Light Oil Fractions from a Pyrolysis Plant-An Option for Energy Use

Kapura Tudu a*, S. Muruganb and S. K. Patelc

a* Research Scholar, National Institute of Technology, Department of Mechanical Engineering, Rourkela, Pin-769008, India
b Associate Professor, National Institute of Technology, Department of Mechanical Engineering, Rourkela, Pin-769008, India
c  Associate Professor, National Institute of Technology, Department of Mechanical Engineering, Rourkela, Pin-769008, India

Abstract

The problems associated with the disposal of waste tyres can be resolved to some extent by pyrolysis process. The light fractions of pyrolysis oil (LFPO) derived from waste automobile tyres in a pilot plant possess properties similar to diesel fuel and hence the LFPO can be used in combustion devices. In the present work, lower proportions (i.e. 5 to 20% at a regular interval of 5% on volume basis) of LFPO collected from a commercial pyrolysis plant were blended with 95 to 80% diesel respectively and used as alternative fuels in a diesel engine without any engine modification. Tests have been carried out to evaluate the performance and emission characteristics of a single cylinder, four stroke, air cooled, direct injection (DI), diesel engine fueled with four different LFPO-diesel blends. The results of the investigation were analysed, compared with diesel operation in the same engine and presented in this paper.

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1. Introduction

The energy demand increases exponentially every year in all the countries. Since the oil crisis began due to the Gulf war from the mid of 1990’s, there has been a continuous shortage of crude oil supply and increase in crude oil prices. Within the last 20 years, the crude oil price increased to several folds, as a result, any country’s economy has
been mainly decided by the availability of crude oil sources. Other fossil fuels are also fastly depleting and it is anticipated that the crude oil reserves may exhaust within 50 years. On the other hand, the oil consumption by the users in all aspects increases continuously. The combustion devices that use fossil fuels emit large pollutants and increase the global warming potential (GWP), ozone depletion potential (ODP). These cause a severe health problem to human beings and deterioration of atmosphere. The above mentioned reasons have led the world to explore the alternative fuels, from various sources. Alternative fuels such as biodiesel, alcohols, and hydrogen are renewable in nature and can be produced as much as possible and replace commercial fossil fuels. Even then, the supply will not meet demand. The organic matter present in various waste substances like agro-waste, industrial and municipal wastes can be converted into useful energy through thermo chemical or biochemical processes. Pyrolysis is a thermo chemical process in which an irreversible chemical change caused by the action of heat in absence of oxygen. This process yields value added products such as fuels or chemicals in the form of solid, liquid or gas. Without oxygen, the process splits the chemical bonds and leaves the energy stored in the organic substance. The main advantages of pyrolysis include compactness, simple equipment, low pressure operation, negligible waste product and high energy conversion efficiency of the order of 83% [1].

In the process of pyrolysis, the feed stock is fed into an oxygen free or less oxygen present reactor and heated. As the temperature rises, the organic matter breaks down to simpler substances and condensed into volume added products. The end products of the reaction depend on the conditions employed; at a lower temperature around 500° C organic liquid predominate, while at a temperature nearer 1000° C a combustible mixture of gases results. The chemical process in pyrolysis is much related to similar distillations of coal to produce synthetic gases, tars, oils and coke. The reaction of water on heated coal with reduced air supply [1]:

\[
\begin{align*}
H_2O + C &\rightarrow H_2 + CO \\
C + O_2 &\rightarrow CO_2 \\
CO_2 + C &\rightarrow 2CO
\end{align*}
\]

The input material needs to be graded to remove the non-combustible materials (e.g. soil, metal) dried if necessary, chopped or shredded and then stored for use. The pyrolysis units are most easily operated below 600 °C.

