EXPERIMENTAL INVESTIGATION OF A DI DIESEL ENGINE USING TYRE PYROLYSIS OIL-DIESEL BLENDS AS A BIODIESEL

R. Senthil Kumar¹,  M. Prabu²

Research scholar, Mechanical Engineering, Annamalai University, Assistant Professor, Prist University, Kumbakonam,

ABSTRACT

Many alternate fuels like Alcohols, Biodiesel, Methanol, Ethanol, LPG, CNG etc have been already commercialized in the transport sector. In this context, pyrolysis of solid waste is currently receiving renewed interest. This research describe a comparison of the use of pyrolysis oils which are the tire pyrolysis oil, plastic pyrolysis oil and diesel oil in the assessment of engine performance, and feasibility analysis. Pyrolysis oils from waste tire and waste plastic are studied to apply with one cylinder multipurpose agriculture diesel engine. It is found that without engine modification, the tire pyrolysis offers better engine performance whereas the heating value of the plastic pyrolysis oil is higher. The plastic pyrolysis oil could improve performance by modifying engine. The economic analysis shows that the pyrolysis oil is able to replace diesel in terms of engine performance and energy output if the price of pyrolysis oil is not greater than 85% of diesel oil. Tests have been carried out to evaluate the performance analysis of a single cylinder direct injection diesel engine fueled with 5%,15%, 25%, 50%,75%and 85% of tyre pyrolysis oil (TPO) blended with Diesel fuel (DF). The TPO was derived from waste automobile tyre through vacuum pyrolysis. Best suitable blend was found and pyrolysis oil was added in concentration of 50%,75%, with diesel.

Keywords: Diesel Engine. Tyre Pyrolysis Oil, Performance, Emission, Combustion.

