Experimental Study of a CI Engine To Estimating The Performance and Emission analysis By using WVO (Karanja oil + Tyre Pyrolysis oil) as Biodiesel Blended oils

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ABSTRACT: *The world is confronted with the twin crises of fossil fuel depletion and environmental degradation. The indiscriminate extraction and consumption of fossil fuels have led to a reduction in petroleum reserves. Alternative fuels, energy conservation and management, energy efficiency and environmental protection have become important in recent years. The increasing import bill has necessitated the search for liquid fuels as an alternative to diesel, which is being used in large quantities in transport, agriculture, industrial, commercial and domestic sectors. Biodiesel obtained from vegetable oils has been considered a promising option. In this paper, an attempt has been made to produce biodiesel from waste vegetable oils and the properties of the produced biodiesel have been studied including its emission characteristics.*

Depleting petroleum reserves, rising petroleum prices, threat to the environment from exhaust emissions and global warming demands an intensive international interested to developing alternative non petroleum fuels for engines. Fossil fuels are the chief contributors to urban air pollution and major source of green house gases (GHGs) and considered to be the prime cause behind the global climate. The idea of using vegetable oils as fuel for diesel engines is not new. With the advent of cheap petroleum, appropriate crude oil fractions were reined to serve as fuel and diesel fuels and diesel engines evolved together.

The tyre pyrolysis oil (TPO) blended with diesel is exhibited longer ignition delay, as a result of the lower cetane number of TPO, as well as the blends. In the experimental investigation, TPO was blended with Karanja Methyl Ester (KOME), whose cetane number is higher than that of diesel, and used as an alternative fuel in a single cylinder, four stroke, air cooled, direct injection (DI) diesel engine developing 3.7kW. Some different blends of varying TPO, from, 100% were considered for the investigation. There was a reduction in the efficiency with 80% TPO in the blend at full load. The combustion, performance and emission behavior of the engine fueled with KOMETPO blends, are compared with those of diesel and Karanja oil blends with tyre pyrolysis method. The results observed were slight reduction of brake thermal efficiency and reduction of hydrocarbon emission, carbon monoxide emission, and smoke emission with increase in carbon dioxide emission using the tyre pyrolysis method of karanja oil . 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.

Keywords: Biodiesel, Performance, Emission analysis , Diesel engine, Karanja oil (Methyl Ester), Tyre pyrolysis oil.

I. INTRODUCTION

The yearly reports in pollutants of atmosphere are also in increasing trend, the need is to develop the eco friendly fuel to meet the fossil fuel depletion. These reasons increase the attention towards vegetable oil as an alternate fuel source. Biodiesel is the name of clean burning fuel, produced from domestic renewable resources. Ethanol is produced from starch based biomass and cellulosic and lingo cellulosic materials by the fermentation process. Biodiesel is produced from vegetable oils, animal fats and algae by the transesterification process. Biodiesel of up to 20% blended with diesel, can be used as fuel in all diesel engines. Nowadays, engines are manufactured to use 100% biodiesel, with little or no modification. The diesel engine can generate lower HC (burned hydrocarbons), CO (carbon monoxide) and particulate emissions with biodiesel. The choice

of vegetable oil as engine fuel naturally depends upon the local conditions prevalent availability of a particular vegetable oil in excess amount.

The research works related to the use of methyl/ethyl esters obtained from Karanja oil in direct injection(DI) engines established different results. However, the availability of seeds is limited, discouraging the use of biodiesel [13,17]. The present energy scenario has stimulated active research interest in non-petroleum, renewable and non-polluting fuels. The world reserves of primary energy and raw materials are obviously limited. The enormous growth of world population, increased technical development and standard of living in the industrial nations has led to this intricate situation in the field of energy supply and demand [7,11]. Important thermo chemical conversion processes include pyrolysis and gasification, while biochemical conversion includes anaerobic digestion.

There are various oils which are being considered worldwide for use in the engines, these include Pongamia oil, Mahua Indica oil Cotton seed oil, Rice bran oil, Sunflower oil, Soyabean oil, Rape seed oil, Jatropha oil and etc. In this investigation Pongamia oil and Mahua oil are used due to their origin is in India and its easy availability [1]. Several studies have been documented on the utilization of biodiesel from these oils for compression ignition (CI) engines [5,6]. Various researchers have studied the performance and the emission and combustion characteristics of a diesel engine, run on blends of methyl/ethyl esters of Karanja, Jatropha, Mahua, Cotton seed oil, Rubber seed oil and Linseed oil with diesel. Some of them have investigated the utilization of these esters in diesel engines with engine modification, while others have studied their effects on varied engine components [2,3,4].Among the non edible seeds produced in India, Karanja is the most preferred because of its high oil content and biodiesel yield[9,10,18].

One distinct advantage with second generation bio fuels is that, any organic substance other than the feed stocks used for the production of first generation bio fuels, can be converted into useful energy and value added products [8,12,14]. This perhaps ensures that the waste is converted into energy thus reducing the disposal of wastes that are available in large quantity. In the present work, karanja biodiesel purchased from Mint-bio fuels ltd., Pirangut Pune. And their physio-chemical combustion properties were provided by same company [16,20]. And then used for performance analysis in "4-stroke 4-cylinder water cooled diesel engine." Pyrolysis is one of the thermo chemical methods to convert waste into useful energy. Several researchers have demonstrated the pyrolysis process for converting carbonaceous such as automobile tyres, rubber, agro waste, and plastic. The pyrolysis of waste automobile tyres yields three value added products; tyre pyrolysis oil, pyrogas and carbon black. Therefore, researchers have investigated the use of TPO as an alternative fuel in both spark ignition (SI) engines and compression ignition (CI) engines and only a few documents are available for reference. Preliminary research revealed that TPO exhibits longer ignition delay in a diesel engine due to high viscosity and poor volatility of fuel [15,19]. This can be reduced by blending TPO with fuels having cetane number higher than that of conventional diesel. The present study is aimed to evaluate the effect of TPO blended with KOME in five different percentages as fuels, on the combustion, performance and emission characteristics of a direct injection (DI) diesel engine

II. MATERIALS AND METHODS

A. Tranesterification

The esters of vegetable oils are produced by transesterification [13, 21, 22]. It is the process of reacting triglyceride For the present investigation.