The disposal of waste is one of the unsolved problems faced by every country in the world. Most of the wastes are convertible in to useful energy or value added products by adopting appropriate suitable methods. Some of them are disposed as it is, and cause severe environmental problems. In the last three decades, many researchers have documented their research works adopting different methods of pyrolysis such as vacuum pyrolysis [2-11], flash pyrolysis [12], fluidised bed pyrolysis [13-15], and steam pyrolysis [16], catalytic pyrolysis [16-21]. Literature are available related to different operating parameters such as heating rate [22-24], pyrolysis temperature [25-28], and characterisation of pyrolysis oil [29], pyro gas [30] and carbon black [31].

In the recent past, a few researchers have established the results on utilisation of tyre pyrolysis oil (TPO) obtained from laboratory level pyrolysis units, as a possible alternative energy source for CI engines. Murugan et al. [32] have carryout various tests to evaluate the performance and emission characteristics of a single cylinder, four stroke, air cooled, direct injection, diesel engine fueled with 10, 30 and 50% blends of Tyre pyrolysis oil (TPO) with diesel. TPO was derived from waste automobile tyres through vacuum pyrolysis in one kg batch pyrolysis unit. Results indicated that, the brake thermal efficiency of the engine fueled with TPO-diesel blends increased with increase in blend concentration and higher than diesel at full load. The HC, CO and smoke emissions were found to be higher at higher loads due to high aromatic content and longer ignition delay at original injection timing. The researchers have also desulphurised the TPO and then distilled through vacuum distillation. Two DTPO-diesel blends at lower (20% DTPO) and higher concentrations (90% DTPO) were used as fuels in the same test engine without any engine modification. The results were compared with the diesel fuel (DF) operation of the same engine. Results indicated that the engine can run with 90% DTPO and 10% diesel fuel [33]. Dogan et al. [34] have studied the effect of Tyre-derived fuel (TDF) on engine performance and exhaust emissions in a diesel engine. The authors tested the TDF in a
single cylinder, four stroke, unmodified, and naturally aspirated, DI high speed diesel engine at full load and four engine speeds (1400, 2000, 2600 and 3200 rpm) by using six test fuels. The experimental test results showed that the DI diesel engine can run with the TDF fuel blends up to TDF90. The smoke opacity, HC, and CO emissions reduced while the NOx emissions increased with the increasing TDF content in the fuel blends. Since, last decade pilot pyrolysis plants have been installed in some of the countries in the world to make the pyrolysis technology a feasible. In the present investigation, light oil fractions (LFPO) obtained in a pilot plant installed for pyrolysis of waste tyres was characterised and used as an alternative fuel in a single cylinder, four stroke, DI diesel engine. The performance and emission parameters ware evaluated compared with diesel operation and presented in this paper.

2. Materials and Methods

2.1. Tyres pyrolysis process

An efficient industrial pyrolysis is a process to treat the waste rubber, waste tyres and industrial plastic wastage as well [31]. Pyrolysis of waste tyres is the decomposition of organic compounds under oxygen free (anaerobic) atmosphere that produces gas, oil, carbon black and steel. Fig. 1 illustrates the schematics layout of a pilot tyre pyrolysis plant.

![Diagram of Pilot Plant for Pyrolysis of Waste Tyres](image)

