EXPERIMENTAL EVALUATION OF A DIESEL ENGINE WITH BLENDS OF DIESEL-PLASTIC PYROLYSIS OIL

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Abstract:
Environmental degradation and depletion of oil reserves are matters of great concern around the globe. Developing countries like India depend heavily on crude oil import of about 125 Mt per annum (7:1 diesel/gasoline). Diesel being the main transportation fuel in India, finding a suitable fuel alternative to diesel is an urgent need. In this context, pyrolysis of waste plastic solid is currently receiving renewed interest. Waste plastic pyrolysis oil is suitable for compression ignition engines and more attention is focused in India because of its potential to generate large-scale employment and relatively low environmental degradation. In the present work the performance and emission characteristics of a single cylinder, constant speed, and direct injection diesel engine using waste plastic pyrolysis oil blends as an alternate fuel were evaluated and the results are compared with the standard diesel fuel operation. Results indicated that the brake thermal efficiency was higher compared to diesel at part load condition. Carbon monoxide, Carbon dioxide and hydrocarbon emissions were higher and oxygen emission was lower compared to diesel operation.

Keywords: Diesel engine, Waste plastic pyrolysis oil, Performance, Emissions

1 Introduction
Waste plastics their disposal creates large problems for the environment. Waste plastics do not biodegrade in landfills, are not easily recycled, and degrade in quality during the recycling process. Instead of biodegradation, plastics waste goes through photo-degradation and turns into plastic dusts which can enter in the food chain and can cause complex health issues to earth habitants. According to a nationwide survey, conducted in the year 2003, more than 15342.46 T of plastic waste is generated daily in our country, and only 40% wt of the same is recycled, balance 60% wt is not possible to dispose off. It is projected that annual post-consumer plastic waste has been reached 5.6 million tons by the year 2008-2009. At these alarming levels of waste plastics generation, India needs to prepare a lot in recycling and disposing the waste. Several processes and means have been attempted to fight against these alarming levels of waste plastics generation. However each process had its drawbacks and economical operational & financial limitations for practical implementation. In this contrast, chemical process such as pyrolysis can be used to safely convert waste plastics into hydrocarbon fuels that can be used for transportation.

2 Waste plastic oil in marine diesel engines
The diesel engine has the highest thermal efficiency of any regular internal or external combustion engine due to its high compression ratio. Diesel engines are most preferred power plants due to their higher thermal efficiency
excellent and driveability. Despite their advantages, they emit high levels of NOx and smoke which will have an effect on human health. Hence, strict emission norms and the depletion of petroleum fuels have necessitated the search for alternate fuels for diesel engines.

Application of Waste Plastic Disposals reduces the experimental heavy fuel oil viscosity. The results showed that waste plastic disposal oil when mixed with heavy oils reduces the viscosity significantly and improves the engine performance. Although Oxides of Nitrogen(NOx) emission slightly increases, the emission of particulate matters (PM), dry soot (DS) and soluble organic fraction (SOF) decreases by half at the mixing ratio of 30 % vol. The kind of plastic materials are HDPE, LDPE, PE, PP, Nylon, Teflon, PS, ABS, and FRP.

3 Pyrolysis

Pyrolysis is the chemical decomposition of organic substances by heating. The word is originally coined from the Greek-derived elements pyro "fire" and lysys "decomposition". Pyrolysis is usually the first chemical reaction that occurs in the burning of many solid organic fuels, cloth, like wood, and paper, and also of some kinds of plastic. Anhydrous pyrolysis process can also be used to produce liquid fuel similar to diesel from plastic waste.

