Industrial Crops and Products 53 (2014) 78–84

Contents lists available at ScienceDirect

Industrial Crops and Products

journal homepage: www.elsevier.com/locate/indcrop

Comparative evaluation of performance and emission characteristics of *Moringa oleifera* and Palm oil based biodiesel in a diesel engine

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ARTICLE INFO

Article history:
Received 30 August 2013
Received in revised form
26 November 2013
Accepted 3 December 2013

Keywords:
Global energy consumption
Edible oil feedstock
Non-edible oil feedstocks, *Moringa oleifera* methyl ester
Engine performance and emissions

ABSTRACT

Biodiesels, which are made from various crops, as well as animal fat, are renewable, bio-degradable, and non-toxic and are eco-friendly compared with fossil fuels. Currently, there are more than 350 oil-bearing crops identified as potential sources for biodiesel production. In this study, the potential of biodiesel obtained from a non-edible oil source (*Moringa oleifera*) was explored and compared with that of palm biodiesel and diesel fuel. The physico-chemical properties of *M. oleifera* methyl ester were determined, and the properties of 5% and 10% (by volume) blends thereof (MB5 and MB10, respectively) were compared with those of palm-oil blends (PB5 and PB10) and diesel fuel (B0). The performance of these fuels was assessed in a multi-cylinder diesel engine at various engine speeds and under the full-load condition whereas emissions were assessed under the both full-load and half load condition. The properties of palm and *M. oleifera* biodiesels and their blends meet the ASTM D6751 and EN 14214 standards. Engine performance test results indicated that the PB5 and the MB5 fuels produced slightly lower brake powers and higher brake specific fuel consumption values compared to diesel fuel over the entire range of speeds examined. Engine emission results indicated that the PB5, MB5, PB10 and MB10 fuels reduced the average emissions of carbon monoxide by 13.17%, 5.37%, 17.36%, and 10.60%, respectively, and reduced those of hydrocarbons by 14.47%, 3.94%, 18.42%, and 9.21%, respectively. However, the PB5, MB5, PB10, and MB10 fuels slightly increased nitric oxide emissions by 1.96%, 3.99%, 3.38%, and 8.46%, respectively, and increased carbon dioxide emissions by 5.60%, 2.25%, 11.73%, and 4.96%, respectively, compared to the emissions induced by B0. *M. oleifera* oil is a potential feedstock for biodiesel production, and the performance of MB5 and MB10 biodiesel is comparable to that of PB5 and PB10 biodiesel and diesel fuel. Because the MB5 and MB10 fuels produce lower exhaust emissions than diesel fuel, these fuels can replace diesel fuel in unmodified engines to reduce the global energy demand and exhaust emissions to the environment.

1. Introduction

Most energy consumed (87%) is derived from fossil fuels, to which crude oil contributes 33.06%, coal 30.34%, and natural gas 23.67% (BP, 2012). The dominance of fossil fuels is primarily due to the fuels' adaptability, high combustion efficiency, availability, reliability, and handling facilities (de Vries, 2008; Mofijur et al., 2013a). However, the reserves of fossil fuels are diminishing; meanwhile, their demand increases every day. However, emissions produced by the combustion of fossil fuels have adverse effects on the environment and human health. It is predicted that greenhouse gas (GHG) emissions from fossil fuels will increase by 39% in 2030 if no significant efforts are undertaken to alleviate them. Numerous factors such as the depletion of petroleum-derived fuels, the threat of climate change, and increasing prices of petroleum products have motivated researchers to seek alternative energy sources (Lim and Teong, 2010; Jayed et al., 2011; Atabani et al., 2012). Therefore, for several decades, many researchers have been developing new alternative energy sources that are readily available, technically feasible, economically viable, and environmentally friendly. Biofuel is a feasible, clean alternative energy source that does not contain any harmful substances and produces fewer harmful emissions than diesel fuel (Mofijur et al., 2013b; Silalertruksa et al., 2012). Biodiesel is one of the best biofuels that can reduce the global dependency on fossil-based diesel fuels and the emissions of environmental pollutants without requiring the modification of vehicles. Biodiesel is non-explosive, biodegradable, non-flammable, renewable, non-toxic, and environmentally friendly, and it has properties that are similar to those of diesel fuel (Ávila and Sodré, 2012; Amani et al., 2013; Thomas et al., 2013). Biodiesel can be obtained by applying transesterification processes to vegetable oils, animal fats,

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0926-6690/$ – see front matter
http://dx.doi.org/10.1016/j.indcrop.2013.12.011

Nomenclature

ASTM	American Society for Testing and Materials
BP	brake power
BSFC	brake specific fuel consumption
CMOO	crude *Moringa oleifera* oil
CPO	crude palm oil
CO	carbon monoxide
CO_2	carbon dioxide
HC	hydrocarbon
POME	palm oil methyl ester
mm	millimeter
MJ/kg	megajoule/kg
MOME	*Moringa oleifera* methyl ester
NO	nitric oxide
NO_x	oxides of nitrogen
PM	particulate matter
rpm	revolution per minute

used cooking oil, and waste grease from restaurants (Vedaraman et al., 2012; Wazilewski et al., 2013). The most common sources of biodiesel are edible oils (palm, rapeseed, sunflower, coconut, peanut, soybean etc.). It has been reported that edible-oil biodiesels are limited in their ability to contribute to climate change mitigation and economic growth and serve as a substitute for petroleum production. The mass production of edible-oil biodiesels would leads to food price increases and would create pressure on land use, making it unsustainable. Recently, non-edible-oil feedstocks such as *Jatropha curcas*, *Moringa oleifera*, *Pongamia pinnata*, rubber oil, and cotton-seed oil have attracted world-wide attention for the production biodiesel.