Tranesterification is the most common method to produce biodiesel, which refers to a catalyzed chemical reaction involving Vegetable oil, and an alcohol to yield fatty acid alkyl esters and glycerol i.e. crude glycerine [Schwab A.W., et al., 1987; Antolin G., et al., 2003].

The process of transesterification is sometimes named methanolysis or alcoholysis. This method is used to convert the corn oil in to corn oil methyl ester. After transesterification, viscosity of Corn oil methyl esters (COME) is reduced by 75-85% of the original oil value. It is also called fatty acid methyl esters, are therefore products of transesterification of Corn oil and fats with methyl alcohol in the presence of a KOH catalyst.

During the reaction, high viscosity oil reacts with methanol in the presence of a catalyst KOH to form an ester by replacing glycerol of triglycerides with a short chain alcohol [Triglycerides (Corn oil) + Methanol □ Corn oil methyl ester + Glycerol] Methanol/methyl alcohol is preferred for COME preparation by using transesterification as it provides better separation of methyl ester and crude glycerin thus facilitating the post-reaction steps of obtaining biodiesel.

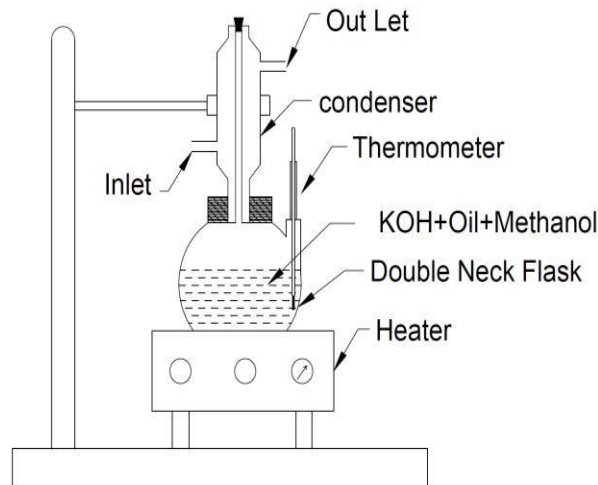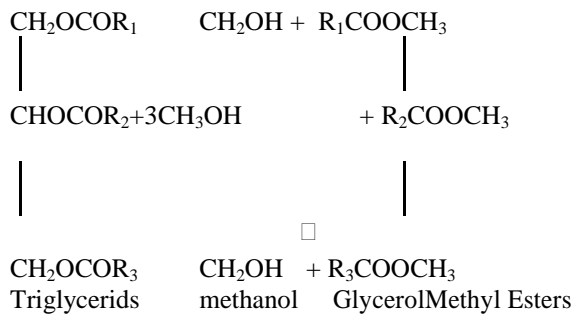with alcohol in the presence of a catalyst, to produce glycerol and fatty acid esters.

Fig. 1. Bio diesel Preparation Set up

B. Pyrolysis process

CH₂OCOR₁   CH₂OH + R₁COOCH₃

CHOCOR₂+3CH₃OH   + R₂COOCH₃

CH₂OCOR₃   CH₂OH   + R₃COOCH₃
Triglycerids   methanol   GlycerolMethyl Esters

The temperature of the reactor was measured by the help of a temperature indicator provided in a temperature controller unit. The temperature of the reactor was controlled by a PID controller.

 In pyrolysis process for deriving wood pyrolysis oil was carried out at 500□ C. The products of pyrolysis in the form of vapour were sent to a water cooled condenser and the condensed liquid was collected in a container. The pyrolysis oil has a high oxygen content burn smoothly and cleanly and has the potential for alternative source. But pyrolysis oil contains many reactive components that can form higher molecular weight species. So these reactions result in an increase in viscosity and decrease in volatility KOME/KOMETPO blends, to prevent any deposits, and cold starting problems

In this study pyrolysis oil was obtained through vacuum pyrolysis process. Thick wood obtained from packing container box taken as sample, cut into small chips, washed, dried. The schematic diagram of the pyrolysis process for deriving wood pyrolysis oil was given in figure 2.This chips were fed into an externally heated mild steel reactor unit. The fed chips were heated up in the reactor unit in the absence of oxygen. The reactor used for production of wood pyrolysis oil is cylindrical in shape with inner diameter 200mm and outer diameter 250mm and a height of 250mmThe reactor is fully insulated by glass wool with thickness 50mmand refractory lining. The heat input to the electrical heater was 3kW.
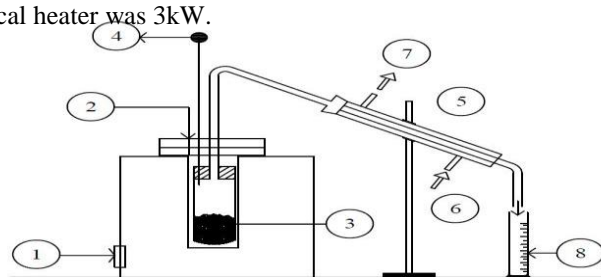

Fig . 2. Pyrolysis setup

1. Furnace 2. Reactor 3. Feed material 4. Temperature controller 5.Condenser 6. Water inlet 7. Water outlet 8. Pyrolysis oil collector

III. ENGINE SETUP AND METHODOLOGY

Experiments have been conducted in a single cylinder, four stroke, air cooled, direct injection, diesel engine with a developing power of 3.7 kW at 1500 rpm. The technical specifications of the engine are given in Table 1, experimental diagram and the schematic diagram of the experimental arrangement is shown in Fig. 3 and 4. Experiments were initially started with diesel and after the engine reached the warm up condition, it was switched over to KOME, and then, the different KOMETPO blends. A data acquisition system, in conjunction with a piezoelectric pressure transducer and crank angle encoder was used for the measurement of the cylinder pressure

In all the cases, the pressure-crank angle diagrams were recorded and processed, to get the combustion parameters by the data acquisition system. A fuel level indicator was used for measuring the total fuel consumption. A U-tube manometer connected with an orifice mounted on air box in the suction was used for measuring the intake air flow rate. A K-type thermocouple was installed to measure the exhaust gas temperature. The exhaust emission of the engine was measured by an AVL DiGas444 exhaust gas analyzer. An AVL437 smoke meter was used to measure the smoke levels. After conducting all the tests with the blends, the engine was again run on diesel, to ensure that there was no fuel trace of the details of the instrumentation adopted in the present investigation.