![Figure 1 Conversion of Plastics waste into Liquid Fuel](image)

### NOMENCLATURE

<table>
<thead>
<tr>
<th>DF</th>
<th>Diesel Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPPO</td>
<td>Waste plastic pyrolysis oil</td>
</tr>
<tr>
<td>WPPO 50</td>
<td>pyrolysis oil + 50% Diesel Fuel</td>
</tr>
<tr>
<td>WPPO 70</td>
<td>70% Waste plastic pyrolysis oil + 30% Diesel</td>
</tr>
<tr>
<td>TFC</td>
<td>Total Fuel Consumption</td>
</tr>
<tr>
<td>BSFC</td>
<td>Brake Specific Fuel consumption</td>
</tr>
<tr>
<td>BMEP</td>
<td>Brake mean effective pressure</td>
</tr>
<tr>
<td>HC</td>
<td>Unburned Hydrocarbon</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>CO2</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>O2</td>
<td>Oxygen</td>
</tr>
<tr>
<td>cSt</td>
<td>centistokes</td>
</tr>
</tbody>
</table>

4 Process technology

This process, involves Pyrolysis technology is thermal degradation process in the absence of oxygen. Plastic waste is treated in a cylindrical reactor at temperature of 300°C – 350 °C. The plastic waste is gently cracked by adding catalyst and the gases are condensed in a series of condensers to give a low sulphur content distillate. All this happens continuously to convert the waste plastics into Fuel that can be used for Generators.

The Catalyst used in this system will prevent formation of all the dioxins and Furans (Benzene ring). All the gases from this process are treated before it is let out in atmosphere. The Flue Gas is treated through scrubbers and water/ chemical treatment for neutralization. The non-condensable gas goes through Water before it is used for Burning. Since the Plastics waste is processed about 300°C - 350°C and there is NO OXYGEN in the processing reactor, most of the Toxics are burnt. However, the gas can be used in dual fuel diesel-generator set for generation of electricity. The process of oil from waste plastics takes place as shown in Figure 1.
**Products Obtained**
The main products of pyrolysis are oil, Hydrocarbon Gas and carbon black. When waste plastic is used as raw material for pyrolysis plants, generally following is the input output ratio:

<table>
<thead>
<tr>
<th>Input Material</th>
<th>Input Quantity</th>
<th>Output Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste mixed plastic scrap</td>
<td>1000kgs</td>
<td>- 650 to 900 lit of Pyrolysis Oil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 50 to 100 Kg of Hydrocarbon Gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 50 to 70Kg of carbon Black</td>
</tr>
</tbody>
</table>

**Table 2: Comparisons of Properties of WPPO, diesel**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Properties</th>
<th>WPPO</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density @ 30 °C in (g/cc)</td>
<td>0.7930</td>
<td>0.84 to 0.88</td>
</tr>
<tr>
<td>2</td>
<td>Ash content (%)</td>
<td>&lt; 0.01% (wt)</td>
<td>0.045</td>
</tr>
<tr>
<td>3</td>
<td>calorific value (kJ/kg)</td>
<td>41,858</td>
<td>42000</td>
</tr>
<tr>
<td>4</td>
<td>Kinematic</td>
<td>2.149</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Viscosity, cSt @ 40°C</td>
<td>51</td>
<td>55</td>
</tr>
<tr>
<td>6</td>
<td>Cetane number</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>Flash point (°C)</td>
<td>45</td>
<td>56</td>
</tr>
<tr>
<td>8</td>
<td>Fire point (°C)</td>
<td>0.01 % (wt)</td>
<td>0.20</td>
</tr>
<tr>
<td>9</td>
<td>Sulphur content (%)</td>
<td>&lt;0.002</td>
<td>&lt;0.035</td>
</tr>
<tr>
<td>10</td>
<td>Acidity (mg KOH/gm)</td>
<td>0.16</td>
<td>0.20</td>
</tr>
<tr>
<td>11</td>
<td>Pour Point, °C</td>
<td>-4</td>
<td>3 - 15</td>
</tr>
</tbody>
</table>

**5 Engine tests**

Engine performance is an indication of the degree of success with which it is doing its assigned job, i.e., the conversion of the chemical energy contained in the fuel into the useful mechanical work.

The degree of success is compared on the basis of the following
1. Total fuel consumption
2. Specific fuel consumption
3. Brake mean effective pressure
4. Break thermal efficiency
5. Mechanical Efficiency
6. Exhaust emissions

Specific fuel consumption is widely used to compare the performance of different engine. Mean effective pressure, gives an indication of engine displacement utilization Higher the mean effective pressure higher will be power developed by the engine for a given displacement. Brake thermal efficiency is the true indication of the efficiency with which the thermodynamic input is converted into mechanical work. It also accounts for combustion efficiency. Exhaust emissions such as unburned hydrocarbons, carbon dioxide, etc, are nuisance for the public environment.

