Technical note

Assessing idling effects on a compression ignition engine fueled with Jatropha and Palm biodiesel blends


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A R T I C L E   I N F O

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A B S T R A C T

In this study, performance of a diesel engine operated with Jatropha and Palm biodiesel blends at high idling conditions has been evaluated. The result obtained from experiment elucidate that, at all idling modes HC and CO emissions of both blends decreases, however, NOx emissions increases compared to pure diesel fuel. Jatropha biodiesel has higher viscosity compared to Palm biodiesel, which might have degraded the spray characteristics and caused slightly improper mixing which might have led to slightly incomplete combustion, thus at both idling conditions, Jatropha blends emitted higher CO and HC compared to Palm biodiesels. Compared to diesel fuel, CO emissions were 5.9–9.7%, 17.6–22.6%, 23.5–29%, 2.9–6.4%, 5.9–14.5% and 11.8–17.74% less, HC emissions were 10.3–11.5%, 24.13–30.76%, 34.5–39%, 6.9–7.7%, 26–27% and 31–35% less and NOx emissions were 8.3–9.5%, 14–15%, 22–25%, 5–7.14%, 10–11.3% and 17–18% more respectively for 5, 10 and 20% blends of Palm and Jatropha biodiesel. Compared to diesel fuel, at high idling conditions brake specific fuel consumption all Palm and Jatropha biodiesel–diesel blends increased. Compared to diesel fuel, BSFC were 1.14–1.35%, 2.28–2.96%, 7.1–8.35%, 2.28–2.69%, 3.98–5.39% and 8.83–9.29% more respectively for 5, 10 and 20% blends of Palm and Jatropha biodiesel.

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1. Introduction

1.1. Background

The most persuasive technological concern of both energy demand and supplying issues are establishing the replacement of fossil fuel-derived energy resources. The detrimental impact on environment due to burning of fossil fuel, the unsteadiness in both fuel demand and supply, and the relevant petroleum products' production cost hiking etc. are intensifying this issue. In 1900, Rudolph first exhibited his invention the diesel engine where He operated the engine with vegetable oil, “peanut oil”. However, as a result of huge availability focuses were shifted from vegetable oils to fuels at that time. But, currently when petroleum fuel is dwindling fast, researchers are looking for an alternative fuel that is eco-friendly, domestically available and technically feasible [1]. Many countries are concentrating on a lot of researches to find a suitable replacement of petroleum fuel [2]. One such solution can be biodiesel as it has similar functional properties as diesel fuel [3]. Biodiesel is biodegradable, non-explosive, renewable, non-flammable, non-toxic and also environment friendly [4]. The major advantage of using biodiesel is that, it can be used in pure form or in blended form with diesel without making any modification [5].

Many researches has been evaluated engine performance of various biodiesel and biodiesel blends [6–9] in diesel engine. However, there has been only few studies that were done to investigate the impact of biodiesel on engine performance and emission during high idling condition [10–12]. Engine running at low load and at low rated speed is known as high idling condition which is a major problem currently faced by the transport industry. Many researches has been done to evaluate the engine performance and emissions using only diesel fuel at idling condition. Researchers found that, NOx emission while engine idling was higher than vehicle running on road by a factor of 1.5 [13]. Increase in load during idling causes increment of NOx emission [14,15]. During idling fuel consumption can be as high as 1.65 gal/h [16], CO emission can be as high as 295 g/h [17], and HC emission can be as high as 86.4 g/h [18]. Compared to driving cycle emission HC...
emission during idling is reported to be 1 to 5 times more than that of driving cycle and idling CO emission were 5%–75% of driving emission [19].

1.2. Objectives

Diesel, Palm and Jatropha are used as fuels in this research work. The considered aims of the study is to study the effect of Jatropha and Palm biodiesel blends on brake specific fuel consumption and engine emissions at high idling conditions.

2. Materials and method

2.1. Crude oil properties

In this research, Jatropha biodiesel was selected because recently it has drawn the attention of Malaysian Government as a source of non-edible feedstock. On the other hand, Palm was selected due to ease of availability and rising interest due to renewability respectively. Fuel properties were measured applying suitable measuring techniques and devices. Table 1 shows physico-chemical properties of crude Jatropha and Palm oil.