1. INTRODUCTION

Fast depletion of the fossil fuels, rising petroleum prices, increasing threat to the environment from exhaust emissions and global warming have generated intense international interest in developing alternative non-petroleum fuels for engines. In the context of fast depletion of fossil fuels and increasing of diesel engine vehicle population, the use of renewable fuel like vegetable oils become more important. Many alternative fuels like biogas, methanol, ethanol and vegetable oils
have been evaluated as a partial or complete substitute to diesel fuel [3, 8, 12]. The vegetable oil directly can be used in diesel engine as a fuel, because their percentage of energy content is high and nearly equal to diesel. The technology of production, the collection, extraction of vegetable oil from oil seed crop and oil seed bearing trees is well known and very simple [2, 9, 11, 16]. The disposal of used tyres from automotive vehicles becomes inexhaustible performance and emission characteristics of a single cylinder direct injection diesel engine fuelled by 10, 30 and 50 percent blends of Tyre pyrolysis oil (TPO) with diesel fuel (DF) [1, 4, 7]. Results showed that the brake thermal efficiency of the engine fuelled by TPO-DF blends increased with increase in blend concentration and higher than Diesel [5, 15, 29]. NOx, HC, CO and Smoke emissions were found to be higher at higher loads due to high aromatic content and longer ignition delay and to used mahua oil as an alternative fuel for diesel engine. The properties of mahua oil were determined [21, 24, 27]. The performance and emissions of a single cylinder, stationary diesel engine was evaluated using mahua oil and compared with standard diesel operation. Mahua oil was preheated to 130°C and the effect of preheating on the engine performance and emissions were determined [6, 12, 16]. The heat release rate of mahua oil was enhanced with preheating [13, 17, 19]. The engine performance improved and smoke, CO and HC emissions decreased while the engine was running with preheated mahua oil. A marginal increase in NOx emission was conducted performance test on diesel engine by using waste plastic oil as alternate fuel. The experimental results have showed a stable performance with brake thermal efficiency similar to that of diesel [18, 20, 23]. Carbon dioxide and unburned hydrocarbons were marginally higher than that of the diesel baseline. The toxic gas CO emission of waste plastic oil was higher than diesel. Smoke reduced by about 40% to 50% using waste plastic oil at all loads. Biodiesel is an alternative fuel for diesel, every year in United States 280 million tyres are being dumped in the landfills, which became an unacceptable solution hence the tyre pyrolysis oil is produced which can used in a useful way [10, 25]. Not only in United States all over the world there is an increase in waste tyres, so scrap tyres are used in the form of pyrolysis tyre oil which is used as a blend with diesel oil, which increases the efficiency of the engine. The purpose of this work is to compare used tyre pyrolysis oil blends with conventional diesel fuel when fueled in a diesel engine. Before this there is need for survey on various alternate fuels used in diesel engines by various researchers. Though many disposal methods are available to dispose the waste automobile tyres, still the problem persists [27, 29]. Pyrolysis of a substance offers value added products such as pyrolysis oil, pyro gas and char. Investigations report that Pyrolysis of waste automobile tyre chips produce Tyre pyrolysis oil, pyrolytic gas and char. It is also reported that TPO has properties similar to that of diesel fuel. In reference, Experimental work was carried out in a one ton batch pyrolysis unit to produce oil, char and gas from waste automobile tyres through pyrolysis process [12, 14, 28]. Commercial tyre pyrolysis processes have had limited application world-wide, although many pilot scale processes have reported considerable success. The majority of the published research on scrap tyre pyrolysis has been conducted at either laboratory or pilot scale. Significant yields of hydrocarbon liquid, and gas have been reported from the pyrolysis of shredded tyres. The emissions of NOx, SO₂, particulate and total unburned hydrocarbons were determined in relation to excess oxygen levels. Throughout the combustion tests, comparison of the emissions was made with the combustion of diesel. The oil was found to contain 1.4% sulphur and 0.45% nitrogen on mass basis and have similar fuel properties to those of diesel [21, 24, 29]. The behavior and chemical analysis of Tyre pyrolysis oil. In this work it is reported that Tyre Oil is a complex mixture of organic compounds of 5-20 carbons and with a higher proportion of aromatics. The emissions characteristics of diesel engines fuelled with neat biodiesel or its blends with diesel fuel have been investigated by many researchers. They found that there are reductions in carbon monoxide, hydrocarbon and smoke emissions, while there is increase in NOx emissions. The major drawback with the vegetable oils as fuel is its high viscosity. Higher viscosity of oils is having an adverse effect on the combustion in the existing diesel engines. Concept of preheating of biodiesel to bring the viscosity equivalent to diesel.
The viscosity of fuels have important effects on fuel droplet formation, atomization, vaporization and fuel-air mixing process, thus influencing the exhaust emissions and performance parameters of the engine. There have been some investigations on using preheated raw vegetable oils such as cottonseed oil in diesel engines. It was observed that more than 30% of the Tyre pyrolysis oil was easily distillable fraction with boiling points between 70 °C and 210 °C, which is the boiling point range specified for commercial petrol. It was mentioned that distillation carried out between 150 °C and 370 °C has a higher proportion of the lighter and heavier products and a lower proportion of the middle range of products than commercial diesel oil. In recent years some experimental studies revealed that the use of TPO derived from waste automobile tyres can be used as an alternate fuel in diesel engines. Despite the operative and expensive approach, the best possible utilisation of TPO is still to be determined. TPO characteristics strongly depend on the pyrolysis process characteristics, process temperature and nature of waste automobile tyres used[12, 15, 17]. Experiments were carried out using crude TPO in a single cylinder diesel engine. Tire pyrolysis has been investigated for more than 20 years. The process converts waste tire into potentially recyclable materials such as flammable gas, pyrolysis oil and carbon black. Composition of the oil depends on reactor design and operating condition [3, 7, 9, 11]. Tire pyrolysis oil plant has been established around the world in order to produce the substitute liquid fuel for heating purpose as found that the tire pyrolysis oil have a high gross calorific Roy et al. conducted experiments on the recycling of scrap tyres to oil and carbon black by vacuum pyrolysis. In this work, a step-by-step approach has been used, from bench-scale batch systems, to a process development unit and finally a pilot plant, to experiment and develop vacuum pyrolysis of used tyres. It was reported that the yield is 55% oil, 25% carbon black, 9% steel, 5% fiber and 6% gas. The maximum recovery of oil is obtained at 415 °C below an absolute pressure of 2 kPa. The specific gravity of this oil was0.95 and its gross heating value was 43 MJ/kg and total sulphur content about 0.8% [2, 6, 22]. It was rich in benzyl and other Petrochemical components. The heat of pyrolysis for the reactions is low and is estimated to be 700 kJ/. The high carbon residue indicated value and high viscosity is due to the large molecular mass and chemical structure. The high carbon residue is responsible for heavy smoke emissions. The use of crude TPO as an alternate fuel showed similar performance and emission characteristics, with that of neat vegetable oils in compression ignition engines. Crude TPO contains char, sand and alkali metals. Wear problems will arise both in the injection equipment and in several other engine parts, such as valves, valve seats, piston rings and liners[7, 17, 27]. In addition, exhaust emissions may be impaired by these solid particles. Though the experimental results have no remarks about the emission of oxides of sulphur, the higher sulphur content will definitely affect the use of crude TPO as an alternate fuel in diesel engines. Crude TPO also contains tar and polymers in the form of gummy materials [10, 24]. Kinetic constants of sulfur compound reactions were evaluated as collecting all sulfur compounds in a single group. Only about 1% of the sulfur present in the loaded tire was detected in the liquid phase, the remaining being released as H2S in the gas phase. The sulfur content of the liquid products of tire pyrolysis should be lower to the commercial diesel fuel did studies on the performance, emission and combustion characteristics of a Light duty DI Diesel Engine with wood pyrolysis oil(WPO)which was blended with different percentage of oxygenated compounds [28]. It was concluded that reliable operations were recorded with WPO–digly me blends with WPO content up to 44.1% by weight. No major trouble was observed on the critical components of the engine [21]. The present study is aimed to modify the fuel to reduce the viscosity and sulphur content of the crude Tyre pyrolysis oil. The properties of modified TPO were also determined and compared with that of crude TPO. The performance, emission and combustion parameters of a single cylinder air cooled DI diesel engine was anlysed running with the DTPO-DIESEL blends and compared with the DIESEL operation [23]. The behavior and chemical analysis of Tyre pyrolysis oil. In this work it is reported that Tyre Oil is a complex mixture of organic compounds of 5–20 carbons and with a higher proportion of aromatics[1, 9, 22]. The percentage of aromatics, aliphatic, nitrogenated
compounds, benzothiazol were also determined in the Tyre pyrolysis oil at various operating temperatures of the pyrolysis process.

