Engine Fuel Production from Waste plastic Pyrolysis (WPO) and Performance Evaluation in a CI engine with Diesel Blend

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Abstract
Plastic waste disposal throughout the world is creating problems and degrading the environment. Today transportation and electric power generation in rural areas mostly depend on fossil fuels. Such extensive use of fossil fuel is resulting in depleting it at an alarming rate. Hence, it is required to produce an alternative fuel to keep them running as well as minimizing waste disposal. Waste plastic pyrolysis oil is identified one of such good alternative. In this study, waste transparent plastic, used for packaging, is used for the conversion of fuel through pyrolysis process. It was observed that yield of plastic oil was approximately 65–70%. However, a liquid yield affects heating rates and heat loss patterns in the reactor system. This paper also presents the effect of waste plastic pyrolysis oil in a diesel engine at various compression ratios with different load and blending with pure diesel (pure diesel, 10%, 20%, 30%, 40%) at constant engine revolution. The performance characteristics include engine brake power, brake thermal efficiency, specific fuel consumption and exhaust emissions. Experimental investigation shows that Plastic oil can be used to save the 40% diesel without loss of power, and its trend do not differ with variation in compression ratio.

1. Introduction

Energy, environment and economy are one of the major contributors for developing the country. Fossil fuels are depleting day by day, which results in rise of petroleum products prices around the globe. This indicates requirement of an alternative cheaper fuel to fulfil the need of transportation, and electric power generation in the rural area. On the other hand, waste product generated with growth of population and its management plays essential role to maintain economic and healthy country. Among many types of Solid waste, plastic waste is a major problem as its non-biodegradable in nature. Plastic usage has become crucial part in today’s world, because of their lightweight, durability, non-perishable nature, faster rate of production and flexibility in design and the demand of commodity [1,2]. In general, plastics are formed using petroleum products and consists of long hydrocarbon chains. These contain many additives such as colouring agents, anti-oxidants and stabilizers [3,4]. High-density polyethylene is a highly used plastic after poly vinyl chloride (PVC) and polypropylene (PP) [5]. Plastics are non-biodegradable polymers and remains more than 100 of years, adding significantly to the problem of waste management [6,7]. Moreover, the huge demand for plastic has created a large amount of plastic waste and its consequences are serious threat to the environment due to its disposal problems. The toxic substances released are causing a threat to vegetation, animal and human health and environment as a whole. In detail, burning of plastic wastes increase the risk of heart disease, aggravates respiratory ailments such as asthma and emphysema and cause rashes, nausea or headaches, and damages the nervous system [1]. According to a survey carried out in India, it found that annual consumption of plastic was nearly 8 million tonnes. Around 70% of this is recycled and remaining plastic waste is going as landfills [1,8]. Wastage of energy is the recent trend in the selection of alternate fuels [9,10]. Fuels and its
2.2 Experimental setup

Waste plastic pyrolysis oil involves subjecting plastic to high temperature for the treatment of chemically decomposing of organic materials in absence of oxygen, otherwise it starts burning. During the process, initially plastics wastes have been cracked gently by adding catalyst, and the gases condensed in a series of condensers to give a low sulphur content distilled WPO. All this happens continuously to convert the waste plastics into fuel. The catalyst used in this system prevents formation of all the dioxins and Furans (Benzene ring). Figure 1 illustrates The laboratory scale pyrolysis setup consisted of a batch reactor sealed at one end and an outlet tube at the other end. An electric furnace used to provide heat to the reactor externally, and 20 gm of waste plastic sample was loaded in each pyrolysis reaction. The condensable liquid products (WPO) collected through the condenser and weighed. After pyrolysis, the solid residue left out inside the reactor and weighed. Reaction have been carried out at different temperatures ranging from 400–500°C. The property of collected WPO was measured as shown in table 1.
The experimental setup is shown in fig.2. The experimental setup consists of single cylinder, four stroke, multi-fuel, research engine connected to eddy current type dynamometer for loading. The engine specification: bore and stroke are 87.7 mm and 110 mm respectively, displacement volume 661cc, opening and closing of intake valve at 45°b TDC and 35.5°a TDC respectively, exhaust valve opening and closing at 35.5°b BDC and 4.5°a TDC respectively, Fuel injection timing 23°bTDC at inlet manifold. The compression ratio can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement.

