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Experimental Investigation of Fuel Properties and Engine Performance Characteristics of a Diesel Engine Fueled by Optimum Blend of Palm and Coconut Biodiesel Under Turbocharged and Non-Turbocharged Conditions

M. I. Arbab[+], H. H. Masjuki, M. Varman, M. A. Kalam, H. Sajjad and S. Imtenan

Center for Energy Science, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

Abstract. Global warming with rapid changes in climate, raising environmental concern and increase in price due to depletion of fossil fuel because of increase in usage are leading scientists to work toward alternative fuel. Biodiesel can be an effective solution in spite of some limitations to use as fuel because of poor fuel properties. In order to overcome these limitations, experiment had been conducted to improve fuel properties of palm biodiesel by blending with coconut and jatropha biodiesel. MATLAB optimization tool was used to find out the optimum blend ratio to achieve overall better fuel properties and a new biodiesel was developed which had been represented by PC (optimum blend of palm and coconut biodiesel. Engine performance and emission were tested using 20% blend of palm and PC biodiesels with petroleum diesel and compared with each other and petroleum diesel under both turbocharged and non-turbocharged conditions. PC20 (blend of 20% PC biodiesel and 80% petroleum diesel) showed the highest engine power at lower BSFC than other tested fuels at full load condition in presence of turbocharger. The emission characteristic of PC20 is also very much comparative of petroleum diesel.

Keywords: Biodiesel, Fuel properties, Optimum blend, Performance, Emission

1. Introduction

The world energy crisis due to depletion of fossil fuel and increasing environmental concerns leading scientists to look for an alternative source of energy which is eco-friendly as well. In order to solve this problem, many countries over the world have started a lot of research [1], [2]. One such solution would be biodiesel as it is nontoxic and biodegradable [3]-[6]. Use of biodiesel minimizes greenhouse gases emission because of close carbon cycle [4].

Many researchers conducted their experiment to improve biodiesel fuel properties blending with petroleum diesel [5]-[7]. In this article, overall fuel properties of biodiesel have been improve by blending two pure biodiesel which is very new concept in this field and the experiment is conducted to find out the effect of biodiesel-biodiesel blends on engine performance and emission. The reason of choosing palm and coconut biodiesel is their good fuel properties. In addition, Malaysia is one of the world largest palm producer and the government has decided to use 40% (about 6 million tons) of total palm produced annually as biodiesel [8]. On the other hand, coconut biodiesel has good emission characteristics [9], [10]. Besides, many researchers conducted their experiment with the blends of single biodiesel [9]-[15]. Most of the cases 15-25% blend of biodiesel with petroleum diesel showed relatively better engine performance than any other blend ratio [11], [12], [14], [16], [17]. Hence, in Malaysia, the use of 5% blend of biodiesel has already been started commercially and EU had aimed to use 20% biodiesel by 2020 [8]. In this experiment 20% blend of

[+] Corresponding author. Tel.:+601 63580809.
E-mail address: (arbab128@yahoo.com).

each of the biodiesels with petroleum diesel has been used to investigate the engine performance and emission characteristics compared to petroleum diesel.

2. Blending method

Experiments were conducted using blends of palm and coconut based biodiesel. Many researchers found from their experiment that most of the important fuel properties like density, kinematic viscosity, oxidation stability, flash point, calorific value and cetane number vary linearly in case of multiple biodiesel blends [5], [18], [19]. Hence, the linear relationship among the fuel properties has been considered to find out the optimum blending ratio and MATLAB optimization tool has been utilized.

3. Experimental Procedure

3.1. Fuel Properties Improvement

Engine performance and emission are directly affected by the physiochemical properties of the fuel like density, viscosity, flash point, oxidation stability, cetane number, iodine value, acid value etc. These properties indicate the quality of a fuel. Among these properties, most of the researchers concentrated their mind to density, kinematic viscosity, oxidation stability, flash point, calorific value and cetane number to determine the quality of fuel [15], [20], [21]. There are different types of standard like ASTM, BS, ISO, etc. to define the fuel properties. These standards have defined the range of each of the fuel properties. Among these standards, ASTM is the most widely followed standard. To meet the standard engine performance and emission, the value of the fuel properties must be in the range.

