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# **Performance and Exhaust Emission Analysis of a Diesel Engine using Neat Diesel Oil and Blends of Pongamia Pinata Methyl Ester (PPME) with Neat Diesel Oil**

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**ABSTRACT:** Compliance with the limited oil reserves on the earth and governmental regulations about the environment to meet emission standards leads to the quest for fuels which are eco-friendly and safe for the human beings. It is now well established that lower blends of biodiesel and diesel works well in the existing engines without any modifications due to the similarity of the bio fuels to the diesel fuel. Experimental investigation was carried out in a single cylinder direct injection diesel engine fuelled with diesel and blends produced with diesel fuel and Pongamia Pinata methyl ester (PPME) in different proportions such as 0, 10, 20, 30, 40% and 100% (B0, B10, B20, B30, B40 and B100). The performance was evaluated in terms of fuel consumption, brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature (EGT) at different load and exhaust emission characteristics were evaluated in terms of hydrocarbon (HC), Carbon monoxide (CO), and oxides of Nitrogen (NO<sub>x</sub>), at different load and compared with diesel fuel. The investigation revealed that all the properties of PPME blends are higher (except calorific value) than neat diesel. Lower caloric value of PPME blends is responsible for higher fuel consumption leading to reduction of brake thermal and indicated thermal efficiency. Presence of higher cetane number PPME blends shows better combustion than neat diesel. Hence emission of PPME blends shows lower pollutants except NO<sub>x</sub> emission than neat diesel.

**KEYWORDS:** Biodiesel, Pongamia piñata methyl ester, Performance, Emissions, Combustion, Blends, cetane number.

## **I. INTRODUCTION**

The most fundamental requirement for human existence into the earth is the energy. The world energy demand has highly increased in few decades and the use of these energy resources has increased major environmental impact. Conventional energy sources, such as coal, oil and natural gas, etc have limited reserves that are expected not to last for long period. Due to limited resources of fossil fuels, rising crude oil prices and the increasing concerns for environment, there has been renewed focus on vegetable oils and animal fats as an alternative to petroleum fuels. The search for alternative fuels which are eco-friendly and can be used as a substitute to conventional hydrocarbon based fuels is in demand due to concerns about depletion of fossil fuel reserves and also growing awareness against global warming [1]. One of the major alternative fuels which have been found to be eco-friendly is biodiesel. Bio-diesel is one

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of these sustainable fuels that consisting of alkyl esters derived from either transesterification of triglycerides obtained from vegetable oils or esterification of free fatty acids from animal fats with short-chained alcohols. There are varieties of species from which biodiesels can be made available. Biodiesels produce carbon dioxide (CO<sub>2</sub>) during combustion but through the process of photosynthesis they recycle CO<sub>2</sub>. Hence they are called as carbon neutral. They are renewable and contain no sulphur. This characteristic of biodiesels can greatly reduce the existing environmental damage caused by acid rain [2]. If these biodiesels can successfully substitute conventional hydrocarbon based fuels in power generation sector they can be used as an emergency energy source. They will also play an important role in improving the financial status of the countries which are facing problem due to the shortage of conventional fuel. Vegetable oil methyl ester from different crops has been tried by researchers in different parts of the world, as fuels for diesel engines. The long chain hydrocarbon structure, vegetable oils have good ignition characteristics, low emissions, biodegradable, non-toxic and better lubricity, however, they cause serious problems such as carbon deposits in the engine cylinder and piston, high density, high viscosity, lower calorific value, high molecular weight and higher production cost [3-4].

## II RELATED WORK

Biodiesel can be mixed with diesel fuel in any proportions or directly used to diesel engine and does not require major changes into the engine. [5]. Use of biodiesel reduces the emissions of soot by 60% and CO by 50% [6]. Hence in this experimental analysis biodiesel blends are used for characterization of the single cylinder Direct Injection (DI) diesel engine.