![Pyrolysis setup for WPO](image1)

![Experimental set for engine performance](image2)

Table 1: properties of waste plastic oil and diesel

<table>
<thead>
<tr>
<th>Properties</th>
<th>Measuring Technique</th>
<th>B100(measured)</th>
<th>DIESEL(Pawar et al., 2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density(kg/m^3)</td>
<td>Hydrometer cylinder</td>
<td>860</td>
<td>890</td>
</tr>
<tr>
<td>Calorific value (kJ/kg)</td>
<td>Bomb calorimeter</td>
<td>39500</td>
<td>42000</td>
</tr>
<tr>
<td>Flash point(°C)</td>
<td></td>
<td>36</td>
<td>&gt;52</td>
</tr>
<tr>
<td>Fire point(°C)</td>
<td></td>
<td>41</td>
<td>&gt;55</td>
</tr>
</tbody>
</table>

In Diesel mode fuel injection point and pressure can be manipulated for research tests. Air temp, coolant temp, Throttle position and trigger sensor are connected to Open ECU which control ignition coil, fuel injector, fuel pump and idle air. Set up is provided with necessary instruments for combustion pressure, Diesel line pressure and crank-angle measurements. These signals are interfaced with computer for pressure crank-angle diagrams. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. The setup has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and hardware interface. Rotameters are provided for cooling water and calorimeter water flow measurement. A battery, starter and battery charger is provided for engine electric start arrangement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption air fuel ratio, A/F ratio, heat balance and combustion analysis. Lab view based Engine Performance Analysis software package Enginesoft provided for on-line engine performance evaluation. All the experiments with different fuel ratios conducted for a constant engine speed of 1500 rpm and with varying CR and load on engine. Water flow through engine adjusted to 230 LPH and 90 LPH through calorimeter. Load varied from 0.0 kg to 12 kg corresponding to zero load to full load. All the performance and emission characteristics were determined by averaging 10 consecutive cycles. For exhaust gas, AVL DiTEST CDS 440 gas analyzer was used. The details of measuring equipment used and its accuracy level are listed in table-2.

3. Results and Discussions

3.1 Brake Power

Figures 1.1, 1.2, 1.3 and 1.4 show the variation of brake power with respect load applied. It indicates that the Brake power increases with increase in load, which is due to increase in amount of fuel to maintain the constant RPM corresponding to load increase. These figures conclude that blending of waste plastic oil
(WPO) with pure diesel are very close trend with pure diesel corresponding to variation of load. Figures also indicate that plastic oil is safer to save the 40% diesel without loss of power, and its trend do not differ with variation in compression ratio.

Table 2. List of measuring equipment used.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measurement</th>
<th>Measurement Technique</th>
<th>Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tachometer</td>
<td>Engine speed</td>
<td>Magnetic Pick-up</td>
<td>1200-1500rpm</td>
<td>± 5rpm</td>
</tr>
<tr>
<td>Thermometer</td>
<td>Temperatures</td>
<td>K-Type Thermocouple</td>
<td>0-1200°C</td>
<td>± 2°C</td>
</tr>
<tr>
<td>Eddy current type Dynamometer</td>
<td>Load</td>
<td>Strain gauge type</td>
<td>0-50kg</td>
<td>± 0.1kg</td>
</tr>
<tr>
<td>Pressure Transducer</td>
<td>Pressure</td>
<td>Piezo sensor</td>
<td>0-5000psi</td>
<td>± 2psi</td>
</tr>
<tr>
<td>AVL DiTEST CDS 440 gas analyzer</td>
<td>Nitrogen oxides</td>
<td>Electrochemical sensor</td>
<td>0-5000ppm vol.</td>
<td>± 5 ppm vol.</td>
</tr>
<tr>
<td></td>
<td>Carbon monoxide</td>
<td>NDIR</td>
<td>0-15% vol.</td>
<td>&lt; 15.0 % vol.: ± 0.02 % vol.</td>
</tr>
<tr>
<td></td>
<td>Carbon dioxide</td>
<td>NDIR</td>
<td>0-20% vol.</td>
<td>&lt; 16.0 % vol.: ± 0, 3 % vol. ≥ 16.0 % vol: ± 5 % o.M.</td>
</tr>
</tbody>
</table>