Fig. 3. Experimental setup

Table.1. Specification of test engine

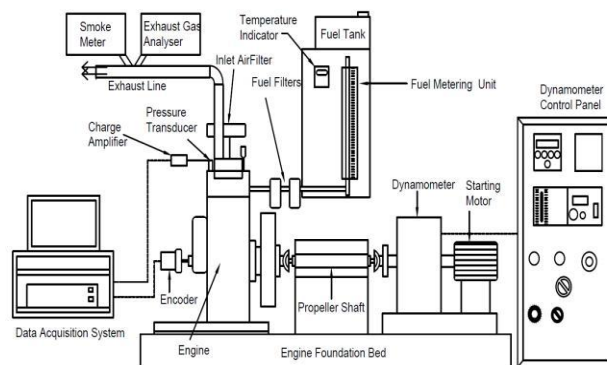| Make	Kirloskar AV-1
Type	Single cylinder, water cooled,
Max.power	3.7 kW at 1500 rpm
Displacement	550 CC
Bore x Stroke	80 x 110 mm
Compression ratio	16.5:1
Fuel injection timing	21deg BTDC
Loading device	Eddy current dynamometer

Fig.4. Schematic Experimental Set up

Table 2. Physical properties of Karanja oil and KOME

Property	Karanja oil	Karanja Methyl Ester
Calorific value (kJ/kg)	39,774	38,450
Density (kg/m^3)	918	880
Kinematic viscosity (cSt)	49.93	5.65
Flash point (°C)	240	170
Cetane number	40-45	50-55
Carbon residue (%)	0.64	0.5

IV.RESULTS AND DISCUSSION

A. Performance parameters

1. Brake thermal efficiency

The important parameters of the diesel engine is shows in the Fig. 5 the variation in the brake thermal efficiency with brake power for diesel and KOMETPO blends. The brake thermal efficiency for diesel is 31.89% at full load, which is the highest among all the fuels tested.

For KOME, KOMETPO20, KOMETPO40, KOMETPO60, KOMETPO80 and KOMETPO100, it is 27.01%, 25.08%, 27.01%, 33%, 32.9% and 31.03% respectively at full load. The thermal efficiency of diesel, KOME and KOMETPO blends increases with increasing brake power. As the brake power increases the heat generated in the cylinder increases, and hence, the thermal efficiency increases. The thermal efficiency of the KOMETPO blends is lower than that of diesel and KOME at full load, as a result of higher density, and poor volatility [22]. At low loads, the thermal efficiency is much lower for the KOMETPO blends than that of diesel. At full load the brake thermal efficiency is higher for KOMETPO60 compared to the other blends.

Fig. 5. Brake thermal efficiency with brake power.
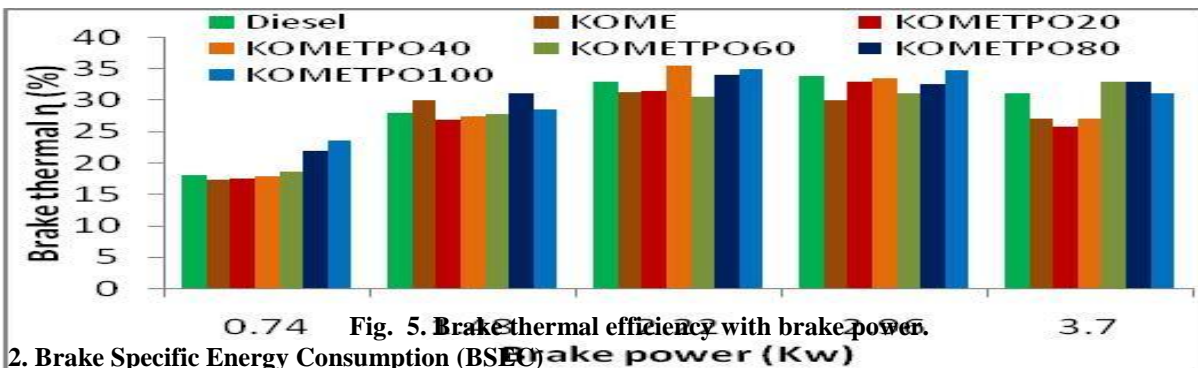
2. Brake Specific Energy Consumption (BSEC)

The brake specific fuel consumption is not a very reliable factor to compare the two fuels, as the calorific value and the density of the blends are marginally different [19]. Fig. 6 shows the variation of BSEC for diesel and the KOMETPO blends, with respect to brake power. The BSEC for diesel is 12.86 MJ/kWh at full load.
For KOME, KOMETPO20, KOMETPO40, KOMETPO60, KOMETPO80 and KOMETPO100, it is 14.05, 16.57, 17.06, 18.06, 19.09 and 23.02 MJ/kWh respectively.