**6 Experimental setup**

The experimental setup of the test engine is shown in Figure 2. The specifications of the test engine are given in Table3. Diesel engine coupled to an alternator loading. The fuel consumption rate was measured on volumetric basis using a burette and a stopwatch. Chromel alumel thermocouple with a digital temperature indicator was used to measure the exhaust gas temperature. A four Gas Analyzer was used to measure the level of HC, CO₂, CO, O₂.
7 Results and Discussions

Three test fuels were used during experiments including neat 100 % diesel fuel and a blend of 50% and 70% with waste plastic pyrolysis oil by volume in the diesel. The tests were carried out for the above proportions of waste plastic pyrolysis oil and diesel.

The engine was not modified in any way for use with waste plastic pyrolysis oil blends. The performance tests were conducted at 1500 rpm with loading of 20, 40, 60, 80, and 100 percent of maximum power. The engine was operated for data collection with 5 minutes at each interval.

The Performance was compared with pure diesel operation. The basic performance parameters such as total fuel consumption, specific fuel consumption break mean efficient pressure and brake thermal efficiency were calculated and presented against load for all attempts as shown in Figure 3 to Figure 8 and Emissions were measured and plotted against load as shown in Figure 9 to Figure 12.

7.1 Total Fuel consumption

Figure 3 compares fuel consumption by mass of WPPO blends with diesel fuel. There was higher fuel consumption when running on WPPO–DF blends. This was due to the higher relative density and lower energy density of WPPO. The net calorific value of the Waste plastic pyrolysis oil is lower than that of diesel fuel. This may cause the increase in fuel consumption. The trends of the blends showed an increase in fuel consumption approximately proportional to the amount of WPPO added to the diesel fuel.

It is normal to have leakage past the injector needle for lubrication purposes. The low viscosity of waste plastic pyrolysis oil was noted to increase this leakage, again resulting in more fuel charge entering the combustion chamber. The results show that the viscosity of the fuel blends decreases with increased Waste plastic pyrolysis oil in the blend.

7.2 Brake Specific Fuel Consumption

The rate of fuel consumption divided by the rate of power production is termed as Brake specific fuel consumption. Brake specific fuel consumptions descend from lower to higher load level. It is related with brake thermal efficiency. At higher load conditions the brake thermal efficiency is increased and brake specific fuel consumption decreased. Figure 4 shows the variation of brake specific fuel consumption (BSFC) with load for WPPO 50, WPPO 70 and diesel fuel. As the load increases, BSFC decreases for all fuel blends. At full load,
WPPO blends show the specific fuel consumption higher than the diesel. The brake power of the engine increases with WPPO blends.

![Figure 3 Load against T.F.C](image1)
![Figure 4 Load against S.F.C.](image2)

### 7.3 Brake Mean Effective Pressure

Engine brake mean effective pressure (BMEP) for the five test fuels is shown in Figure 5. BMEP for pure diesel fuel is less than all the waste plastic pyrolysis oil - diesel blends. This is due to change in high heating value which increases heat release rate of the fuel and consequently increasing BMEP.

![Figure 5. Load against B.M.E.P](image3)
![Figure 6 Load against Brake thermal efficiency](image4)

Also, BMEP for different fuels increase with the increase of load remains nearly constant. All these results are consistent with the results reported for similar automotive engines. This means that, the using measuring system is accurate and suitable for obtaining many other data. Good mixture formation is the main factor for good diesel engine performance. This factor is highly influenced by viscosity, density, volatility and fuel heating value.

### 7.4 Brake Thermal Efficiency

The variation of brake thermal efficiency with load for WPPO-DF blends is shown in Figure 6. The brake thermal efficiency is high for the WPPO-DF blends than diesel. WPPO is a mixture of hydrocarbons varying...
from C_{10} to C_{30} having both low and heavy fractions with aromatics. Because of the changes in composition, viscosity, density and calorific value of WPPO-DF blends the brake thermal efficiencies of WPPO-DF blends are low particularly at full load.