Figure 1.1 Variation of brake power with load applied and blends

Figure 1.2 Variation of brake power with load applied and blends

Figure 1.3 Variation of brake power with load applied and blends

Figure 1.4 Variation of brake power with load applied and blends
3.2 Brake thermal efficiency

Brake thermal efficiency (BTE) signifies how efficiently engine is capable to convert fuel into mechanical energy. Figures 2.1, 2.2, 2.3 and 2.4 illustrate the graph between the brake thermal efficiency and load applied from no load to full load corresponding to 0.0 to 12.00kg. It shows that the variation of brake thermal efficiency with compression ratio of 15, 16, 17 and 18. The brake thermal efficiency tends to be the same at lower load for all blends to the compression ratio of 15, 16 and 17, however, it varies for compression ratio 18. Brake thermal efficiency (BTE) increases with respect to increase in load, compression ratio, blending ratio up to 40%, and for all blend. However, the gap of BTE of diesel and blended fuels are different. Figure 2.1 shows maximum BTE at full load for diesel and B40 are 33.54% and 38.18% respectively at CR 15. Figure 2.2 shows that at maximum load BTE for diesel and B40 are 33.2% and 37.76% correspondingly at CR 16 at maximum load, BTE for diesel and B40 are 33.15% and 38.47% respectively at CR17. Figure 2.4 shows that at maximum load BTE for diesel and B40 are 33.33% and 38.7% at CR 18. This may be due to possession of higher calorific value of WPO and its blends with diesel than pure diesel (Panda et al. 2016).

3.3 Specific fuel consumption

Figures 3.1, 3.2, 3.3 and 3.4 represents about the variation of brake specific fuel consumption (BSFC) with respect to different load applied in kg up to full load equivalent to no load - full load, and compression ratio of 15, 16, 17 and 18. These graph prove that as the load increases, BSFC decreases continuously for all blends.
and to all compression ratio. This is because, when the load increases temperature inside the cylinder increases, reduces delay period, total combustion timing increases and result proper combustion of fuel. It can also be noticed that trend of falling BSFC corresponding to load applied is almost same for pure diesel and B40 blend, however it differs for lesser ratio of blend and lower load. The variation in BSFC at maximum load for diesel and B40 is 0.26 ±0.04 kg/kWh. Moreover, compression ratio 17 and 18 provide lesser BSFC of B40 blend at low load in comparison to CR 15 and 16. These trends of BSFC is all because of possessing high calorific value of WPO and better combustion toward higher compression ratio.

3.4 CO emissions
A toxic gas Carbon monoxide (CO) emitted from the engine, measured at tail pipe corresponding to variation of load, and at compression ratio of 15, 16, 17 and 18 are shown in the figures 4.1, 4.2, 4.3 and 4.4 respectively. The CO produced during the combustion due to lack of oxygen, poor air entertainment, mixture preparation and incomplete combustion (Heywood, J.B., 1984). It observed that Carbon monoxide (CO) decreases with increase in load, blend ratio up to 40% of WPO, and compression ratio. CO emissions decreases continuously for all blends, and the value of emission in volume percentage for B40 and pure diesel at maximum load are 0.04 and 0.03, 0.03 and 0.02, 0.02 and 0.02, 0.03 and 0.01 corresponding to CR 15, 16, 17, and 18 respectively. The reason behind decreased CO emission may be due to increase in combustion efficiency and better mixing. It can be noticed that the decreased in the value of CO emission with increase in load, blending ratio, and compression ratio fall are in the range of 0.13 to 0.01 volume percentage.
NOx emissions

