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# EXPERIMENTAL AND TESTING OF PONGAMIA BIODIESEL WITH DIFFERENT BLENDS BY USING THE CI ENGINE

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**Abstract: - Besides, comparing the measured performance and the exhaust emissions (exhaust smoke and oxides of nitrogen), a detailed combustion analysis of the acquired cylinder pressure histories on these samples has been attempted. From this analysis, the maximum reduction in exhaust smoke level is found to be 32 % and the CO level are decreased by 25 % with the 20% Pongamia methyl ester as compared to that of the diesel. In the first stage of the work, the effects of various nozzle opening pressures like 180 bar, 200 bar and 200 bar with 20% Pongamia methyl ester blend are investigated. It is observed that the nozzle opening pressure at 200 bar showed an improvement in brake thermal efficiency and 42% reduction exhaust smoke level with 10% increase in NOx concentration at full load compared to that of the base engine with diesel fuel. The peak pressure and heat release are increased by 3 bar and 4 J/ oCA respectively at full load. Ignition delay and the combustion duration are also decreased due to better atomization and vaporization air and fuel at higher injection pressures.. In the second stage of the work, the effect of Titanium oxide coated (500 microns Ceramic coating by plasma spraying method) piston with 20% Pongamia methyl ester blend is investigated. It is observed that 20% PME showed an improvement in the engine brake thermal efficiency by about 1.6% and 34% reduction in exhaust smoke level and the CO and HC emissions are also decreased compared to that of the base engine with diesel fuel. The peak pressure and heat release are increased by 4 bar and 8 J/ oCA respectively at full load. vii | P a g e In the third stage of the work, the effect of Di-ethyl ester as fuel additive with 20% Pongamia methyl ester blend is investigated. It is observed that the DEE with 20% PME showed an improvement in the engine brake thermal efficiency and 17% reduction in exhaust smoke level and the CO and HC emissions are also decreased compared to that of the base engine with diesel fuel. The peak pressure and heat release are increased by 2.5 bar and 6 J/ oCA respectively at full load. Ignition delay and the combustion duration are also decreased due to better combustion of the oxygenated fuel and more oxygen present in the biodiesel. Finally, it is concluded that the 20 % Pongamia methyl ester blend with TiO2 coated piston engine operation gave a better performance and considerable reduction in exhaust emissions and also the combustion properties are improved. This may be due to more heat retainment in the ceramic coated piston compared to that of the other two techniques. The NO emissions for 10% DEE with B20 blend are almost equal to that diesel fuel with the base engine.**

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## I INTRODUCTION

### 1.1 INTRODUCTION OF BIO DIESEL:

The ever increasing demand for petroleum based fuels and the uncertainty in their availability has been a matter of concern world over. The huge outflow of foreign exchange on one hand and increasing emissions causing environmental hazards on the other, have triggered interest in alternatives to gasoline and diesel. Oil provides energy for 95% of transportation and the demand continues to rise, particularly in rapidly developing countries like India and China. The requirement of gasoline and diesel is expected to be about 13 MMT and 66 MMT by 2011-2012. The domestic supply of crude oil in India will satisfy only about 22% of the demand and the rest will have to be met from imported crude oil. Crude oil prices and availability are subject to great volatility depending upon the international situation and relationships between the countries. Moreover, import of petroleum is a major strain on a country"s foreign exchange resource. Hence, steps are being taken to reduce dependence on oil imports. Diesel engines are the best for power plants today because of their high thermal efficiency, good torque characteristics and ability to cater to a wide range of applications. In India, majority of the power plants for heavy transportation, agriculture as well as industries use diesel engines and hence the consumption of diesel is almost six times higher than that of petrol. The cost of diesel is going up in an uncontrollable way and so is the cost of transportation. Costs of transportation affect the price of all commodities and in turn the economic progress of the country. A nation‟s development is strongly dependant on the availability of fuels for transportation, agriculture and power generation. Thus, India, like many developing countries faces the major challenge of meeting the high demand for oil. Only by using the renewable sources of fuel with clean combustion, we can reduce emissions and also the dependence on conventional petroleum sources. Therefore, there is a need to stimulate the use of renewable energy sources to increase the rate of economic growth and national development. This is particularly significant for a country like India with plenty of wastelands where plants to produce bio-fuels can be cultivated. This activity also will generate employment for the poor. If the energy need of rural areas can be met by locally available fuels, then the problem of large imports of crude oil can be eased out a little. Fuels suitable for rural applications should have the capability to be used with little processing. Several alternative fuels are being considered for use in engines. The potential alternatives fuels are gaseous fuels and liquid fuels.

### 1.2 LIQUID FUEL

Liquid fuels are preferred for IC engines because they are easy to handle, transport, store and have reasonably good calorific value. The liquid fuels are alcohol and vegetable oils.

