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

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Abstract

Ever increasing drift of energy consumption, unequal geographical distribution of natural wealth and the quest of low carbon fuel for cleaner environment are sparking off the production and use of biodiesels in many countries around the globe. In this work, different physicochemical property of palm and jatropha combined biodiesels have been presented which is acceptable according to ASTM standard of biodiesel specification. This paper presents experimental results of the research carried out to evaluate brake specific fuel consumption (BSFC), engine power, exhaust and noise emission characteristics of palm and jatropha combined blends in a single cylinder diesel engine at different engine speed ranged from 1400 to 2200 rpm. Though PBJB5 and PBJB10 biodiesels showed slightly higher BSFC compared to diesel fuel but all measured emission parameters and noise emission were significantly reduced, except for nitrogen oxides (NOx) emission. Carbon-monoxide (CO) emission for PBJB5 and PBJB10 were reduced 9.53% and 20.49% compared to diesel fuel. On the contrary, hydrocarbon (HC) emission for PBJB5 and PBJB10 were reduced 3.69% and 7.81% compared to diesel fuel. Produced sound levels of PBJB5 and PBJB10 were also reduced 2.5% and 5% compared to diesel fuel.

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Keywords: Biodiesel; Palm-jatropha combined blend; characterization; Engine performance; Emission analysis; Noise

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1. Introduction

Modern civilization and transport system are very much dependent on fossil fuels which are non-renewable in nature. Rapidly growing demand of transport fuel and industrialization has caused serious threat to the environment and energy security of the world [1]. Global fossil fuel consumption was increased around 40% in the year of 2011 than that of 2010 [2]. Moreover, only half of the usual energy demand can be supplied until 2023 with the current liquid fuel reserve [3]. This enormous drift of fossil fuel consumption is affecting our environment hazardously. These environmental degradation effects include global warming, air quality deterioration, ozone depletion, eutrophication, photochemical smog, oil spills, and acid rain [4]. Moreover, noise produced from road and rail traffic adversely affects human health. Lately, around 20% populations in the European Union suffer from unacceptable noise level [5].

Biofuel has so far been backed by the government policies of many countries due to greater energy security, reducing environment pollution, sustainability and other socio-economic issues [6]. The projection of Stuart Staniford back in 2008 on primary energy production from 1970 to 2050 strongly supports the increasing trend of renewable energy consumption profoundly [7]. The sustainability of biofuels progressively promoting its acceptance and market demand will rise in near future. Around 27% transport fuel will be completely replaced by biofuels within 2050 according to International Energy Agency [8]. Among all edible biodiesel feedstock, palm is one of the most productive and economically suitable as alternative biodiesel source. In recent years, researches have been carried out on performance and emission of palm biodiesel by several researchers. Investigations showed slightly higher BSFC but hydrocarbon (HC) and carbon monoxide (CO) emission were reduced significantly (30-65%) for palm biodiesel compared to diesel fuel though NOx emission increased [9]. On the contrary, jatropha is a potential non-edible feedstock and jatropha plant can be grown almost anywhere, even on gravely, sandy and saline soils. Recent experiments showed slight reduction in power and increase in BSFC for all tested jatropha biodiesels compared to diesel fuel. Significant reduction of HC, Smoke and particulate matter emission were observed for all tested biodiesels compared to diesel fuel. CO and NOx emission increased slightly. However, experimental investigation on palm and jatropha combined blends was not found [10].

This experimental endeavor deals with the possibility of using palm and jatropha combined biodiesel blends in energy generation in order to reduce air and noise pollution. Results of performance and emissions of palm and jatropha combined biodiesel blends in a single cylinder diesel engine are also represented graphically and compared with diesel fuel, palm biodiesel blends and jatropha biodiesel blends.

2. Property test

A total of seven test fuels were prepared for conducting research. The test fuels chosen were (a) 100% neat diesel fuel (D100), (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 (PBJB5), (g) 10% palm and 10% jatropha biodiesel with 80% diesel fuel (PBJB10). These blended percentages are volume based proportions. Blending was performed by a blending machine at 4000 rpm for 10-15 min.

