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Properties and use of *Moringa oleifera* biodiesel and diesel fuel blends in a multi-cylinder diesel engine

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ABSTRACT

Researchers have recently attempted to discover alternative energy sources that are accessible, technically viable, economically feasible, and environmentally acceptable. This study aims to evaluate the physico-chemical properties of *Moringa oleifera* biodiesel and its 10% and 20% by-volume blends (B10 and B20) in comparison with diesel fuel (B0). The performance and emission of *M. oleifera* biodiesel and its blends in a multi-cylinder diesel engine were determined at various speeds and full load conditions. The properties of *M. oleifera* biodiesel and its blends complied with ASTM D6751 standards. Over the entire range of speeds, B10 and B20 fuels reduced brake power and increased brake specific fuel consumption compared with B0. In engine emissions, B10 and B20 fuels reduced carbon monoxide emission by 10.60% and 22.93% as well as hydrocarbon emission by 9.21% and 23.68%, but slightly increased nitric oxide emission by 8.46% and 18.56%, respectively, compared with B0. Therefore, *M. oleifera* is a potential feedstock for biodiesel production, and its blends B10 and B20 can be used as diesel fuel substitutes.

1. Introduction

The reserves of petroleum-derived fuels are diminishing with their increasing demand every day. Moreover, the combustion products that result from burning these fuels are considered harmful to the environment. Several factors such as depletion of petroleum derived fuel, climate change, and increase in the price of petroleum products have generated interest in discovering alternative energy sources among researchers [1–3]. In the last decades, many researchers worldwide have searched for new alternative energy sources that are available, technically feasible, economically viable, and environmentally acceptable [4]. Biodiesel is considered one of the best alternative energy sources because of its potential to reduce dependency on fossil diesel fuel, capacity to decrease environmental pollutant output, and application in compression ignition (CI) engines with no modification [5,6]. Biodiesel is nonexplosive, biodegradable, nonflammable, renewable, nontoxic, environment friendly, and similar to diesel fuel [7,8]. The main advantages of biodiesel include the following: it can be blended with diesel fuel at any proportion; it can be used in a CI engine with no modification; it does not contain any harmful substances; and it produces less harmful emissions to the environment than diesel fuel [9,10].

Biodiesel can be obtained through transesterification of vegetable oils, animal fats, waste cooking oil, and waste restaurant greases [11]. It originates from edible and nonedible sources. The most common edible oils of biodiesel include palm oil, rapeseed oil, sunflower oil, coconut oil, and peanut oil, whereas the nonedible oil sources of biodiesel are Jatropha, neem, cotton, jojoba, rubber, Moringa, Mahua, castor, and animal tallow [12,13]. The present study aims to evaluate the potential of biodiesel production from *Moringa oleifera* oil as a promising feedstock that is easily accessible worldwide. This study characterizes the physico-chemical properties of *M. oleifera* biodiesel and its 10% and 20% by-volume blends. The properties that were investigated include kinematic viscosity, density, flash point, cloud point, pour point, and cold filter plugging point, viscosity index, and oxidation stability. Then, the performance of the 10% and 20% by-volume blends of *M. oleifera* biodiesel was assessed in a diesel engine. The relevant fuel properties of *M. oleifera* biodiesel, such as engine performance and emission characteristics, were fully investigated and compared with those of diesel fuel.

2. Literature review

M. oleifera is a member of the Moringaceae family, which mainly grows in tropical countries [14]. This drought-tolerant

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Nomenclature

ASTM	American Society for Testing and Materials
BP	brake power
B0	diesel fuel
B10	10% biodiesel + 90% diesel
B20	20% biodiesel + 80% diesel
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
CMOO	crude *Moringa oleifera* oil
CO	carbon monoxide
CO_2	carbon dioxide
FAC	fatty acid composition
FT-IR	Fourier transform-Infra red
HC	hydrocarbon
NO	nitric oxide
NO_x	oxides of nitrogen
PM	particulate matter

pioneer species is locally known in Malaysia as kachang kelur, but commercially it called "ben oil" or "behen oil." *M. oleifera* contains behenic (docosanoic) acid and significantly prevents oxidative degradation. *M. oleifera* can be used for medicinal and clinical purposes, and contains a substantial amount of nutrition value. The species is locally distributed in northwest India, Southeast Asia, Africa, South America, and Arabia [15,16]. However, it is also currently available in the Central America, Philippines, North America, Malaysia, and Cambodia. *M. oleifera* grows fast, can withstand a wide range of rainfall (25 cm to 300+ cm per year), and sustain life in poor soil (pH 5–9) [17,18]. The height of *M. oleifera* tree can range from 5 m to 10 m [19]. The seeds of *M. oleifera* are triangular and contain approximately 40% of oil by weight. The oil produced from the seed kernel of *M. oleifera* is golden yellow. *M. oleifera* oil reportedly contains elevated amounts of oleic acid, which comprises approximately 74.41% of its entire fatty acid profile [20].