2. TYRE PYROLYSIS OIL

The pyrolysis of scrap tyres has been the subject of numerous studies. The pyrolysis process, when applied to tyres, is described as the degradation of the rubber, using heat, in the absence of oxygen. The organic volatile matter of tyres is decomposed into lower molecular weight products inorganic component remain in the residue and may potentially be recycled. The product compositions are dependent on the pyrolysis conditions as well as the composition of the feed tyres. The process is usually conducted under oxygen insufficiency or in an inert gas at either atmospheric or reduced pressures and in temperatures ranging from 300°-1000°C. The rubber feed can be in the form of granulate or sometimes whole tyres. The process is highly endothermic with a typical energy consumption. Initially an automobile tyre was cut into a number of pieces and the bead, steel wires and fabrics were removed. Thick rubber at the periphery of the tyre was alone made into small chips. The tyre chips were washed dried and fed into a mild steel pyrolysis reactor unit. The pyrolysis reactor used was a full insulated cylindrical chamber of inner diameter 110 mm and outer diameter 115 mm and height 300 mm. Vacuum was created in the pyrolysis reactor and then externally heated by means of 1.5 kW heaters. The process was carried out between 4500°C and 650°C in the reactor for 2 hours and 30 minutes. The products of pyrolysis in the form of vapour were sent to a water cooled condenser and the condensed liquid was collected as a fuel. The non condensable gases were let out to atmosphere. The TPO collected was crude in nature. For an output of 1 kg of TPO about 2.09 kg of waste tyres feedstock was required. The product yields from the process are: Tyre Pyrolysis Oil (50 %), Pyro gas (40 %) and char (10 %). The heat energy required to convert the waste tyres into the products was around 7.8 MJ/kg. The residence time of the pyrolysis process was 90 minutes. TPO was filtered by fabric filter and again filtered by micron filter to remove impurities, dust, low and high volatile fractions of hydrocarbons.