7.5 Mechanical efficiency

From Figure 7, it is clear that the mechanical efficiency of the engine increases with an increase in load under all operating conditions. On pure diesel mode at full load, the mechanical efficiency is found to be 67.5%. At full load, the mechanical efficiency is 71.2% with WPPO 50 and 72.29% with WPPO 70. A rise of about 1.07% is observed with the WPPO 70 which indicates that the engine produces the more power as blend of the waste plastic pyrolysis oil is increased.

7.6 Exhaust Gas Temperature

Figure 8 shows the variation of exhaust gas temperature with load waste plastic pyrolysis oil and its diesel blends. The results show that the exhaust gas temperature increased with load in all cases. Higher exhaust gas temperature in the case of WPPO compared to DF is due to higher heat release rate. It may also be due to the oxygen content of the WPPO, which improves combustion.

7.7 Hydrocarbon emission

The variation of hydrocarbons with load for tested fuels is shown in Figure 9. Hydrocarbon ranges from 27ppm low load to 33 ppm at full load for DF operation. For WPPO 50, it varies from 28 ppm at low load to 32 ppm at full load and for WPPO 70, it varies from 29 ppm at low load to 32 ppm at full load. From the results, it can be noticed that the concentration of hydrocarbon of WPPO-DF blends is marginally higher than DF. When the WPPO-DF blends is injected and mixes with air, because of non-homogeneity of fuel air mixture some local spot in the combustion chamber will have mixture that will be too lean to combust properly. In a combustion chamber some fuel spots may be too rich with insufficient oxygen to burn all the fuel. Hence, some local spots with rich and lean mixture would be available in the combustion chamber. In fuel rich zones some fuel droplets do not react due to lack of oxygen and the combustion may be incomplete. This is the reason for higher HC emission in the case of WPPO-DF blends compared to DF. At lower loads due to lean mixture, the hydrocarbon ranges of WPPO and DF is less while at higher loads due to higher quantity of fuel admission, hydrocarbon. In the case of WPPO, the fuel spray becomes finer and effective combustion takes place.
7.8 Carbon monoxide

The variation of carbon monoxide with brake power is depicted in Figure 10. Since, CI engines are operating with lean mixtures; the CO emission would be low. CO emission is toxic so it must be controlled. CO is an intermediate product in the combustion of a hydrocarbon fuel, so its emission results from incomplete combustion. Therefore, emission of CO is greatly dependent on the air fuel ratio relative to the stoichiometric proportions. Rich combustion invariably produces CO, and emissions decreases nearly linearly with the deviation from the waste plastic pyrolysis oil diesel blends are higher than diesel. The reason behind this increase of CO emission is incomplete combustion due to reduced in-cylinder temperatures. The rapid increase in CO emission at higher loads is due to higher fuel consumption.

7.9 Carbon dioxide

As shown in Figure 11, it can be observed that the variation of carbon dioxide emission with load for DF and WPPO-DF operation. From the results, it is observed that the amount of CO₂ produced while using WPPO-DF blends is higher than DF at all load conditions. Carbon dioxide is a desirable byproduct that is produced when the carbon from the fuel is fully oxidized during the combustion process. As a general rule, the higher the carbon dioxide reading, the more efficient the engine is operating.

7.10 Oxygen

The variation of brake thermal efficiency with load for WPPO-DF blends is shown in Figure 12. It is clear that oxygen present in the exhaust gas is decreases as the load increases. It is Obvious that due to improved combustion, the temperature in the combustion chamber can be expected to be higher and higher amount of oxygen is also present, leading to formation of higher quantity of NOx, in WPPO-DF blends. Oxygen (O₂) readings provide a good indication of a lean running engine. Misfires typically cause high O2 output from the engine.
8 Conclusions

From the tests conducted with waste plastic oil and diesel on a DI diesel engine, the following conclusions are arrived:

- Part Load Thermal efficiency is higher than the diesel fuel operation
- CO emission increased with waste plastic pyrolysis oil compared to diesel operation.
- Unburnt hydrocarbon emission is higher than the diesel
- Oxidation of fuel is good at part loads which results higher CO₂
- Waste plastic pyrolysis oil can be used alternate fuel to the diesel.

REFERENCES