The conventional petroleum fuels for internal combustion engines will be available for few years only, due to tremendous increase in the vehicular population. Moreover, these fuels cause serious environmental problems by emitting harmful gases into the atmosphere at higher rates. Generally, pollutants released by engines are CO, Unburnt hydrocarbons, NOx, smoke and limited amount of particulate matter. At present, alternative fuels like methyl esters of vegetable oil (commonly known as biodiesels), alcohols etc. are in the line to replace the petroleum fuels for IC engines. In the present study an experimental investigation was carried out with pongamia oil as an alternative fuel in a compression ignition engine. The problems associated with vegetable oil are high viscosity, low volatility and high reactivity, but at the same time their higher cetane number, lower sulphur content and higher oxygen concentration are the desirable properties to use as a fuel in compression ignition engines. The process of transesterification of vegetable oil with methyl alcohol provides a significant reduction in viscosity, thereby enhancing the physical properties of vegetable oil. The current paper reports a study carried out to investigate the combustion, performance and emission characteristics of Pongamia oil methyl ester with diesel fuel on a single-cylinder, four-stroke, direct injection and water cooled diesel engine. This study gives the comparative measures of brake specific fuel consumption, brake specific energy consumption, brake thermal efficiency, mechanical efficiency, exhaust gas temperature, air-fuel ratio, volumetric efficiency, CO, CO2, HC, NOx and smoke opacity. Biodiesel can be blended at any ratio with diesel fuel. The properties of Pongamia biodiesel are determined, and found that its properties are near to diesel.

INTRODUCTION
High petroleum prices demand the study of biofuel production. Non-edible vegetable oils have been found to be promising crude oils for the production of biodiesel. World annual petroleum consumption and vegetable oil production is about 4.018 and 0.107 billion tons, respectively. The cost of biodiesel and demand of vegetable oils can be reduced by non-edible oils. Biodiesel is a clean burning recycled fuel made from vegetable oils. It is chemically called Fatty Acid Alkyl Ester. Biodiesel is 100% vegetable oil based. Biodiesel is made up of almost 10% oxygen, making it a naturally "oxygenated" fuel. It is obtained by reaction of vegetable oil with alcohol in presence of catalyst. Using vegetable oils is therefore beneficial to the environment, economy and to the atmosphere. The direct use of vegetable oils as fuel can cause numerous engine problems like poor fuel atomization, incomplete combustion and carbon deposition on fuel injector and engine fouling. Hence the viscosity of vegetable oils can be reduced by several methods which include blending of oils, micro-emulsification, pyrolysis and transesterification. Among this transesterification is widely used for industrial biodiesel production. Because it gives high yield with low temperature, pressure and short reaction time. The advantages of biodiesel as diesel fuel are ready availability, renewability, higher combustion efficiency, lower sulfur and, higher cetane number, and higher biodegradability. The main advantages of biodiesel include domestic origin, reducing the dependency on imported petroleum, high flash point, and inherent lubricity in the neat form. Major disadvantages of biodiesel are higher viscosity, lower energy content, higher cloud point and pour point, higher nitrogen oxide (NOx) emissions, lower engine speed and power, and higher engine wear.