With the increase in brake power the BSEC decreases for diesel, and KOME as well as for all the KOMETPO blends. The engine consumes more fuel with the KOMETPO blends than with diesel, to develop the same power output, due to the lower calorific value of the KOMETPO blends. This is because the energy content of both KOME and TPO is lower compared to that of diesel, which leads to injection of higher quantities of the fuel for the same power output in comparison with diesel. The BSEC is the lowest for KOMETPO80; further increasing TPO percentage results higher BSEC due to lower calorific value.
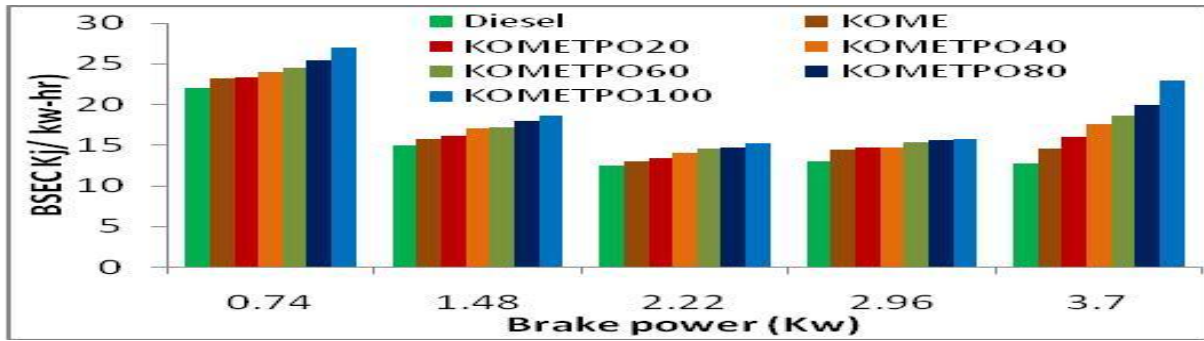
Fig. 6. Brake specific energy consumption with brake power

3. Exhaust Gas Temperature (EGT)

Fig. 7 illustrates the variation of the exhaust gas temperature, with respect to brake power. The exhaust gas temperature gives an indication about the amount of heat going waste with the exhaust gases [12]. It can be observed from the figure that with the increase in brake power the EGT increases for all the tested fuels. The EGT value for diesel at full load was 300 °C. It can also be observed that the values of EGT were 350, 255, 325, 385, 370 and 360 °C for KOME, KOMETPO20, KOMETPO40, KOMETPO60, KOMETPO80 and KOMETPO100 respectively at full load. As a result of increased combustion duration, a higher exhaust gas temperature is recorded for the KOMETPO blends.
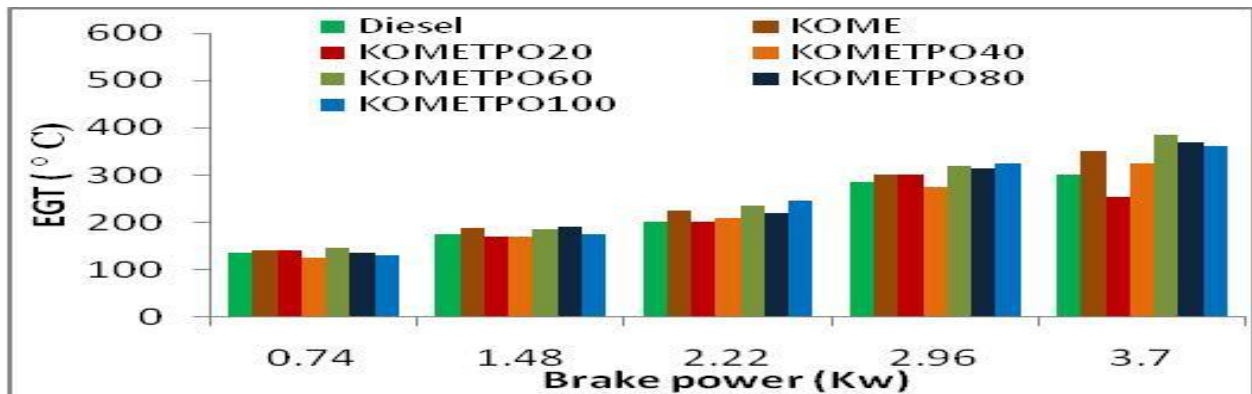

Fig. 7. Exhaust gas temperature with brake power.

B. Emission parameters
1. Carbon monoxide (CO) emission

Fig. 8 shows the trend of CO emission for diesel and the KOMETPO blends, with respect to brake power. Generally, CI engines are operated with a lean mixture. Therefore, the CO emission is found to be lesser than that in the SI engines. It can be observed from the figure that the CO emission in g/kW h decreases with increasing brake power. The CO emission is lower for KOME, KOMETPO80 and KOMETPO80 compared to that of diesel at full load, because the excess oxygen present in the KOME is helpful for better combustion [9]. The values of CO emission for diesel, KOME, KOMETPO20, KOMETPO40, KOMETPO60, KOMETPO80 and KOMETPO100 are 6.3, 4.5, 4.9, 5.4, 6.1, 6.9 and 7.9 g/kWh respectively, at full load operation

2. Hydrocarbon (HC) emission

The emission show the characteristics of the tyre pyrolysis value give the effective values of the HC emission is lower at part load, but tends to increase at higher loads for all the fuels investigated in this study. For KOME, KOMETPO80 and KOMETPO100, the HC emission is found to be less compared to that of diesel. This could be due to the complete combustion of KOME.

