Evaluation of Performance, Combustion and Emission Characteristics of a Compression Ignition Engine using Methyl Esters of Mahua Oil

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Abstract

The increase in fuel price due to inflation and the ruminative shortage in the supply of conventional fuels have led to a serious research and development on the alternate fuel sources. In India one of the option is plant which are available in plenty and can be used as bio fuels. The current utilization of non-edible oilseeds which are available is very low. Bio diesel from 'Mahua' seed is one option. 'Mahua' is known as 'Illupaimaram' in Tamil and 'Hippi' in Kannada, can be successfully grown in wastelands and dry lands. The seeds of the tree are popularly known as Indian butter tree. In this work, experiments were carried out to study and analyses the emission, combustion and performance characteristics of the mahua methyl esters. For the analysis, the setup consisting of a single cylinder, water-cooled, four stroke diesel engines is used. Initially the engine is run with the diesel fuel and the performance was analyzed. Then the experiments were conducted with blended fuels, mahua methyl esters (B20, B40 and B60) , added in volume basis, and the performance was analyzed. All the tests were conducted with varying conditions of load over the entire range of engine operation. The engine performance parameters such as the BTE (Brake thermal efficiency), SFC (Specific fuel consumption), and emission from exhaust (CO2, CO, NOx, HC and O2) were recorded. The results of the selected mahua mixtures are compared with the neat diesel fuel. Engine performance using the mahua oil and its blends were on par with the experiments performed using pure diesel fuel at most of the loads. The carbon monoxide (CO) and hydrocarbon (HC) emissions of the mahua oil and its blends were found to be lower than that of the diesel fuel at all loads. The carbon dioxide (CO2) and nitrogen oxides (NOx) emissions were higher for mahua oil blends than that of pure diesel fuel at all loads.
Keywords- Bio diesel, Alternate Fuels, Blending, Engine Testing, Exhaust emission

I. INTRODUCTION

The factor, Environmental pollution due to burning of non-renewable fuels and also the inability to replenish has resulted in a need for developing an environment friendly and a renewable resource. The biodiesel obtained from vegetable oils has been recognized world over as one of the strong contenders for reductions in exhaust emissions [1]. With the petroleum crises, prices have been increasing, and there is also a rising concern of the environment and effect of greenhouse gases. The use of vegetable oils as a substitute of conventional fossil fuel is found to be ideal and advantageous. First of all, their availability is aplenty and found everywhere in the world. Secondly, they are renewable as the vegetables, producing oil seeds, can be planted year after year. Thirdly, they are greener to the environment, as they seldom contain sulphur element in them. This makes vegetable fuel studies interesting among the various popular investigations. Vegetable oils possess similar thermal properties as that of diesel fuel. The disadvantage of vegetable oils is that they have a very high viscosity. Modern diesel engines have fuel-injection systems that are sensitive to viscosity changes. A way to avoid these problems is to reduce the viscosity of vegetable oil and have better performance. There are some methods to reduce the viscosity of vegetable oil. Fuel blending is one of the methods. It has the advantages of improving the use of vegetable oil fuel with minimal fuel processing and engine modification. Several countries including India have already begun substituting the conventional diesel by a certain amount of bio-diesel. Worldwide bio-diesel production is mainly from edible oils such as soybean, sunflower and canola oils. Since, India is not self-sufficient in edible oil production, some non-edible oil seeds available in the country are tapped for bio-diesel production. With the abundance of forest and plants such as the non-edible oils Pongamiapinnata (karanja), Jatropha curcas (jatropha), Madhucaindica (Mahua), Shorearobusta (Sal), Azadirachtaindica A Juss (neem) and Heveabraziliensis (rubber), not much attempt has been made to use its esters as a substitute for diesel except jatropha [2]. Moreover, there are plenty of wastelands available in India, which can be utilized for growing such oil rich seed crops. The recent biodiesel research in India has been towards the use of algae biodiesel, waste cooking-oil biodiesel, fish-oil biodiesel, etc. But not much work has been reported on biodiesel production from mahua oil, which has an estimated annual production potential of 181 thousand tons in India [3], when compared to other non-

edible oil seeds. Mahua is a large deciduous tree that contains a light brownish berry, which contains the seeds. On average a tree can yield 1.6 kg for a period of 60 years or more [Fig 1]. Upon drying and decertification, kernels yield around 40% oil by wt. depending upon storage conditions. Apart from the oil, other parts of this tree such as fruit and flower are also beneficial. The use of mahua oil bio-diesel as an alternate fuel for diesel engines and the performance, combustion and emission studies carried out on single cylinder direct injection diesel engine are presented in this paper.