Ejaz and Jamal [7] have reviewed diesel engine tests results that carried out by earlier researchers using vegetable oil based fuels. Most of the researchers have used sunflower oil, rapeseed oil, cottonseed oil, soybean oil, palm oil and peanut oil as fuel for diesel engines in different modes. They concluded that coking is a major problem for unmodified vegetable oils in diesel engine. But, chemically processed biodiesel blends with diesel can be used effectively and efficiently in diesel engine for longer duration.

Mc Donnel [8] conducted an experiment to investigate the effect of semi-refined rapeseed oil on a diesel engine. In this study, it was reported that engine performance was better with 25% blend and use of rapeseed oil over a longer period of time was found to shorten the injector life due to carbon build up even though there was no wear of the engine components or contamination of lubricating oil.

Ramadhas et al. [9] have focused on the advantages, challenges and technical difficulties of using vegetable oil based fuels in diesel engines. It was reported that the feedstock price of vegetable oils, homogeneity are the major challenges. Engine durability, popularization of environmental benefits of vegetable oils, and effects of glycerol on engine life are the primary technical difficulties of biodiesel.

Pradeep and Sharma [10] conducted an experiment on a single cylinder diesel engine running on rubber seed oil and its blends with diesel. The brake thermal efficiency was found to be less for biodiesel blends compared to diesel. Higher combustion duration and lower heat release rate were recorded for biodiesel.

Yoshimoto [11] an experiment was conducted on a single cylinder four stroke diesel engine to investigate the spray characteristics, engine performance, emissions and combustion characteristics of water emulsions of the blended fuel with equal proportions of rapeseed oil and diesel. It was observed that the performance was improved with slightly increased emissions of CO and NO<sub>x</sub> with knock free combustion.

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Vol. 8, Issue 10, October 2019

Almeida and Al-Shyoukh [12] conducted an experiment on a diesel generator with preheated palm oil for different temperatures. They observed reduction of NO<sub>x</sub> emissions and increase of CO, HC, and CO<sub>2</sub> emissions.

Anand and Kannan [13] conducted an analysis of performance and emissions of a variable compression ratio diesel engine running at constant speed using cotton seed oil based biodiesel (COME) in blend proportion of 5 to 20% with diesel. They observed higher brake thermal efficiency and lower brake specific fuel consumption.

Devan and Mahalakshmi [14] have carried out experiments to study the performance, emission and combustion characteristics of a diesel engine running on Methyl Ester of Paradise Oil (MEPS) and its blends with diesel. Significant reduction in smoke and unburned hydrocarbon emissions by 40% and 27% for MEPS 100 was observed. However, there was an increase of NO<sub>x</sub> emission by 8% for MEPS 100.

Suryanarayanan et al. [15] analyzed the performance and emission characteristics of a diesel engine by using methyl esters of Sunflower oil, Palm oil, Jatropha oil, Rice bran oil and waste cooking oil and compared with those of diesel. It was observed that Sunflower oil Methyl Ester (SUME) has the highest brake thermal efficiency throughout the range of loads while Palm oil Methyl Ester (PAME) has the lowest specific fuel consumption among the biodiesels. On the other hand, NO<sub>x</sub> emissions are found to be highest for SUME. All biodiesels record lesser CO, HC and soot emissions compared to diesel.

The aim of the present study is to experimentally investigate the effect of different biodiesel (PPME) blends with diesel and neat diesel on the performance and emission characteristics of a diesel engine.

## III. MATERIALS AND METHODS

### 3.1. Production of Pongamia pinata Methyl Ester and its properties:

Biodiesel is produced from vegetable oil or animal fat, where mono alkyl ester is the main product and glycerol is the by product. Vegetable oil mostly contains triglycerides. Transesterification of vegetable oil is done to produce biodiesel which reduces the viscosity, and improve cetane number compared to the vegetable oil. It is the process which involves the reaction between triglycerides of vegetable oil and alcohol in the presence of catalyst and heat to obtain biodiesel and glycerol.