2.2. Biodiesel production process

If the crude oil contains higher FFA then two step processes is required. As the acid value of crude Jatropha oil was much higher two step (acid-base catalyst) processes were selected, but for Palm oil only transesterification process were selected as its acid value was within the limit. For the production of biodiesel 1 L batch reactor was used in the laboratory.

Acid-catalyzed process — In this process, the esterification process was carried out using methanol (6:1 M ratio) and 1% (m/m oil) of potassium hydroxide (KOH) and maintained at 60 °C for 3 h under vacuum conditions for 1 h to remove methanol and water from the esterified oil.

Alkaline-catalyzed process — In this process, the esterified oil was reacted with methanol (6:1 M ratio) and 1% (m/m oil) of potassium hydroxide (KOH) and maintained at 60 °C for 2 h and 400 rpm stirring speed. After completion of the reaction, the produced biodiesel was deposited in a separation funnel for 12 h to separate glycerol from biodiesel. The lower layer which contained impurities and glycerol was drawn off.

2.3. Fatty acid composition

Fatty acid with and without double bond is known as unsaturated and saturated fatty acid respectively. The fatty acid composition (FAC) of Jatropha and Palm biodiesel was tested using gas chromatography (GC). Table 2 shows the operating conditions of the GC. The results of FAC of Jatropha and Palm biodiesel is shown in Table 3.

2.4. Properties analysis

The physico-chemical properties of the produced biodiesel were characterized according to the ASTM D6751 standards. Each property test was repeated three times.

Saponification Number, Cetane number and Iodine value were calculated by using the fatty acid composition results and the following empirical equations (1)–(3) respectively [20,21]

$$SN = \sum \frac{560 \cdot A_i}{MW_i}$$

Table 1

<table>
<thead>
<tr>
<th>Properties</th>
<th>Units</th>
<th>Standards</th>
<th>Jatropha oil</th>
<th>Palm oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic viscosity at 40 °C</td>
<td>mm²/s</td>
<td>ASTM D445</td>
<td>51</td>
<td>39.43</td>
</tr>
<tr>
<td>Density at 15 °C</td>
<td>kg/m³</td>
<td>ASTM D4052</td>
<td>917</td>
<td>901</td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>ASTM D93</td>
<td>218</td>
<td>169</td>
</tr>
<tr>
<td>Pour point</td>
<td>°C</td>
<td>ASTM D97</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Cloud point</td>
<td>°C</td>
<td>ASTM D2500</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Calorific value</td>
<td>MJ/kg</td>
<td>ASTM D240</td>
<td>38.66</td>
<td>39.45</td>
</tr>
<tr>
<td>Iodine value</td>
<td>g Iodine/100 g</td>
<td></td>
<td>95</td>
<td>57</td>
</tr>
<tr>
<td>Acid value</td>
<td>Mg KOH/g oil</td>
<td></td>
<td>11</td>
<td>3.6</td>
</tr>
<tr>
<td>Cetane number</td>
<td>—</td>
<td>ASTM D613</td>
<td>46</td>
<td>54</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Property</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier gas</td>
<td>Helium at 23.8 psi</td>
</tr>
<tr>
<td>Linear velocity</td>
<td>44 cm/s @ 100 °C</td>
</tr>
<tr>
<td>Flow rate</td>
<td>Air – 450 ml/min</td>
</tr>
<tr>
<td>Detector temperature</td>
<td>250 °C</td>
</tr>
<tr>
<td>Column head pressure</td>
<td>23.8 psi</td>
</tr>
<tr>
<td>Column dimension</td>
<td>30 m × 250 mm × 2.5 μm</td>
</tr>
<tr>
<td>Injector</td>
<td>Split injector, 50:1 ratio, 0.3 μL injection volume</td>
</tr>
<tr>
<td>Temperature ramp 1</td>
<td>100 °C hold for 0 min</td>
</tr>
<tr>
<td>Temperature ramp 2</td>
<td>10 °C/min to 250 °C, hold for 5 min</td>
</tr>
</tbody>
</table>
where $A_i$ is the weight percentage of each fatty acid component, $D$ is the number of double bonds present in each fatty acid and $MW_i$ is the molecular weight of each fatty acid component.

