Industrial Crops and Products 59 (2014) 96–104

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Performance, emissions, and heat losses of palm and jatropha biodiesel blends in a diesel engine

M.J. Abedin*, H.H. Masjuki, M.A. Kalam*, A. Sanjid, S.M. Ashrafur Rahman, I.M. Rizwanul Fattah

Centre for Energy Sciences, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 22 January 2014
Received in revised form 30 April 2014
Accepted 4 May 2014
Available online 27 May 2014

Keywords:
Diesel engine
Performance
Emission
Heat loss
Biodiesel

ABSTRACT

After the successful implementation of B5, 5% palm (*Elaeis guineensis*) based biodiesel, in Malaysia on June 1, 2011, the Malaysian government is now looking to phase out B5 by replacing it with B10 or even a higher blending ratio. Being non-edible feedstock, jatropha (*Jatropha curcas*) can play a vital role along with the existing palm oil. This experiment was conducted in a four-cylinder diesel engine fuelled with B5, 10%, and 20% blends of palm (PB10 and PB20) and jatropha (JB10 and JB20) biodiesel and compared with fossil diesel at full load and in the speed range of 1000 to 4000 RPM. The brake power was decreased on average 2.3% to 10.7% while operating on 10% and 20% blends of palm and jatropha biodiesel. An average of 26.4% BSFC increment was observed for PB20 and JB20 blends. An average of 30.7% carbon monoxide (CO) and 25.8% hydrocarbon (HC) emission reductions were found for 20% blends. On average, the nitrogen oxides (NO_x) emission is decreased by 3.3% while operating on PB10 and PB20 blends, whereas it is increased by 3.0% while operating on JB10 and JB20 blends.

1. Introduction

Climate change, limited efficiency of automotive engines and stringent antipollution laws imposed by governments have created a stimulus to explore more efficient engines with acceptable emissions level. In this context, biodiesel can be a promising solution due to its comparable properties with fossil diesel fuel (Abedin et al., 2013; Jayed et al., 2009). It is non-toxic, non-flammable, biodegradable, and also environment-friendly. In addition, biodiesel can be used either pure or blended with fossil diesel fuel at any proportions and can be burnt by existing diesel engines without any further modifications (Mofijur et al., 2013; Rahman et al., 2013).

Oilseeds, in particular palm oil, are the main (about 73%) agricultural product of Malaysia. According to the United States Department of Agriculture (USDA), Malaysia is the World's second largest producer (32.7%) and exporter (40.0%) of palm oil, behind Indonesia (production, 53.3%, and export, 49.5%) (United States Department of Agriculture (USDA), 2013). As a non-edible feedstock, *Jatropha curcas* has drawn the attention of the Malaysian government. Few projects on jatropha cultivation have started and 57,601 hectares of jatropha are expected by 2015 (Mofijur et al., 2012). Palm oil based B5 biodiesel first rolled out in central regions of Malaysia on June 1, 2011, and then nationwide in early 2013. B5 is now available at 247 BHPetrol stations in Kuala Lumpur and consumes 1.03 million liters of palm-oil biodiesel each month, which saves nearly 12.4 million liters of fossil diesel fuel consumption per year (Paultan.org, 2011). After the successful implementation of B5, the Malaysian government is now looking to go beyond 5% (i.e., 10% or even higher) by mid-2014 (Mysinchew.com, 2013).

Most of the articles published regarding palm and jatropha biodiesel are based on single-cylinder engines and are subjected to biodiesel properties, engine performance, and emission analyses. It is reported that in a four-cylinder diesel engine (Canakci et al., 2009) at full load and different engine speeds using various palm biodiesel blends (5%, 10%, 20%, and so on), the power is almost same as diesel for 10% biodiesel and decreased with the increase of the blend ratio. The same article also reported that BSFC is higher

Abbreviations: BSFC, brake specific fuel consumption [g/KW h]; B5, 5% palm biodiesel + 95% diesel; B10, 10% biodiesel (any) + 90% diesel; FAME, fatty acid methyl ester; FFA, free fatty acid; LPG, liquefied petroleum gas; LHV, lower heating value [kJ/kg]; PB10, 10% palm biodiesel + 90% diesel; PB20, 20% palm biodiesel + 80% diesel; IC, internal combustion; JB10, 10% jatropha biodiesel + 90% diesel; JB20, 20% jatropha biodiesel + 80% diesel; RPM, revolution per minute.

* Corresponding authors at: Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia. Tel.: +60 1 82697028/+60 3 79676863; fax: +60 3 79675317/+60 3 79674448.