Fig. 1. Pyrolysis setup

3. CHARACTERISTICS OF PYROLYSIS OIL

Pyrolysis is a complex series of chemical and thermal reactions to decompose or depolymerize organic material under oxygen-free conditions. The products of pyrolysis include oils, gases and char. The pyrolysis oil products in this research are from tire and plastic which are dissimilar in physical properties and chemical properties. The appearance of the tire pyrolysis oil is thick-liquid and dark colour oil whereas the appearance of the plastic pyrolysis oil is grease oil like and dark colour oil at 30°C (room temperature). They all strong smell due to the high aromatic substance. As the comparison usage of this research is in diesel engine, the pyrolysis oil from process is a mixture of carbon composition which are C5-C20 in tire pyrolysis oil and C10-C30 in plastic pyrolysis oil. The oil requires dis-tillation process to differentiate the diesel-like oil from other compounds. The distillation temperature applied in this research is 180°C. The substance that evaporates before 180°C is taken out. The remaining is analyzed and tested in one cylinder multipurpose agriculture diesel engine.

3.2. Various Steps of TPO

The modification of the crude TPO involves three stages, (i) removal of moisture content (ii) Desulphurisation process (iii) Vacuum distillation method.

3.2.1. Removal of moisture

Initially crude TPO was heated up to 100 °C, in a cylindrical vessel for a particular period to remove the moisture, before subjecting it to any further chemical treatment.

3.2.2. De Sulphurisation process

The moisture free crude TPO contains impurities, carbon particles and sulphur particle. A known volume of concentric hydrosul-phuric acid (6-7%) was mixed with the crude TPO and stirred well. The mixture was kept for about 20 h. After 20 h, the mixture was found to be in two layers. The top layer was a thin mixture and lower one was thick sludge. The top layer was taken for vacuum distillation and the sludge was removed and disposed off.

3.2.3. Vacuum distillation method

Vacuum distillation process was carried out to separate the lighter and heavier fraction of hydrocarbon oil. A known sample of chemically treated crude TPO was taken for vacuum distillation process. The sample was externally heated in a closed chamber. The vapour leaving the chamber was condensed in a water cooled condenser and the DTPO was collected separately. Non condensable volatile vapours were left to the atmosphere. The distillation was carried out between 180 °C and 240 °C. 75% of TPO was distilled in the distillation whereas 10% of TPO was left out as pyrogas and 15% was found as sludge. The time taken for obtaining 250 ml DTPO and 800 ml DTPO were 25 min and 60 min respectively. The DTPO has irritating odour like acid smell. The odour can be reduced with the help of adding some masking agents or odour removal agents. Several tests were conducted to characterize the DTPO in order to evaluate physical, chemical and thermal properties. DTPO has about 7% higher heating value than crude TPO. This is due to the elimination of the impurities, moisture, carbon particle, sulphur and sediments. Three test fuels have been taken for the experimental work. The first one is standard diesel fuel (DIESEL) and other two are DTPO75 and DTPO85. DTPO75 is 75% DTPO blended with 25% DIESEL on volume basis. DTPO85 is 85% DTPO blended with 15% DIESEL on volume basis.
Table 1: Properties of TPO

<table>
<thead>
<tr>
<th>Property</th>
<th>Diesel</th>
<th>Tyre Pyrolysis oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating value (k.T/kg)</td>
<td>42500</td>
<td>42580</td>
</tr>
<tr>
<td>Sulphur</td>
<td>1.2%</td>
<td>0.06%</td>
</tr>
<tr>
<td>Carbon residue (% by weight)</td>
<td>&lt;0.38</td>
<td>0.11</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>0.840</td>
<td>0.843</td>
</tr>
<tr>
<td>Kinematic Viscosity(cSt) at 40°C</td>
<td>3.5</td>
<td>3.2</td>
</tr>
</tbody>
</table>