3. Blending of biodiesel

The test fuels are blended at various ratios by using a homogenizer device at a speed of 2000 rpm. The homogenizer was fixed on a clamp on a vertical stand, which allows changing of the homogenizer’s height.

4. Engine test

The engine test was done with an in-line four cylinder CI engine which was coupled with an eddy current dynamometer. Two idling conditions (1000 RPM 10% load and 1200 RPM 12% load) were considered in this investigation. 5%, 10% and 20% (PB5, JB5, PB10, JB10 and PB20, JB20) blends of Jatropha and Palm along with diesel fuel have been used to run the engine.

5. Results and discussion

5.1. Fuel properties

Table 6 which shows the important physico-chemical properties of Jatropha and Palm biodiesel. The major physico-chemical properties of Jatropha and Palm biodiesel are comparable with those of diesel fuel.

The densities of all the biodiesels were found to be higher than diesel fuel, as expected. Kinematic viscosity is influenced by the fatty acid profile of the biodiesel [22]. As seen from Table 4, the kinematic viscosity levels of the biodiesel satisfied ASTM standards. Jatropha biodiesel have slightly higher kinematic viscosity (4.74 mm$^2$/s) compared to Palm biodiesel (4.65 mm$^2$/s). Also, density of Jatropha biodiesel (867 kg/m$^3$) is higher than Palm biodiesel (857 kg/m$^3$). The calorific values of all biodiesels were, as expected, found to be less than diesel fuel. Jatropha biodiesel have a lower calorific value of 39.827 MJ/kg whereas Palm biodiesel have 39.9 MJ/kg. Flash point of all the biodiesels were found to be much lower than that of diesel fuel.
higher than the ASTM standards (Jatropha 186 °C, Palm 181 °C) which makes them safe for use. Pour point value indicates the pumpability, as it indicates the waxy nature of the oil. Pour points of all the tested fuels were within ASTM standards (Jatropha 3 °C, Palm 11 °C). The cloud point has much greater importance in countries where the weather is cold. Cloud point of all the tested biodiesels were within the ASTM limit (Jatropha 4 °C, Palm 10 °C). Cetane value indicates the duration of ignition delay period, higher cetane number (59.5) compared to Jatropha biodiesel (51.7). The cloud point has much greater importance in countries where the weather is cold.

5.2. CO emission

Fig. 2 depicts that, at all idling modes, Diesel fuel emitted highest CO emission compared to both Palm and Jatropha biodiesel blends. Secondly, Jatropha biodiesels blends emitted more CO compared to Palm biodiesel blends. Compared to diesel fuel, CO emissions for PB5, PB10, PB20, JB5, JB10 and JB20 were 5.9–9.7%, 17.6–22.6%, 23.5–29%, 2.9–6.4%, 5.9–14.5% and 11.8–17.7% less respectively. Compared to Palm biodiesel blends, Jatropha biodiesel blends showed less decrease of CO emissions due to the reason that Jatropha biodiesel has higher viscosity compared to Palm biodiesel, which might have degraded the spray characteristics and caused slightly improper mixing which might have led to incomplete combustion.

5.3. HC emission

Fig 3 represents HC emissions at different idling conditions of Palm and Jatropha biodiesel blends compared to diesel fuel. It can be seen that, diesel fuel emits highest amount of HC at all conditions. From the figure it can be seen that, HC emissions follow the trends of CO emissions. Increase in blend percentages decreases HC emissions. As there is higher oxygen concentration in the biodiesel–diesel blends which enhances the oxidation of unburned hydrocarbons, HC emission decreases with increase in percentages of biodiesel blends. Furthermore, increase in speed decreases HC emission for all tested fuel. This is due to the reason that increase in speed ensures better mixing of air and fuel. Compared to diesel fuel, HC emissions for PB5, PB10, PB20, JB5, JB10 and JB20 were 10.3–11.5%, 24.13–30.76%, 34.5–39%, 6.9–7.7%, 26–27% and 31–35% less respectively.