Fig. 1: Mahua seed

II. EXPERIMENTAL SECTION

A. Oil Extraction

The Trans esterification process is the reaction of a fat/oil with an alcohol to form esters and glycerol. Under normal conditions, this reaction will precede either exceedingly slow [4]. For this reason a catalyst (either an acid or a base) should be used to speed up the reaction. The acid catalyzed Trans esterification process is comparatively slower than alkali catalyzed reaction.

In our experiments the process involves heating the mahua oil, from which the biodiesel fuel can be extracted. The oil is held at the temperature of 65 to 70 deg Celsius for a certain period of time. For 1000 ml of mahua oil, 300 ml of methanol and 30g of potassium hydroxide as catalyst are added to chemically react and produce glycerol and methyl esters. After this the whole mixture is stirred for 1 hour.

Fig. 2: Experimentation

At the end of the mixing stage, a separating flask allows the mixture to settle down. Separating and settling can be done on a single flask. Subsequently allowing the mixture to be in the flask for 24 hours, allows the settling to take place properly where the glycerin gets settled down and methyl esters get separated. The methyl esters yielded are then washed by spraying distilled water over the solution in order to get a clear solution of methyl esters.

$$\text{Mahua Oil} + \text{Methanol} \rightarrow \text{Biodiesel} + \text{Glycerin}$$

Catalyst: KoH (potassium hydroxide)

B. Biodiesel Washing

Crude methyl ester was purified by washing gently with warm water. Washing was carried out at pH 4.5 in order to neutralize the residual catalyst and soap. Excess amount of water may be presenting the washed methyl esters. According to the ASTM

standard of biodiesel, this amount of water must be lowered to a maximum of0.05% (v/v) (Anonymous, 2002). Anhydrous sodium sulfate (Na2SO4) was used to remove excess amount of water.

C. Engine Testing Setup

All analysis and experiments were performed on the experimental setup consisting of a single cylinder, four stroke , air cooled, constant speed (1500 rpm), direct injection Kirloskar diesel engine coupled to an electrical resistance loaded dynamometer. The engine specifications are given in [Table 1]. A burette and a stop watch were used to measure the fuel flow rate on volume basis. The exhaust gas temperature was noted using type J - thermocouple and a digital display. Fuel consumption was measured using a manometer. The standard AVL437C smoke meter in Hart ridge smoke Units (HSU) was used to measure the smoke intensity. Using a non-dispersive infrared analyzer, the exhaust emissions of unburned NOx, CO2, HC, CO and O2 were measured on a dry basis.

To measure cylinder pressure, heat release rate and indicated mean effective pressure AVL combustion analyzer with 619 Indi meter Hardware and Indwin software version 2.2 were used in which data from 100 consecutive cycles can be recorded. Recorded signals were processed with special software to obtain combustion parameters like maximum rate of pressure rise, heat release rate and peak pressure.

In order to prevent water vapour and particulates entering into the analyzer, the exhaust gas was passed through a cold trap (moisture separator) and filter element. HC and NOx were measured in ppm. CO, CO2 and O2 emissions were measured in terms of volume percentage.

