Fuel 181 (2016) 985–995

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

# Assessment of performance, emission and combustion characteristics of palm, jatropha and *Calophyllum inophyllum* biodiesel blends

I.M. Monirul [a,*], H.H. Masjuki [a], M.A. Kalam [a,*], M.H. Mosarof [a,*], N.W.M. Zulkifli [a], Y.H. Teoh [a,b], H.G. How [a]

[a] Center for Energy Science, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] School of Mechanical Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia

## HIGHLIGHTS

- All of biodiesel blends showed almost 7.5% higher BSFC than diesel fuel.
- Diesel produces higher BP and BTE compared to biodiesel blends.
- JB20 produced 7.49% and 14.90% lower CO and HC emissions compared to diesel.
- JB10 produced 31.79% lower amount of smoke opacity than diesel fuel.
- PB20 has lower emission and better engine performance than diesel fuel.

## ARTICLE INFO

*Article history:*
Received 11 January 2016
Received in revised form 26 March 2016
Accepted 4 May 2016
Available online 9 May 2016

*Keywords:*
Renewable energy
Diesel engine
Biodiesel
Performance
Emission and combustion

## ABSTRACT

Biodiesel is an alternative diesel fuel that is produced from renewable resources. Energy studies conducted over the last two decades focused on solutions to problems of rising fossil fuel price, increasing dependency on foreign energy sources, and environmental concerns. Palm oil biodiesel is mostly used in Malaysia. Engine performance and emission tests were conducted with a single-cylinder diesel engine fueled with palm, jatropha and *Calophyllum inophyllum* biodiesel blends (PB10, PB20, JB10, JB20, CIB10, and CIB20) and then compared with diesel fuel at a full-load engine speed range of 1000–2400 rpm. The average brake specific fuel consumption increased from 7.96% to 10.15% while operating on 10%, and 20%, blends of palm, jatropha and *C. inophyllum* biodiesel. The average brake power for PB10 and PB20 were 9.31% and 12.93% lower respectively compared with that for diesel fuel. JB10 showed higher amount of brake specific fuel consumption than diesel and other biodiesel blends. PB20 produces comparatively lower CO and HC emissions than diesel and biodiesel blends. JB10 showed 31.09% lower smoke opacity than diesel fuel. Diesel produces lower amount of $NO_X$ emission compared to biodiesel blends. The higher peak cylinder pressure and heat release rate were found with CIB blends compared to diesel fuel, palm and jatropha biodiesel blends. Results indicated that PB20 has better engine performance, and lower emission compared with diesel and biodiesel blends. Thus, PB20 is suitable for use in diesel engines without the need for any engine modification.



## 1. Introduction

Nowadays, biodiesel plays an important role in helping overcome oil shortages and mitigating environmental effects in petroleum fuel fields worldwide [1]. Energy consumption has increased because of the wide use of fossil fuels in power plants, transportation vehicles, electric generators, mining equipment, and locomotives [2,3]. Prices of fossil fuels, such as coal, gas, and petroleum, are rising day by day [4]. Biodiesel is used as an alternative diesel fuel in transport vehicles and is produced from edible and non-edible vegetable oils [5]. It is biodegradable, oxygenated, nontoxic, sulfur-free, sustainable, renewable, and can be used in diesel engines, either in pure form or blended with diesel without any engine modification [6–9]. The use of fossil fuels, which produce high amounts of greenhouse gas emissions, can increase environmental pollution. Rail and road traffic produce more noise that can affect human health. In the European Union, 20% of the population suffers from this type of noise [10]. Moreover, many researchers observed that biodiesel shows low regulated and unregulated emissions [3,11]. Using biodiesel in diesel engines can reduce

* Corresponding authors.
*E-mail addresses:* monirulislam3103@gmail.com (I.M. Monirul), kalam@um.edu.my (M.A. Kalam), mosarof.hossain.rubel@gmail.com (M.H. Mosarof).

http://dx.doi.org/10.1016/j.fuel.2016.05.010
0016-2361/

**Nomenclature**

| | | | |
|---|---|---|---|
| BP | brake power | FAME | fatty acid methyl ester |
| BSFC | brake specific fuel consumption | GC | gas chromatography |
| BTE | brake thermal efficiency | JB | jatropha biodiesel |
| CIB | *Calophyllum inophyllum* biodiesel | JOME | jatropha oil methyl ester |
| CIME | *Calophyllum inophyllum* methyl ester | PB | palm biodiesel |
| FAC | fatty acid composition | POME | palm oil methyl ester |

harmful emissions, such as carbon monoxide, carbon dioxide, unburned hydrocarbon, and particulate matters [12–14]. The parameters of diesel engine performance, such as brake specific fuel consumption (BSFC), brake power (BP), brake torque, and brake thermal efficiency, must be improved to reduce emissions [13,15,16]. Fuel injection systems have played a vital role in improving fuel economy and reducing engine emissions. In injection systems, injection timing, injection duration, fueling, and injection pressure are the most important parameters that adversely affect engine performance and emissions [17,18]. Low emissions and high engine performance can be attained by recirculating exhaust gasses [19].

