Production of palm and jatropha based biodiesel and investigation of palm-jatropha combined blend properties, performance, exhaust emission and noise in an unmodified diesel engine


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A B S T R A C T

An ever increasing drift of energy consumption, unequal geographical distribution of natural wealth and the quest for low carbon fuel for a cleaner environment are sparking off the production and use of biodiesels in many countries around the globe. In this work, palm biodiesel and jatropha biodiesel were produced from the respective crude vegetable oils through transesterification, and the different physicochemical properties of the produced biodiesels have been presented, and found to be acceptable according to the ASTM standard of biodiesel specification. This paper presents experimental results of the research carried out to evaluate the BSFC, engine power, exhaust and noise emission characteristics of a combined palm and jatropha blend in a single-cylinder diesel engine at different engine speeds ranging from 1400 to 2200 rpm. Though the PBJB5 and PBJB10 biodiesels showed a slightly higher BSFC than diesel fuel, all the measured emission parameters and noise emission were significantly reduced, except for NO emission. CO emissions for PBJB5 and PBJB10 were 9.53% and 20.49% lower than for diesel fuel. By contrast, HC emissions for PBJB5 and PBJB10 were 3.69% and 7.81% lower than for diesel fuel. The sound levels produced by PBJB5 and PBJB10 were also reduced by 2.5% and 5% compared with diesel fuel due to their lubricity and damping characteristics.

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1. Introduction

Modern civilization and transport systems are very dependent on fossil fuels which are non-renewable in nature. The rapidly growing demand for transport fuel and industrialization has caused serious threats to the environment and energy security of the world (Hussan et al., 2013). Global fossil fuel consumption increased by around 40% in 2011 compared with 2010 (British Petroleum, 2011). Moreover, only half of the usual energy demand can be supplied until 2023 with the current liquid fuel reserve (Owen et al., 2010). This enormous drift of fossil fuel consumption is seriously affecting our environment. These environmental degradation effects include global warming, air quality deterioration, ozone depletion, eutrophication, photochemical smog, oil spills, and acid rain (Abedin et al., 2013; Rizwanul Fattah et al., 2013). Among all automotive vehicles, diesel-operated vehicles are most popular due to their fuel efficiency and low emission of CO, HC and CO₂ (Kurani and Sperling, 1988). But it has been experimentally demonstrated that many human health hazards are associated with exposure to diesel exhaust emissions (Kagawa, 2002; Mills et al., 2007). Moreover, noise produced by road and rail traffic adversely affects human health. Around 20% of the population of the European Union suffers from unacceptable noise levels (Nijland and van Wee, 2008; Oltean-Dumbrava et al., 2013). Therefore, research must be carried out in order to reduce the noise level of diesel engines.

Biofuel has so far been backed by government policies in many countries due to its greater energy security, reduced environmental pollution, sustainability and other socio-economic issues (Pereira et al., 2012; Sanjid et al., 2013). The projection by Stuart Stanford back in 2008 on primary energy production from 1970 to 2050 strongly supports the increasing trend of renewable energy consumption (Stanford, 2008). The sustainability of biofuels is progressively promoting its acceptance and market demand will rise in the near future. Around 27% of transport fuel will be completely replaced by biofuels by 2050 according to the International Energy Agency IEA (2011). Though crude vegetable oils are incompatible with engines due to their high viscosity and low volatility, transesterified vegetable oils blended with diesel at up to 20% of total volume can certainly be considered in view of energy, environmental and economic concerns (Atabani et al., 2012).
Transesterification is the chemical reaction which yields biodiesel and glycerol from crude vegetable oil. Biodiesels and their blends with diesel fuel have similar properties to diesel fuel and meet the standard specification of the ASTM and EN test methods (Atabani et al., 2013). Apart from increasing NOx emission, most biodiesels reduce different pollutant emissions (Rahman et al., 2013a). Moreover, all the carbons released by the combustion of biofuel are fixed by the plant through the process of photosynthesis. This is the concept of “carbon neutral fuel”, emphasized by the Kyoto Protocol, which establishes the contribution of using biofuel in the prevention of global warming (Jayed et al., 2011). Though the utilisation of edible biodiesel feedstock has been criticized by some environmentalists, with a proper management system and an efficient supply chain, the use of biodiesel can reduce greenhouse gas emission as well as securing the food supply (Ng et al., 2012).