Fig.1 Pilot Plant for Pyrolysis of Waste Tyres

The plant has a cylindrical rotary type, pyrolysis reactor (1). The plant has a batch process with a capacity is 10 tons. The length of the reactor is approximately 6.6 m and diameter is 2.8 m. The reactor is rotated with the help of an electric motor (2) and pulley arrangement. The pyrolysis reactor is initially heated up by waste wood. The wood consumption per batch is about 2 ton. In the pilot plant, the shredded tyres are fed into the pyrolysis reactor. The front end of the reactor has a door with fasteners. The door can be opened or closed by unlocking or locking the fasteners. The other end of the reactor is connected to sealing elements (3) and a flexible connection (4). An oil separator (5) is connected to the reactor by the sealing element and the flexible connection. The volatile vapour evolves during pyrolysis pass through the oil separator, where heavy oil is separated by gravity and collected in a heavy oil tank (6). A damper (7) is provided at the outlet of the oil separator that connects a bench of water cooled condenser tubes (8-12). Further, the volatile gases enter to bunch of water cooled condenser tubes where the light oil fractions are converted into liquid. A cooling tower (13) is used to bring down the temperature of coolant near atmospheric temperature, which is used in the water cooled condenser. A smooth inspect mirror (14) is used to know that whether the gas is converted in liquid form or not. Light oil is collected in a tank (15). A certain quality of gases
which is not condensed in heavy oil tank passes through a water sealing (16) and enters into a gas recycling system. The non-condensable gas is cleaned in the gas recycling system and then given to a gas burner (17) which is located in the reactor for heating. A pump (18) is used to recirculate the coolant leaving the cooling tower to condenser. The pyrolysis reactor and the accessories are operated by motors and pumps with the help of a controlled panel. The initial temperature at which volatile vapours evolve in the reactor is around 160°C at about four hours of plant operation. During the process, carbon black and steel are also generated. The yields of products obtained in a pilot plant are given bellows;

- Fuel oil (40 to 45%)
- Carbon black (30 to 35%)
- Steel wire (3 to 5%)
- Non-condensable gases (8 to 10%)
- Moisture (3 to 5%)

Moisture is removed from TPO at 100°C by heating. Therefore, the CV is higher for LFPO than that of TPO.

Table 1 gives the physical properties of diesel, TPO and LFPO. The following products are obtained in a real time pyrolysis plant.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel</th>
<th>TPO</th>
<th>LFPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³ @20°C)</td>
<td>830</td>
<td>920</td>
<td>910</td>
</tr>
<tr>
<td>Kinematic viscosity (cSt@40°C)</td>
<td>2.4</td>
<td>3.77</td>
<td>3.06</td>
</tr>
<tr>
<td>Calorific value (MJ/kg)</td>
<td>43.8</td>
<td>38</td>
<td>39.2</td>
</tr>
<tr>
<td>Flash point by Abel method (°C)</td>
<td>50</td>
<td>43</td>
<td>30</td>
</tr>
<tr>
<td>Fire point (°C)</td>
<td>56</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Cetane number</td>
<td>45-50</td>
<td>-</td>
<td>25-30</td>
</tr>
<tr>
<td>Sulphur Content (% wt)</td>
<td>0.29</td>
<td>0.72</td>
<td>1.17-4.00</td>
</tr>
</tbody>
</table>

*Properties of TPO obtained as crude from a lab level pyrolysis reactor [32].

Table 2 indicates the tyre pyrolysis done early by the many researchers and compare with LFPO.

<table>
<thead>
<tr>
<th>Product</th>
<th>NAI1</th>
<th>NA2</th>
<th>NA3</th>
<th>EU1</th>
<th>EU2</th>
<th>EU3</th>
<th>EU4</th>
<th>EU5</th>
<th>EU6</th>
<th>EU7</th>
<th>LFPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor type</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Feedstock (kg)</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>1</td>
<td>504</td>
<td>686</td>
<td>175</td>
<td>86</td>
<td>86</td>
<td>130</td>
<td>8000-10000</td>
</tr>
<tr>
<td>Average pressure (kPa)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>0.9</td>
<td>-</td>
<td>3.4</td>
<td>1.2</td>
<td>2.8</td>
<td>1.6</td>
<td>4.7</td>
<td>19</td>
</tr>
<tr>
<td>Maximum bed temperature (°C)</td>
<td>530</td>
<td>530</td>
<td>530</td>
<td>536</td>
<td>-</td>
<td>520</td>
<td>513</td>
<td>496</td>
<td>424</td>
<td>520</td>
<td>375-440</td>
</tr>
<tr>
<td>Number of consecutive runs</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*A=Multiple hearth furnace; B=Laboratory batch reactor; C=Horizontal, pilot reactor
NAI-EU7- Data reference from "Vacuum pyrolysis of used tyres"
2.2. FTIR Analysis of light fractions pyrolysis oil (LFPO):