But addition of the TPO percentage results in higher HC emission. This is because; the TPO has higher aromatic content, and hence may result in incomplete combustion and more HC emission for KOMETPO60, KOMETPO80 and KOMETPO100 compared to the other fuels tested. The HC values for diesel, KOME, KOMETPO20, KOMETPO40, KOMETPO60, KOMETPO80 and KOMETPO100 are 0.06, 0.03, 0.08, 0.13, 0.21, 0.26, and 0.29 g/kWh at full load.
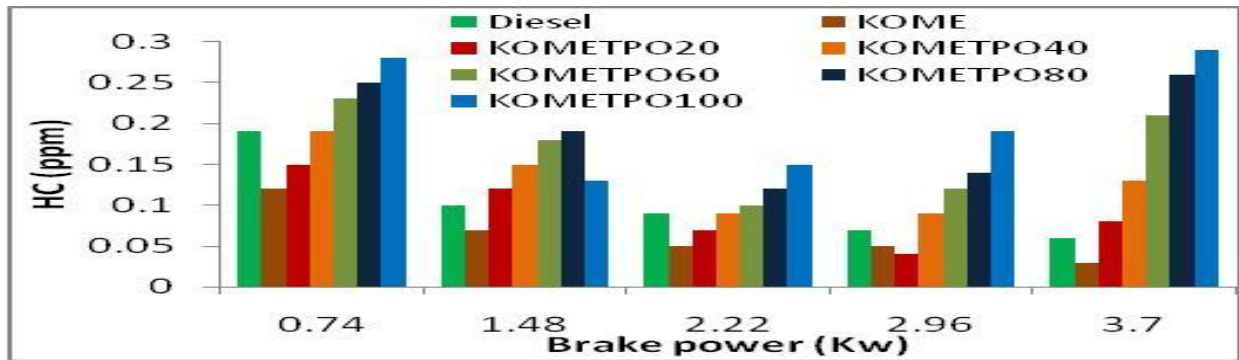
Fig. 9. Unburnt hydrocarbons with brake power

3. Nitric Oxide (NO) emission

Two important factors affecting the formation of NO_x in a CI engine are the combustion temperature and the availability of oxygen. Fig. 10 shows the variation of NO emission with brake power for diesel, KOME

and the KOMETPO blends. The NO emission for diesel, KOME and all the KOMETPO blends increases as the brake power increases. This is expected, because with increasing brake power, the temperature prevailing in the combustion chamber increases. The NO emission is higher for KOME and the KOMETPO blends compared to that of diesel at all loads. This may be due to the availability of the excess oxygen present in KOME [17]. While increasing the TPO percentage, the NO emission decreases, because of lower heat release rates than that of KOME. The values of NO emission for diesel, KOME, KOMETPO20, KOMETPO40, KOMETPO60, KOMETPO80 and KOMETPO100 are 4.2, 5.1, 4.9, 3.9, 4.9, 3.9, and 3.8 g/kW h respectively, at full load operation.
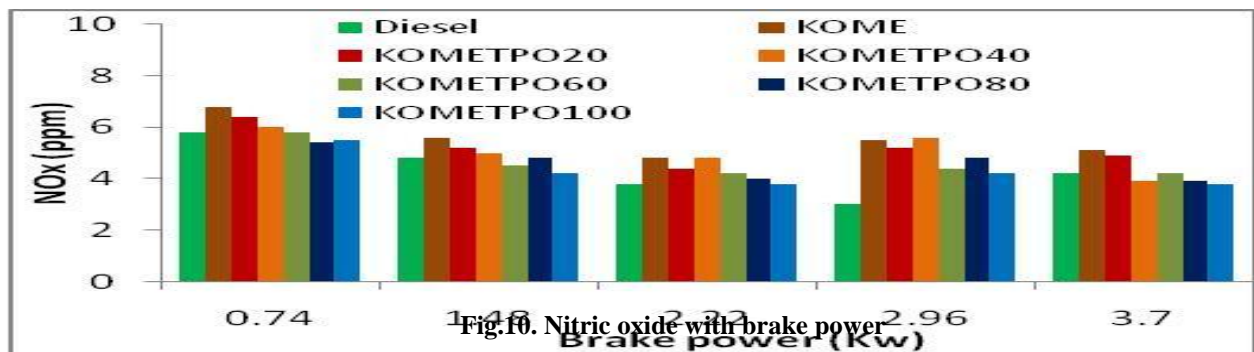

Fig.10. Nitric oxide with brake power

4. Smoke emission

Smoke is the result of incomplete combustion, and is formed in the rich mixture zone in the combustion chamber [14].Fig. 11 illustrates the smoke emission measured in the engine exhaust, for the fuels tested in this study. With an increase in the brake power, the air fuel ratio decreases as the fuel injected increases, and hence results in higher smoke. In comparison with diesel, the smoke is less for KOME, KOMETPO20 and KOMETPO40, and more for KOMETPO60, KOMETPO80 and KOMETPO100 at all loads. The presence of oxygen in the KOME may be helpful in breaking the aromatic content that is available in less percentage with KOMETPO80 and KOMETPO100.
 But, further increase of the TPO percentage, results in an increased aromatic content, which gives higher smoke. Longer ignition delay and combustion duration are also the reasons for higher smoke in the case of KOMETPO60, KOMETPO80 and KOMETPO100. The smoke values for diesel, KOME, KOMETPO20, KOMETPO40, KOMET-PO60, KOMETPO80 and KOMETPO100 are 92%, 58%, 62%, 66%, 90%, 96%, and 98% respectively, at full load.
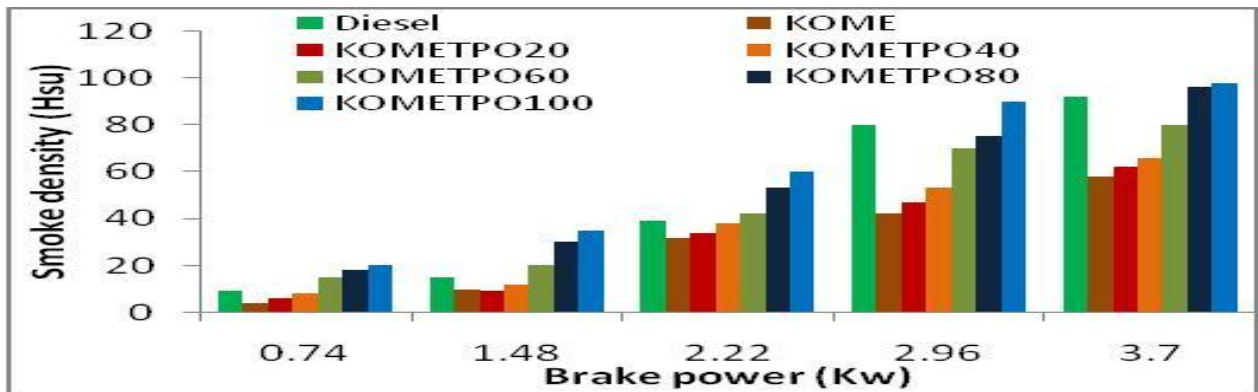
Fig. 11. Smoke with brake power.