Table 1: Engine specifications

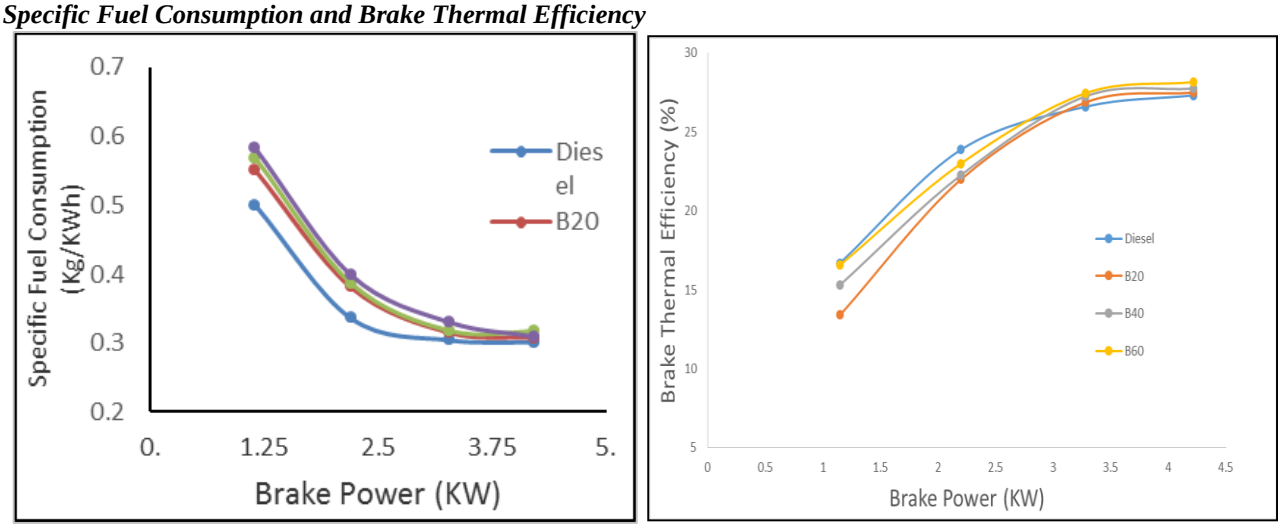
Type	*Air Cooled , Four Stroke , Electrically Loaded*
Number of Cylinders	*1*
Compression Ratio	*17:5:1*
Bore Diameter	*87.5 mm*
Stroke	*110 mm*
Speed	*1500 rpm*
Orifice Diameter	*13.4*
Rated Power	*4.4 kw*

All the tests were repeated to get a precise value. Initially, the engine was run on diesel. Then the engine was run on B20 (20% biodiesel + 80% diesel), B40 (40% biodiesel + 60% diesel), B60 (60% biodiesel + 40% diesel).

III. RESULTS AND DISCUSSION

Presently, the demand of energy is met by fossil fuels (coal, petroleum and natural gas). However, at the current rate of production, the world production of liquid fossil fuel (petroleum and natural gas) will decline by the year 2030. As energy consumption grows, there is an increase in the emissions of greenhouse gases, with significant impact on global climate change. The various engine performance of the engine are described here.

A. Specific Fuel Consumption and Brake Thermal Efficiency



Graph. 1: Specific fuel Consumption and Brake Thermal Efficiency

The variation in SFC and BTE with load for different fuels is presented in [Graph 1]. The SFC, in general, was found to increase with the increasing proportion of bio- diesel in the fuel blends with diesel, whereas it decreased sharply with increase in load for