Table 1: Apparatus used for testing fuel properties

Properties	Apparatus
Density & Kinematic Viscosity	Stabinger Viscometer SVM 3000, Manufacturer: Anton Paar
Induction Time	873 Biodiesel Rancimat,Manufacturer: Metrohm
Flash Point	Pensky-Martens flash point-automatic NPM 440; Manufacturer: Normalab, France
Calorific value	Semi auto bomb calorimeter Model: 6100EF, Manufacturer: Parr, USA

Table 2: Experimentally investigated individual fuel properties

Properties	**Standard and limit**	**Coconut biodiesel**	**Palm biodiesel**	**Diesel**	**PC**
Density (g/cm^3)	-	0.8594	0.8592	0.8331	0.8597
Kinematic Viscosity at 40^o C (cSt)	ASTM-D445 (1.9-6)	4.6281	4.6175	3.556	4.6295
Induction time (hrs)	ASTM (3hrs min)	5.12	3.24	-	3.66
Flash Point (^{o}C)	ASTM-D93 (130^{o}C min)	136.5	188.5	77.5	180.5
Calorific Value (kJ/g)	-	36.985	39.907	44.664	38.5555

In this experiment, new biodiesels with improved fuel properties were developed by blending palm (PB) and coconut (CB) biodiesel. The list of apparatus used to find out the fuel properties is presented in Table 1 and the individual fuel properties of PB and CB are presented in Table 2. After that MATLAB code was developed considering linear relationship to find out the optimum blend ratio. The boundary conditions that were considered for the MATLAB optimization are mentioned in Table 3 and also the optimum blend ratios. Then using the optimum blend ratio and the linear equations the theoretical fuel properties value for the blends were determined. Finally the blend was prepared according to the optimum blend ratio and the fuel properties of the blends were tested in the lab (Table 2).

Table 3: Boundary conditions and optimum blending ratio derived using MATLAB

<table>
<tr><th colspan="3">Properties</th><th>PC</th></tr>
<tr><td rowspan="6">Boundary Limits</td><td rowspan="2">Maximum</td><td>Density (gm/cm^3)</td><td>0.86</td></tr>
<tr><td>Kinematic Viscosity at 40^{o}C (cSt)</td><td>4.62</td></tr>
<tr><td rowspan="4">Minimum</td><td>Induction time (hrs)</td><td>3</td></tr>
<tr><td>Flash Point (^{o}C)</td><td>160</td></tr>
<tr><td>Calorific Value (kJ/g)</td><td>39</td></tr>
<tr><td>Cetane Number</td><td>55</td></tr>
<tr><td colspan="4">Optimum Blend Ratio (%)</td></tr>
<tr><td colspan="2">Palm biodiesel</td><td colspan="2">Coconut biodiesel</td></tr>
<tr><td colspan="2">87.6</td><td colspan="2">12.4</td></tr>
</table>

3.2. Engine Test

The experiment was conducted using an inline four cylinder, water cooled, turbocharged diesel engine. The engine specification is listed in Table 5. The schematic experimental setup is shown in Fig. 1.

In this study, the engine was run at full loaded condition at different engine speed ranged from 1000 rpm to 4500 rpm at an interval of 500. First of all engine performance and emission were tested using petroleum diesel at non-turbocharged condition and considered it as the base line for the comparison. Then the engine performance and emission data for petroleum diesel (OD), P20 (blend of 20% PB and 80% petroleum diesel) and PC20 (blend of 20% PB-CB optimum blend and 80% petroleum diesel) were recorded under non-turbocharged and turbocharged condition. The collected data under non-turbocharged condition are represented as Diesel, P20, and PC20. On the other hand, Diesel_T, P20_T and PC20_T represent data under turbocharged condition.

Table 4: Engine specification

Multi-cylinder diesel engine	
Engine type	4 cylinder inline
Displacement	2.5 L (2,476 cc)
Bore	91.1 mm
Stroke	95.0 mm
Power	65kW at 4200 rpm
Torque	185 N m, at 2,000 rpm
Compression ratio	21:1

4. Results and Discussion

4.1. Fuel properties

From the experimental fuel properties of CB, PB and OD (Table 2); it is obvious that the density of all biodiesels is very close to each other and about 3-3.5% higher than petroleum diesel. The kinematic viscosity of CB and PB is also very close to each other and about 0.4% higher than other biodiesels. PB had an induction time very close to the ASTM standard (3 hours) and CB had the highest (5.12 hours). The flash point of all the biodiesel is high enough except the CB which is very close to the minimum ASTM limit (130^{o}C). The calorific value (CV) of the biodiesels is on average 11% lower than OD. CB has got the lowest CV (36.98 kJ/g).

Fig. 2 shows the variation between the theoretical (obtained using the optimum blend ratio and the linear equations used in MATLAB) and experimental (obtained from lab test) fuel properties.

4.2. Engine Performance

Fig. 3 illustrates the engine brake power at full load operating condition. Biodiesel blends shows higher brake power than OD for most of the cases. Presence of additional oxygen in biodiesel gives better combustion and results more power. However, JPC20 shows maximum increment of power throughout the test and about 2% and 3.5% average power increment is observed than that of OD under non-turbocharged and turbocharged condition respectively.