The reaction can be completed in a single step or two steps that depended on the percentage of free fatty acid or acid value of the oil used. If free fatty acid is more than 4%, then two steps method is to be followed. In that case both alkali (KOH or NaOH) and acid (H<sub>2</sub>SO<sub>4</sub>) is used as a catalyst whereas if free fatty acid is less than 4% then only alkali (KOH or NaOH) is used as catalyst.

In this study 1 litre sample vegetable oil is heated in glass container above 100 °C to remove moisture content in it. Then moisture free oil is taken in a round bottom flask and heated around 50-60°C on a hot plate having magnetic stirrer arrangement. Then 200 ml methanol and 4.5 gm potassium hydroxide is taken into a separate flask and shake that mixture well up to KOH dissolved fully and become potassium methoxide solution. Then, potassium methoxide solution is added to the heated oil. The mixture was stirred continuously. After the completion of reaction, the products are allowed to settle down for 8 to 12 hours in separating funnel. The mixture separate into two layers, the lower layer contains glycerol and the upper layer contains methyl ester of pongamia pinata oil which is separated and purified using water. The purified biodiesel was then distilled to remove moisture and finally desired quality of biodiesel was obtained. Numbers of tests are conducted to analyze the composition and physical-chemical properties of diesel, biodiesel and blends of biodiesel with diesel. B0, B10, B20, B30, B40 and B100 represent various volumetric biodiesel quantities in

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Vol. 8, Issue 10, October 2019

the test fuel (biodiesel–diesel blend). Properties of all the test fuels are presented Table 1. It is comprehended that the physicochemical properties of biodiesel differ from that of conventional diesel; which could affect the diesel engine performance and emission characteristics without any further modification of the engine hardware. The heating value of all biodiesel blends is decreasing with increasing biodiesel concentration in the blends.

**Table 1 Properties of the test Fuels**

Properties	Units	Diesel	B10	B20	B30	B40	B100
Viscosity at 35°C	cSst	2.3	2.74	2.87	3.12	3.27	10.29
Density(at 35°C)	Kg/m <sup>3</sup>	826	836	841	848	856	886
Pour point	°C	-3	1.7	2.6	2.8	3.2	4.2
Flash Point	°C	52	54	57	60	73	134
Fire point	°C	56	68	77	84	97	152
Calorific value	kJ/kg	44,567	42820	41426	40215	39400	35670
Ash content	% by mass	Nil	0.018	.023	0.031	0.031	0.087
Cetane number		44	46	46	47	48	51

### 3.2. Experimental Procedure:

The experimental work carried out to investigate the performance and exhaust emission characteristics at different load conditions and compared with diesel fuel. Different blends of pongamia piñata methyl ester (PPME) with diesel fuel and pure diesel were used to test a single-cylinder, four-stroke, and water cooled diesel engine with rope brake dynamometer having a rated output of 3.72 kW at a constant speed 1500 rpm. The technical specifications of the engine are given in Table 2, and the schematic diagram of the experimental setup is shown in Figure 1. The power output of the engine was measured by rope brake dynamometer that was coupled with the engine. The exhaust emissions like HC, CO, CO<sub>2</sub> and NO<sub>x</sub> were measured by AVL exhaust gas analyzer. Temperature indicator was used for the measurement of exhaust gas temperature. Engine is started under no load condition and then warmed up at the rated speed of 1500 rpm and all the readings are taken under steady state conditions at various loads of 0 kg, 3 kg, 6 kg, 9 kg 12 kg and 15 kg.

Experiments were carried out initially using neat diesel fuel to generate the base line data. Engine performance characteristics like brake power, brake thermal efficiency, indicated thermal efficiency, brakes specific fuel consumption etc were quantified based on recorded test parameters like fuel flow rate, temperatures, air flow rate, load etc. The engine was warmed up and before taking all readings, the engine was allowed to come at steady state condition. All the observations are taken thrice to get a reasonable value.