EXPERIMENTAL SET UP OF ENGINE

5.1 ENGINE SET UP

The experiments are conducted on 5.2 kW Kirloskar engine; direct injection single cylinder water cooled having 87.5 mm bore and 110 mm stroke. It consist of a test bed, a diesel engine, an eddy current dynamometer, a data acquisition system, a computer, an operational panel, exhaust emission analyzers, a smoke meter, sensors to measure lubricating oil temperature, exhaust temperature at the manifold a pressure sensor to measure in-line cylinder pressure, a pressure sensor to measure fuel line pressure. Two filters are installed, one at exit of tank and other at fuel pump. Fuel is fed to the pump under gravity. Lubricating oil temperature is measured by using a thermocouple. The cooling water temperature is maintained constant throughout the research work by controlling the flow rate of fuel. The exhaust gas composition was analyzed by using exhaust gas analyzer and smoke meter. The engine was tested at constant speed of 1500 rpm throughout its power range using PME 10, PME 20, PME 40, PME 60, PME 80 and PME 100. The engine performance and emission characteristics investigated. The tests were conducted with diesel, Pongamia oil methyl ester with load, from no load to full load by steps of 12.5%. The engine was coupled with dynamometer to provide the brake load. Two separate fuel tanks were used for the diesel fuel and Pongamia oil methyl ester (PME). The performance
parameters evaluated are brake thermal efficiency, brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC) and the emissions measured were carbon monoxide (CO), carbon dioxide (CO₂), hydrocarbon (HC), and oxides of nitrogen (NOx), were measured by using AVL five gas analyzer and the smoke was measured by AVL smoke meter. From the investigation it can be concluded that biodiesel can be used as an alternative to diesel in a compression ignition engine without any engine modifications.

RESULTS AND DISCUSSIONS

1) Brake Specific Fuel Consumption:
The variation in brake specific fuel consumption (BSFC) with different loads at constant engine speed is shown in Fig.1 All the blends have higher BSFC than diesel because of a decrease in calorific value, higher density and higher viscosity of biodiesel with an increase in biodiesel percentage in the blends. Hence results in higher bulk modulus, which results in more discharge of fuel for the same displacement of the plunger in the injection pump, thereby resulting increase in BSFC. The BSFC for the blend of B20 is lower than the other blends and higher than that of diesel.

2) Brake Specific Energy Consumption:
The variation in brake specific energy consumption (BSEC) with different loads at constant engine speed is shown in Fig.2 Brake specific energy consumption is defined as the amount of energy consumed per unit brake power. The brake specific energy consumption is determined for pongamia biodiesel and diesel blends as the product of the specific fuel consumption and the calorific value. It is observed that the decreasing values of BSEC with increasing load. For the biodiesel blends, BSEC values are slightly higher than diesel. This may be due to the lower calorific value of Pongamia methyl ester compared to the diesel. It is observed from the graph that the BSEC for B20 is lower than the other blends as compared to that of diesel fuel. The presence of the oxygen molecule in the pongamia fuel blend may be the reason for the lower BSEC. As the pongamia biodiesel concentration in the blend increases, the BSEC for all the fuels increases initially at lower loads and at higher loads its value is close to that of diesel for all the blends due to the better combustion.

3) Brake Thermal Efficiency:
The variation in brake thermal efficiency with different loads at constant engine speed is shown in Fig. 3. The thermal efficiency of diesel and biodiesel blends increases with increasing brake power. The brake thermal efficiency of the pongamia biodiesel and its blends are lower than the diesel due to its lower calorific value. As the brake power increases the heat generated in the cylinder increases, and hence, the thermal efficiency increases. The maximum thermal efficiency is observed as 26.91% for the B20 blend, whereas for diesel it is 27.12% at full load. The drop in thermal efficiency with increase in proportion of biodiesel is because of its high viscosity, high density, poor volatility, lower calorific value and poor atomization of biodiesel which affects mixture formation of the fuel and leads to poor combustion. At full load conditions BTE of B20 is about 0.8% less than that of diesel.

4) Mechanical Efficiency:
The variation in mechanical efficiency of diesel and various blends of Pongamia biodiesel at different loads is shown in Fig. 4. It is observed that the mechanical efficiency is increased with increase in load, which is mainly due to reduction in frictional and heat losses with load. At full load Blend B20 has the maximum mechanical efficiency of 81.63%, which is very near to the efficiency of diesel, i.e. 83.05%. This increase in blend B20 may be due to higher cetane number of the fuel.

5) Exhaust Gas Temperature:
The variation in exhaust gas temperature of diesel and various blends of Pongamia biodiesel at different loads is shown in Fig. 5. The exhaust gas temperature provides the qualitative information about the progress of combustion in engine. It can be observed from figure that the increase in brake power induces...
the increase in exhaust gas temperature. The exhaust gas temperature for all the blends is higher than that of diesel. The exhaust gas temperature is lower at the rated load of the engine for all the blends than diesel which can be attributed to a lower cylinder gas temperature and lower combustion duration\(^7\).