### 1.3 ALCOHOL

Many countries like Brazil, Mauritius, U.S and few European countries are using ethanol blended fuel in automobiles. Ethanol is produced from sugar molasses, wood, maize beet etc. Ethanol is processed from any feed stock such as corn, wheat, sugar cane, tapioca, and other grains. The grain is first ground and cooked with water to convert the starch to sugar with enzyme. The sugar is then fermented with yeast to produce raw ethanol and a high protein material. The raw ethanol is distilled to get anhydrous ethanol.

Methanol is produced from coal, natural gas, farm waste, municipal waste etc. The municipal wastes are first shredded and then passed under a magnet to remove ferrous materials and then gasified with oxygen. The synthesis gas is cleaned by water scrubbing and other means to remove any particulates, H2S and CO2. Further CO-shift conversion for H2-CO-CO2 adjustment, methanol synthesis and methanol purification are accomplished.

### 1.4 VEGETABLE OIL

The concept of using vegetable oil as fuel for diesel engine is nothing new. As early as 1910, Rudolf Diesel demonstrated his engine with peanut oil in France and said that the diesel engine can be fed with vegetable oils that would help considerably in the development of agriculture of the countries. It has also been said that the use of vegetable oils as engine fuels would become significant in the long run, when the demand for petroleum products goes up. Vegetable oils as alternative fuels offer an advantage because of their comparable properties with that of diesel. But a serious objection for the use of vegetable oils is their high cost. The present scenario is that the market prices of vegetable oils are higher than petroleum fuels. However, it is anticipated that the cost will come down as the developments in agriculture and oil extraction methods improve. There are about 350 varieties of oil seeds identified. Out of these, India has more than 200 types of oil seed varieties. The vegetable oils may be classified into edible and non-edible oil. India being agriculture based country, the agricultural lands are plants or trees viz. Jatropha, Pongamia pinnatta, Madhuca Indica, Cashew, and Neem etc. can be cultivated / planted in the wasteland / barren lands with lesser cost and labor.

## 2 LITERATURE REVIEW

Vegetable oil was one of the first fuels used in the internal combustion engine. Rudolph Diesel first developed the diesel engine in 1904 with the intension of running of variety of fuels. He had demonstrated his engine running with peanut oil at the world exhibition held at Paris in 1900. Since then, the use of vegetable oil as fuel for diesel engine has been reported in the research papers, even though the availability of fossil fuel was plenty and price was cheaper at that time. The use of vegetable oil and its methyl ester in diesel engine has been reviewed and discussed in this chapter.

1. Use of straight vegetable oil (SVO) in diesel engine
2. Use of vegetable oil blends

### 2.1 USE OF STRAIGHT VEGETABLE OIL (SVO) IN DIESEL ENGINE

Experiments have been conducted with a number of vegetable oil like rapeseed oil, sunflower oil, soybean oil, rice bran oil, neem oil, palm oil, rubber seed oil, Jatropha oil, karanja oil, coconut oil, etc as fuel in diesel engines ad acceptable performance over a short period of time in unmodified diesel engine has been reported. However, studies also indicate that long-term use of vegetable oils results in problems like heavy smoke emissions and carbon deposition in various parts of the engine due to high viscosity and carbon residue. Use of 100% vegetable oils in diesel engine results in almost same engine power with slightly lower thermal efficiency in comparison to diesel engine.

**BRUWER ET AL (1980)** have studied the use of sunflower oil as fuels in tractors. It has been reported that, after 1000 hours of operation, the power loss was only 8%. It has been further reported that the power loss was reduced by replacing the injectors and injection pump. It has been concluded that the carbon deposit in the engine after 1300 hours of operation was equivalent to that of diesel operation. However, the carbon deposit in injectors was higher. It has been concluded that the sunflower oil could be an alternative fuel for diesel and also that it developed severe carbon deposit.

**BARSIC AND HUMKE (1981)** investigated the performance and emission characteristics of a single cylinder naturally aspirated direct injection diesel engine with 100 % sunflower or 100% peanut and their blends (50% by volume) and the results were compared with diesel. They have reported similar performance and higher emissions with vegetable oils. Carbon monoxide and hydro carbon emissions were higher for 50 percent vegetable oil diesel fuel blends than 100 percent vegetable oil or 100percent diesel fuel for some engine speeds and loads. These higher emissions are due to high fuel viscosity and fuel spray characteristics of vegetable oil.

**BACON ET AL (1981)** have evaluated the use of several vegetable oils as potential fuel for diesel engine. It has been stated that the vegetable oils developed acceptable power, but these oils caused high carbon build up in the combustion chamber. It has been concluded that the continuous running of an engine with vegetable oil at part-load and at mid-speed caused rapid carbon deposit on the injector tips. It has been further concluded that long-term engine testing has to be carried out to determine the overall effects of using vegetable oils in a diesel engine.