**Table: 2. Technical specification of test engine**

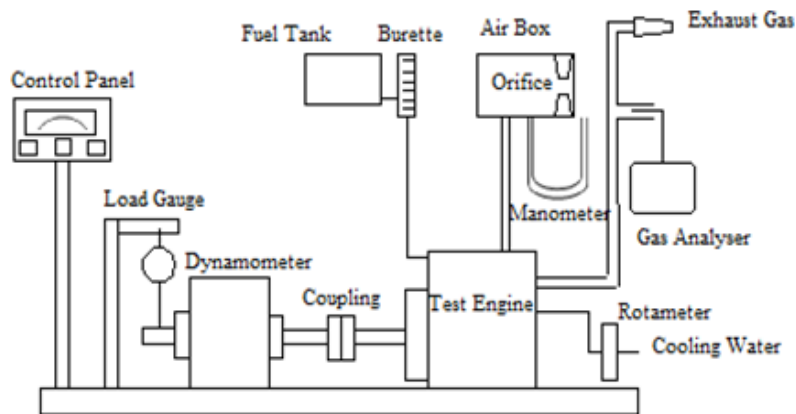
Made	Kirloskar
Model	AV1
Number Cylinder	Single Cylinder
Number of Stroke	4 - stroke
Bore × Stroke	80 × 110 mm
Rated Output	3.72 kW
Compression Ratio	16.5 : 1
Rated Speed	1500 rpm
Type of Cooling	Water Cooling

## International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 8, Issue 10, October 2019



*Figure.1. Schematic diagram of the experimental set up*

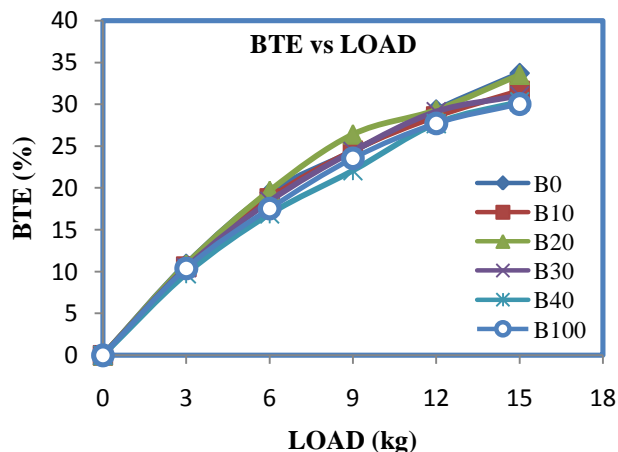
### IV. RESULTS AND DISCUSSION:

The output obtained from the experiment is plotted to determine the performance analysis and exhaust emission analysis.

#### 4.1 Performance analysis

##### 4.1.1 Brake Thermal Efficiency (BTE) v/s Load

In Fig2 the brake thermal efficiency is plotted against different loads for different blends of Pongamia piñata methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine. BTE gives an idea of the output power generated by the engine with respect to heat supplied in the form of fuel. It was observed that with the increase of the load brake thermal efficiency increase in all cases due to increase of combustion quality and reduction of heat loss at higher engine load. At medium load condition BTE of B20 was slightly higher than the neat diesel due to additional lubrication of B20 but at the full load condition BTE of B20 quite closer to neat diesel. It was also observed that the brake thermal efficiency of diesel fuel 3.7% higher than B100 due to low calorific value and higher viscosity of biodiesel.



*Fig.2. Brake Thermal Efficiency v/s Load*

## International Journal of Innovative Research in Science, Engineering and Technology

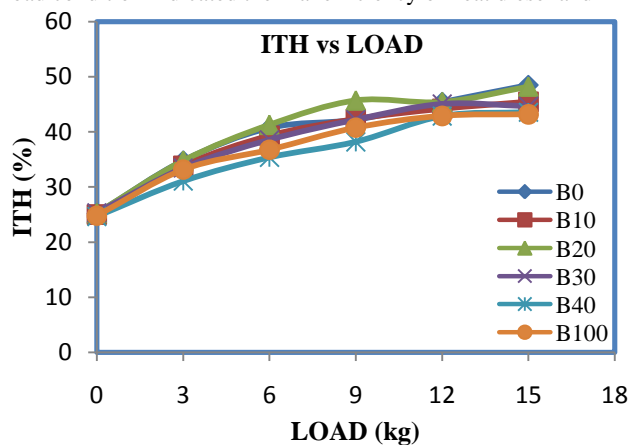
(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 8, Issue 10, October 2019