5.4. NOx emission

Fig 4 demonstrates NOx emission at different idling conditions for diesel, Palm and Jatropha biodiesel blends. Diesel fuel exhibited lowest emission at all condition. As blend percentages of biodiesel increases emission increases. Biodiesel blends produce higher emission due to having higher cetane number and lower ignition delay. It is observed that, idling speed increases emission decreases due to the fact that increase in speed reduces the ignition delay which results in less amount of time to form NOx. Also, compared to diesel fuel, biodiesels are more oxygenated fuel and contains 12% more molecular oxygen than diesel, which raises chamber temperatures and improves combustion thus NOx emissions increases [20]. Compared to diesel fuel, NOx emissions for PB5, PB10, PB20, JB5, JB10 and JB20 were 8.3–9.5%, 14–15%, 22–25%, 5–7.14%, 10–11.3% and 17–18% more respectively. Compared to Jatropha blends, Palm biodiesel blends emits higher NOx. As, Palm biodiesel have higher cetane number compared to Jatropha biodiesel, ignition delay is shorter compared to Jatropha. As a result, the fuel mixture and initial combustion products have a longer residence time at elevated temperatures.
temperature, thus emits higher NOx compared to Jatropha biodiesel blends.

There has been several studies that tried to investigate how biodiesel affect combustion phasing and influences NOx emissions. Combustion period can be sub-divided into three separate periods: ignition delay period, pre-mixed combustion period, and diffusion combustion period. The ignition delay period is the time between start of injection and start of ignition. This period is related to the cetane number of the fuel, with higher cetane leading to shorter ignition delay. Typically, biodiesel fuels have higher cetane numbers than petroleum diesel [23,24]. A shorter ignition delay could allow the fuel mixture and initial combustion products to have a longer residence time at elevated temperature, thereby increasing thermal NOx formation. Again, during the pre-mixed combustion period, fuel and air that have already mixed ignite, causing a rapid rise in temperature and pressure. The extent to which these temperature and pressure increases occur depends upon the amount of fuel that has already been injected, which is related to the length of the ignition delay. With longer ignition delays (related to low cetane number), more fuel is injected and mixed with air before ignition occurs, thus leading to more extreme temperature and pressure increases. And thus increases NOx emission.

5.5. Brake specific fuel consumption

Brake Specific Fuel Consumption (BSFC) is considered a measure of combustion efficiency, how efficiently a given amount of fuel is being converted into a specific amount of horsepower. Fig. 5 shows the brake specific fuel consumption at different idling conditions for diesel, Palm and Jatropha biodiesel blends. At all conditions diesel fuel consumption rate was lowest, and as blend percentages increased BSFC increased due to having lower heating value compared to diesel fuel. From fig it is also evident that in idling speed, BSFC increases, as increase in idling speed results in more fuel consumption. Compared to diesel fuel, BSFC for PB5, PB10, PB20, JB5, JB10 and JB20 1.14–1.35%, 2.28–2.96%, 7.1–8.35%, 2.28–2.69%, 3.98–5.39% and 8.83–9.29% more respectively.

5.6. In-cylinder pressure

As biodiesel have higher cetane number, at the initial stage, combustion starts earlier compare to diesel fuel. Thus, heat release rate of biodiesel blends is higher than diesel fuel. Thus, biodiesel blends achieve higher peak pressure than diesel fuel. Figs. 6 and 7 depicts the in-cylinder pressure of a) Palm and b) Jatropha biodiesel blends compared to diesel fuel.

When the engine is running at low load, residual gas temperature and wall temperature are low. Therefore, injection charge temperatures are also significantly low, which in turns increases injection delay period. Thus for diesel fuel combustion starts later compared to biodiesel and its blends. Consequently, for diesel fuel, the peak cylinder pressure reaches a lesser value far away from the top dead center in the expansion stroke. Again, for biodiesel and its blends peak cylinder pressure take place earlier. From these two figures it can be depicted that, at both idling modes, Palm and Jatropha biodiesel blends exhibited higher peak pressure compared to Diesel fuel.