4. EXPERIMENTAL

A single cylinder, water cooled, four stroke direct injection compression ignition engine with a compression ratio of 16.5:1 and developing 3.7 kW power at 1500 rpm was used for this work (Figure 1). The specification of the test engine is shown in Table 2. The engine was coupled with an eddy current dynamometer. Fuels used were diesel, tyre pyrolysis oil and blends. Load was applied in 5 levels namely, 20%, 40%, 60%, 80% and 100%. Load, speed, air flow rate, fuel flow rate, exhaust gas temperature, exhaust emissions of HC, CO and smoke were measured at all load conditions. The Redwood Viscometer is used to measure the viscosity of fuels at various temperatures. The exhaust gas analyzer model Horiba MEXA-584L was used to measure carbon monoxide (CO) and hydrocarbon (HC) levels. The analyzer is a fully microprocessor controlled system employing non-destructive infrared techniques. All the tests were conducted by starting the engine with diesel only. After the engine was warmed up, it was then switched to Tyre pyrolysis blend. At the end of the test, the engine was run for some time with diesel to flush out the tyre pyrolysis from the fuel line and the injection system.

Fig. 2-Experimental setup
Table 2: Specification of test engine

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

5. RESULTS AND DISCUSSION

5.1. Performance

5.1.1. Brake thermal efficiency

The important performance shows of the brake thermal efficiency with BMEP for the tested fuels is. It can be observed from the figure that thermal efficiency is 34% at full load for diesel. It can also be observed that the efficiencies for 50%, 75%, 100% tyre pyrolysis oil are 38.2%, 24.6%, 21.6% respectively. The thermal efficiencies of pyrolysis blends are lower compared to diesel. This may be due to the lower heating value and inferior combustion of pyrolysis. The increase in the thermal efficiency for 50% compared to 75% may be attributed to better fuel atomization due to lower viscosity. Reduction in thermal efficiency by about 14% is higher than that of the other blends of the pyrolysis oil is eventually closer to the mixing of the distilled process to solve the different purposes.
5.1.2. Brake specific energy consumption (BSEC)

The brake specific fuel consumption of all tested fuels is shown in Fig. 3 shows the comparison of the BSEC with BMEP for the different tested fuels of pyrolysis oil. It is clear from the graph that as the load increases the BSEC decreases for all fuels as expected. At the same time, it can be seen that BSEC increases with increase in the standard operating condition. This behavior is obvious since the engine will consume more fuel tyre pyrolysis blends than diesel, to gain the same power output owing to the lower calorific value of tyre pyrolysis blends.

5.1.3. Exhaust gas temperature

Fig. 4 shows the variation of the exhaust gas temperature with BMEP gives the proper mixing ratio of the oil that gradually increase the ratio of the temperature level that immediately falls on the different proportion for the tested fuels. The exhaust gas temperature decreases with increase in the blend concentration and the values are lesser compared to diesel. The exhaust gas temperature varies from 210 °C at no load to 342 °C at full load for diesel, 234 °C at no load to 432 °C at full load for 50% and 256 °C at no load to 454 °C at full load for 75% of pyrolysis. The reasons for lower exhaust gas temperatures for tyre pyrolysis blends are due to lower viscosity which results a lesser penetration of the fuel into the combustion chamber and the lesser amount of heat is produced and to reach the maximum temperature.
5.2. Emission

5.2.1. Oxides of nitrogen

Fig. 5 shows the comparison of NO\textsubscript{x} emission with BMEP for different tested fuels. It can be observed from the figure that NO\textsubscript{x} emission increases with increases in tyre biodiesel blends lower in diesel. NO\textsubscript{x} varies from 500 ppm at no load to 2180 ppm at full load. It can also be observed that NO\textsubscript{x} varies from 389 ppm at no load to 2198 ppm at full load for 50% and 366 ppm at no load to 2123 at full load at 75%. Two important parameters result in the formation of NO\textsubscript{x}. The in-cylinder temperature has a strong effect on the formation of NO\textsubscript{x}. If the combustion temperature is higher, then higher NO\textsubscript{x} is formed that may be slightly change operation of the tyre oil the lower in-cylinder temperature is the reason for the lower NO\textsubscript{x} levels than that of diesel for the maximum in-cylinder pressure falls immediately on the different mixing operation of the temperature measurement.