6) Air – Fuel ratio:

The variation of Air-Fuel ratio of diesel and various blends of Pongamia and diesel oil at different loads is presented in Fig. 6. It was observed that the air-fuel ratio decreases with an increase in the load for all fuels. Also the air-fuel ratio decrease with increase in the concentration of pongamia oil in the blends. Fuel consumption is high for biodiesel blends compared to diesel and air flow is constant. Hence air-fuel ratio decreases with increase in load. The air-fuel mixing process is affected by the atomization of biodiesel due to its higher viscosity. With increase in air-fuel ratio (leaner mixture) the combustion temperatures are lowered and cylinder wall temperatures are reduced and hence the delay period increases. The rate of pressure rise is unaffected but the maximum pressures may be lowered. With increase in load, air-fuel ratio decreases, operating temperature increase and hence, delay period decreases\(^1\).

7) Carbon Monoxide:

Figure 7 represents the effect of BP on CO. The formation of carbon monoxide is attributed to the fuel oxidation from combustion. The major reason to the CO formation is insufficient time and oxygen for oxidation of CO to CO2. It can be observed that CO emissions increase with increasing engine load, due to increase in the peak combustion temperature and the associated increase in the rate of dissociation reaction. The test results indicates that pongamia biodiesel blends gives lower of CO emissions compared to diesel for all the loads which is attributed to the presence of oxygen molecule in the biodiesel. At higher load the CO emissions increases because of insufficient time. The CO emissions are lower for all the biodiesel blends than that of diesel for all the loads. At full load, higher reduction in CO emissions were observed as 85.24% for the PME (B100) and its blends B20, B40, B60 and B80 have CO emissions as 72.13%, 65.5%, 65.5% and 80.32% respectively less compared to diesel. However at over load the CO emissions are increases because of incomplete combustion due to less time availability for combustion process and there is less available time to convert the oxygen molecule present in biodiesel to CO2.

8) Carbon Dioxide:

The variation in carbon dioxide formation during the test for different blends is shown in Fig. 8. It is observed that the carbon dioxide (CO2) emission is increased with increase in load for all the blends due to increase of the BSFC as shown in figure. For all the blends the emissions of CO2 is more when compared with diesel. Also the carbon dioxide increases with the increase in the concentration of pongamia oil in the blends. This is caused mainly due to the presence of more oxygen content in the biodiesel which converts carbon monoxide to carbon dioxide, and also due to the higher combustion temperature\(^1\).

9) Hydrocarbons:

The variations in hydrocarbon emissions at different engine load for pongamia biodiesel and diesel blends are shown in Fig. 9. Hydrocarbon emission is the result of incomplete combustion. The biodiesel blends exhibit lower HC emission at all the loads. The emission of HC increases at higher loads for the blends of biodiesel and diesel. This is because of relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at high engine load. The emissions of hydrocarbon for biodiesel is lower than that of diesel fuel due to higher cetane number because of shorter ignition delay of biodiesel may be responsible for this decrease. Higher temperature of burnt gases in biodiesel fuel helps in preventing condensation of higher hydrocarbon reducing unburnt HC. At part load the HC emissions of blends are much lesser than the HC emissions at full load compared with diesel because of complete combustion\(^1\).

10) NOx:

The variation in the NOx emissions at different engine load is shown in Fig. 10. Oxides in the engine exhaust are the combination of nitric oxide (NO) and nitrogen dioxide (NO2). Nitrogen and oxygen react relatively at high temperature. Therefore high temperature and availability of oxygen are the two main reasons for formation of NOx. When the more amount of oxygen is available, the higher the peak combustion temperature the more is NOx formed. The NOx emission for all the blends is more than that of diesel for all the loads. At lean and rich air-fuel mixture the NOx concentration is comparatively low. As the engine is approaching the rated load the NOx
emission is higher. It can be observed that the engine running on biodiesel or its blends increase NOx emission 21-34% compared with that of diesel. The reason may be presence of oxygen molecule in biodiesel which makes possible a more complete combustion and thus an increased combustion temperature, which facilitates the generation of NOx especially at high engine loads.16,17