Among the conventional edible biodiesel feedstock, palm is one of the most productive and economically suitable as an alternative biodiesel source. Average oil yield from a palm tree is 3–4 times higher than any other conventional biodiesel feedstock like rapeseed or sunflower. Besides, palm oil production needs less N-fertilizers and the energy needed in palm mills is provided by the combustion of palm fibres and shells, which reduces the carbon footprint (de Vries, 2008). According to the Malaysian Palm Oil Board, Malaysia is producing 19.4 million tons of crude palm oil every year (Tahir et al., 2013). Though palm oil is edible, this huge production of palm oil definitely permits the production of biodiesel from palm oil. Besides, using biodiesel based on waste frying palm oil in diesel engines will not affect the food supply (Canakci et al., 2009). By contrast, jatropha is a potential non-edible feedstock and the jatropha plant can be grown almost anywhere, even on gravel, sandy and saline soils. Its water requirement is extremely low. Hence, the use of jatropha seed oil is no threat to existing cultivable land and the food chain, unlike some other conventional edible feedstock. The plant itself can improve soil quality so that it can be used for other crops in the future. Extraction of biodiesel from jatropha seeds is simple and jatropha biodiesel exhibits more useful fuel properties than any other second-generation biodiesel feedstock. Jatropha oil is favoured over palm oil due to its cold filter plugging point (CFPP) value, which makes it a better option for use in cold climates (Kalam et al., 2012).

In recent years, studies have been carried out by several researchers on the performance and emission of palm biodiesel. Ndayishimiye and Tazerout (2011) investigated the performance and emission of a single-cylinder DI diesel engine fuelled with CPO blends, preheated palm oil and palm biodiesel—diesel blends. They found slightly higher BSFC for all the tested biofuels compared with diesel fuel. Engine BTE was slightly increased for CPO blends but decreased for all the other fuels tested. HC and CO emissions were reduced significantly (30–65%) for palm biodiesel compared with all the other fuels tested, though NOx emission increased. Song et al. (2012) used pure palm biodiesel and 20% palm biodiesel blend to evaluate NOx emission and soot formation in a 4-cylinder medium duty diesel engine. On average, the biodiesel emitted a higher level of NOx than diesel fuel, though NOx formation exhibited some inconsistency across all the fuels tested, while smoke concentration was consistently lower for palm biodiesel. Yusaf et al. (2011) investigated the performance and emission of a 4-cylinder Perkins diesel engine fuelled with 25%, 50% and 75% CPO blends. At higher engine speed, they found lower BSFC and higher torque for the CPO blends, but the brake power produced was slightly lower. Oxygen and NOx emissions were reduced, while CO and EGT were increased for CPO blends compared with diesel fuel.

Mofjühr et al. (2013) experimented with a 4-stroke, DI single-cylinder diesel engine fueled with 10% and 20% jatropha biodiesel and measured the engine performance and emission. Higher BSFC, lower torque and lower brake power were found for jatropha biodiesels compared with diesel fuel. HC was reduced by up to 10% and CO was reduced by up to 25% for jatropha biodiesel, while NOx emission increased by up to 6%. Chauhan et al. (2012) investigated the performance and emission of 5%, 10%, 20%, 30% and 100% jatropha biodiesel blends in a single-cylinder, DI diesel engine. They found that engine performance for jatropha biodiesel was comparable with the diesel fuel. Smoke, HC and CO emissions were reduced, but increased NOx emissions were found over the whole range of experiments. Sahoo and Das (2009) compared the combustion characteristics of jatropha, polanga and karanja based biodiesel in a 4-stroke, single-cylinder diesel engine. They reported a shorter ignition delay period for pure jatropha biodiesel compared with diesel fuel and karanja biodiesel. However, regarding peak cylinder pressure, polanga biodiesel was superior to jatropha and karanja biodiesel. Sahoo et al. (2009) carried out research on the same feedstock in a 3-cylinder, AVL make CI engine to evaluate the engine performance and emission characteristics. They reported a slight reduction in power and increase in BSFC for all the biodiesels tested compared with diesel fuel. However, the maximum increase in power was observed for the 50% blend of jatropha biodiesel and the maximum BSFC reduction was observed for the 20% blend of jatropha biodiesel. Significant reductions of HC, smoke and particulate matter emission were observed for all the biodiesels tested compared with the diesel fuel. However, their CO and NOx emissions increased slightly.