5.2.2. Hydrocarbon emission

The emission of tyre oil and diesel at various operating condition is due to the higher oxygen content and cetane number of the emission level from the Fig. 6 shows the comparison of Hydrocarbon emission in the exhaust for the tested fuels. HC varies from 21.5 ppm at no load to 35 ppm at full load for diesel, and it varies from 29.7 ppm at no load to 41 ppm at full load and from 31 ppm at low load to 39 ppm at full load 50% and 75% tyre pyrolysis oil. HC is slightly higher at peak load for 50% and 75% as compared to diesel. This may be attributed to two reasons. One is that the fuel spray does not propagate deeper into the combustion chamber. The other reason is unsaturated
hydrocarbons present in the tyre which are unbreakable during the combustion process due to the large amount of the emission occurs in the different proportion mixing levels.

Fig. 8  Hydrocarbon emission with BMEP

5.2.3. Carbon monoxide emission

The CO emission of the tested fuels increases with increasing BMEP. The CO emissions was higher than that of diesel, irrespective of injection pressure and injection timing. This is due to higher oxygen content and higher cetane number of the biodiesel. Fig. 7 shows the comparison of Carbon monoxide emission with BMEP The concentration vary from 0.043% at no load to 0.065% at full load for diesel, 0.069% at no load to 0.069% at full load for 50% tyre pyrolysis oil and 0.079% at no load to 0.073% at full load for 75% tyre oil,. The fuel air mixture filled inside the cylinder is very lean and some of the mixtures nearer to the wall to increase the size of the volume, the flame will not propagate to flow continuously move steadily without any deviation. Therefore, they do not find time to undergo combustion which results higher CO emission for tyre blends than that of diesel.

Fig. 9- CO emission with BMEP

5.2.4. Smoke emission

The smoke emission of tyre oil at all loads was higher due to the higher oxygen content and absence of sulphur content in tyre oil. The oxygen content of ensures post flame oxidation and increase the flame speed. Fig. 10 shows the comparison of smoke level with BMEP. It is observed that smoke increases with increase in blend percentage but higher smoke emission than that of diesel at full load. Smoke varies from 2.58 to 2.43 for diesel 2.16 at no load to 2.09 at full load for 50% and 2.1 at no load to 1.65 at full load for 75% tyre oil as the aromatic content increased with constant cetane number, particulate emission increases at high load. From the figure 10 it can be noticed that the smoke emission is higher for 50% 755 of the tyre pyrolysis oil due to the presence of higher sulphur content.
5.3. Combustion parameters

5.3.1. Pressure crank angle diagram

Fig. 10 indicates the cylinder pressure with crank angle for different fuels at full load. Cylinder pressure obtained at full load indicates higher values for 50%, 75% of the tyre oil compared to diesel. At low BMEP condition, the cylinder gas peak pressure of the tyre oil was lower than that of the diesel. It can be noticed that the combustion of tyre oil blends takes place earlier than diesel. Peak pressure of a CI engine depends on the combustion rate in the initial stages, which is influenced by the amount of fuel burnt in the premixed combustion. At medium and higher BMEP, the cylinder gas pressure of tyre oil is slightly higher than the diesel fuel. The premixed combustion is dependent on the delay period and the mixture preparation. It may be seen that the ignition delays are longer by about 3° CA and 3.7° CA fo 50% and 75% respectively than that of diesel operation and the peak pressures increased by about 1.6 bar and 2.8 bar for 50% and 75% respectively. This is due to the poor volatility of tyre oil and low temperature environment inside the cylinder. This is because the combustion starts earlier due to the advancement of the fuel injection timing after further small droplets of injected fuel at high injection pressure and the oxygen content of biodiesel leads to better combustion.