Fig.10. Variation of NOx with Brake power

11) Smoke Opacity:

Figure 11 represents the smoke emission measured in the engine exhaust. Any volume in which fuel is burned at relative fuel-air ratio greater than 1.5 and at pressure developed in diesel engine produces soot. The amount of soot formed depends upon the fuel-air ratio and type of fuel. If this soot, once formed finds sufficient oxygen it will burn completely. If soot is not burned in combustion cycle, it will pass through the exhaust, and it will become visible. The size of the soot particles affects the appearance of smoke. Black smoke largely depends upon the airfuel ratio and increases rapidly as the load is increased and available air is depleted. It can be observed from the figure that smoke opacity for the blends of biodiesel comparable with that of diesel for all the loads. In comparison with diesel, the smoke is less for biodiesel blends at full load because of complete combustion. For over load the smoke opacity is maximum, which is due to incomplete combustion. This may be due to the higher viscosity, lower volatility and poor atomization of the fuel.18

Fig. 11. Variation of Smoke Opacity with Brake power

12) P-0 DIAGRAM FOR NO LOAD WITH ALL BLENDS

The variations in the cylinder pressure with crank angle for diesel and biodiesel at different engine speeds are shown in Fig.12. As per the above curve at No load with all the blends, injection starts at 23° bTDC, i.e. at 337°CA and the combustion starts at 367°CA (7° after TDC) for B00, 365°CA (5° after TDC) for B20, B40, B60, B80 and B100 respectively. The delay period for diesel is 30°CA. Similarly the delay period for other blends (B20, B40, B60, B80 and B100) is 28°CA respectively. The cycle peak pressure reaching is high with diesel than the blends and it is occur at around 3°CA from TDC with peak pressure of 71.7 bar as compared to 7°CA from TDC for the B20 with peak pressure of 49.77 bar, this is mainly due to lower heat value and the injection characteristics of the fuel. The results show that the peak cylinder pressure of the engine running with biodiesel is slightly higher than the engine running with diesel. The main cause for higher peak cylinder pressure in the CI engine running with biodiesel is because of the advanced combustion process initiated by easy flow-ability of bio-diesel due to the physical properties of biodiesel. In addition, due to the presence of oxygen molecule in biodiesel, the hydrocarbons achieve complete combustion resulting in higher cylinder pressure. It can be seen that the cylinder pressure increases with increasing load for both diesel and biodiesel blends 19.

Fig.12. Pressure and Crank Angle Diagram for No load, all blends

13) P-0 DIAGRAM FOR PART LOAD WITH ALL BLENDS

Figure 13 shows the variation of cylinder pressure with crank angle at part load. As per the above graph at Part load with all the blends, injection starts at 23° bTDC, i.e. at 337°CA and the combustion starts at 361°CA (1° after TDC) for B00, 361°CA (1° after TDC) for B20, B40, B60, B80 and B100 respectively. The delay period for diesel is 24°CA. Similarly the delay period for other blends (B00, B20, B60, B60 and B100) is 24°CA respectively. The cycle peak pressure reaching is high with diesel than the blends and it is occur at around 3°CA from TDC with peak pressure of 71.7 bar as compared to 7°CA from TDC for the B20 with peak pressure of 49.77 bar, this is mainly due to lower heat value and the injection characteristics of the fuel. The results show that the peak cylinder pressure of the engine running with biodiesel is slightly higher than the engine running with diesel. The main cause for higher peak cylinder pressure in the CI engine running with biodiesel is because of the advanced combustion process initiated by easy flow-ability of bio-diesel due to the physical properties of biodiesel. In addition, due to the presence of oxygen molecule in biodiesel, the hydrocarbons achieve complete combustion resulting in higher cylinder pressure. It can be seen that the cylinder pressure increases with increasing load for both diesel and biodiesel blends.