**YARBROUGH ET AL (1981)** have studied the performance of a diesel engine with six variants of sunflower oil as fuel. It has been reported that the refined sunflower oil gave satisfactory results. It has been further reported that degumming and dewaxing the vegetable oil prevented engine failure. It has been concluded that raw sunflower oil could not be a fuel but modified sunflower oil could be used as a better fuel.

**PYROR ET AL (1983)** have also conducted short and long term engine performance tests using 100% soy bean oil in a small diesel engine. It has been reported that the short-term test with soy bean oil indicated performance similar to that of diesel fuel and long-term engine testing could not be carried out due to power loss and carbon build up on the injectors. It has been concluded that the soy been oil could be considered for short term operation.

**SEPPO ET AL (1997)** have tested a turbo charged four cylinder direct injection diesel engine using mustard oil. It has been reported that the engine developed power equal to that of diesel. It has been further stated that the 12 | P a g e smoke and NOx emissions were lower than diesel. It has been concluded that long term tests be carried out.

**Yu et al (2002)** have tested the use of waste cooking oil as alternative fuel for diesel engine. It has been further reported that the combustion characteristics were similar to that of diesel fuel. It has also been reported that the peak pressure was little higher and it occurred earlier by 1.1o -3.8o CA than diesel. It has also been stated that the engine performance deteriorates for long term use, because, heavy carbon deposition on the piston crown is higher than diesel. It has been concluded that the waste cooking oil developed similar engine performance but deteriorated after long use.

**Pugazvadivu and Jayachandran (2003)** have tested a single cylinder direct injection diesel engine with waste frying oil as fuel. It has been stated that the specific fuel consumption and smoke emission was marginally higher than diesel, but NOx emissions were lower than diesel which were due to low solubility of waste frying oil.

**Laxminarayana Rao et al (2004)** have investigated the use of unrefined rice bran oil, coconut oil and neem oil on a direct injection diesel engine. It has been reported that the brake thermal efficiency was lower for vegetable oil than diesel, due to lower calorific value. It has also been reported that the carbon dioxide and hydrocarbon emissions were slightly higher than diesel, but NOx emissions were lower than diesel. It has been conducted that the sluggish combustion and increased fuel consumption are due to lower caloric value and atomization.

**2.2USE OF HEATING OF VEGETABLE OIL**

Use of raw vegetable oil as fuel for diesel engine has an important drawback due to its high viscosity. This affects the spray formation and leads to poor combustion. Preheating the vegetable oil would reduce viscosity.

During heating, the heavy fatty components of the vegetable oil are broken or cracked into lighter components and thereby viscosity is also reduced. In this section, the available literature on preheating are grouped and presented.

**Barsic and Humke (1981)** have investigated the use of peanut oil as fuel in a single cylinder direct injection diesel engine. It has been reported that the preheating of vegetable oil to 70-90o C dissolved the wax contents of the oil. It has been further reported that the preheating prevented the clogging of fuel filters and fuel lines. It has been concluded that the preheating of vegetable oil resulted in reduced viscosity leading to smooth flow and better fuel spray formation.

**RYAN ET AL (1983)** have studied the effect of preheating the vegetable oil in direct injection diesel engine. It has been reported that the preheating of vegetable oil to 140oC reduced the viscosity of the vegetable oil to that of diesel. It has been further reported that the preheated fuel improved the performance of the engine due to the improvement in spray pattern, atomization and cetane rating. It has been concluded that there was improvement in performance and reduction in smoke emission.

**MURAYAMA ET AL (1984)** have studied the effect of rapeseed oil preheated at 200oC in naturally aspirated direct injection diesel engine. An empirical relation has been found to determine the different preheating temperatures at which the viscosity of vegetable oil becomes equal to the viscosity of diesel. It has been reported that the preheating was effective in reducing carbon build up and ring sticking.It has been further reported that the brake specific fuel consumption decreased with the use of preheated oil than that of raw rapeseed oil at ambient conditions.

**RAJASEKARAN ET AL (1997)** have tested the IDI diesel engine with preheated diesel as fuel at different speeds. It has been reported that the temperature was maintained from 60 to 75oC in steps of 5oC. It has been further reported that the soot reduction was nearly 50% for preheated diesel emission and that there was no remarkable change in brake thermal efficiency. It has been reported that the smoke density showed reduction for preheated diesel. It has been concluded that the preheated fuel in IDI engine showed reduction in soot emission.

**BOSE ET AL (2001)** have investigated the effect of preheated Karanja oil and its methyl esters in a direct injection diesel engine. It has been reported that the karanja oil methyl ester gave higher thermal efficiency than diesel. It has also been reported that at higher injection pressure the performance was improved. It has been concluded that by 4o advancing the injection timing the CO and CO2 emission levels were little higher.