NOx emission at the exhaust tail of an engine have been measured in parts per million (ppm) for different blends of WPO with pure diesel and with the variation of compression ratio (CR) from 15-18 are plotted as function of load in figures 5.1, 5.2, 5.3 and 5.4. The reason of NOx formation is mainly due to availability of oxygen, reaction time and higher temperature during combustion. Figures depict that NOx emission increases upto 10 kg (80% load) and decreases thereafter for the compression ratio 15 and 16, however, increasing trend of NOx is continue for CR 17 and 18 throughout the load range. It can be observed that NOx emission of B40 is very close to pure diesel at lower load up to the 50% and higher for further increased load for all CR. Increasing of NOx with load and blends increment might be due to higher heat released and higher combustion temperature. Moreover, could be due to longer ignition delay owing to the presence of long chain carbon compounds in WPO (Panda et al., 2016). Figure show that at maximum load NOx emission for diesel and B40 is 316ppm and 282ppm respectively for CR 15, 321ppm and 294ppm for CR 16, 382ppm and 305ppm for CR 17 and 472ppm and 468ppm for CR 18. Which indicates NOx emission is proportional to the CR increase, along with load and all blends.

CO2 emissions

Increasing tendency of CO2 emission corresponds to the complete combustion, however CO emission shows incomplete combustion. CO2 emission decreases corresponding to increasing thermal efficiency.
emission measured at exhaust tail at different blends (B10,B20,B30,B40) and compression ratio (15,16,17 and 18) with respect to load applied are shown in figures 6.1, 6.2, 6.3 and 6.4.

Figure 5.1: Variation of NOx with Load and Blends

Figure 5.2: Variation of NOx with Load and Blends

Figure 5.3: Variation of NOx with Load and Blends

Figure 5.4: Variation of NOx with Load and Blends

Figure 6.1: Variation of CO2 with Load and Blends

Figure 6.2: variation of CO2 with Load and Blends
Figures illustrate that CO$_2$ emission of B40 is lower for all compression ratios, when compared with diesel. CO$_2$ emissions increase with respect to load for all blends, and at maximum load, emission for diesel and B40 is almost same as 1.9% and 1.8% respectively at CR 15, 1.9% and 1.7% respectively at CR 16, 2.1% and 2.1% respectively at CR 18. The average emission of CO$_2$ increases sharply up to the 60% to 70% (8-10 kg) of load and further slows down. This indicates that after 60% load engine gives better performance, although CO$_2$ emission is high.

4. Conclusion

An intensive experimental study was conducted on a single cylinder 4-stroke diesel engine to appraise the effects of performance and exhaust emission operating with WPO and its blends with diesel. The following conclusions are drawn from the experimental study:

1. The use of Waste Plastic Oil blended fuel in a diesel engine causes improvement in engine performance and exhaust emissions. Plastic oil is save to use till 40% blended with diesel without loss of power, and its trend do not differ with variation in compression ratio.

2. Waste Plastic oil addition results in the increase of Brake Thermal Efficiency (BTE) and decrease in the specific fuel consumption. BTE for diesel and B40 are 33.33% and 38.7% at CR 18 at maximum load. The BSFC reduces with increase in CR. The variation in BSFC observed at maximum load for diesel and B40 is 0.26 ±0.04 kg/kWh at CR 18.

3. Waste plastic oil addition results in significant reduction in exhaust emissions. Carbon monoxide (CO) decreases with increase in load, increase in blend ratio up to 40% of WPO and increase in compression ratio. NOx emission of B40 is very closed to pure diesel at lower load up to the 50% and higher for further increased load for all CR. CO$_2$ emission of B40 is lower for all compression ratios, when compared with diesel. CO$_2$ emissions increase with respect to load for all blends, and at maximum load emission for diesel and B40 are almost same.

References