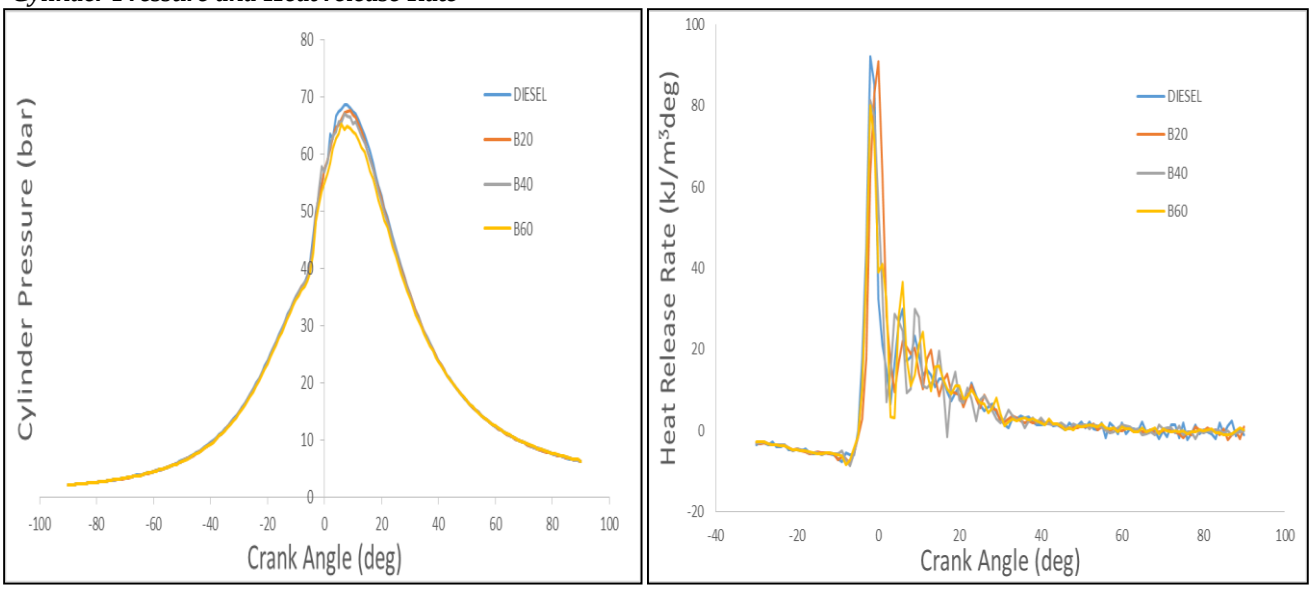
all fuels. The main reason for this is that the percentage increase in fuel required to operate the engine is less than the percentage increase in brake power due to relatively less portion of the heat losses at higher loads. The heat content of pure B100 was lower than High Speed Diesel HSD by about 12%. Due to these reasons, the SFC for other blends, namely B40, B60, B80 and B100 were higher than that of HSD. Similar trends of SFC with increasing load in different bio-diesel blends were also reported by other researchers [5][6] while testing bio-diesels obtained from karanja and rubber seed oils. At full load conditions the SFC obtained are 0.3095 kg/kw-hr, 0.317 kg/kw-hr, 0.3077 kg/kw-hr, 0.306 kg/kw-hr or fuels B20, B40, B60 and diesel respectively. SFC for the blends of B20, B40, and B60 was higher than that of diesel by 1.14%, 3.59%, and 0.56% respectively.

It can be seen from this graph that the BTE in general, reduced with the increasing concentration of bio- diesel in the blends. The maximum BTE were 27.84%, 27.95% and 27.96% for B20, B40 and B60 respectively, as compared to 27.32% for diesel. This could be attributed to the presence of increased amount of oxygen in bio-diesel, which might have resulted in its improved combustion as compared to pure diesel.

The variations in BTE for different blends at maximum or full load conditions was considerably less than those at part loads due to the increased temperatures inside the cylinder as more amount fuel is burnt at higher loads. At full load conditions, the mean BTE of B60 was about 3.67% higher than that of diesel, while at lower loads the mean BTE of B20 was about 19.76 % lower than that of diesel, which could be attributed to the significantly lower efficiencies of bio-diesel blends especially at lower loads.

The performance of the engine with bio diesel is comparable to that with conventional diesel, in terms of brake thermal efficiency. Similar results were obtained by other researchers [1][2][4][10][13][18] while using bio diesel from soybean, sunflower, canola, olive, and rubber seed oils.

