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Performance and emission characteristics of a diesel engine fueled with palm, jatropha, and moringa oil methyl ester

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ABSTRACT

This paper aims to investigate the diesel engine performance and emission characteristics fueled with moringa biodiesel and compare those with the performance and emission characteristics of palm biodiesel, jatropha biodiesel, and diesel fuel. In this study, only 20% of each biodiesel (described by MB20, PB20, and JB20, respectively) was tested in diesel engine, given that open literature indicates the possible use of biodiesel of up to 20% in a diesel engine without modification. The physical and chemical properties of all fuel samples are also presented and compared with ASTM D6751 standards. A naturally aspirated multi-cylinder, four-stroke direct-injection diesel engine was used to evaluate their performance at different speeds and full load condition. All biodiesel fuel samples reduce brake power (BP) and increase brake-specific fuel consumption (BSFC) than diesel fuel. Engine emission results indicated that blended fuel reduces the average carbon monoxide (CO) and hydrocarbons (HC) emissions except nitric oxides (NO) emissions than diesel fuel. Among the biodiesel-blended fuel, Palm biodiesel showed better performance and minimal emission than jatropha and moringa biodiesel fuel. Although PB20 showed better performance, but performance of MB20 biodiesel blend is comparable with other fuels. Correspondingly, 20% of moringa biodiesel can be used in a diesel engine without any engine modification.

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1. Introduction

Diesel engines are widely used than petrol engines in heavy duty application to produce power given its higher combustion efficiency (Mofijur et al., 2013). Accordingly, the demand of fossil diesel fuel is increasing, but their reserves are depleting every year (Silitonga et al., 2015). Diesel fuel is currently one of the main resources of energy; however, their combustion in internal combustion results in harmful emission to the environment, which in turn causes global warming (McCarthy et al., 2011). Finding an alternative fuel and source of energy to meet the global energy demand is highly needed. Biodiesel is renewable and one of the better alternative fuels for diesel engines. Biodiesel can be produced from vegetable oils and animal fats (Hassan et al., 2015; Ávila and Sodré, 2012) through the transesterification process (Gomes Filho et al., 2015; Yunus Khan et al., 2015). Biodiesel can be mixed with diesel fuel, and up to 20% percentage of biodiesel can be used in a diesel engine without any major engine modification (Tan et al., 2012). Biodiesel can be produced from both edible and non-edible oils (Amani et al., 2013; Silitonga et al., 2014; Zhang et al., 2015). A total of 350 oil bearing crops have been identified worldwide to produce biodiesel. Among the biodiesel sources, the common edible oil sources for biodiesel production are peanut oil, soybean oil, sunflower oil, safflower, corn oil, rice bran oil, palm oil, coconut oil, and so on; and non-edible oil sources include *Jatropha curcas*, *Pongamia glabra* (karanja), *Madhuca indica* (Mahua), *Salvadora oleoides* (Pilu), cotton seed oil, tobacco, *Calophyllum inophyllum*, moringa, and croton, among others (Chammoun et al., 2013; Atabani et al., 2014). The physical and chemical characteristics of biodiesel fuel from different sources are different, which may not always meet the standard specifications. Biodiesel fuel with its different properties, may affect the combustion characteristics in a diesel engine. For example, biodiesel has higher viscosity and density, which may cause poor spray and atomization in the injection process (Rao, 2011). In addition, biodiesel has a higher cetane number than does diesel fuel, which shortens the ignition delay period (Can, 2014).

Research on biodiesel should be focused on properties, including their effects on engine performance, emission, and combustion

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characteristics. Different studies related to engine performance and emission using biodiesel from edible and non-edible oil sources can be found in the literatures (Rahman et al., 2014; Chauhan et al., 2012; Habibullah et al., 2014; Sanjid et al., 2014). For example, Habibullah et al. (2014) studied the performance and emission of 30% palm biodiesel blend with diesel fuel in a diesel engine, and compared with the performance and emission of biodiesel and diesel fuel. All the biodiesel fuel blends increase the brake-specific fuel consumption (BSFC) by 8.55–9.03%, and decrease the brake thermal efficiency by 3.84–5.03% than diesel fuel; furthermore, their emission studies indicated that biodiesel blended fuel reduces CO and HC emission by 13.75–17.97% and 18.26–31.21%, respectively (Habibullah et al., 2014). Sanjid et al. (2014) studied the performance and emission characteristics of palm, jatropha, and the combined blend in a diesel engine at different engine speeds. Combined blend of palm and jatropha biodiesel increases BSFC by 7.55–19.82% and lowers CO and HC by 9.53–20.49% and 3.69–7.81%, respectively (Sanjid et al., 2014). Despite the existence of different literature related to the uses of biodiesel from palm (edible) and jatropha (non-edible) oil sources in diesel engines, only a limited number of studies examine the performance and emission of moringa biodiesel in diesel engines. Recently, many studies have been published on the production of biodiesel from moringa oil and their characterization (Rashid et al., 2008; Kafuku et al., 2010); however, very few authors have described the performance of moringa biodiesel in a diesel engine (Mofijur et al., 2013; Rajaraman et al., 2009). Moreover, several studies found biodiesel from edible and non-edible oils including their use as a fuel in diesel engines, but no extensive report exists on the comparison of jatropha, palm, and moringa methyl ester performance in a multi-cylinder diesel engine.