C. Combustion parameters
1. Cylinder pressure

Fig. 12 shows the comparison of the cylinder pressure of the KOME and KOMETPO blends with diesel at full load condition. The KOMETPO blends follow a cylinder pressure pattern similar to that of diesel at full load condition. The oxygen content and higher cetane number of KOME are the reasons for the earlier ignition of these blends and KOME, than that of diesel at full load. The reduced oxygen content of KOMETPO60, KOMETPO80 and KOMETPO100 may reduced the ignition to later than that of KOME, KOMETPO60 and KOMETPO80 at full load.KOMETPO80 shows the shortest ignition delay at full load among all the blends tested in this study. The commencement of the ignition is earlier by about 1CA than that of the diesel at full load. The ignition of KOME tyre pyrolysis to 2 CA earlier that full load of the diesel
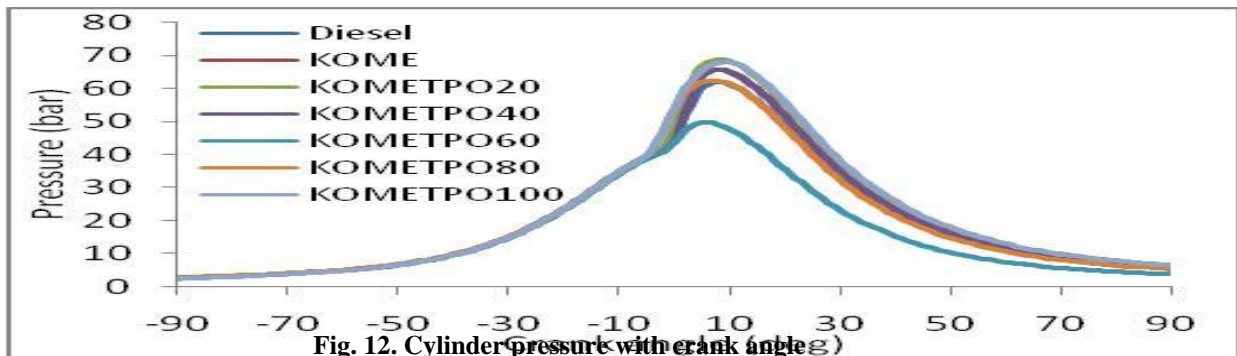

Fig. 12. Cylinder pressure with crank angle

2. Heat release rate
The amount of heat release in the premixed combustion of a CI engine depends on the ignition delay, air fuel mixing rate and the heating value of the fuel [18]. Fig. 13 illustrates the heat release rate pattern with respect to the crank angle at full load. It is apparent from the figure, that the heat release rate is the highest for diesel and the lowest for KOMETPO100 at full load. The diesel curve is followed by that of KOME, KOMETPO20, KOMETPO40, KOMETPO60 and KOMETPO80 at full load. The accumulation of diesel is more in the delay period, which releases the maximum heat, as it has a higher calorific value. The heat release rates for KOME and its TPO blends are lower due to their shorter ignition delays and higher viscosities than that of diesel at full load. KOMETPO20 gives the maximum heat release rate compared to the other KOMETPO blends. The different boiling point compounds in TPO may undergo chemical reactions with KOME, and result in a higher heat release rate. The maximum heat release rates for diesel and KOME are 49.51 and 53.54 J/°CA respectively at full load. The maximum heat release rate for KOMETPO80 is recorded as 39.55 J/°CA at full load.
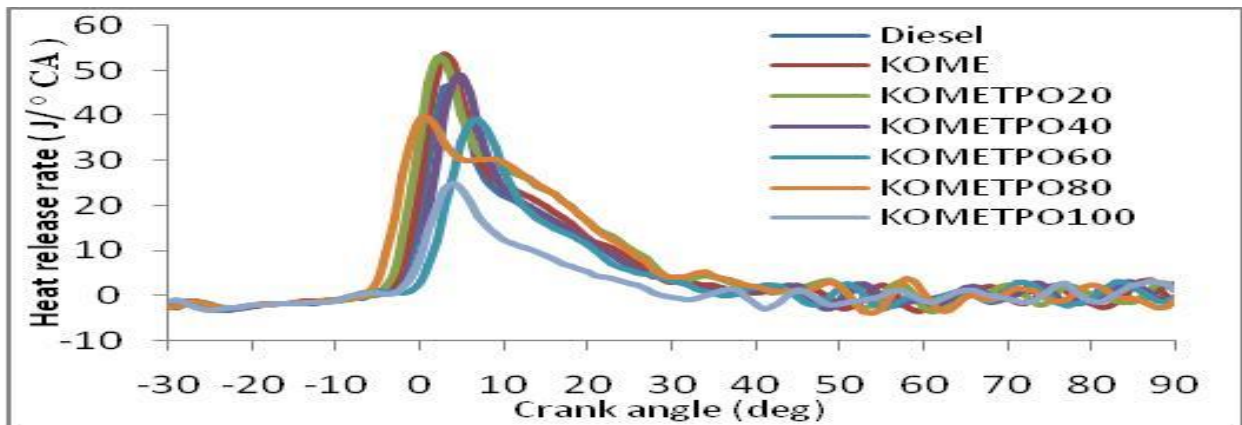
Fig. 13. Heat release rate with crank angle