B. Cylinder Pressure and Heat release Rate

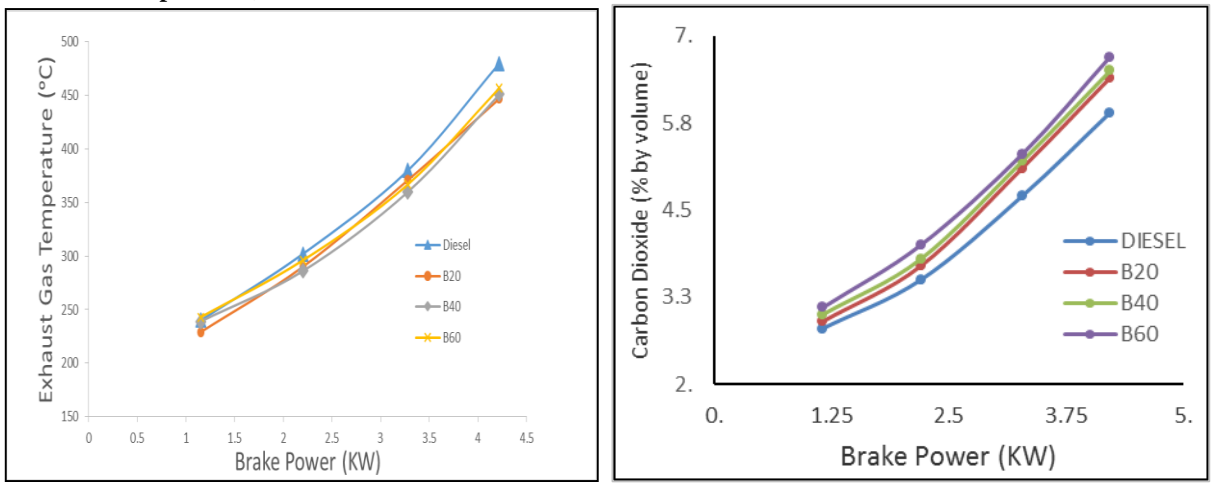


Graph. 2: Cylinder pressure and Heat release Rate

In a compression-ignition engine, the peak cylinder pressure depends on the burned fuel fraction during the premixed burning phase [7], i.e. the initial stage of combustion. The cylinder pressure characterizes the ability of the fuel to mix well with air and burn. The cylinder pressure variations for diesel and bio-diesel blends of B20, B40 and B60 are shown in [Graph 2].It can be seen that the peak cylinder pressures of the bio-diesel and its blends are lower than that of the diesel due to higher brake specific fuel consumption of bio-diesel. The occurrence of peak cylinder pressure of diesel is little earlier than that of bio-diesel. The oxygen content of the biodiesel increases fuel–air mixing rate in the cylinder compared to diesel, and this phenomenon extends the combustion duration of each stroke thereby enhancing the combustion efficiency resulting in a higher thermal efficiency. The maximum pressure for diesel is 65.021 bar and for bio-diesel B20, B40 and B60 are 68.194 bar, 67.741 bar and 68.752 bar respectively.

It can be observed that the heat release rate is high for diesel. This is due to the premixed and uncontrolled combustion phase. The peak value of heat release rate was 59.025 kJ/m3deg for diesel and 57.584 kJ/m3deg for B60. Higher heat release rate for diesel can be attributed to the higher calorific value of diesel than that of bio-diesel blends.

C. Exhaust Gas Temperature, Carbon dioxide



Graph 3: Exhaust gas temperature and Co2

The variation of exhaust gas temperature with brake power is shown in [Graph 3]. Exhaust gas temperature is an indication of the extent of conversion of heat into work, which happens inside the cylinder [8]. It is noted that the exhaust gas temperature using different bio-diesel blends at various load levels are nearly the same. Exhaust gas temperature increases with increase in power for all the fuels.