In diesel engines, various sliding engine parts produce more friction between the metal contact surfaces, which reduces engine reliability. Lubricity is one of the most important factors in extending engine life [20]. Lubrication is needed to reduce friction and wear between the engine sliding parts. Generally, fuel lubricity depends on dynamic viscosity, which is the function of temperature, pressure, density, and viscosity [21]. Engine components such as fuel pump, piston–cylinder liner, fuel injector, fuel depositors, and piston rings produce more friction; hence, these components require lubrication to reduce friction [22]. Carbon particle deposition, high viscosity and density, unsaturated fatty acid composition, corrosive nature, injector coking, and filter plugging are the main drawbacks of the lubrication effect [23]. Nevertheless, biodiesel provides better engine performance, lubricating performance, and lower emissions compared with diesel fuel.

Ozsezen and Canakci [24] observed the performance and emission of palm biodiesel that filled a six-cylinder diesel engine. They observed that BP decreased about 2.5% and BSFC increased about 7.5%. Palm biodiesel had lower HC (14.29%), CO (86.89%), and smoke (67.65%) emissions but a high amount of $NO_X$ (22.13%) emission compared with diesel fuel. When diesel and palm biodiesel blends fueled in a KIR-LOSKAR TV-1 type four-stroke diesel engine with varying loads of 20–100% at a constant speed (800 rpm) and full-load condition, BSFC showed for pure palm biodiesel and diesel fuel were 0.2749 and 3.31491 kg/kW h respectively. BSFC of 25%, 50%, and 75% palm biodiesel blends observed to be 2.59%, 8.93%, and 9.25% higher compared with those of diesel fuel [25]. Dorado et al. [26] reported that biodiesel blends showed slightly lower BSFC compared to ordinary diesel fuel. The effects of injector deposits, filter plugging, corrosion, and piston pump wear could be caused by oxidation stability in diesel and biodiesel [27]. Liaquat et al. [28], observed exhaust emissions for palm oil biodiesel used in a four-stroke DI diesel engine. The engine exhaust emissions were observed by a BOSCH gas analyzer, and the test was conducted on a 250 h engine speed at 2000 rpm. CO and $CO_2$ emissions decreased with increasing percentage of biodiesel in the blend. Diesel was given a higher amount of HC compared with palm biodiesel at full- and middle-load conditions [29]. Ong et al. [30], observed single-cylinder diesel engine performance and exhaust emissions within fueled high free fatty acid *Calophyllum inophyllum* biodiesel blends. CIB10 showed highest BTE and good engine performance. BSFC and EGT of CIB10 showed lower engine performance compared with diesel fuel. CIB10 reduced CO and smoke emission, although a slightly higher $NO_X$ emission was observed compared with diesel fuel. Adding some additives with CI biodiesel blends also reduced $NO_X$ emission [12].

Many researchers have investigated and compared palm and jatropha biodiesel blends with diesel fuel, whereas other studies compared palm and *Calophyllum inophyllum* (*C. inophyllum*) biodiesel blends with diesel fuel [13,31]. However, no study has been conducted that compares palm, jatropha, and *C. inophyllum* biodiesel blends with diesel fuel. The aim of this study, to observe the performance, emissions and combustion characteristics of a diesel engine by using palm, jatropha, and *C. inophyllum* biodiesel blends and also compare them. Finally, evaluating which biodiesel blend has better engine performance, lower emissions and combustion characteristics.

## 2. Materials and methods

### 2.1. Biodiesel production and blends

The crude palm oil collected from a Malaysian local market and crude *C. inophyllum* and *jatropha oil* were collected from a foreign supplier. The transesterification process was used to produce palm and CI biodiesel. Crude palm, jatropha and *C. inophyllum* oil were mixed with 25% methanol (V/V) and 1% KOH (w/w). In this process, the chemical reaction was obtained within 2 h by the maintaining a constant temperature of 60 °C and stirring speed of 1000 rpm. After the first step was completed, biodiesel was poured into a funnel to separate glycerin from biodiesel; the whole separation process took 12 h. After the reaction was completed, the lower layer was drawn off because it contained glycerin and some impurities. The methyl ester was washed with distilled water to remove the impurities. Distilled water (50% V/V) was sprayed over the esters at 60 °C. This process was repeated several times until all impurities from the methyl ester were completely removed. Then, methyl ester was dried with a rotary evaporator and filtered using filter paper. After all the steps were completed, the final product was collected for the experiment. POME, JOME and CIME were mixed with diesel to produce biodiesel blends. Three types of biodiesel blends were produced for palm and CI biodiesel, including PB10 (10% POME + 90% diesel), PB20 (20% POME + 80% diesel), JB10 (10% JOME + 90% diesel), JB20 (20% JOME + 80% diesel), CIB10 (10% CIME + 90% diesel), and CIB20 (20% CIME + 80% diesel). A total of six biodiesel blends and diesel were used in this experiment.

### 2.2. Fatty acid composition of biodiesel methyl ester

Gas chromatography (GC) was used to measure fatty acid composition of POME, JOME and CIME. This instrument shows fatty acid composition results in weight percentage. Fatty acid compositions of POME, JOME and CIME are shown in Table 1. For FAC analysis, 0.02 g of biodiesel was diluted with 1.5 ml hexane in a small vial; the diluted sample was charged with a flame ionization detector within 2 μl, which was connected by Perkin-Elmer GC. Then, each peak was identified and compared with the standard value