3. Ignition delay

The ignition delay is evaluated as the time difference measured in the crank angle between the start of injection and the start of ignition [14]. It is seen from Fig.14 that the ignition delay of diesel is longer in comparison with KOME, KOMETPO80, and KOMETPO100 at full load. This may be due to the higher cetane number of KOME, which gives better ignition quality. And also the presence of oxygen results in improved chemical reactions and more complete combustion. It is quite interesting, that on further increasing the blend percentage, the ignition delay becomes longer for KOMETPO60, KOMETPO80, and KOMETPO100, due to the lower cetane number of the injected fuel. The values of ignition delay for diesel, KOME, KOMETPO80, KOMET-PO20, KOMETPO60, KOMETPO80 and KOMETPO100 are 12, 11.13, 11.18, 12, 12.04, 13.8 and 12.6 °CA respectively at full load
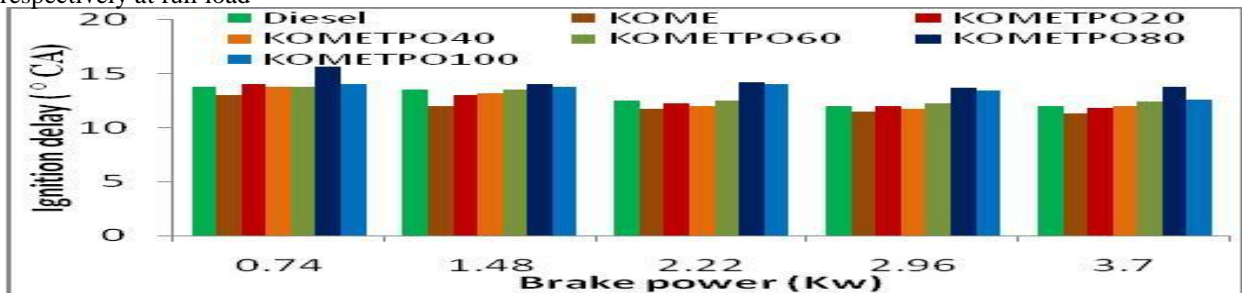

Fig. 14. Ignition delay with brake power

4. Combustion duration

Fig. 15 shows the variation of the combustion duration with brake power. It can be observed from the figure that the combustion duration increases with an increase in the brake power for all the tested fuels, which may be due to the increase in the quantity of fuel injected. It is also evident from the figure, that the combustion duration is shorter for KOME, KOMETPO80, and KOMETPO100 compared to that of diesel operation. Increasing the TPO percentage in the KOMETPO blends, results in longer combustion duration. This may be due to the high boiling point compounds present in TPO, and its lower cetane number, which takes more time for the chemical reaction [10].

At full load, the values of the combustion duration for diesel are 38.34 °CA, while the values are 37.89, 37.32, 37.8, 56.88, 65.4, and 58.85 °CA for KOME, KOMETPO20, KOMETPO40, KOMETPO60, KOMETPO80, KOMETPO100.
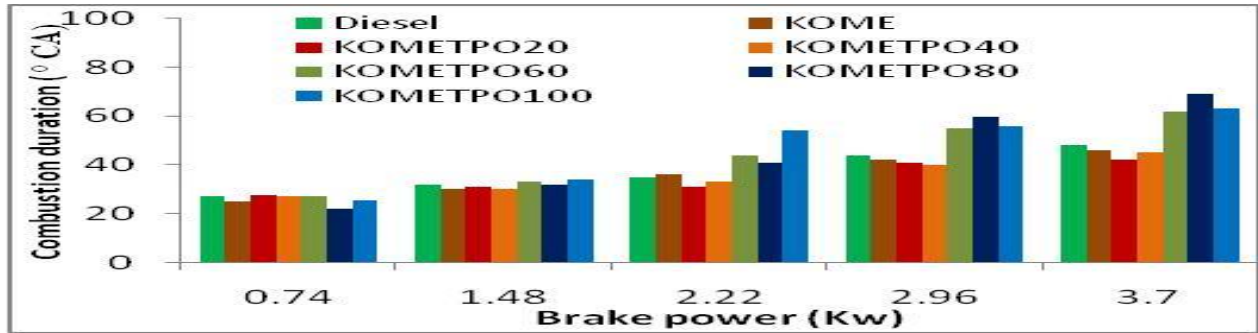
Fig. 15.Combustion duration with brake power

5. Cumulative heat release rate

The variation of cumulative heat release with crank angle is presented in the figure 16. The figure 16 shows that there is a tendency of earlier heat release for KOME and TPO but the cumulative heat release value of diesel fuel quickly exceeds the diesel, KOMETPO20, KOMETPO40, KOMETPO60, KOMETPO80, KOMETPO100 blend even though combustion for diesel fuel starts later. The main reason for the decreases in the KOME is lower heating value of KOMETPO40 and other KOMETPO80 based blend as compared to diesel fuel. KOMETPO increased with the rise in the engine load to the increase in the quantity of fuel injected into the cylinder. KOME increased with the increased in engine load for all tested fuels. It is seen that the premixed combustion region is lesser for KOMETPO indicating that with neat diesel fuel greater mixing is enhanced. The slight high viscosity and density of KOMETPO result in inferior atomization and vaporization and lead to reduction in fuel air mixing rates. Hence, more burning occurs in the diffusion phase. This could explain the lower NOx, higher CO and HC emissions with KOMETPO .
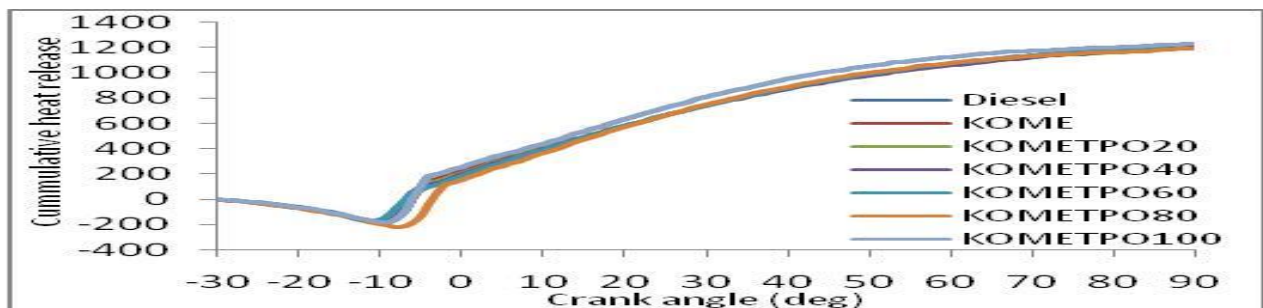

