respectively.

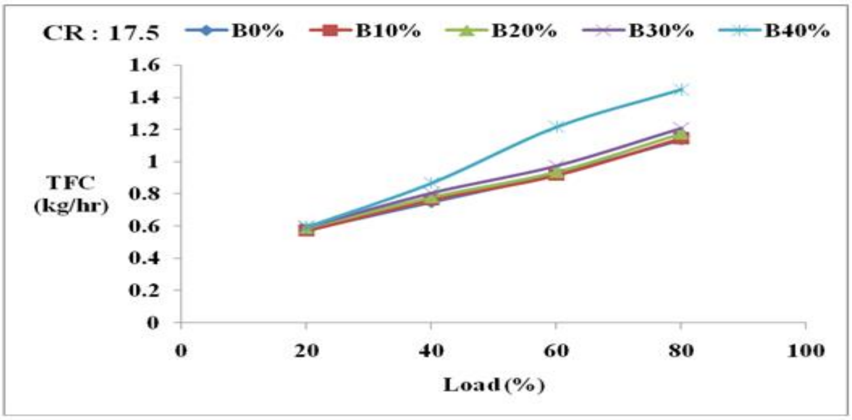

Figure 5. BTE vs. Load (%), CR=17.5

Brake Specific Energy Consumption

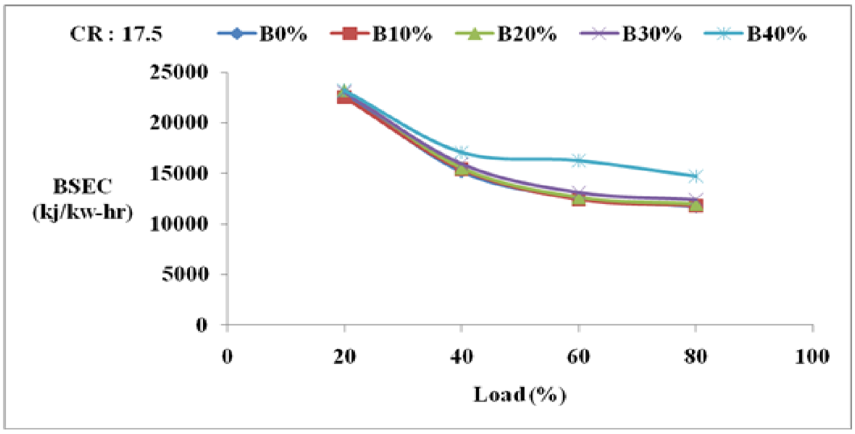

Figure 6. BSEC vs. Load (%), CR=17.5

Figure 6 shows the variation in the specific energy consumption of the brake with the load at different percentages of diesel biodiesel blends with Mahua oil. It has been observed that the specific energy consumption of the brake decreases with the load in all cases. With an 80% load, the specific energy consumption of the engine brake during operation with a clean diesel engine is 11738.52 kJ / kWh / h, while it is 11778.05 kJ / kW-h, 11957.56 kJ / kW-h, 12408.80 kJ / kW- hr, 14705.12 kJ / kWhh when the engine runs on diesel with 10% Mahua biodiesel, Mahua biodiesel, 30% Mahua biodiesel and 40% Mahua Biodisel oil, respectively.

Emissions

Carbon Monoxide

The effect of the charge on carbon monoxide (Co) emissions for diesel, Mahua's pure biodiesel and its mixtures is shown in Figure 7. It can be seen in the figure that the highest Co emissions were obtained with mixtures of Mahua and diesel biodiesel and Mahua biodiesel clean mode of operation.

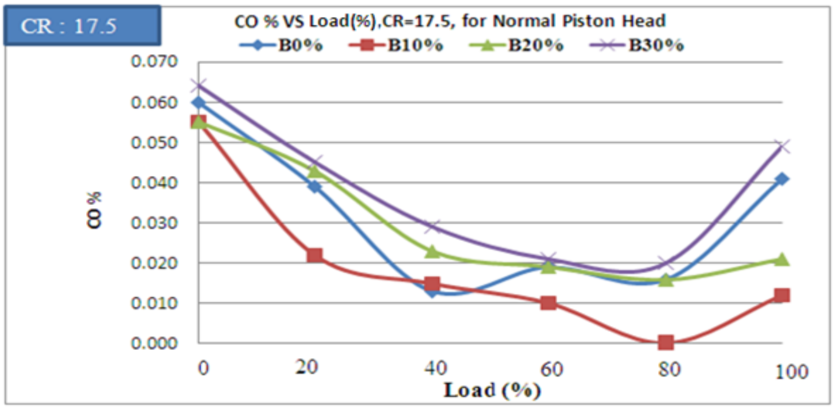

Figure 7. CO vs. Load (%), CR=17.5

The CO is 0.1, 0.13, 0.13, 0.12, 0.26% for diesel, B-10, B-20, B-30 and B-40, respectively, at 100% load. The higher Co emissions in the engine exhaust can be attributed to the polymerization occurring in the spray core; this also caused the concentration of the spray core and decreased the penetration rate (Rajesh and Saravanan, 2015). The low volatility polymers have influenced the atomization process and the mixture of air and fuel causing a locally rich mixture, which leads to a difficulty in the atomization and vaporization of pure Mahua biodiesel due to an inadequate product spray pattern. This characteristic increases incomplete combustion and therefore an increased emission of Co.