**BARI ET AL (2002)** have investigated the effect of preheated palm oil on a diesel engine. Preheating of oil results in lower viscosity and provided smooth fuel flow and it has not affected the injection systems. It has been reported that the cylinder pressure was increased by 6% and shorter ignition delay by 2.6o CA. It has also been reported that the CO and NOx emissions were increased by 9.2% and 29.3% respectively compared to diesel fuel.

**NWAFOR (2003)** have conducted a test on a diesel engine with preheated vegetable oil. It has been reported that there is no significant reduction in brake specific fuel consumption and increase in HC emissions at higher loading conditions. It has also been reported that the pre heated oil increase cylinder pressure and it was beneficial at lower load conditions.

## 3 METHODOLOGY

The step by step methodology that was followed is given by:

1. Selection of suitable vegetable oil methyl ester (Pongamia oil) for the study based on its availability.

2. Selection of a suitable single cylinder diesel engine and development of an experimental set-up with necessary instruments to study the performance, emission and combustion characteristics.

3. Mounting a piezo-electric pressure transducer on the cylinder head and developing an optical TDC position sensor and circuits for obtaining pressure- crank angle data.

4. Fabrication of a set-up for the production of methyl ester of vegetable oils (biodiesel) by the transesterification process and preparation.

5. Conducting experiments with diesel and Pongamia methyl ester and its diesel blend with the base engine operation. And compare the performance, emission and combustion parameters with the diesel.

6. Conducting experiments with diesel and Pongamia methyl ester and its diesel blend with various nozzle opening pressures. And compare the performance, emission and combustion parameters with the base engine.

7. Conducting experiments with diesel and Pongamia methyl ester and its diesel blend with TiO2 coated piston operation. And compare the performance, emission and combustion parameters with the base engine.

8. Conducting experiments with diesel and Pongamia methyl ester and its diesel blend with Diethyl ether as fuel additive. And compare the performance, emission and combustion parameters with the base engine.

## 4EXPERIMENTAL SET UP AND PROCEDURE

The scarcity of edible oil prompted researchers to search for suitable alternative non-edible oil fuel for internal combustion engines, especially for diesel engine. The objective of the present investigation is to use one of the non-edible oil, namely, Pongamia methyl ester and its diesel blend used as fuel in a diesel engine. The combustion, performance and emission characteristics of a single cylinder four stroke water cooled DI diesel engine were studies using the above fuels.

### 4.1EXPERIMENTAL SET-UP

An experimental set up was developed to conduct experiments on the selected compression ignition engine in different single fuel and dual fuel modes to evaluate performance, emission and combustion parameters at different operating conditions. This chapter discusses the details of the equipment used like engine, dynamometer, fuel and air flow measuring systems, emission measuring instruments and cylinder pressure measure systems etc.

**4.2TEST ENGINE** A single cylinder 4-stroke water-cooled direct injection diesel engine with a displacement volume of 553 cc, compression ratio 16.5:1 developing 3.7 kW at 1500 rpm with a dynamometer was used for the present project work. The specifications of the engine are listed in Table 4.1 The engine is fitted with conventional fuel injection system, which has a three hole nozzle of 0.2mm separated at 120 degrees, inclined at an angle of 60 degrees to the cylinder axis.. The injector opening pressure recommended by the manufacturer was 180 bar. The centrifugal governor which is fitted on the engine enables the automatic regulation of the engine speed. The combustion chamber is hemispherical in shape with the overhead valve arrangement operated by push rods. A provision was made to mount a piezoelectric pressure transducer flush with the cylinder head surface in order to measure cylinder pressure. The injection system of the engine was periodically cleaned and calibrated as recommended by the manufacturer. The specifications of the test engine are given in Appendix 1.

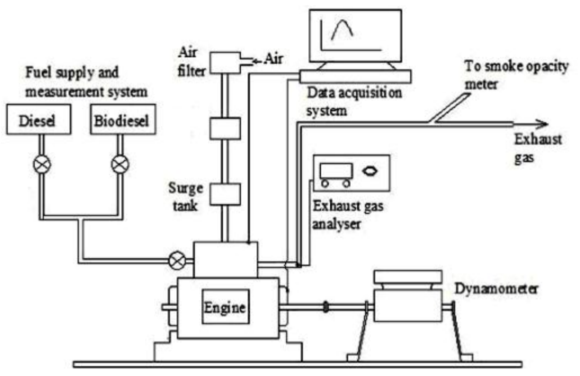


**fig1.Schematic of experimental setup**

**2.Photographic views of base engine and TiO2 Coated piston**

**4.3ENGINE INSTRUMENTATION**

**4.3.1 PRESSURE MEASUREMENT** A piezoelectric pressure transducer (Kistler Instruments, Switcher land, model 6613CQ09-01) was installed in the engine cylinder head to acquire the combustion pressure-crank angle history. The sensitivity of the pressure transducer is 25 pC/bar. The pick up was water-cooled type. The piezoelectric transducer produces a charge output, which is proportional to the in-cylinder pressure.