1.1. Botanical description of palm and Moringa oleifera feedstocks

The palm tree reaches an average height of 20 m or more at maturity. The biophysical limits of the tree are as follows: altitude: up to 900 m, mean annual temperature: 27–35 °C, and mean annual rainfall: 2000–3000 mm. The root system consists of primary and secondary roots in the top 140 cm of soil. Leaves can reach 3–5 m in adult trees. Leaf blades have numerous (100–160 pairs) long leaflets with prominent midribs that taper to a point; these leaflets are arranged in groups or singly along the midrib, sometimes occurring in different planes.

M. oleifera, a member of the *Moringaceae* family, grows mainly in tropical countries and is a drought-tolerant species. The seeds of *M. oleifera* are triangular in shape and contain approximately 40% oil by weight (Atabani et al., 2013a,b). The oil produced from the seed kernel of *M. oleifera* is golden yellow in color. Recent studies have indicated that *M. oleifera* is native to Malaysia.

1.2. Objectives of the paper

Recently, many studies (Kalam and Masjuki, 2008; Patil and Deng, 2009; Safieddin Ardebili et al., 2011) concerning the production of biodiesel from edible oil and its use as a fuel for diesel engines have been published. In addition, a few authors (Rashid et al., 2008; da Silva et al., 2010; Kafuku et al., 2010; Rashid et al., 2011) have discussed the potential production of biodiesel from non-edible oils such as palm and *M. oleifera* oil. However, there is no report that provides a comparative evaluation of the performance of palm and *M. oleifera* biodiesel blends in diesel engines (Rahman et al., 2013). Only Rajaraman et al. (2009) has reported on the performance and emission characteristics of *M. oleifera* methyl ester and its blends (B20-B100) in a diesel engine under various load conditions. The authors reported that, compared to diesel fuel, *M. oleifera* methyl ester blends exhibit lower brake thermal efficiency (BTE) because of their lower heating value and higher viscosity and density than diesel fuel. With respect to engine emissions, *M. oleifera* methyl ester blends produce lower HC, CO, and PM emissions but higher NO_x emissions compared to diesel fuel. Therefore, the primary objective of this study was to examine non-edible oil sources, such as *M. oleifera*, as a potential feedstock for biodiesel production. In this investigation, a mixture of 5% palm and 5% *M. oleifera* oil with 95% diesel fuel was selected as a B5 reference fuel to improve its physic-chemical properties and assess its performance in a diesel engine, as is suggested by the Malaysian government.

Table 1
Properties of crude Palm oil (CPO) and Crude *Moringa Oleifera* oil (CMOO).

Properties	Units	Standards	CPO	CMOO
Dynamic viscosity	mPa s	ASTM D445	36.30	38.90
Kinematic viscosity at 40 °C	mm^2/s	ASTM D445	40.40	43.33
Kinematic viscosity at 100 °C	mm^2/s	ASTM D445	8.43	8.91
Viscosity Index	–	N/A	192.1	193.1
Density	kg/m^3	ASTM D4052	898.4	897.5
Flash point	°C	ASTM D93	165	268.5
Pour point	°C	ASTM D97	9	11
Cloud point	°C	ASTM D2500	8	10
Calorific value	MJ/kg	ASTM D240	39.44	38.05
Acid value	mgKOH/g oil	ASTM D664	3.47	8.62

2. Materials and methods

2.1. Materials

Crude palm oil (CPO) was collected from the Forest Research Institute, Malaysia (FRIM), and *M. oleifera* oil (CMOO) was generously supplied by a colleague (personal communication). All other chemicals, reagents, and accessories were purchased from local markets. Table 1 shows the properties of CPO and CMOO.

2.2. Production of palm and Moringa oleifera methyl esters

Palm and *M. oleifera* methyl esters were produced at the energy laboratory of the University of Malaya using a 1-L batch reactor, a reflux condenser, a magnetic stirrer, a thermometer, and a sampling outlet. To produce palm biodiesel, crude palm oil was reacted with 25% (v/v oil) methanol and 1% (m/m oil) potassium hydroxide (KOH) and maintained at 60 °C for 2 h and a stirring speed of 400 rpm. After the completion of the reaction, the produced biodiesels were deposited in a separation funnel for 15 h to separate glycerol from biodiesel. The lower layer, which contained impurities and glycerol, was drawn off. *M. oleifera* methyl ester was produced using an acid-base catalyst process. Before initiating the esterification process, the crude *M. oleifera* oils were heated to 60 °C using a temperature-controlled rotary evaporator (IKA) under vacuum to remove moisture. For the esterification process, a 12:1 molar ratio of methanol to crude oil and 1% (v/v) sulfuric acid (H_2SO_4) were added to the preheated oil and stirred at 600 rpm and 60 °C for 3 h. Then, the esterified oil was separated from the excess alcohol, sulfuric acid, and impurities using a separator funnel. The separated esterified oil was then heated to 60 °C in the rotary evaporator for 1 h to remove the methanol and water. For the transesterification reaction, a 6:1 molar ratio of methanol to oil and 1% (m/m oil) potassium hydroxide (KOH) were mixed with the preheated esterified oil and stirred at a constant speed of 600 rpm at 60 °C temperature for 2 h. After the reaction was complete, the methyl ester was kept in a separation funnel for 24 h. Then, the glycerol in the lower layer was drained out, and the methyl ester was washed with warm distilled water (3 times), dried in the rotary