Unburned Hydrocarbon

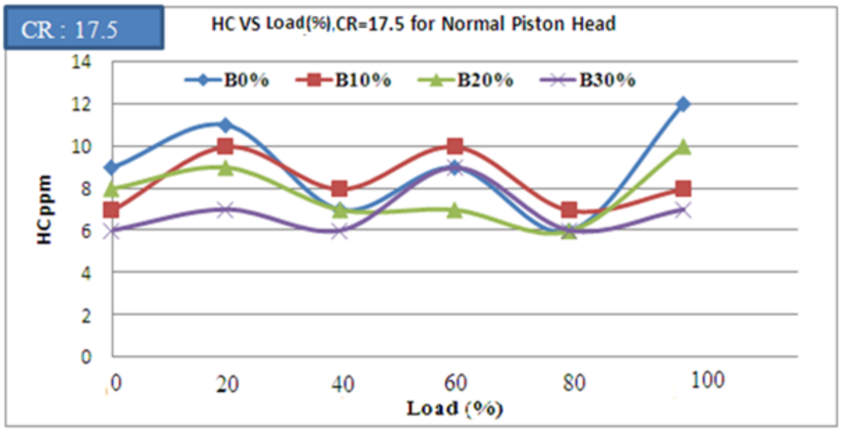

Figure 8. HC vs. Load (%), CR=17.5

The effect of the load on unburnt hydrocarbon (Hc) emissions from diesel, Mahua's pure biodiesel and their mixtures is shown in Figure 8. It can be seen in the figure that the lowest Hc emissions were obtained with Biodiesel blends Mahua Mahua and Mahua biodiesel mode of operation for loads exceeding 40%. The emission of Hc is 42, 37, 39, 31, 32 ppm for diesel, B-10, B-20, B-30 and B-40, respectively, at 40% load. The lower Hc emissions in the engine exhaust can be attributed to the efficient combustion of biodiesel and Mahua mixtures due to the presence of fuel-related oxygen and heating conditions at higher loads. While with lower loads (up to 40%), higher HC emissions were observed with Mahua biodiesel and diesel blends and Mahua ordered biodiesel operations. This is due to the fact that lower pressures and lower cylinder temperatures caused by lower combustion rates have been found at lower loads. This characteristic translates into higher Hc emissions.

Nitrogen Oxide

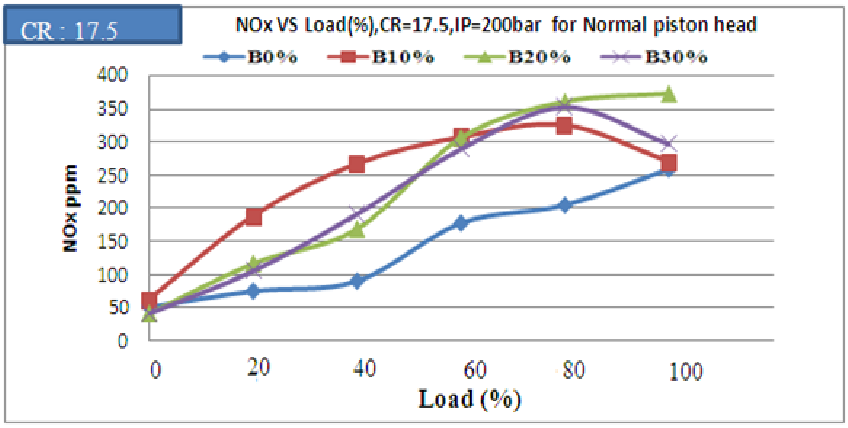

Figure 9. NOx vs. Load (%), CR=17.5

Nitric oxide (No) is generally formed at a temperature above 1500°C. High temperature, especially in regions containing O2, and time spent at these temperatures are very favorable to lack of formation. Also the quantities of N2 and O2 existing in the region are factors that are not formed. Figure 9 shows no changes depending on the engine load. It was observed that there were no higher emissions of biodiesel and Mahua mixtures than diesel in almost all loads. The increase in emissions not with the increase in the percentage of Mahua biodiesel may be due to the delayed combustion. Furthermore, the higher oxygen content of biodiesel leads to more complete combustion, with the result of higher peaks in the combustion temperature which cause a greater absence of emissions. However, the higher viscosity and density of biodiesel has caused a delayed combustion phase which translates into the slower combustion characteristics of Mahua biodiesel.

Conclusion

Performance characteristics, thermal efficiency of the brakes, specific fuel consumption for the brakes and characteristics of the temperature and emissions of exhaust gases, carbon monoxide, unburnt hydrocarbons, nitrogen oxides and smoke from a direct vertical injection with a single cylinder Kirloskar TV -1 using the Mahua biodiesel and the diesel-Mahua biodiesel blends as fuels have been experimentally studied. The following conclusions are based on experimental results.

- As the proportion of Mahua biodiesel increases in the mixture, the thermal efficiency of the brake decreases. For B40, the thermal efficiency of the brake was 14.3% lower than that of full load diesel.
- In addition to the proportion of Mahua biodiesel in the mix, plus the increase in specific fuel consumption for the brakes for each given load.
- Carbon monoxide emissions doubled with an orderly Mahua biodiesel operation compared to full load diesel mode.
- With a 20% load, HC emissions for biodiesel and Mahua blends are quite high. At higher loads, with the increase in the amount of Mahua biodiesel in the mix, Hc emissions decrease.
- NOx emissions are higher for Mahua pure biodiesel and mixtures than diesel in almost all loads.

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