### 4.1.2 Indicated Thermal Efficiency (ITE) v/s Load

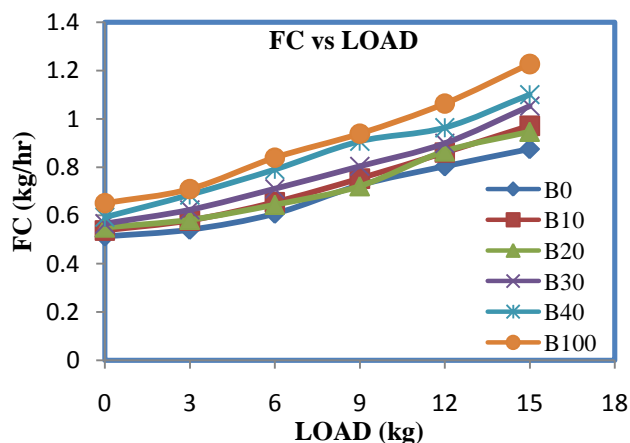
In Fig3 the indicated thermal efficiency is plotted against different loads for different blends of Pongamia piñata methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine. It was observed that with the increase of the load indicated thermal efficiency increase in all cases due to increase of combustion quality, reduction of frictional loss and reduction of heat loss at higher engine load. At medium load condition Indicated thermal efficiency of B20 was slightly higher than the neat diesel due to additional lubrication of B20 but at the full load condition indicated thermal efficiency of neat diesel and B20 approximately same.



*Fig.3. Indicated Thermal efficiency v/s Load*

### 4.1.3 Fuel Consumption v/s Load:

In Fig4 the Fuel consumption is plotted against different loads for different blends of Pongamia piñata methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine. FC indicates the mass of fuel consumed to produce power for a particular time. During calculating FC load into the engine and calorific value of the fuel is not considered. It was observed that with the increase of the load fuel consumption increases in all cases to produce more amount of energy. Consumption of neat diesel fuel was lower than the blends of biodiesel with the diesel and fuel consumption was highest for pure bio-diesel in all loads of the engine. It indicated that with the increase of the ratio of biodiesel in the blends, fuel consumption increase due to higher specific gravity, poor spray characteristics and lower calorific value of biodiesel.



*Fig.4. Fuel consumption v/s Load*

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 8, Issue 10, October 2019

### 4.1.4 Brake Specific Fuel Consumption (BSFC)

The variation of Brake specific fuel consumption with load for different blends of Pongamia piñata methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine are shown in fig.5. It was observed that the brake specific fuel consumptions decreased with the increase of load. The brake specific fuel consumption of biodiesel blends is higher than the neat diesel in all load conditions due to high viscosity, low calorific value of the biodiesel blends. The brake specific fuel consumption for B20 blend is closer to the neat diesel fuel.