Machining for installation of the pressure transducer was carried out in the cylinder head and the engine main shaft was coupled to a precision shaft encoder with the resolution of 0.5o crank angle. A TDC marker was used to locate the TDC position in every cycle of the engine. The cylinder pressure data were acquired for 50 consecutive cycles and then averaged in order to eliminate the effect of cycle-tocycle variations. The personal computer (PC), through an analog to digital converter (ADC) reads the output of the charge amplifier. There is a small drift in the voltage measured (-2mV/s) due to charge leakage in the pressure transducer. Since the signal from a piezoelectric transducer indicate only relative pressures, it is 31 | P a g e necessary to have a means of determining the absolute pressure at some point in the cycle. Hence, it had to be referenced to in order to get the actual pressure. This was done by assuming that the cylinder pressure at suction BDC is equal to the mean intake manifold pressure. The specification of the pressure transducer and the charge amplifier are given in Appendix 2.

**4.3.2TDC POSITION SENSOR**

The TDC position sensor was developed and used to indicate the position of TDC by providing a voltage pulse exactly when the TDC position was reached. This sensor consists of a matched pair of infra red diode and phototransistor so that infra red rays emitted from the diode fall on the phototransistor when it is not interrupted. A continuous disc with a small cut at the TDC position with respect to sensor point was made to get the signal when the piston reaches TDC exactly. At this point the output voltage from photo-transistor rises to 5 volts and at all the other points it is zero. Voltage signals from the optical sensor were fed to an analog to digital converter and then to the data acquisition system along with pressure signals forrecording.

**4.3.3ANALOG TO DIGITAL CONVERTER**

Engine cylinder pressure and TDC signal are acquired and stored on a high speed computer based digital data acquisition system. A 12 bit analog to digital (A/D) converter was used to convert analog signals to digital signals. The A/D card had external and internal trigger facility and with sixteen ended channels. During experiments, data for 50 cycles are recorded and signals are then passed through specially developed software to obtain the combustion parameters.

### 4.4TEMPERATURE MEASUREMENT

Temperature of the exhaust gas was measured with Chromel Alumel (KType) thermocouples. A digital indicator with an automatic room temperature compensation facility was used and it was calibrated periodically.

### EXHAUST GAS ANALYSER

The use of a five gas exhaust analyzer (AVL 444 DIGAS) can be used to measure the exhaust gas emissions such as CO, CO2, HC, O2 and NO in the exhaust. A photographic view of the exhaust gas analyzer showing a sample result for the present research work is shown in Figure 4.3 and the photographic view of the exhaust gas analyzer used is shown in Figure 4.4. The detailed specifications of the AVL five gas analyzer are presented in Appendix 3.


**fig 3.Photographic view of the exhaust gas analyzer showing a sample results**

### SMOKE MEASUREMENT

The exhaust smoke level was measured by using a standard BOSCH smoke measuring apparatus. This measuring instrument consists of a sampling pump that sucks a definite quantity (330cc) of exhaust sample through a white filter paper. The reflectivity of the filter paper was then measured using a standard Bosch smoke meter that consists of a light source and an annular photo detector surrounding it. Before every sampling, it was ensured that the exhaust from the previous measurement was completely driven off from the tube and pump. The photographic view of the smoke meter is shown in Figure 4.5. The specifications of the smoke meter are given in Appendix 3

**fig 4. Photographic view of the Smoke meter**

### 4.5PONGAMIA TREES

Milletia pinnata is a species of tree in the pea family, Fabaceae, native in tropical & temperate Asia including parts of India, China, Japan, Malaysia, Australia & Pacific islands. It is often known by the synonym Pongamia pinnata and it was moved to the genus Milletia only recently. Pongamia pinnata is one of the few nitrogen fixing trees (NFTS) to produce seeds containing 30-40% oil. It is often planted as an ornamental and shade tree but now-a-days it is considered as alternative source for Biodiesel. This species is commonly called pongam, karanja, or a derivation of these names.

It is a legume tree that grows to about 15–25 meters (15–80 ft) in height with a large canopy which spreads equally wide. It may be deciduous for short periods. The leaves are soft, shiny burgundy in early summer and mature to a glossy, deep green as the season progresses. Flowering starts in general after 3–4 years. Cropping of pods and single almond sized seeds can occur by 4–6 years. Small clusters of white, purple, and pink flowers blossom on their branches throughout the year, maturing into brown seed pods. Evaporation of surface water and its root nodules promote nitrogen fixation, a symbiotic process by which gaseous nitrogen (N2) from the air is converted into ammonium.