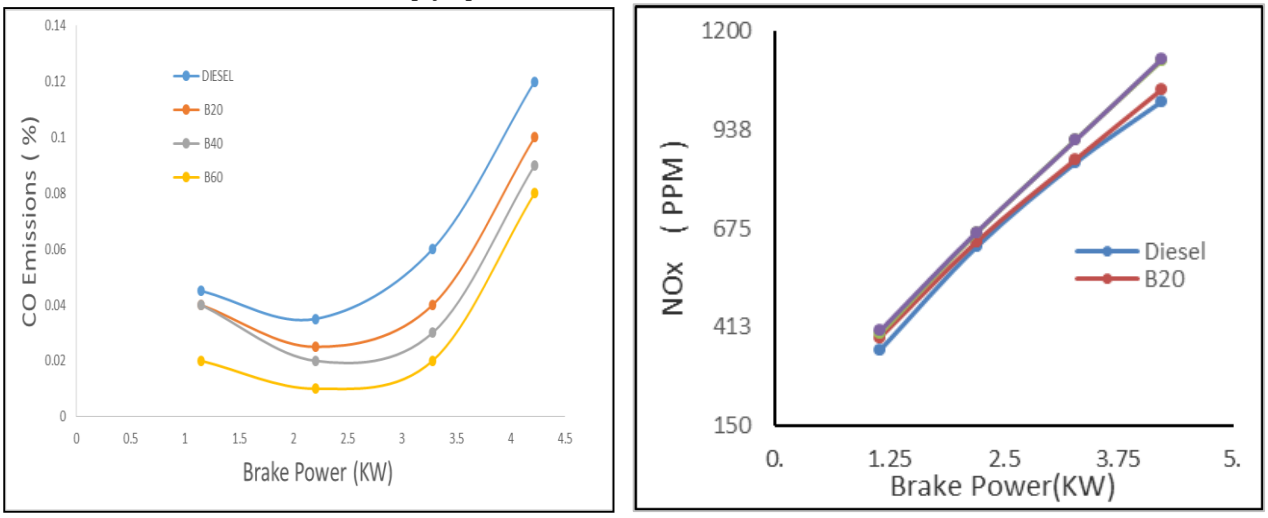
As the bio-diesel fuel concentration is increased, the exhaust gas temperature also increases but that is still less than that of diesel. B20 indicated lowest exhaust gas temperature than other fuels both at most loads. This decrease in the exhaust gas temperature can be attributed to the high viscosity of the bio-diesel and also the change in injection characteristics.

Since the EGT for bio-diesel blends are lower than that of diesel, it is not essential that the heat produced by bio-diesel blends are effectively converted in to work. The decrease in heat may also be due to the formation of H2O molecules near the exhaust, which cools the output gas. The excess water generated can be because of the use of bio-diesel blends, which has more oxygen content than diesel. The variation of CO2 with brake power is shown in [Graph 3].

As expected, it is noted that the carbon dioxide emission increases with increase in load. The carbon dioxide emission is found to increase with increase in the concentration of bio-diesel blends as more carbon monoxide gets oxidized to carbon dioxide. B60 emits more carbon dioxide, which indicates the complete combustion of the fuel.

D. Carbon Monoxide, NOx Emission

The variation of CO with Brake power is shown in [Graph 4]. The carbon monoxide emissions are found to be increasing with the increase in load. It was noted that at low and medium loads, the carbon monoxide emissions are low. At full load, the carbon monoxide emissions of the fuels increase significantly. At full load, the carbon monoxide emission for B60 fuel is about 53% lower than that of diesel. It is also observed that the CO emission increase as the value of fuel air ratio becomes greater than the stoichiometric value. Lower CO emissions of bio-diesel blends may be due to their more complete oxidation as compared to diesel. CO produced during combustion of biodiesel converted into the more stabilized CO2 by taking up the extra oxygen molecule present in the bio-diesel chain and thus reduced CO formation. It can be observed from [Graph 4] that the CO initially decreased with load and later increased sharply up to full load.