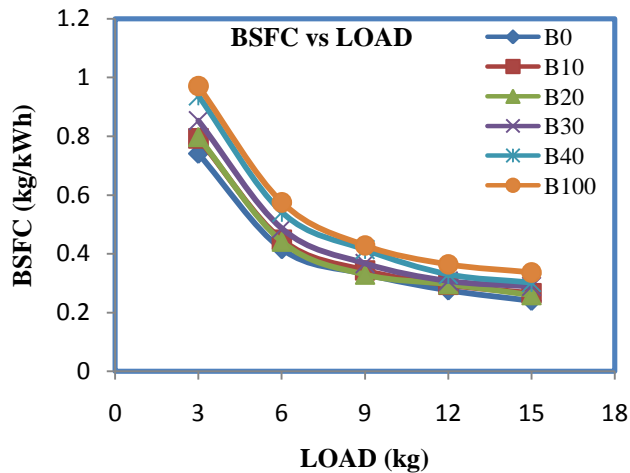


Fig.5. Brake Specific Fuel Consumption v/s Load

### 4.1.5 Exhaust Gas Temperature (EGT) v/s Load

The variation of exhaust gas temperature (EGT) with load for different blends of Pongamia piñata methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine are shown in fig.6. It was observed that the exhaust gas temperature increases with the increase of the load. The exhaust gas temperature of the biodiesel blends in all load condition is higher than the neat diesel fuel due to high flash point temperature, low volatility, high viscosity and slow combustion of the biodiesel blends. The exhaust gas temperature of biodiesel B100 was observed 76°C higher than diesel fuel.

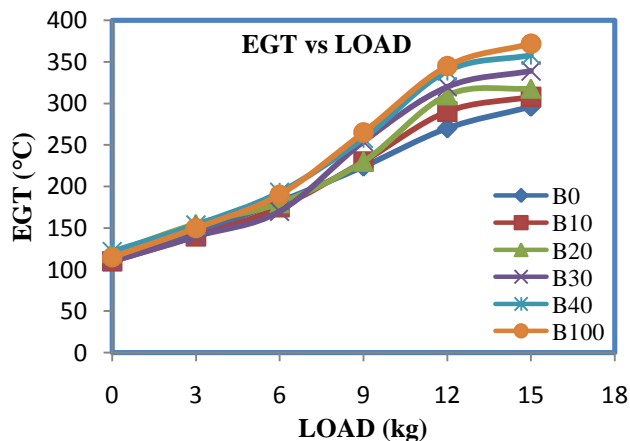


Fig.6. Exhaust Gas Temperature v/s Load



## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 8, Issue 10, October 2019

### 4.1.6. Volumetric Efficiency v/s load

The variation of volumetric efficiency with load for different blends of Pongamia piñata methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine are shown in fig.7. It was observed that the volumetric efficiency of the engine decreased with the increase of load for all the biodiesel blends and neat diesel. This is because as the fresh charge enters into the hot engine cylinder, heat is transferred from the hot flue gases and hot combustion chamber walls to the fresh charge and raising its temperature resulting in a decrease in mass of fresh charge admitted and a reduction of volumetric efficiency. Also exhaust gas into the clearance volume reduced amount of fresh charge into the cylinder resulting reduction of volumetric efficiency.

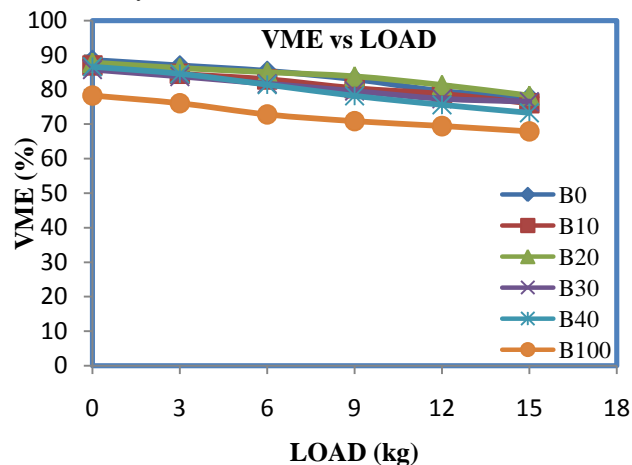


Fig.7. Volumetric Efficiency v/s Load

### 4.2 Emission Analysis

#### 4.2.1 Hydrocarbon emission (HC)

The variation of hydrocarbon emission with load for different blends of Pongamia piñata methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine are shown in fig.8. It was observed that the hydrocarbon emission of different blends of PPME was gradually reduced with the increase in the concentration of biodiesel with diesel. Ignition delay plays an important role for the formation HC. The higher cetane number of biodiesel fuel reduces the ignition delay leading to better combustion of biodiesel than neat diesel as a result formation of lower HC. Higher concentration of O<sub>2</sub> in biodiesel facilitates the complete combustion of biodiesel than neat diesel resulting lower HC formation.