Experimental investigations on engine performance, emission and noise for a combined palm and jatropha blend were not found in scientific indexes. This experimental endeavour deals with the possibility of using combined palm and jatropha biodiesel blends for energy generation in order to reduce air and noise pollution. The steps in the transesterification undertaken to obtain biodiesel from crude vegetable oil, as well as the characterisation of the produced biodiesel are described. Performance and emission results for combined palm and jatropha biodiesel blends in a single-cylinder diesel engine are also represented graphically and compared with diesel fuel, palm biodiesel blend and jatropha biodiesel blend.

2. Materials and methodology

This research work was carried out with the aim of analysing the performance and emissions of a single-cylinder diesel engine using...
combined palm and jatropha biodiesel blends of different proportions and comparing the same parameters with palm biodiesel blend, jatropha biodiesel blend and neat diesel fuel. A convenient method of producing biodiesel from crude vegetable oil available in the market was also developed, which is easily achievable in the laboratory. A total of six biodiesel blends of palm and jatropha methyl ester were used to run the diesel engine without any engine modification.

2.1. Feedstock and chemicals

Oils of palm fruit and jatropha seed were purchased from the Forest Research Institute of Malaysia (FRIM). FRIM usually collects the feedstock from local farms in Malaysia and Indonesia respectively. All the chemicals needed for transesterification were purchased from LGC Scientific, Kuala Lumpur, Malaysia.

2.2. Transesterification process

Transesterification was performed in two steps: (1) acid esterification and (2) the base transesterification process. Methanol was used as solvent with H$_2$SO$_4$ and KOH for the acid and base transesterification respectively. The first step is needed if the acid value of the crude oil is greater than 4 mg KOH/gm. The acid value was calculated directly by titration. For the jatropha oil both steps were needed and for palm oil only the base transesterification was needed. Using the acid catalyst, the first step reduced the FFA level of the product was collected after filtration.

2.3. Fatty acid composition (FAC)

Different vegetable oils have different FAC. The FAC is unique for a particular species. Table 1 shows the FAC results of the produced palm and jatropha biodiesels. GC analysis (Agilent 6890 model) was used to obtain the FAC result. Table 2 shows the GC operating conditions.

2.4. Test fuel

The transesterification, blending and analysis of the test fuels were carried out at the Energy Laboratory and the Engine Tribology Laboratory, Department of Mechanical Engineering, University of Malaya. A total of seven test fuels were prepared for conducting the research. The test fuels chosen were (a) 100% neat diesel fuel (B0), (b) 10% palm biodiesel with 90% diesel fuel (PB10), (c) 10% jatropha biodiesel with 90% diesel fuel (JB10), (d) 20% palm biodiesel with 80% diesel fuel (PB20), (e) 20% jatropha biodiesel with 80% diesel fuel (JB20), (f) 5% palm and 5% jatropha biodiesel with 90% diesel fuel (PBJ5), (g) 10% palm and 10% jatropha biodiesel with 80% diesel fuel (PBJ10). These blended percentages are volume-based proportions. Blending was performed by a blending machine at 4000 rpm for 10–15 min. The density, viscosity and calorific value of the test fuels remain close to the B0 fuel up to 20% blends.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>GC operating condition.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
<td>Specifications</td>
</tr>
<tr>
<td>Carrier gas</td>
<td>Helium</td>
</tr>
<tr>
<td>Linear velocity</td>
<td>24.4 cm/s</td>
</tr>
<tr>
<td>Flow rate</td>
<td>1.10 mL/min (column flow)</td>
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<td>Detector temperature</td>
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</tr>
<tr>
<td>Column head pressure</td>
<td>56.9 kPa</td>
</tr>
<tr>
<td>Column dimension</td>
<td>BPX 70, 30.0 m × 0.25 μm × 0.32 mm ID</td>
</tr>
<tr>
<td>Injetor</td>
<td>240.0 °C</td>
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<tr>
<td>Temperature</td>
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<td>Temperature ramp</td>
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</tr>
<tr>
<td>8 °C/min 192.0 °C (hold for 5 min)</td>
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</tr>
</tbody>
</table>
Moreover, as using biodiesel blends increases BSFC, using more than 20% biodiesel may not be economically effective. Hence, blends with up to 20% biodiesel were experimented on in this study.