Table 1 shows the summary of the equipment and methods used to determine fuel properties and Table 2 shows measured fuel properties of all tested fuels.
Table 1 List of equipment used for testing fuel properties

| Property                        | Equipment                      | Model   | Manufacturer         | Standard method     | Accuracy  |
|---------------------------------|--------------------------------|---------|----------------------|---------------------|-----------|
| Kinematic viscosity and density | Stabinger Viscometer SVM 3000 | Anton Paar |                       | ASTM D7042          | ± 0.1 mm²/s |
| Flash point                     | Pensky–martens flash point tester | NPM 440 | Normalab, France     | ASTM D93            | ± 0.1°C   |
| Cloud and pour point            | Cloud and pour point tester NTE 450 | Normalab, France | ASTM D2500          | ± 0.1°C   |
| Calorific value                 | Semi auto bomb calorimeter 6100EF | Perr, USA | ASTM D240           | ± 0.001 MJ/kg      |

Table 2 Measured fuel properties of all tested fuels

| Properties       | D100 | PB100 | JB100 | PB20 | JB20 | PB10 | JB10 | PBJB5 | PBJB10 | ASTM D 6575-02 |
|------------------|------|-------|-------|------|------|------|------|-------|--------|----------------|
| Density (kg/m³)  | 830.5| 859.2 | 862.2 | 836.5| 840.2| 833.5| 835.6| 834.6 | 837.5  | -              |
| Viscosity at 40°C (mm²/s) | 3.602| 4.617 | 4.723 | 3.983| 3.992| 3.704| 3.752| 3.728 | 3.985  | 1.9-6.0        |
| Flash point (°C) | 71   | 172.5 | 182.5 | 90.5 | 93.5 | 82.5 | 73.5 | 90.5  | >130   |               |
| Cloud point (°C) | 4    | 16    | 3     | 7    | 4    | 5    | 3    | 6     | 5      | -3~12         |
| Pour point (°C)  | -8   | 15    | 3     | -1   | -3   | -3   | -5   | -3    | -5     | -15~10        |
| Calorific value (MJ/kg) | 46.40| 39.907| 39.794| 44.1 | 43.3 | 45.5 | 44.7 | 45.8  | 45.1   |               |

3. Experimental Set up

Fig. 1 shows the test rig set up for the experimental study. The major specifications of the engine are shown in Table 3. Schematic diagram of the engine test rig is shown in Fig. 1. Data were collected through DYNAMAX 2000 data control system. To determine the exhaust emission BOSCH exhaust gas analyser was used. NI sound level measurement system was adopted to measure the sound level. A series of PCB 130 array microphones (model 130D20) were used in this regard. Microphones were positioned 1m away from the engine faces according to SAE recommendations for microphone position. Similar experiments were also performed by Zhang and Bing [11] by following similar standard.

Fig.1. Schematic diagram of the engine test rig
Table 3 Test engine specification

| Manufacturer | Yanmar Co. Ltd |
|--------------|----------------|
| Model No     | YANMAR TF 120-M |
| Engine type  | 4 – stroke DI diesel engine |
| Number of cylinders | One |
| Aspiration  | Natural aspiration |
| Cylinder bore | 92 mm |
| Stroke       | 96 mm |
| Displacement | 0.638 L |
| Continuous rated output | 2400 rpm |
| Rated power  | 7.7 kW |
| Cooling system | Radiator cooling |
| Compression ratio | 17.7 |
| Injection pressure | 200 kg/cm² |

4. Results and Discussion

In Fig. 2 average BSFC for PBJB5 and PBJB10 were found 7.55% and 19.82% higher than diesel fuel respectively. As fuel is fed into the engine on a volumetric basis, to produce 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 2.44% and 6.54% higher than PB10 and PB20 respectively. On the contrary, average BSFC for PBJB5 and PBJB10 were found 4.29% and 4.24% lower than JB10 and JB20 respectively due to their lower density and viscosity than jatropha biodiesel blends.