5.3.2. Ignition delay

Ignition delay is the period between the start of fuel injection. The ignition delay period decreases with increasing BMEP for all the test fuels. Tyre oil showed shorter ignition delay when compared with diesel fuel. The diesel fuel is staring from no load at 12.5 CA to end point of 10.9, 11.9 at the start to 6.9 of the end point in 50% and 10.6 at start and 9.3 at the end point of the 50%
and 75% of the tyre pyrolysis oil resulted in the low gas temperature environment and further increases in the ignition delay period. Hence, it can be concluded that the effect of injection timing on ignition delay is more the dominant than injection pressure. This is mainly due to the higher cetane number of biodiesel and catalytic effect of the metal based additive that resulted in better combustion leading to the maximum temperature inside the cylinder and causing the reduction in physical delay.

5.3.3. Cylinder peak pressure

The variation of cylinder peak pressure with BMEP for tyre oil and diesel operation at different loads is given in Fig. 13. It may be noticed from the figure that the cylinder peak pressure is increased with increase in Tyre oil blend. The cylinder peak pressure for diesel increased from 58.43 bar at no load to 76.5 bar at full load. The cylinder peak pressure increased from 57.2 bar at no load to 71.8 bar at full load for 50% of tyre oil operation. It can also be noticed that cylinder peak pressure increased from 53.4 bar at no load to 73.57 bar at full load for 75% of tyre oil. This is because, the combustion starts earlier due to the advancement in fuel injection timing where as the shorter ignition delay period of biodiesel occurs due to the increase in the injection pressure. In a CI engine, the peak pressure depends on the combustion rate in the initial stages, which is influenced by the amount of fuel taking part in the uncontrolled combustion phase, which is governed by the delay period. It is found that the maximum cylinder pressure at optimized operating condition is slightly higher than that of diesel and occurs at an earlier crank angle.
5.3.3. Heat release rate

The heat release rate is negative during the ignition delay period. The negative heat release rate values of the test fuels after the ignition was mainly due to the cooling effect caused by fuel vaporization and heat losses from the engine cylinder walls. Fig. 14 shows the heat release of the tyre pyrolysis operation at full load. The first stage is from the start of ignition to the point where the heat release rate drops and this is due to the ignition of fuel air mixture prepared during the delay period optimized operating condition biodiesel showed maximum heat release rate. This due to the increased accumulation of the fuel due to shorter ignition delay as the injection of fuel takes place earlier in the compression process and the maximum heat release rate occurs during pre mixed combustion phase. The second stage starts from the end of the first stage to the end of combustion. diesel shows into the combustion chamber and the start of combustion. The lowest heat release rate at initial stage and longer combustion duration at full load. The rate of maximum rate of heat release 75% tyre is the highest compared to diesel and 50% of tyre oil, as expected since fuels with longer ignition delay show higher rate of heat release at initial stage of combustion owing to higher injection pressure. The maximum heat release is 56.62, 89.57, 96.94 J/°CA for diesel, 50% 75% of tyre pyrolysis oil respectively. This is attributed to the early start of combustion due to higher cetane number the shortens the ignition delay, higher oxy-gen content of biodiesel and the catalytic effect of tyre oil which ensures better combustion resulting in higher cylinder temperatures.

![Fig. 14- Heat release rate with crank angle](image)