2.5. Equipment for fuel property test

The density, kinematic viscosity, flash point, cloud point, pour point and calorific value – the six main physicochemical properties of all the test fuels – were measured following standard methods. Table 3 shows a summary of the equipment and methods used to determine the fuel properties. SN, CN and IV were calculated by using the fatty acid composition results and the following empirical equations (1), (2) and (3) respectively (Devan and Mahalakshmi, 2009; Mohibbe Azam et al., 2005). The density, kinematic viscosity, ash point tester NPM 440 Normalab, France ASTM D93

Table 3

<table>
<thead>
<tr>
<th>Property</th>
<th>Equipment</th>
<th>Model</th>
<th>Manufacturer</th>
<th>Standard method</th>
<th>Accuracy</th>
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</thead>
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<td>SVM 3000</td>
<td>Anton Paar</td>
<td>ASTM D7042</td>
<td>±0.1 mm²/s</td>
</tr>
<tr>
<td>Flash point</td>
<td>Pensky–martens flash point tester</td>
<td>NPM 440</td>
<td>Normalab, France</td>
<td>ASTM D93</td>
<td>±0.1 °C</td>
</tr>
<tr>
<td>Cloud and pour point</td>
<td>Cloud and pour tester</td>
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<td>Normalab, France</td>
<td>ASTM D2500</td>
<td>±0.1 °C</td>
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<tr>
<td>Calorific value</td>
<td>Semi auto bomb calorimeter</td>
<td>6100 EF</td>
<td>Perr, USA</td>
<td>ASTM D240</td>
<td>±0.001 MJ/kg</td>
</tr>
</tbody>
</table>


2.7. Exhaust gas analyser

To determine the exhaust emission, a BOSCH exhaust gas analyser was used. HC and NO were measured in ppm. CO and CO₂ were measured in % vol using the BOSCH analyser. Gas analyser details and the pollutant measuring method are presented in Table 5.

2.8. Uncertainty analysis

Uncertainty was calculated through the analysis of the instruments’ accuracy and precision, along with the repeatability of the measurement. All experiments were performed several times and data were collected at least three times. Average values were used for graph plotting. Uncertainty analysis of NO emission is presented in the Appendix. Uncertainty analysis of other performance and emission data was performed in a similar way.

3. Results and discussion

3.1. Fuel properties

Each property test was repeated three times and mean values are presented in the table. The measured properties of the biodiesels and neat diesel fuel are represented in Table 6, with the ASTM and EN standard values of biodiesel properties for comparison.

The densities of all the biodiesels were found to be higher than diesel fuel, as expected. However, the densities of PBJB5 and PBJB10 were found to be slightly lower than JB10 and JB20, but slightly higher than PB10 and PB20 respectively.

Kinematic viscosity is influenced by the fatty acid profile of the biodiesel (Knothe and Steidley, 2005). As seen from Table 6, the kinematic viscosity levels of the biodiesels satisfied ASTM D-6751 02 and EN 14104-2003 standards. The kinematic viscosities of PBJB5 and PBJB10 were found to be slightly higher than diesel fuel, which is acceptable.

The calorific values of all biodiesels were, as expected, found to be less than B0. However, the calorific values of PBJB5 (45.8 MJ/kg) and PBJB10 (45.1 MJ/kg) were found to be close to B0.

The flash points of PBJB5 and PBJB10 were found to be higher than B0, which thus provides an advantage over B0 in terms of transport and handling. The measured flash point values are presented in Table 6. Although the flash point values of most of the tested fuels were not within ASTM and EN standards, the values are still safe enough for handling.