5.7. Error analysis

Experimental error and uncertainty can arise from instrument selection, condition, calibration, environment, observation, reading, and test planning. Uncertainty analysis is thus required in...
order to prove the accuracy of the experiments. Table 7 displays a summary of measurement accuracy and the relative uncertainty of various parameters, including fuel consumption, CO, HC, and NOx emission.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Accuracy</th>
<th>Relative uncertainty</th>
<th>Reading (idle mode 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSFC</td>
<td>±0.005 g/kWh</td>
<td>±(1/29) = 0.00017 g/kWh</td>
<td>351 g/kWh</td>
</tr>
<tr>
<td>CO</td>
<td>±0.001 ppm</td>
<td>±(1/180) = 0.0000055 ppm</td>
<td>0.00555 ppm</td>
</tr>
<tr>
<td>HC</td>
<td>±0.01 ppm</td>
<td>±(1/29) = 0.0034 ppm</td>
<td>29 ppm</td>
</tr>
<tr>
<td>NOx</td>
<td>±0.01 ppm</td>
<td>±(1/180) = 0.0000555 ppm</td>
<td>180 ppm</td>
</tr>
</tbody>
</table>

6. Conclusions

Biodiesel has been produced from Palm and Jatropha oil and its properties have been evaluated in the lab. Also, an unmodified diesel engine was operated with Diesel, Palm and Jatropha biodiesel—diesel blends at high idling conditions and engine performance and emissions were measured. 10% and 20% biodiesel blends were used the most important outcomes derived are summarized as follows:

- Jatropha biodiesel have slightly higher kinematic viscosity (4.74 mm²/s) compared to Palm biodiesel (4.65 mm²/s).
- Jatropha biodiesel have a lower calorific value of 39.827 MJ/kg whereas Palm biodiesel have 39.9 MJ/kg, which both are less than diesel fuel, as expected.
- As biodiesel have higher oxygen content they ensures better combustion, thus less CO and HC emission compared to diesel fuel. At both idling modes, Diesel fuel exhibited highest CO and HC emissions at both idling conditions.
- Jatropha biodiesel has higher viscosity compared to Palm biodiesel, which might have degraded the spray characteristics and caused slightly improper mixing which might have led to slightly incomplete combustion, thus at both idling conditions, Jatropha blends emitted higher CO and HC compared to Palm biodiesels.
- Compared to diesel fuel, CO emissions for PBS, PB10, PB20, JB5, JB10 and JB20 were 5.9—9.7%, 17.6—22.6%, 23.5—29%, 2.9—6.4%, 5.9—14.5% and 11.8—17.74% less respectively.
- Compared to diesel fuel, HC emissions for PBS, PB10, PB20, JB5, JB10 and JB20 were 10.3—11.5%, 24.13—30.76%, 34.5—39%, 6.9—7.7%, 26—27% and 31—35% less respectively.
- However, higher oxygen content results in higher NOx emissions. At both idling conditions, Diesel fuel emitted lowest NOx.
- Palm biodiesel have higher cetane number compared to Jatropha biodiesel, ignition delay is shorter compared to Jatropha, thus emits higher NOx compared to Jatropha biodiesel blends.
- Compared to diesel fuel, NOx emissions for PBS, PB10, PB20, JB5, JB10 and JB20 were 8.3—9.5%, 14—15%, 22—25%, 5—7.14%, 10—11.3% and 17—18% more respectively.
- Compared to diesel fuel, at high idling conditions brake specific fuel consumption all Palm and Jatropha biodiesel—diesel blends increased.
- With the increase of blend percentages brake specific fuel consumption of biodiesel increases.
- Compared to diesel fuel, BSFC for PBS, PB10, PB20, JB5, JB10 and JB20 1.14—1.35%, 2.28—2.96%, 7.1—8.35%, 2.28—2.69%, 3.98—5.39% and 8.83—9.29% more respectively.
- At both idling condition PB20 emitted lowest CO and HC emissions, however, also emitted highest NOx emissions too. And, Brake specific fuel consumption of JB20 was highest at both condition.

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References