The Fourier Transform Infrared Spectroscopy (FTIR) offers a quantitative and qualitative analysis for organic and inorganic samples. The spectra produce a profile of the sample a distinctive molecular fingerprint that can be used to screen and scan samples for many different components. It identifies chemical bonds in a molecule by producing an infrared absorption spectrum. The FTIR is an effective analytical instrument for detecting functional groups and characterising covalent bonding formation. The FTIR test was carried out with Perkin Elmer Spectrum ONE equipment which has a scan range of 450-4000 cm\(^{-1}\) with a resolution of 1.0 cm\(^{-1}\). The FTIR analysis of LFPO reveals that, the functional group present in it are almost aromatics and hydrocarbons. Table 3 gives the FTIR analysis of LFPO and diesel. The compounds of light fraction oil are alkanes, alkenes, aromatic compounds, but in case of diesel compounds are alkanes, alkenes, alcohol, nitrate, chloride and bromide.

Table 3: FTIR Analysis of light fraction oil compare with diesel fuel

<table>
<thead>
<tr>
<th>Wave number(cm(^{-1}))</th>
<th>Bonds</th>
<th>Class of compounds</th>
<th>Frequency range (cm(^{-1}))</th>
<th>Bonds</th>
<th>Class of compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>2921.33</td>
<td>C-H, Stretch</td>
<td>Alkanes</td>
<td>3095-3005</td>
<td>C=C stretching</td>
<td>Alkenes</td>
</tr>
<tr>
<td>2812.72</td>
<td>C-H, Stretch</td>
<td>Alkanes</td>
<td>3000-2800</td>
<td>C-H stretching</td>
<td>Alkenes</td>
</tr>
<tr>
<td>1605.47</td>
<td>C=C, C=N, Stretch</td>
<td>Alkenes, Amide</td>
<td>1680-1620</td>
<td>C=C stretching</td>
<td>Alkenes</td>
</tr>
<tr>
<td>1461.19</td>
<td>O-H, Bending</td>
<td>Alcohol</td>
<td>1600-1525</td>
<td>Carbon-carbon stretching</td>
<td>Aromatic compounds</td>
</tr>
<tr>
<td>1376.55</td>
<td>Nitrate</td>
<td>Nitrate</td>
<td>1520-1220</td>
<td>C-H bending</td>
<td>Alkenes</td>
</tr>
<tr>
<td>722.05</td>
<td>C- Cl</td>
<td>Chloride</td>
<td>1035-830</td>
<td>C=C stretching</td>
<td>Alkenes</td>
</tr>
<tr>
<td>468.67</td>
<td>C-Br</td>
<td>Bromide</td>
<td>825-650</td>
<td>C-H out of plane bending</td>
<td>Aromatic compounds</td>
</tr>
</tbody>
</table>

2.3 GC-MS Analysis of LFPO

The Gas chromatography (“GC”) and mass spectrometry (“MS”) make an effective combination for chemical analysis. Gas chromatography (GC) is used to separate mixtures into individual components using a temperature-controlled capillary column. Smaller molecules with lower boiling points are travel down the column more quickly than larger molecules with higher boiling point. The mass spectrometry (MS) is used to identify the various components from their mass spectra. Each compound has a unique or near unique mass spectrum that can be compared with mass spectral databases and thus identified. Through use of standards, quantification is also possible. The GCMS analysis can work on liquids, gases and solids. For liquids, the sample is directly injected into the GC [36]. Table 4 gives the comparison of results obtained from GC-MS analysis for LFPO and diesel. From the table it is found that the major compounds present in the LFPO are p-Xylene Benzene, 1,3-dimethyl, Benzene, 1-ethyl-4-methyl, D-Limonene, 1H-Indene, 2,3-dihydro-1,1,5-trimethyl-, Naphthalene, 2,7-dimethyl, Quinoline, 4,8-dimethyl, Naphthalene, 2,3,6-trimethyl, Heptadecanenitrile, Octadecanenitrile and Hexadecanenitrile. In diesel fuel the compounds are 1-Ethyl-Methylcyclohexane, Propyl cyclohexane, M-Ethyl methyl benzen, Decane, n-Undecane, Dodecane, n-Hexadecane, Octadecane, Octacosane and Tetracosane. The benzene, Hexadecane, Octadecane, 1-ethyl-4-methyl compounds are commonly available in both fuels.
Table 4: GC-MS Analysis of major compounds present in LFPO compare with diesel fuel