The pour point value indicates the pumpability, as it indicates the waxy nature of the oil. The pour points of PBJB5 and PBJB10 were found to be −3 °C and −5 °C, which favours their use in cold climates. However, the pour points of all the tested fuels were within the ASTM limit for biodiesel standard.

The cloud points of all the tested fuels were within the ASTM limit for biodiesel standard. The cloud points of PBJB5 and PBJB10 were found to be 2 °C and 1 °C higher than B0. Though the cloud point value is of limited concern in tropical and hot countries in
Asia, it has much greater importance in countries where the weather is cold.

3.2. Performance analysis

Engine performance was evaluated in terms of BSFC and engine brake power output. The following section will describe the results of these performance parameters.

3.2.1. Brake power

The variation of power output with engine speed for all the tested biodiesels and diesel fuel is presented in Fig. 3. The maximum brake power outputs of PBJB5 and PBJB10 were 5.1 and 4.9 kW at 2200 rpm engine speed, whereas the maximum brake power output for B0 was 5.5 kW. This reduced power for PBJB5 and PBJB10 may be explained by the higher density and viscosity values, which resulted in poor atomization and lower combustion efficiency (Kalam et al., 2011). However, the maximum brake power output of PBJB5 was found to be slightly lower than PB10 and slightly higher than JB10. By contrast, the maximum brake power output of PBJB10 was found to be slightly lower than PB20 and slightly higher than JB20. This trend can likewise be described by the viscosity and density variation among biodiesel blends.

3.2.2. Brake specific fuel consumption

The BSFC refers to the ratio between fuel mass flow rate and engine power. The variations in BSFC values with engine speed for all the tested fuels are presented in Fig. 4. However, in the case of biodiesel, the BSFC values were determined to be higher than that of B0. The higher density and lower heating value of biodiesel result in this obvious increase of BSFC (Mofjur et al., 2013; Shahabuddin et al., 2012). Average BSFC for PBJB5 and PBJB10 were found to be 7.55% and 19.82% higher than B0 respectively. As fuel is fed into the engine on a volumetric basis, to produce the same amount of power, more biodiesel is needed than diesel fuel due to its higher density and lower calorific value. On average, the BSFC of PBJB5 and PBJB10 were found to be 2.44% and 6.54% higher than PB10 and PB20 respectively. These higher BSFC values of PBJB5 and PBJB10 were due to their higher density and viscosity than PB10 and PB20. On the other hand, average BSFC for PBJB5 and PBJB10 were found to be 4.29% and 4.24% lower than JB10 and JB20 respectively due to their lower density and viscosity than the jatropha biodiesel blends. The lowest BSFC values for PBJB5 and PBJB10 were 0.33 kg/kWh and 0.35 kg/kWh at 2000 rpm speed. However, all the tested fuels showed their lowest BSFC at 2000 rpm.

3.3. Emission analysis

Emission analysis was conducted at engine speeds ranging from 1400 to 2400 rpm. The following section describes the results for CO, CO2, HC, NO and noise emission.