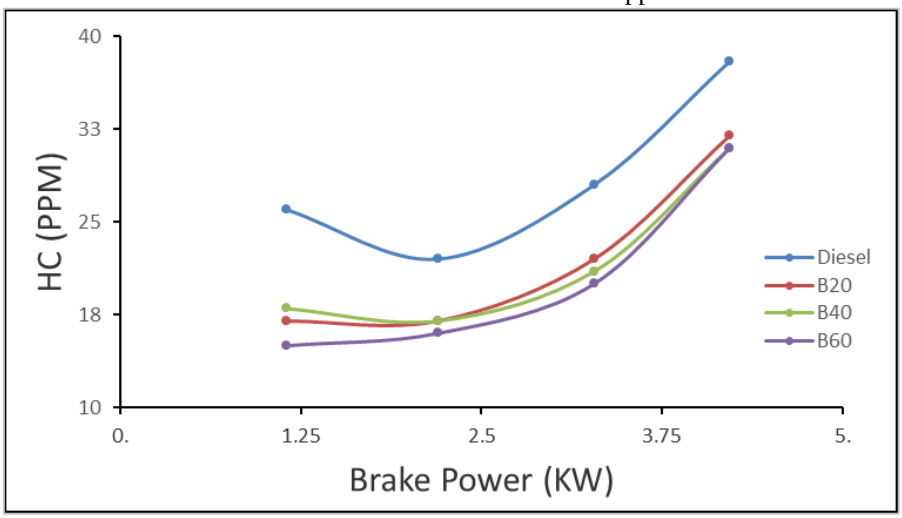
Graph 4: Co and NoX emission

This trend was observed for all the fuel blends which were tested. Initially, at no load condition, cylinder temperatures might be too low, which increased with loading due to more fuel injected inside the cylinder. At elevated temperature, performance of the engine improved with relatively better burning of the fuel resulting in decreased CO. Loading further leads to smoke formation, due to the excess fuel. Similar results were obtained [1][2][4][10][13][18] while using bio diesel from soybean, sunflower, canola, olive, rubber seed oils.

The NOx values as parts per million (ppm) for different fuel blends of bio-diesel and diesel in exhaust emissions are plotted as a function of load in [Graph 4]. From this figure, it can be seen that with the increase in the proportion of bio-diesel in the blends, there was an increase in the NOx emissions, when compared with that of pure diesel. This could be attributed to the increased exhaust gas temperatures and the fact that biodiesel has some nitrogen and oxygen content in it more than the diesel fuel which facilitated NOx formation. Generally, the value of NOx concentration varies linearly with that of the load of engine [9]. As the load increases, the overall fuel–air ratio increases resulting in an increase in the average gas temperature in the combustion chamber and hence NOx formation, which is sensitive to temperature increase. At lower loads, NOx emissions are almost the same for all fuels whereas for higher loads (say 100% load) the NOx emission indicates a value of 1126 ppm for B60 which is 11.15 % higher than diesel.

E. Hydrocarbon Emission

[Graph 5] shows the variation of hydrocarbon with that of the brake power. It is observed that the emission of hydrocarbon of various fuels is lower in low and medium loads but then increases at higher loads. This is actually because, at higher loads, where more fuel is injected into the engine cylinder, the availability of free oxygen is less for the reaction. Hence HC emissions for all bio-diesel blends are found to be lower than that of diesel at all loads. The main reason for this is the replacement of hydrogenated fuels (diesel) by bio-diesel (oxygenated fuels) to produce bio-diesel blends. For 25% engine load, HC emissions of B60 is 73.34% lesser than diesel. At 100% load HC emission for B60 is about 31ppm which is 22.58 % lesser than that of diesel.



Graph 5: Brake power vs HC

IV. CONCLUSIONS

The experimental results show that the engine performance using mahua oil and its blends are comparable to pure diesel fuel at 75 % and 100 % loads. The carbon monoxide (CO) emissions from the mahua oil and its blends were found to be significantly lower than that of the diesel fuel at all loads. The hydrocarbon (HC) emissions of mahua oil and its blends are also lower than that of diesel fuel at most of the loads. But there is an increase in the emissions of nitrogen oxides (NOx) and carbon dioxide (CO2) emissions from the mahua oil and its blends compared to that of the diesel fuel at the full loads. Effectively mahua oil can effectively replace at least 25% of the diesel fuel as a viable alternate fuel owing to its lower carbon monoxide. Mahua is a fast regeneration rural growing tree with many economic and health benefits. Preparation of bio-diesel from mahua can also aid in increase of rural employment.

In the future there can be much more effective ways to increase the pure ester percentage yield from the seeds and also try out different methods for increasing the engine performance such as BTH by employing variable injection pressures.

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