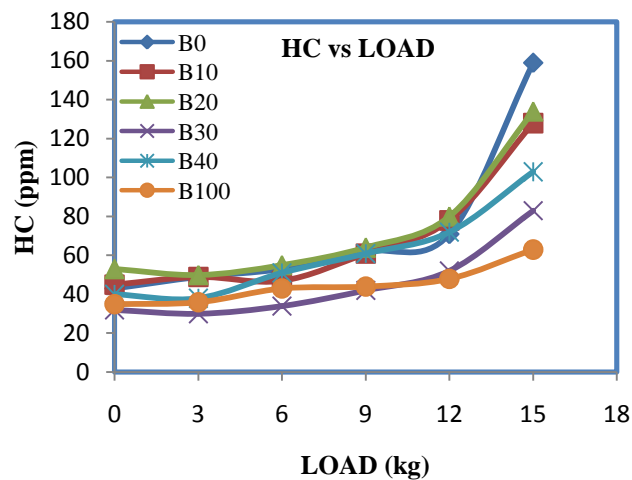


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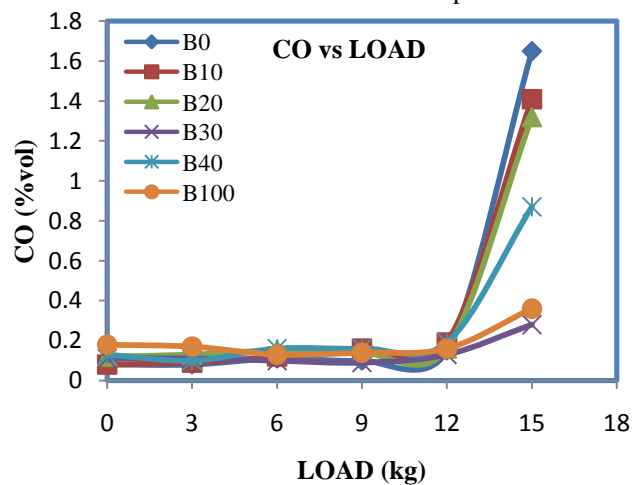
Vol. 8, Issue 10, October 2019



**Fig.8. Hydrocarbon Emission v/s Load**

### 4.2.2 Carbon Monoxide emission (CO)

The variation of carbon monoxide emission with load for different blends of Pongamia piñata methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine are shown in fig.9. Higher CO emission is mainly due to the poor mixing of fuel with air and incomplete combustion of fuel. It was observed that the CO emission of different blends of biodiesel was gradually reduced with increase in the concentration of biodiesel with diesel. Because biodiesel having more oxygen than neat diesel which facilitates the complete combustion of fuel.



**Fig.9. Carbon monoxide Emission v/s Load**

### 4.2.3 Carbon Dioxide emission (CO<sub>2</sub>)

The variation of carbon dioxide emission with load for different blends of Pongamia piñata methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine are shown in fig.10. It was observed that the carbon dioxide emission increases with the increase of the load. Carbon dioxide is normal product of combustion. Generally after combustion of hydrocarbon present in fuel should produce only CO<sub>2</sub> and water. It was found that amount of CO<sub>2</sub>

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 8, Issue 10, October 2019

increased while HC and CO emission decreasing with the increased concentration of biodiesel and this is an indication of complete combustion.