<table>
<thead>
<tr>
<th>R. time (s)</th>
<th>Area (%)</th>
<th>Name of compound</th>
<th>Molecular formula</th>
<th>R. time (s)</th>
<th>Area (%)</th>
<th>Name of compound</th>
<th>Molecular formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.290</td>
<td>4.85</td>
<td>p-Xylene, 1,3-dimethyl</td>
<td>C_{8}H_{10} or C_{6}H_{4}CH(CH_{3})_{2}</td>
<td>3.065</td>
<td>0.98</td>
<td>1-Ethyl-Methylcyclohexane</td>
<td>C_{6}H_{14}</td>
</tr>
<tr>
<td>4.859</td>
<td>6.24</td>
<td>Benzene, Benzene,</td>
<td>C_{9}H_{12}</td>
<td>3.359</td>
<td>1.06</td>
<td>Propyl cyclohexane</td>
<td>C_{6}H_{12}CH_{3}</td>
</tr>
<tr>
<td>5.236</td>
<td>2.17</td>
<td>Benzonitrile, Benzene,</td>
<td>C_{6}H_{2}CN or C_{6}H_{2}O</td>
<td>3.782</td>
<td>1.04</td>
<td>M-ethyl methyl benzene</td>
<td>C_{10}H_{18}</td>
</tr>
<tr>
<td>5.962</td>
<td>15.24</td>
<td>o-Cymene, 1,2,3,4-tetramethyl</td>
<td>C_{6}H_{6}CH_{2}C_{2}H_{4}</td>
<td>4.274</td>
<td>3.51</td>
<td>Decane</td>
<td>C_{6}H_{12}</td>
</tr>
<tr>
<td>6.035</td>
<td>5.19</td>
<td>D-Limonene, 1H-Indene,</td>
<td>C_{10}H_{16}</td>
<td>5.822</td>
<td>2.14</td>
<td>n-Undecane</td>
<td>C_{11}H_{24}</td>
</tr>
<tr>
<td>10.45</td>
<td>2.19</td>
<td>2,3-dihydro-1,1,5,trimethyl-Naphthalene, 2,7-dimethyl</td>
<td>C_{10}H_{16}</td>
<td>7.356</td>
<td>2.71</td>
<td>Dodecane</td>
<td>C_{14}H_{28}</td>
</tr>
<tr>
<td>12.207</td>
<td>3.77</td>
<td>Naphthalene, 2,7-dimethyl</td>
<td>C_{10}H_{12}</td>
<td>15.959</td>
<td>3.38</td>
<td>n-Hexadecane</td>
<td>C_{16}H_{34}</td>
</tr>
<tr>
<td>12.411</td>
<td>4.58</td>
<td>Quinoline, 4,8-dimethyl</td>
<td>C_{10}H_{2}N, C_{11}H_{14}</td>
<td>17.885</td>
<td>2.57</td>
<td>Octadecane</td>
<td>C_{12}H_{26}</td>
</tr>
<tr>
<td>13.587</td>
<td>4.65</td>
<td>Naphthalene, 2,3,6-trimethyl</td>
<td>C_{10}H_{12}</td>
<td>19.648</td>
<td>1.61</td>
<td>Octacosane</td>
<td>C_{18}H_{36}</td>
</tr>
<tr>
<td>19.585</td>
<td>2.68</td>
<td>Heptadecanenitrile,</td>
<td>C_{10}H_{2}N, C_{11}H_{14}N, C_{12}H_{16}N</td>
<td>20.476</td>
<td>1.35</td>
<td>Tetracosane</td>
<td>H(C_9H_18)_2H</td>
</tr>
</tbody>
</table>

3. Engine Experimental Analysis

3.1. Engine setup and methodology

Experiments have been conducted in a single cylinder, four stroke, air cooled, DI, diesel engine with developing power of 4.4 kW at 1500 rpm. A schematic diagram of the experimental arrangement is shown in Fig. 2.