**fig 5 Photographic view of Pongamia tree with fruits**

### 4.6TRANSESTERIFICATION OF PONGAMIA METHYL ESTER

Transesterification is an effective way to reduce the viscosity of the vegetable oils. During the process of

Transesterification triglyceride of vegetable oil (Pongamia oil) react with alcohol (methanol/ethanol) in the presence of catalyst say NaOH or KOH and form glycerol and vegetable oil ester. A specified quantity of vegetable oil (1000ml) and methanol (450 ml) were taken in the round bottom flask. A few grams of (10gm) of NaOH were also added to the flask after starting the stirring process. The contents were heated up to 60oC and stirred vigorously for 45 minutes till the ester was formed. The mixture was cooled to room temperature and few drops of hydrochloric acid were added to neutralize it.

### 4.6.1TABLE1COMPARISONOF PROPERTIESOF DIESEL, PONGAMIA OIL AND ITS METHYL ESTER

| Properties | Diesel fuel | Pongamia oil | Pongamia ester |
|---|---|---|---|
| Density (kg/m$^3$) | 830 | 912 | 880 |
| Kinematic Viscosity @ 40 °C (cSt) | 3.01 | 41.06 | 4.25 |
| Heating value MJ/kg) | 42.5 | 34 | 38.3 |
| Pour point (°C) | 4 | 3 | 3 |
| Flash point (°C) | 50 | 241 | 180 |
| Fire point (°C) | 63 | 253 | 223 |
| Cloud point (°C) | 5 | 7 | 6 |
| Cetane number | 48 | 40 | 55.84 |
| Carbon Residue | 0.02 | 0.64 | 0.05 |
| Ash Content (%, w/w) | 0.01±0.0 | 0.005 | 0.03 |
| Oxygen (%, w/w) | 1.19 | - | 11 |

### 4.6.2 TABLE 2 TEST MATRIX

| Sl No. | Variables | Fuels Used | Requirement |
|---|---|---|---|
| **1.Normal operation** | | | |
| | Torque zero to maximum at rated speed of 1500 rpm | 1.Diesel<br>2. Pongamia methyl ester<br>3. Pongamia methyl ester blend | Base line data generation |
| **2. Various nozzle opening pressures** | | | |
| | Torque zero to maximum at rated speed of 1500 rpm | 1. Pongamia methyl ester<br>2. 20% Pongamia methyl ester blend | Evaluation of performance, emission and combustion parameters |
| **3. Titanium oxide coated piston operation** | | | |
| | Torque zero to maximum at rated speed of 1500 rpm | 1. Pongamia methyl ester<br>2. 20% Pongamia methyl ester blend | Evaluation of performance, emission and combustion parameters |

## 5 ANALYSIS AND PROCEDURE

In this section the details of combustion and heat release analysis of experiments conducted in various modes of operation are presented. All the tests were conducted at the rated speed of 1500 rpm. All readings were taken only after the engine attained stable operation. The gas analyzers were switched on before starting the experiments to stabilize them before starting the measurements. All the instruments were periodically calibrated. The injector opening pressure and injection timing were kept constant at the rated value throughout the experiments. The following paragraphs describe the procedure adopted for the analysis of the experimental data obtained during this investigation.

The injection timing is kept constant in all the experiments. The dynamic injection timing was used to calculate the ignition delay. The engine output was varied from no load to full load in steps of 25%, 50%, 75% and 100% in the normal operation of the engine. At each load the fuel flow rate, air flow rate, exhaust gas temperature, emissions of carbon monoxide, hydrocarbon and oxides of nitrogen and smoke readings were recorded. The pressures crank angle history of 50 cycles was also recorded by using the data acquisition system and the personal computer. The following sections explain the analysis and procedure for the performance and combustion parameters of the diesel engine.

## 6 RESULTS AND DISCUSSION

The present investigation concerns improvement in combustion, performance and emission characteristics of a single cylinder, four stroke, water cooled DI diesel engine with Pongamia methyl ester (PME) using different blends like B10,B20 and B100, various nozzle opening pressures, Titanium oxide coated piston ($TiO_2$) have been investigated. The results of performance and emission parameters are based on the study of the combustion parameters, like ignition delay, cylinder pressure, rate of heat release and combustion duration; these have been measured and presented in the following sections.