Recent studies [21,22] have investigated the potential of biodiesel production from edible oil and nonedible oil sources, and their utilization in a diesel engine. Only a few studies [14,16,23–26] have reported on the potential of biodiesel production from *M. oleifera*, a nonedible oil source, and evaluated the blends of *M. oleifera* in a multi-cylinder diesel engine. Only Rajaraman et al. [27] have reported on the performance and emission characteristics of *Moringa* oil methyl ester and its blends (B20 to B100) in a direct injection diesel engine at various load conditions. They reported that *M. oleifera* blend exhibits lower brake thermal efficiency (BTE) than diesel fuel because of the former's lower heating value and higher viscosity and density than the latter. In engine emissions, *M. oleifera* blend produces lower HC, CO and PM emission but NO_x emission than diesel fuel. The properties of *M. oleifera* biodiesel and its blends meet the ASTM D6751 specifications, which are the standard specification for biodiesel (B100) fuels and indicate the product's suitability to be used in diesel engines.

3. Materials and methods

3.1. Materials

Crude *M. oleifera* oil (CMOO) was collected from University Sains Malaysia. All other chemicals, reagents, and accessories were purchased from LGC Scientific Sdn Bhd (Malaysia). The experimental investigation was performed using diesel fuel (B0), B10 (90% diesel and 10% *M. oleifera* biodiesel), and B20 (20% *M. oleifera* biodiesel and 80% diesel).

3.2. Equipment list

Table 1 highlights the equipment used to measure the physicochemical properties of *M. oleifera* biodiesel and its blends.

3.3. Biodiesel production

The high acid value of CMOO causes a problem during the separation process. Therefore, a two-step process (acid–base catalyst) was suggested to convert *M. oleifera* oil into biodiesel (methyl ester). The production of biodiesel was conducted at the Energy Lab of University Malaya using a 1 L batch reactor with a reflux condenser, a magnetic stirrer, a thermometer, and a sampling outlet. The summary of the biodiesel production process is given in Table 2. Furthermore, a comprehensive view of the biodiesel production processes is furnished in the following section.

3.3.1. Acid-catalyzed process

For biodiesel production, an acid-catalyzed process was used before transesterification to reduce the high acid value of crude oils. In this process, a molar ratio of 12:1 methanol to CMOO and 1% (v/v oil) of sulfuric acid (H_2SO_4) were added to the preheated oil at 60 °C for 3 h at 600 rpm stirring speed. After the reaction, the product was transferred to a separating funnel to separate the esterified oil (lower layer) from the upper layer, which includes excess alcohol, sulfuric acid, and impurities. The lower layer was then loaded into a control rotary evaporator (IKA) and heated at 60 °C under vacuum conditions for 1 h to remove methanol and water from the esterified oil. After esterification, the acid value was reduced to less than 4.

3.3.2. Alkaline-catalyzed process

In the alkaline-catalyzed process, a molar ratio of 6:1 of methanol and 1% (w/w oil) of potassium hydroxide (KOH) were added to the preheated esterified *M. oleifera* oil at 60 °C for 2 h at 600 rpm stirring speed. After the reaction, the produced methyl ester was deposited in a separation funnel for 16 h to separate glycerol from methyl ester. The lower layer, which contains glycerol and impurities, was drained.

3.3.3. Post-treatment process

The methyl ester was washed with warm distilled water to remove the impurities and glycerol. In this process, 50% (v/v oil) of distilled water at 60 °C was sprayed over the surface of the ester and stirred gently. This washing process was repeated several times until the pH of the biodiesel became neutral. The lower layer was discarded, and the upper layer was poured into a control rotary evaporator (IKA) to remove water and excess methanol from methyl ester. The methyl ester was poured into a flask, dried using anhydrous sodium sulfate (Na_2SO_4), and then further dried using the control rotary evaporator. Finally, the produced biodiesel was filtered using a qualitative filter paper (150 mm diameter, No. 1) to obtain the final product. The percentage of yield of the produced biodiesel was more than 90%.