The engine has a bore of 87.5 mm and a stroke length of 110 mm with a compression ratio 17.5:1. The engine is provided with a bowl-in piston. The injection timing of fuel set by the manufacturer is 23 °bTDC and the nozzle opening pressure is 200 bar. A fuel sensor measures the total fuel consumption and gives input to a data acquisition system. A U-tube manometer connected with an orifice mounted on air box in the suction measures the intake air flow rate. A K-type thermocouple installed near the exhaust manifold measures the exhaust gas temperature. The exhaust emissions such as unburnt Hydrocarbon (HC), Carbon monoxide (CO), Carbon dioxide (CO\_2) and Nitric oxide (NO) are measured by an AVL DiGas444 exhaust gas analyser. Initially the engine was run with diesel to obtain the reference data for no load, 25%, 50%, 75% and full load. After conducting all the tests with the blends, the engine was again run on diesel, to ensure that there was no fuel trace of different blends.
4. Results and Discussion

4.1. Performance parameters

4.1.1. Brake Specific Energy Consumption (BSEC)

BSEC is a reliable parameter, when two fuels with different density and heating value are blended together and used in an engine [37]. Fig. 3 shows the variation of BSEC for diesel and LFPO blends, with respect to brake power.

![Fig. 3 Variation of brake specific energy consumption with the brake power](image)

The BSEC for diesel is 12.29 MJ/kWh at full load and it is approximately 12.75, 14.4, 13.33, 11.8 and 11.35 MJ/kWh for the LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 diesel blends respectively. As the load increases, the BSEC decreases for diesel, and all the LFPO diesel blends, because of increase in cylinder temperature. The BSEC for diesel is found to be the lowest among all the fuels tested in this study. This is attributed to a better and complete combustion and higher heating value than these of LFPO blends. The engine consumes more fuel with the LFPO diesel blends than that of diesel to develop the same power output. This is because of lower heating value and higher density of the blends. The BSEC is the lowest for LFPO40 11.35 MJ/kWh due to lower calorific value, among all the LFPO blends.

4.1.2. Exhaust Gas Temperature (EGT)

The exhaust gas temperature gives an indication about the amount of heat going waste with the exhaust gases [38]. Fig. 4 illustrates the variation of the exhaust gas temperature with respect to brake power. It can be observed from the figure that with the increase in the load the EGT increases for all the tested fuels with load in this study. The viscosity of LFPO diesel blends are found to be marginally higher than that of diesel and therefore, the EGT is noticed higher for all the LFPO diesel blends than that of diesel fuel, throughout the load spectrum. The EGT value for diesel at full load is to be found about 338 °C and 340, 370, 345, 344, 339 °C for LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 respectively at full load. The combustion of LFPO blends may be delayed due to higher viscosity and density.
This may be the reason for higher exhaust gas temperature with all the blends. A higher exhaust gas temperature is recorded for the LFPO10 blend among the LFPO blends.