### 6.1PRESSURE-CRANK ANGLE DIAGRAM

Figure 6.1 shows the variation of the cylinder peak pressure with the crank angle at full load. The peak pressure depends on the amount of fuel taking part in the uncontrolled combustion phase, which is governed by the delay period and the spray envelope of the injected fuel (Heywood 1998). Thus, the higher viscosity and poor volatility of the PME results in a lower peak pressure as compared to that of diesel. The cylinder peak pressures for diesel, B20 and B100 are 69 bar and 67 bar and 65 bar respectively at full load

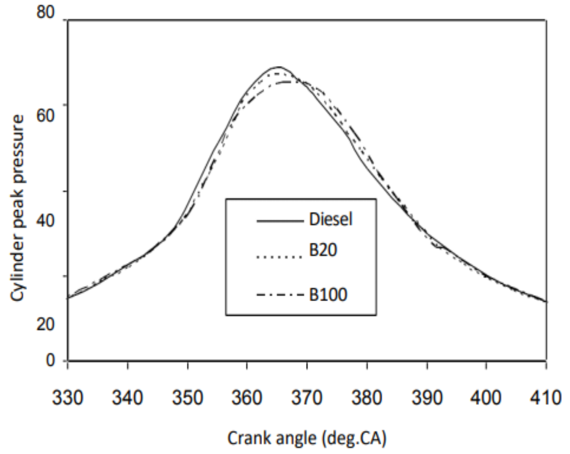


**Figure 6 Variation of Cylinder pressure with CA at full load**

**6.2 Peak cylinder pressure** Figure 6.2 shows the variation of peak cylinder pressure with brake power for diesel and biodiesel blends. The peak cylinder pressure in the diesel engine also depends on the viscosity of the fuel. During the ignition delay, the droplets have sufficient time to spread in fresh air. Most of the fuel admitted would have evaporated and formed a combustible mixture with air, which results in complete combustion. The peak pressure decreases for 100% PME, which has high viscosity that results in increased physical delay

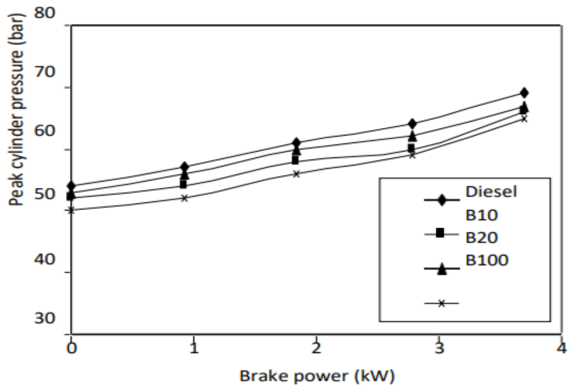


**Figure 7Variation of peak pressure with BP**

**6.3 HEAT RELEASE RATE**

In a CI engine, during the combustion process the burning proceeds in three distinguishable stages. In the first stage, the rate of burning is generally very high and lasts for only a few crank angle degrees. It corresponds to the period of rapid cylinder pressure. The second stage corresponds to a period of gradual decrease in the cylinder pressure. This is the main heat- release period and lasts about 40oCA. Normally about 80 percent of the total fuel energy is released in the first two stages. In the third stage of combustion, about 20 percent of the total fuel energy is released. From the heat release diagram, it is seen that the magnitude of the initial peak of heat release in the premixed combustion phase depends on the ignition delay period.

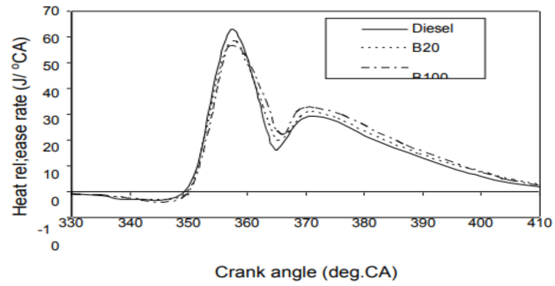


**Figure 8 Variation of Heat release rate with CA at full load**

**6.4MAXIMUM HEAT RELEASE RATE**

Figure 6.4 shows the peak heat release rate with brake power for the base engine at full load. The peak heat release rate for diesel, B10, B20 and B100 varies from 48 J/oCA to 63 J/oCA, 43 J/oCA to 52 J/oCA, 46 J/oCA to 58J/oCA and 44 J/oCA to 55 J/oCA respectively, at full load. It is noticed that the peak heat release rate is lower for 100% PME compared to diesel and other blends at all loads. This may be due to the high specific gravity and relatively poor mixing, which leads to longer ignition delay and hence, a lower heat release rate. Due to this longer ignition delay, the premixed combustion decreased for 100%PME and its blends compared to diesel. The maximum heat release rate for B20 is increased due to better atomization and vaporization of low viscosity of biodiesel blend.