Fig. 16. Cummulative heat release with Crank angl

6. Cylinder peak pressure

The variation of the cylinder peak pressure at different values of brake power is shown in Fig. 17.More diesel might be accumulated in the delay period as a result of longer ignition delay and this is the reason for the highest cylinder peak pressure for diesel, than that of KOME and its TPO blends at full load. The peak pressures for diesel, KOME, KOMETPO20 KOMETPO40, KOMETPO60, KOMETPO80 and KOMETPO100 at full load operation are 80, 77, 75, 78, 60, 65 and 65.5bar at full load. The cylinder peak pressure decreases with increasing percentage of TPO

after 20%. In the case of KOMETPO60, KOMETPO80 and KOMETPO100 the cylinder peak pressures are lower as a result of lower heat release rates. KOMETPO80 gives a higher peak pressure of 79.95bar in comparison with the other KOMETPO blends.
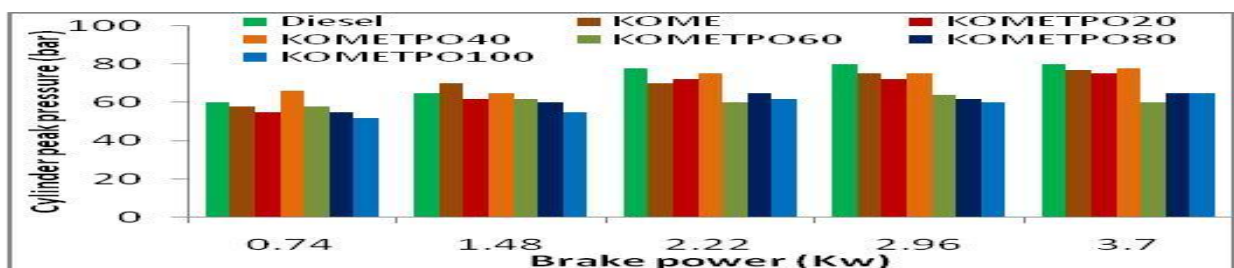

Fig. 17. Cylinder peak pressure with brake power

7. Maximum rate of pressure rise

Fig. 18 depicts the variation in maximum rate of pressure rise with brake power for diesel, KOME and KOMETPO blends. The rate of pressure rise is the first derivative of cylinder pressure that relates to the smoothness of the engine operation. The maximum rate of pressure rise increases initially with load, and then decreases due to the prominent influence of the premixed phase at lower loads, while the role of the diffusion phase of combustion remains significant at higher loads [14]. The maximum rate of pressure rise is higher for diesel at full load. The maximum rates of pressure rise are 5.4, 3.2, 4.6, 3.2, 3.01, 3, and 3.2 bar/°CA for diesel, KOMETPO of 20%, 40%, 60%, 80% and100% at full load respectively. Interestingly, the rates of pressure rise for the KOMETPO blends are much lower than that of diesel except 80% and KOMETPO100 at full load. In low and part load operations, the rate of pressure rise is unpredictable, because of the aromatic nature of the TPO
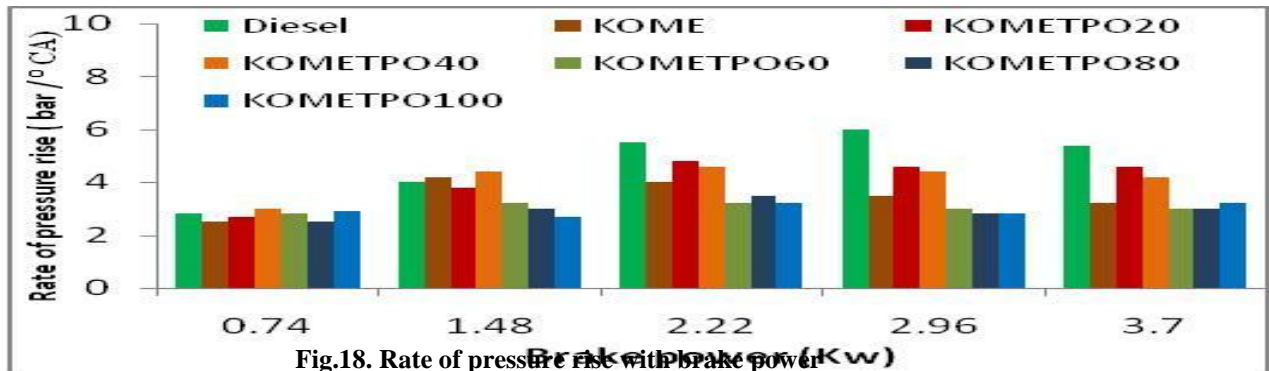

Fig.18. Rate of pressure rise with brake power

V. CONCLUSIONS

• KOMETPO80 gives the optimum result, compared to the other blends.

• The peak pressure lowers by about 1 bar for KOMETPO80 in comparison with diesel at full load.

•Ignition delay for KOMETPO60 is almost equal to that of diesel at full load operation.

• The combustion duration for diesel is 37.89 °CA at full load. It decreased by about 0.54 °CA for KOMETPO80

• Nitric oxide emission was higher by about 24% for KOMETPO80, in comparison with diesel at full load.

• The CO, HC and smoke emissions were lower by about 9.09%, 8.6% and 26% respectively f0r 80% of the karanja   oil in the tyre pyrolysis method, compared to diesel at full load

• The BSEC for diesel is 11.86 MJ/kWh at full load. The BSEC increased by about 7.8%for 80% of the karanja oil, than that of diesel operation at full load.

•The EGT is higher for 80% compared to that of diesel at full load.

•At full load, the brake thermal efficiency is almost the same, i.e., 29.88% and 29.89% for KOMETPO80 and diesel respectively, at full load.

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