4.2. Emission parameters

4.2.1. Carbon monoxide (CO) emission

Fig. 5 shows the trend of CO emission for diesel and the LFPO diesel blends, with respect to brake power. Generally, the 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 decreases with increasing load at no load and part loads, the CO emission is found to be high and the deviation in CO emission between no load and full load is also much higher. All full load, the CO emission per kWh for all the LFPO blends is found to be higher in comparison with diesel. This may be due to poor mixing and incomplete combustion of blends. The CO emission for diesel, LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 are to be found 0.01454, 0.013359, 0.0440, 0.03067, 0.03144 and 0.03229 g/kWh respectively, at full load operation.
4.2.2. Hydrocarbon (HC) emission

The HC emission is occurred due to incomplete combustion inside the combustion chamber and the variation of HC emission levels with respect to equivalence ratio, deposits on walls. [38]. The variation of HC emission with respect to brake power for diesel and the LFPO diesel blends is shown in Fig. 6. It can be observed that the HC emission tends to decrease at higher loads for all the fuels. For LFPO10, LFPO15, LFPO20 and LFPO40, the in HC emission is found to be higher compared to that of diesel at full load. This could be due to the complete combustion of diesel fuel and incomplete combustion of all LFPO blend. This is because; the LFPO has higher viscosity and low heating value.

![Fig. 6: Variation of unburnt hydrocarbons with the brake power](image)

The HC emissions values for diesel, LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 are found 0.0360, 0.0459, 0.0481, 0.05062, 0.05309 and 0.042071 g/kWh at full load respectively.

4.2.3. Nitric Oxide (NO) emission

The parameter affecting formations of NOx in a CI engine are the combustion duration, temperature, higher compression ratio, pressure and the availability of oxygen [38-39].

![Fig.7: Variation of nitric oxide with the brake power](image)
Fig. 7 depicts the variation of NO emission with brake power for diesel and the LFPO diesel blends. The NO emission per kWh for diesel and all the LFPO diesel blends decrease as the load increases. The value of NO emission is found to be the highest for diesel at full load among all the fuels tested in this study. This may be due to higher heating value and complete combustion than the all given blends. The value of NO emission higher for diesel is 1.290 g/kWh at full load. While increasing the LFPO percentage, the NO emission decreases. The values of NO emission for diesel, LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 are 1.290, 1.1885, 0.6776, 0.524, 0.86817 and 1.08201 g/kWh respectively, at full load operation.

4.2.4. Smoke emission

Smoke is occurred due to the incomplete combustion inside the combustion chamber, and normally formed in the rich zone [38-41]. Fig. 8 illustrates the smoke emission measured in the engine exhaust, for the fuels tested in this study.

With an increase in the load, the air fuel ratio decreases as the fuel injected increases, and hence results in higher smoke. The smoke emission for diesel is found to be the lowest at full load among all the fuels in this study. The LFPO has high density and viscosity so high smoke emission is recorded. The values of smoke emission for diesel, LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 are 61.2, 78, 93.9, 95, 82.2 and 69.2% respectively, at full load operation.

5. Conclusions

In the present study, the LFPO collected from a pilot plant was used as alternative fuel, in a single cylinder, four stroke, air cooled and DI diesel engine. The conclusions of the investigation are as follows:

- The BSEC is found to be the lowest for LFPO40 11.35 MJ/kWh due to lower calorific value.
- As a result of poor volatility and density a higher exhaust gas temperature is recorded for LFPO blend. The EGT value for diesel at full load was 338 °C and 340, 370, 345, 344, 339 °C for LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 respectively at full load.
- The CO emission for diesel, LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 are to be found 0.01454, 0.013359, 0.0440, 0.03067, 0.03144 and 0.03229 g/kWh respectively, at full load operation respectively. The CO emission decreases with increasing load but in full load LFPO10 has more 0.044 g/kWh compare to other blends.
The HC emissions values for diesel, LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 are found 0.0360, 0.0459, 0.0481, 0.05062, 0.05309 and 0.04207 g/kWh at full load respectively.

The values of NO emission for diesel, LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 are 1.290, 1.1885, 0.6776, 0.524, 0.86817 and 1.08201 g/kWh respectively, at full load operation. The NO emission is found to be higher for LFPO5 blend compared to all fuels.

The values of smoke emission for diesel, LFPO5, LFPO10, LFPO15, LFPO20 and LFPO40 are 93.9, 95, 82.2, and 69.2 % respectively, at full load operation. The LFPO15 blend is optimum smoke emission and diesel is less in percentage.

References