5.3.4. Rate of pressure rise

Fig. 15 shows the comparison of the rate of pressure rise for the tested fuels at full load. It can be observed that the rate of pressure is higher for Tyre pyrolysis operation compared to that of diesel operation. This may be due to the longer ignition delay of DTPO which results in rapid pressure raise in the premixed combustion phase. Rate of pressure rise is indicative of noisy operation of an engine. A value exceeding 6bar/ca is generally considered as unacceptable. Also premixed combustion heat release is higher for tyre pyrolysis based blend which may be responsible for higher rate of pressure rise. The maximum heat release rate of the standard diesel, 50%,75% tyre oil is 4.8, 5.4, 3.7bar/deg CA .This is due to 50% of tyre pyrolysis oil produce higher heat release of the pressure rise approaches closer to the diesel operation with a value of a blend of pyrolysis oil. In a compression ignition engine, the rate of pressure rise depends up on the combustion rate in the initial stages, which in turn is influenced by the amount of fuel taking part in the uncontrolled combustion. The uncontrolled or premixed combustion phase is influenced by the delay period and the mixture preparation during the delay period. Interestingly the rates of pressure rise for diesel is much lower than that of tyre pyrolysis at full load condition.
5.3.5 Maximum cylinder pressure

The variations of the mass fraction burnt with the crank angle for Tyre pyrolysis blends and standard diesel at full load is given in Fig. 16. The mass fraction burnt of blends is slightly higher than that of standard diesel at full load. Due to the oxygen content of the blend, the combustion is sustained in the diffusive combustion phase. The mass fraction burnt for the fuel blend standard diesel is higher than tyre oil blends for crank angle 340º-360º and 5% tyre pyrolysis is nearly close to the standard diesel for crank angle 360º-390º. The highest rate of burning shows that the efficient rate of combustion. The engine operates in rich mixture and it reaches stoichiometric region at higher compression ratio. More fuel is accumulated in the combustion phase and it causes rapid heat release. Cyclic variation are affected by many engines and operating variables like fuel properties, mixtures composition, charge homogeneity, ignition, in cylinder charge motion and exhaust dilution, etc. In cylinder pressure is an important indicator of the cyclic variations. Since the measurement of air fuel ratio for the individual cycle are not possible in practice, in cylinder pressure traces of 100 continuous cycles were analyzed for peak pressure variation. The optimum pressure is found in diesel for entire cycle compared to all other tyre oil blends. The traces of cyclic variation confirmed that the lean fuel combustion existed in the entire test run irrespective of the fuel used.
5.3.6 Cumulative heat release rate

The variation of cumulative heat release with crank angle is presented in the figure 17. The figure shows that there is a tendency of earlier heat release for tyre pyrolysis but the heat release rate value of diesel fuel quickly exceeds the heat release for 50%, 75% blends even through combustion for diesel fuel starts later. The main reason for the decreases in the heat release is lower heating value of diesel, 50% and 75% is 289.86, 579.38, 619.31 are the following values to increase the cumulative heat release rate value. 75% of the pyrolysis blend gets high values as compared to diesel fuel. Heat release increased with the rise in the engine load due to the increases in the quantity of fuel injected into the cylinder. Heat release increased with the increases in the engine load for all tested fuels. It can be seen that the heat release rate compared to diesel. This is due to higher exhaust gas temperature and NOx emission and also the dual effects of the complete combustion because of presence of the oxygen molecules in biodiesel and the higher heating values. Because of the vaporization of the fuel accumulated during ignition delay, at the beginning the curve a negative cumulative heat release is observed after combustion is initiated, the heat release values become positive.

![Cumulative heat release rate with Crank angle](image)

6. CONCLUSION

- Brake thermal efficiency increases with increase in 50% of tyre pyrolysis oil compared with diesel.
- NOx values for 50% and 75% of the tyre pyrolysis oil is lesser than compared to the diesel.
- Diesel values are higher in both the CO and HC. This may be due to the presence of unsaturated hydrocarbon in the tyre pyrolysis oil compared to the diesel.
- The exhaust gas temperature decreases with increase in the blend concentration and the values are lesser compared to diesel.
- Smoke is higher for tyre pyrolysis blends compared to diesel.
- Ignition delay is longer in tyre pyrolysis oil than compared to the diesel
- Cylinder peak pressures are higher in tyre pyrolysis than compared to diesel
- Heat release rate and rate of pressure rise is initially high in the initial stage of the tyre pyrolysis oil than compared to the diesel.
- Engine is mainly run with the proper combination of the tyre pyrolysis blends.
- In full tyre pyrolysis oil the engine cannot be run continuously.
REFERENCES