Fig.13. Pressure and Crank Angle Diagram for Part load, all blends

14) P-0 DIAGRAM FOR FULL LOAD WITH ALL BLENDS

Figure 14 shows the variation of cylinder pressure with crank angle at full load. As per the above graph at Full load with all the blends, injection starts at 23° bTDC, i.e at 337°CA and the combustion starts at...
The release rate also the reason for lower peak pressure and lower heat release. Poor atomization and slow heat release affect the combustion of viscous fuel. The advancement in attaining peak pressure is due to high rate of pressure rise while inducting pongamia biodiesel compared to that of diesel operation. The advancement in peak pressures while inducting pongamia biodiesel because of instantaneous combustion i.e. in first stage of combustion the pongamia biodiesel gets fired and burnt very quickly and for second stage the diesel was burned progressively. This may be due to the higher cetane number of PME, which gives better ignition quality. Also the presence of oxygen molecule results in improved chemical reactions and more complete combustion. If further increasing the blend percentage, the ignition delay becomes longer. The peak pressures are observed near TDC position, the higher peaks can be observed at higher loads than that of lower and part loads. The lower peak pressures at lower loads can be attributed to lower fuel availability for combustion thus having lower heat release rates. The pongamia-diesel blends are inferior to pure diesel in terms of heating value, will have lower instantaneous heat release rates. The peak cylinder pressures are low with biodiesel blends in comparison to diesel since the heating value of biodiesel is lower than that of diesel resulting in lower heat release. Poor atomization and slow heat release rate also the reason for lower peak pressure for pure biodiesel.

These reductions of emissions could be due to complete combustion of fuel.

- The NOx emission for B20 is increased by 6.2% at 4.25 kW load and 24% and at Full load compared to diesel, and as the concentration of pongamia increases the NOx emission is also increases.
- The combustion starts earlier for biodiesel and its blends than for diesel. The peak cylinder pressure of biodiesel (B100) is higher than that of diesel at No load. The peak cylinder pressure of biodiesel is higher than that of biodiesel and its blend at part load. The peak cylinder pressure of biodiesel (B40) blend is higher than that of diesel at full load.

From all these observations, it could be concluded that the blends of pongamia with diesel up to 20% by volume could replace diesel for running the diesel engine with less emissions, without modifying the engine and without sacrificing the power output. This will thus help in controlling air pollution to a great extent.

**REFERENCES**

1. H. RAHEMAN and A G PHADATARE, Emissions and Performance of Diesel Engine from Blends of Karanja Methyl Ester (Biodiesel) and Diesel.
2. P.V.RAO, Effect of properties of Karanja methyl ester on combustion and NOx emissions of a diesel engine.
5. Shivakumar, et al., Performance and emission characteristics of a 4 stroke c.i. engine operated on honge methyl ester using artificial neural network.
8. S. S. KARHALE, et al., Studies on Comparative Performance of a Compression Ignition Engine with Different Blends of Biodiesel and Diesel under Varying Operating Conditions
9. T. ELANGO, T. SENTHILKUMAR, Performance and emission characteristics of ci engine fuelled with non edible vegetable oil and diesel blends.
10. Nagarhalli M. V., et al., Emission and performance characteristics of karanja biodiesel and its blends in a c.i. engine and it’s economics.
12. Sudipta Choudhury and Dr. P.K.Bose; KARANJA OIL – ITS POTENTIAL AND SUITABILITY AS BIODIESEL.
13. Production of Karanja Biodiesel and its Utilization in Diesel Engine Generator Set for Power Generation.
14. Hirpara Kirankumar D, Non-edible oil (karanja) for the production of biofuel in india.
15. P. Googi, Pongamia oil - a promising source of bio-diesel.
17. SP Wani and TK Sreedevi, Pongamia’s Journey from Forest to Micro-enterprise for Improving Livelihoods.
20. Engine performance and emission results of blends of transesterified pongamia oil and diesel were compared with the results obtained with neat diesel. The following are the major conclusions that are drawn.