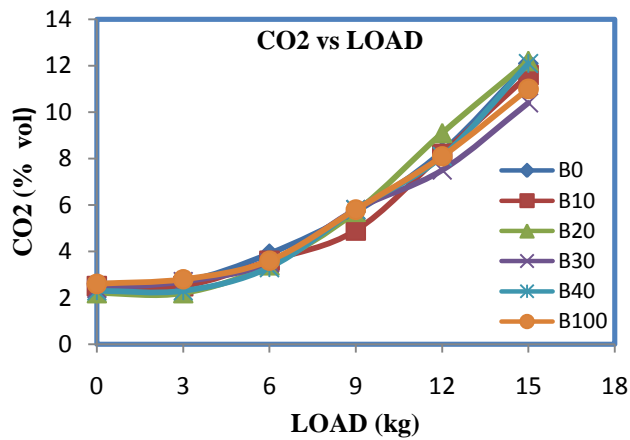


Fig.10. Carbon dioxide Emission v/s Load

#### 4.2.4 Oxides of Nitrogen emission (NO<sub>x</sub>)

The variation of oxides of nitrogen (NO<sub>x</sub>) emission with load for different blends of Pongamia pinta methyl ester with diesel and neat diesel at constant speed 1500 rpm of the engine are shown in fig.11. It was observed that the NO<sub>x</sub> emission of all the biodiesel blends higher than the diesel and increased with the increase in the concentration of biodiesel with diesel and the load in the engine due to the high combustion temperature in the combustion chamber for extra oxygen molecules of biodiesel and high cetane number of the biodiesel blends.

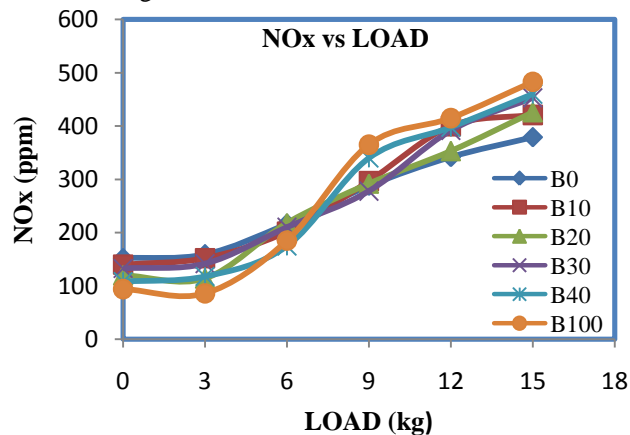


Fig.11. Nitrogen Oxides Emission v/s Load

### V. CONCLUSION

A four stroke water cooled single cylinder direct injection diesel engine was run successfully using Pongamia piñata methyl ester (PPME) and its blends (B10, B20, B30, B40 and B100) with diesel and neat diesel as fuel. The

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(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 8, Issue 10, October 2019

performance and emission characteristics have been analyzed and compared to baseline diesel fuel. The following conclusions are made with respect to the experimental results.

- a) At the full load condition BTE and ITE of B20 closer to neat diesel and the brake thermal efficiency of diesel fuel 3.7% higher than B100 due to low calorific value and higher viscosity of biodiesel
- b) With the increase of the ratio of biodiesel in the blends, fuel consumption increase due to higher specific gravity, poor spray characteristics and lower calorific value of biodiesel.
- c) The brake specific fuel consumption of biodiesel blends is higher than the neat diesel in all load conditions due to high viscosity, low calorific value of the biodiesel blends. The brake specific fuel consumption for B20 blend is closer to the neat diesel fuel.
- d) The volumetric efficiency of the engine decreased with the increase of load for all the biodiesel blends and neat diesel due to less amount of fresh charge admitted in the engine cylinder.
- e) The exhaust gas temperature of the biodiesel blends in all load condition is higher than the neat diesel fuel due to high flash point temperature, low volatility, high viscosity and slow combustion of the biodiesel blends.
- f) The CO & HC emission of different blends of biodiesel was gradually reduced with increase in the concentration of biodiesel with diesel. Because biodiesel having more oxygen than neat diesel which facilitates the complete combustion of fuel.
- g) The amount of CO<sub>2</sub> increased while HC and CO emission decreasing with the increased concentration of biodiesel and this is an indication of complete combustion.
- h) NO<sub>x</sub> emission was increased with the increase in the concentration of biodiesel with diesel and the load in the engine due to the high combustion temperature in the combustion chamber for extra oxygen molecules of biodiesel and high cetane number of the biodiesel blends.

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