![Fig.2. Variation of BSFC with engine speed](image1)

![Fig.3. Variation of engine power with engine speed](image2)

The variation of power output with engine speed for all tested biodiesels and diesel fuel is presented in Fig.3. Maximum power output of PBJB5 and PBJB10 were 5.1 kW and 4.9 kW at 2200 rpm engine speed, whereas maximum power output for D100 was 5.5 kW. Reduction of power for PBJB5 and PBJB10 may be explained due to higher density and viscosity value which resulted poor atomization and lower combustion efficiency [12]. However, maximum power output of PBJB5 was found slightly lower than PB10 and slightly higher than JB10. On the contrary, maximum power output of PBJB10 was found slightly lower than PB20 and slightly higher than JB20. This trend can also be described similarly by the viscosity and density variation among biodiesel blends.

Comparison of the CO emissions of PBJB5 and PBJB10 with other fuel samples at different engine speed is shown in Fig.4. Average CO emission of PBJB5 and PBJB10 were found 9.53% and 20.49% lower than D100. All tested biodiesels showed less CO emission than D100 due to the additional oxygen content of biodiesels than diesel
fuel which ensures complete combustion. On average, the CO emission of PBJB5 and PBJB10 were found 2.66% and 3.84% lower than JB10 and JB20 respectively. These lower CO values of PBJB5 and PBJB10 were due to their lower density and viscosity than JB10 and JB20. Higher density and viscosity result in poor fuel atomization and spray formation which leads to incomplete combustion, hence increases CO emission. On the contrary, average CO emissions for PBJB5 and PBJB10 were found 1.18% and 3.21% higher than PB10 and PB20 respectively.

Variation of HC emission in parts per million (ppm) for all tested fuels against load is presented in Fig.5. Average HC reduction amount for PBJB5 and PBJB10 were 3.69% and 7.81% lower than D100. High oxygen content of biodiesel also aids to complete combustion, hence reduce HC emission. Average HC emission of PBJB5 and PBJB10 were found 1.53% and 1.72% lower than JB10 and JB20 respectively. However, HC emission for PBJB5 and PBJB10 were found slightly higher than PB10 and PB20.

The NOx values in ppm for all tested fuels in the exhaust emissions are plotted as a function of engine speed in Fig.6. NOx emission of D100 was found 2.81% and 6.84% lower than PBJB5 and PBJB10 respectively. In addition to inducted air inside the engine cylinder, oxygenated biofuels add some more oxygen which influences the formation of NOx. However, NOx emission of PBJB5 and PBJB10 were slightly lower (1-1.8%) than PB10 and PB20. On the contrary, average NOx formation of PBJB5 and PBJB10 were found almost same as JB10 and JB20 respectively.

Though, sound level can be measured from all directions from the engine, highest level of sound were produced from the engine front side [11]. Therefore, only front side sound level was considered in Fig.7 and sound levels were increased with the speed for all tested fuels. Sound level of all biodiesels were found lower than that of diesel fuel. Higher viscosity of biodiesel provides lubricity and damping which result in the decrease of sound level. In percentage, average sound level of PBJB5 and PBJB10 were reduced by 2.5% and 5% compared to D100. However, average sound level of PBJB5 and PBJB10 were slightly varied with same percentage blends of palm and jatropha biodiesels.
3. Conclusion

Important findings of this experimental endeavour are summarised as follows:

- A considerable amount of CO reduction were found for PBJB5 (9.53%) and PBJB10 (20.49%) than that of D100.
- Average HC reduction amount for PBJB5 and PBJB10 were 3.69% and 7.81% lower than D100.
- NO\textsubscript{x} emission was increased in case of all tested biodiesels compared to D100. However, NO\textsubscript{x} emission of PBJB5 and PBJB10 were found slightly lower than PB10 and PB20 blends respectively and almost same for JB10 and JB20 blends.
- In percentage, average sound level of PBJB5 and PBJB10 were reduced by 2.5% and 5% compared to D100.

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

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