3.3.1. Carbon monoxide emission

Generally, CO formation results from incomplete combustion (Mofjur et al., 2013). Incomplete combustion occurs when the flame front approaches the crevice volume and a relatively cool cylinder liner (Kalam and Masjuki, 2004). Hence, the flame temperature is cooled down and results in incomplete progression to CO2. Comparison of the CO emissions of PBJB5 and PBJB10 with other fuel samples at different engine speeds is shown in Fig. 5. The average CO emissions of PBJB5 and PBJB10 were found to be 9.53% and 20.49% lower than B0. All the tested biodiesels showed less CO emission than B0 due to the additional oxygen content of biodiesels compared with diesel fuel, which ensures complete combustion. On average, the CO emissions of PBJB5 and PBJB10 were found to be 9.53% and 20.49% lower than B0. All the tested biodiesels showed less CO emission than B0 due to the additional oxygen content of biodiesels compared with diesel fuel, which ensures complete combustion. On average, the CO emissions of PBJB5 and PBJB10 were found to be 9.53% and 20.49% lower than B0. All the tested biodiesels showed less CO emission than B0 due to the additional oxygen content of biodiesels compared with diesel fuel, which ensures complete combustion. On average, the CO emissions of PBJB5 and PBJB10 were found to be 9.53% and 20.49% lower than B0. All the tested biodiesels showed less CO emission than B0 due to the additional oxygen content of biodiesels compared with diesel fuel, which ensures complete combustion. On average, the CO emissions of PBJB5 and PBJB10 were found to be 9.53% and 20.49% lower than B0. All the tested biodiesels showed less CO emission than B0 due to the additional oxygen content of biodiesels compared with diesel fuel, which ensures complete combustion. On average, the CO emissions of PBJB5 and PBJB10 were found to be 9.53% and 20.49% lower than B0. All the tested biodiesels showed less CO emission than B0 due to the additional oxygen content of biodiesels compared with diesel fuel, which ensures complete combustion. On average, the CO emissions of PBJB5 and PBJB10 were found to be 9.53% and 20.49% lower than B0. All the tested biodiesels showed less CO emission than B0 due to the additional oxygen content of biodiesels compared with diesel fuel, which ensures complete combustion.
1.18% and 3.21% higher than PB10 and PB20 respectively, which can be explained similarly by the viscosity and density of PBJB5 and PBJB10 being higher than PB10 and PB20.

3.3.2. Carbon dioxide emission

CO$_2$ emission indicates complete combustion of fuel inside the engine cylinder, which occurs at high cylinder temperatures (Arbab et al., 2013). Hence, the CO$_2$ emissions for all fuels increased with the increase in load, as expected. A comparison of CO$_2$ emissions for biodiesels with diesel fuel is presented in Fig. 6. The overall CO$_2$ emissions of PBJB5 and PBJB10 were slightly higher than that of B0. Due to the high oxygen content of biodiesel, combustion occurs more completely. Thus, CO$_2$ emission increases. However, the CO$_2$ emission of PBJB5 and PBJB10 showed a slight variation compared with the corresponding blend percentages of palm and jatropha biodiesel.

![Fig. 2. Experimental set-up.](image)

<table>
<thead>
<tr>
<th>Table 5</th>
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<tbody>
<tr>
<td>Details of Bosch exhaust gas analyser.</td>
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<tr>
<td>Equipment name</td>
</tr>
<tr>
<td>BOSCH gas analyser</td>
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![Fig. 3. Variation of engine power with engine speed.](image)

1.18% and 3.21% higher than PB10 and PB20 respectively, which can be explained similarly by the viscosity and density of PBJB5 and PBJB10 being higher than PB10 and PB20.

![Fig. 4. Variation of BSFC with engine speed.](image)
3.3.3. Hydrocarbon emission

Variation of HC emission in ppm for all the tested fuels against load is presented in Fig. 7. All fuels exhibited lower HC emission at lower engine loads and higher HC emission at higher engine load conditions. This is due to less oxygen being available for reaction when more fuel is injected into the engine cylinder at higher engine load (Kalam et al., 2011). Average HC reduction amounts for PBJB5 and PBJB10 were 3.69% and 7.81% less than B0. In the case of biodiesel, more complete combustion occurs than with diesel fuel due to the advanced combustion phasing. Moreover, the high oxygen content of biodiesel also aids complete combustion, and hence reduces HC emission (Lapuerta et al., 2008). Average HC emissions of PBJB5 and PBJB10 were found to be 3.69% and 7.81% less than B0. In the case of biodiesel, more complete combustion occurs than with diesel fuel due to the advanced combustion phasing. Moreover, the high oxygen content of biodiesel also aids complete combustion, and hence reduces HC emission (Lapuerta et al., 2008). Average HC emissions of PBJB5 and PBJB10 were found to be 1.53% and 1.72% lower than JB10 and JB20 respectively. However, HC emissions for PBJB5 and PBJB10 were found to be slightly higher than PB10 and PB20. This comparative HC emission result for PBJB5 and PBJB10 with other biodiesels can be explained by viscosity and density variation, as explained in the case of CO emission.