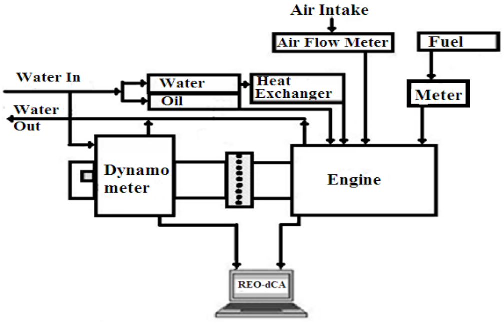

Fig. 1: Schematic of engine test bed

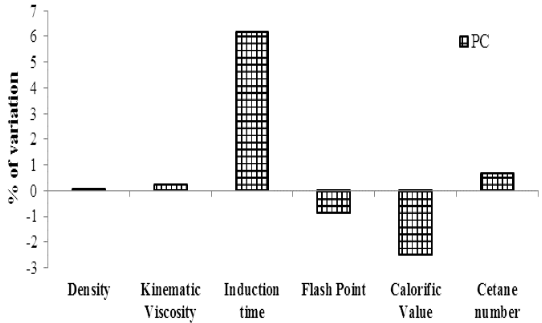

Fig. 2: Percentage (%) of variation between theoretical and experimental blended fuel properties

Fig. 4 shows the percentage change of BSFC of the engine for blends of the biodiesels and OD with respect to OD at non-turbocharged condition at different engine speeds. Under non-turbocharged condition, all the biodiesels show higher fuel consumption though at higher speed, higher combustion temperature and higher oxygen containing characteristic of biodiesel give better combustion and lower the fuel consumption. However, lower calorific value of CB causes the higher BSFC of PC20 at higher speed. On the other hand, under turbocharged condition, all the fuels show lower fuel consumption and PC20 shows the maximum reduction of fuel consumption than any other fuels.

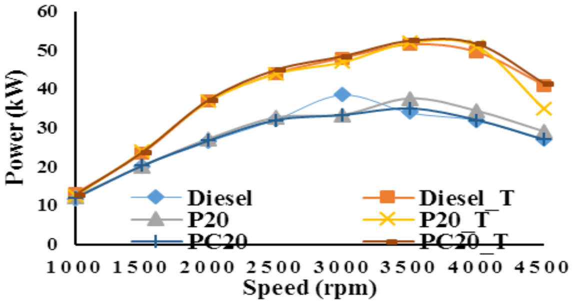

Fig. 3: Engine brake power at different speed

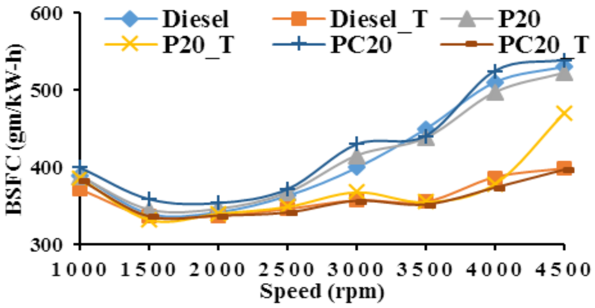

Fig. 4: Engine BSFC at different speed

The brake thermal efficiency characteristics at different speed are shown in Fig. 5. All the biodiesel blends show higher thermal efficiency than that of OD throughout the test except P20 under turbocharged condition. Under non-turbocharged condition, irregularity is observed as the engine is designed to run with turbocharger. However, in most of the cases, higher efficiency is observed. PC20 shows the maximum thermal efficiency under turbocharged condition and average 5-6% higher than OD. On the other hand, P20 shows the maximum efficiency under non-turbocharged condition.

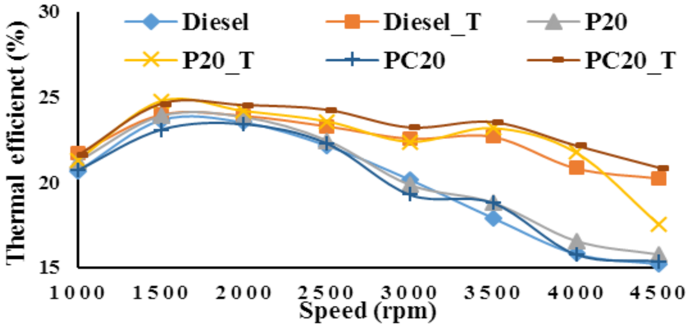

Fig. 5: Engine brake thermal efficiency at different speed

5. Conclusion

In this study our main objectives were to improve fuel properties of biodiesel and test the engine performance and emission characteristics of the biodiesel blends in a turbocharged engine to compare with petroleum diesel at non-turbocharged condition. The following conclusions are drawn as a summary of the experiment:

- Fuel properties can be improved by blending two or more biodiesels. There is an optimum blend ratio to improve fuel properties and the properties of fuel vary linearly in case of multiple fuel blends.
- 20% blend of biodiesel can give better engine performance. Optimum blend of palm-coconut biodiesel showed the highest brake power and lowest BSFC at full loaded condition.
- Considering engine performance and emission characteristics, PC can be a good option to replace palm biodiesel blends which is commercially available at present.

6. Acknowledgement

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