Accordingly, the current study mainly aims to evaluate the performance of moringa biodiesel in a multi-cylinder diesel engine and compare that with the performance of palm and jatropha biodiesel. This study presents the physical and chemical properties of palm, jatropha, and moringa biodiesel and their 20% by volume blends. Next, the performance and emissions of 20% by volume blends of palm, jatropha, and moringa biodiesel in a diesel engine are assessed and compared with the performance and emissions of diesel fuel.

2. Materials and method

2.1. Materials

Crude palm oil (CPO) and crude jatropha oil (CJO) were collected from the Forest Research Institute, Malaysia (FRIM), while crude moringa oil was collected from Tanzania, Africa through a personal correspondence. All other chemicals, reagents, and accessories were purchased from the local markets.

2.2. Biodiesel production

Free fatty acid (FFA) and acid values are the main identifiers of the production process. If crude oil contains higher acid value, then, two step processes are required considering the formation of fatty acid salts during the conversion of FFA into FAME (fatty acid methyl ester) using an alkaline catalyst. The fatty acid salt prevents the separation of FAME layer from glycerin. The acid values of crude palm, jatropha and moringa oils were measured to be 3.47, 10.7, and 8.62 mgKOH/g oil, respectively. Accordingly, two-step (acid–base catalyst) processes were selected to convert crude jatropha and moringa oil into jatropha and moringa biodiesel. Furthermore, only the transesterification process was selected to convert palm biodiesel.

2.2.1. Esterification process

In this process, the molar ratio of methanol to refined jatropha and moringa oils were maintained at 12:1 (50% v/v). 1% (v/v) of sulphuric acid (H_2SO_4) was added to the pre-heated oils at 60 °C for 3 h under 600 rpm stirring speed in a glass reactor. When this reaction was completed, the products were poured into a separating funnel to separate the excess alcohol, sulphuric acid, and impurities presented in the upper layer. The lower layer was separated and entered into a rotary evaporator, and heated at 95 °C under vacuum conditions for 1 h to remove methanol and water from the esterified oil.

2.2.2. Transesterification process

In this process, crude palm oil and esterified moringa and jatropha oils were reacted with 25% (v/v) of methanol and 1% (m/m) of potassium hydroxide (KOH), and maintained at 60 °C for 2 h and 600 rpm stirring speed. After the reaction was completed, the produced biodiesel was deposited in a separation funnel for 15 h to separate glycerol from biodiesel. The lower layer which contained impurities and glycerol was drawn off.

2.3. List of equipment used for property analysis

The physico-chemical properties of the produced biodiesel such as fatty acid composition, cetane number, density, kinematic viscosity, calorific value, and flash point, were measured according to the ASTM standards. Table 1 shows the equipment used in this study. Palm biodiesel was found to have the highest saturated fatty acids (44.6%), followed by the jatropha (22.6%), and moringa biodiesel (18.6%). Furthermore, palm biodiesel has the highest cetane number (59) than jatropha (51) and moringa biodiesel (56). Table 2 shows the major fuel properties of used biodiesel. Then, the test fuels were blended with diesel for 20 min using a homogenizer operated at 2000 rpm to be used in the engine.

2.4. Engine test

A Mitsubishi Pajero (model 4D56T) multi-cylinder diesel engine was used to perform the performance and emission test. In this study, B20 of each biodiesel has been used given that up to 20% by volume biodiesel has been reported to be possibly used in a diesel engine without any modifications. Also the properties of B20 are within the limit of ASTM D6751 standards. The engine was run at full load condition and at different speeds ranging from 1000 rpm

Table 1
List of equipment used in the characterization of fuels.

Property	Equipment	Manufacturer	Standard method	ASTM D6751 limit	Accuracy
Kinematic viscosity at 40 °C	SVM 3000-automatic	Anton Paar, UK	D 7042	1.9–6.0	±0.35%
Density at 40 °C	SVM 3000-automatic	Anton Paar, UK	D 7042	–	±0.1 kg/m^3
Flash point	Pensky-martens flash point—automatic NPM 440	Norma lab, France	D 93	130 min	±0.1 °C
Calorific value	C2000 basic calorimeter—automatic	IKA, UK	D 240	–	±0.1% of reading
Cloud point	Cloud and pour point tester—automatic NTE 450	Norma lab, France	D 2500	Report	±0.1 °C
Pour point	Cloud and pour point tester—automatic NTE 450	Norma lab, France	D 97	–	±0.1 °C
CFPP	Cold filter plugging point—automatic NTL 450	Norma lab, France	D 6371	–	–

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