3.3.4. Nitric oxide emission

Generally NO emission is influenced by the cylinder pressure, temperature and oxygen content of fuel (Palash et al., 2013; Rahman et al., 2013b). The NO values as ppm for all the tested fuels in the exhaust emissions are plotted as a function of engine speed in Fig. 8. NO formation increased with engine speed for all the tested fuels, because at high speed cooling could not be performed properly and the combustion temperature increased. A higher combustion temperature increases NO by stimulating NO-forming reactions. The NO emission of B0 was found to be 2.81% and 6.84% lower than PBJB5 and PBJB10 respectively. Because of their respective chemical structures, all biodiesels contain invariably the same level of excessive oxygen compared with diesel fuel. In addition to the inducted air inside the engine cylinder, oxygenated biofuels add some more oxygen, which influences the formation of NO. However, NO emissions of PBJB5 and PBJB10 were slightly lower (1–1.8%) than PB10 and PB20. As the cetane numbers of PB10 and PB20 were found to be higher than PBJB5 and PBJB10, the higher cetane number reduces the ignition delay, which increases the combustion time and temperature, and hence increases NO (Hoekman et al., 2012). On the other hand, the average NO formations of PBJB5 and PBJB10 were found to be almost the same as JB10 and JB20 respectively.

3.3.5. Noise emission

The combustion noise is influenced by the maximum pressure rise rate (dp/d\(\delta t\)) and increases with rising pressure. Thus, noise can be controlled by the reduction in the ignition delay period, so the engine can run more smoothly. Shorter ignition delay reduces the pressure rise inside the cylinder. Although the sound level can be measured from all directions from the engine, the highest levels were produced from the front of the engine (JunHong and Bing, 2005). Therefore, only the front sound level was considered in Fig. 9 and sound levels increased with speed for all the tested fuels. Sound levels of all the
biodiesels were found to be lower than that of B0. The higher viscosity of biodiesel provides lubricity and damping, which result in decrease of the sound level. Moreover, the higher cetane number of the biodiesel blends may decrease the ignition delay, which results in reduction of the maximum pressure rise inside the cylinder. The improved combustion efficiency of biodiesels due to their high oxygen content may also be a sound reduction factor. In percentage terms, the average sound levels of PBJB5 and PBJB10 were reduced by 2.5% and 5% compared with B0. However, the average sound levels of PBJB5 and PBJB10 varied slightly with the same percentage blends of palm and jatropha biodiesels.

4. Conclusion

In this work, the engine performance, emissions and noise of PBJB5 and PBJB10 palm and jatropha combined biodiesel—diesel blends were investigated and compared with B0, palm and jatropha biodiesel blends. At the expense of a slight increase in BSFC and NO emissions, the PBJB5 and PBJB10 biodiesels showed better emission characteristics than B0.

The following conclusions can be drawn from the present experimental endeavour:

- The calorific value of PBJB5 was found to be 45.8 MJ/kg, which was close to B0. Besides, PBJB5 and PBJB10 both have advantages over B0 in terms of transport and handling as their flash points were found to be higher.
- A considerable amount of CO reduction compared with B0 was found for PBJB5 (9.53%) and PBJB10 (20.49%). By contrast, the average HC reductions for PBJB5 and PBJB10 were 3.69% and 7.81% lower than B0.
- NO emission was increased for all the tested biodiesels compared with B0. However, NO emissions of PBJB5 and PBJB10 were found to be slightly lower than the B10 and B20 blends respectively, and almost the same for the B10 and JB20 blends.
- In percentage terms, the average sound levels of PBJB5 and PBJB10 were 2.5% and 5% lower than B0.
- Further research can usefully be carried out to analyse engine combustion characteristics and other emission parameters such as particulate matter, smoke, etc.

This experimental study supports the use of palm and jatropha combined biodiesel—diesel blends in diesel engines without the need for any substantial engine modification.

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Appendix. Uncertainty level of NO emission for PBJB5

<table>
<thead>
<tr>
<th>Test</th>
<th>ppm</th>
<th>1 ppm</th>
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Uncertainty level of NO emission for PBJB5: ± 0.62%.

References