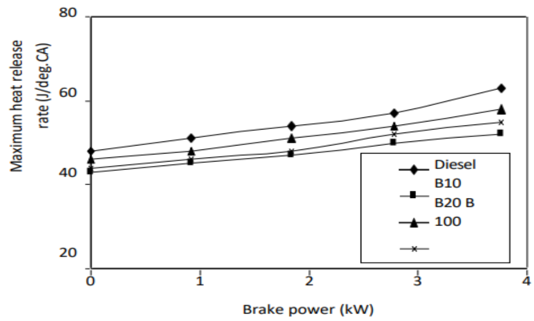


**Figure 9 Maximum heat release rate with BP**

**6.5 BRAKE THERMAL EFFICIENCY**

The variation of Brake thermal efficiency with brake power for different fuel blends are shown in Figure 6.5. In all the cases brake thermal efficiency is increased due to reduced heat loss with increased in load. The maximum efficiency obtained for diesel, B10, B20 and B100 are 30.45%, 28.24% 28.74%, and 26.62% at full load respectively. The increase in BTE for B20 may be due to the better atomization and vaporization for fuel particles and the calorific value of the B20 blend almost equal to that of diesel, resulting in higher BTE compared to that of all biodiesel blends. The decrease in BTE for B100 and B10 may be due to low viscosity and low volatility of fuel which leads to and poor atomization of biodiesel, and hence low brake thermal efficiency

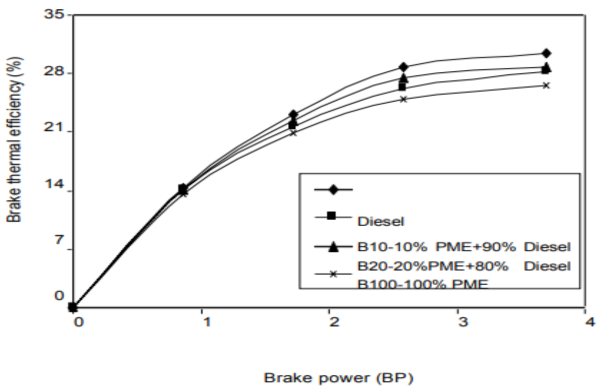


**Figure 10 Variation of brake thermal efficiency with BP**

## 6.6NITROGEN OXIDE EMISSION (NO)

The variation of nitrogen oxide emissions with brake power for biodiesel blends are presented in Figure 6.6. The formation of nitrogen oxides is significantly influenced by the cylinder gas temperature and the availability of oxygen during combustion. The NO for B20 is 512 ppm and for B100 is 568 ppm whereas for the diesel it is 486 ppm at full load conditions. It is observed that the increase in NO emission for the biodiesel may be due to more oxygen atoms present in the biodiesel.

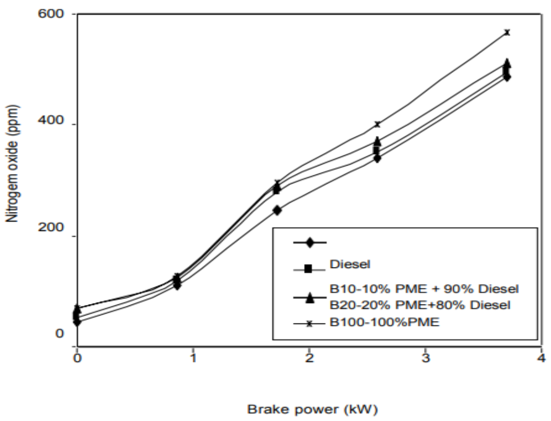


**Figure 11 Variation of NOx emission with BP**

## 6 .7SMOKE EMISSION

The variation of smoke emissions at different engine load are presented in Figure 6.7. The exhaust of the CI engines contains solid carbon particles that are generated in the fuel-rich zones within the cylinder during combustion. These are seen as exhaust smoke and cause an undesirable odorous pollution. The smoke emission increases with an increase in the load for all fuels. The smoke density for diesel is 3.6 BSU at full load, whereas for B20 and B100 it is 2.8 BSU and 2.4 BSU at full load. The reduction in smoke for biodiesel blends may be due to more oxygen atom present in the biodiesel, resulting in better combustion of biodiesel.

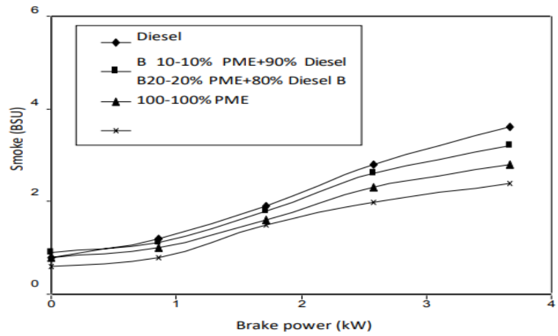


**Figure 12**

**Variation of Smoke emissions with BP**

## 7. CONCLUSION:

From the above investigations, it can be observed that 20% Pogamia methyl ester (B20) with the TiO2 coated piston gave better performance and reductions in exhaust emissions compared to 20%Pogamia methyl ester with various nozzle opening pressures and 10% oxygenated fuel additive Di-ethyl ether (DEE) due to better vaporization of B20 air fuel mixture by more heresulting in complete combustion of biodiesel diesel blends resulting in complete combustion of biodiesel diesel blends

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