E-mail addresses: joynul06me@siswa.um.edu.my (M.J. Abedin), kalam@um.edu.my (M.A. Kalam).

http://dx.doi.org/10.1016/j.indcrop.2014.05.001
0926-6690/

Nomenclature

C	specific heat [kJ/kg K]
$\dot{m}$	mass flow rate [kg/s]
N	engine speed [rev/s]
P	power [kW]
Q	heat [kJ]
T	temperature [K]

Subscripts

a	air
b	brake
exh	exhaust
f	fuel
g	gas
oil	lubricating oil
s	supplied
w	water
un	unaccounted

for palm biodiesel compared to diesel fuel. They also found lower CO, HC, and smoke emissions and higher NO_x emission for palm blends. In a six-cylinder engine (Ozsezen and Canakci, 2011) using palm biodiesel, it is observed that the power is decreased about 2.5% and the BSFC is increased about 7.5%. The article also reported lower CO (86.89%), HC (14.29%), and smoke (67.65%) emissions and higher NO_x (22.13%) emission compared to diesel fuel. In a jatropha-fuelled three-cylinder engine (Sahoo et al., 2009), it is reported that the brake power is slightly increased and the BSFC is much higher compared to diesel at full load and different engine speeds. It is also reported that HC and smoke emissions are lower and CO and NO_x emissions are higher for jatropha blends. In a jatropha-fuelled four-cylinder engine (Manickam et al., 2009), it is reported that the power is decreased except at optimised injection timing, and the BSFC is always higher at full load and different engine speeds. In the same literature, it is observed that all emissions except NO_x are lower compared to diesel fuel. However, according to single-cylinder engine reports, the results are similar (lower brake power and higher BSFC) for palm (Ndayishimiye and Tazerout, 2011; Ng and Gan, 2010; Sharon et al., 2012) and jatropha (Chauhan et al., 2012; Ganapathy et al., 2011; Mofijur et al., 2013) biodiesel, though a few exceptions are also found (Agarwal and Agarwal, 2007; Huang et al., 2010; Tan et al., 2012). Similar emission results are reported for single-cylinder engines, but two researchers (Jindal et al., 2010; Sundaresan et al., 2007) reported higher CO emission while operating on jatropha biodiesel blends, and a few researchers (Kinoshita et al., 2003; Ng et al., 2012) reported slightly lower NO_x emission while operating on palm biodiesel blends. According to the previously cited articles, the lower calorific value, higher kinematic viscosity, and density of biodiesel cause poor fuel spray and atomisation which results in lower brake power, and higher BSFC. The contradictory results are attributed to the complete combustion characteristics of biodiesel for having more oxygen molecules in their structure. This factor is also responsible for the lower CO and HC emissions of biodiesel. Researchers claimed that the high in-cylinder combustion temperature associated with oxygenated biodiesel is the main reason for higher NO_x emission. The contradictory emission results, like lower NO_x emission, are attributed to the lower in-cylinder temperature due to the lower calorific value of biodiesel.

An IC engine is a complex of machinery and instrumentation, all of which must work together as a whole. It can be considered as a thermodynamic (open) system, which is an effective concept for understanding the thermodynamic behaviour of the system. It is linked to the idea of "control volume", a space enclosing the system and surrounded by an imaginary surface often known as the "control surface" (Fig. 1). If one can identify all the mass and energy flows into and out of a system, then it is possible to visualise the inside of that system by drawing up a thermal balance sheet of the inflows and outflows (Abedin et al., 2013). Heat loss analysis and thermal balancing are investigated by using hydrogen-gasoline (Yüksel and Ceviz, 2003), alcohol-diesel blends (Ajav et al., 2000), LPG fuel (i.e., liquefied petroleum gas) (Özcan and Söylemez, 2006), and biodiesel (Canakci and Hosoz, 2006; Debnath et al., 2013). They reported that all the heat losses are higher except exhaust heat loss while using biodiesel. The reason is attributed to the promotion of better combustion of biodiesel. The reason for lower exhaust heat loss is attributed to the lower concentration of HC and CO emissions in the exhaust gas for biodiesel (Canakci and Hosoz, 2006).

The objective of this experiment is to find out the variations in engine performance and emissions as well as heat loss characteristics while operating on diesel, B5, and 10%, and 20% blends of palm and jatropha biodiesel.

2. Materials and methods

2.1. Biodiesel production

Crude vegetable oils were converted to biodiesel by applying (a) acid esterification and (b) base trans-esterification processes. Crude palm oil only needed base trans-esterification process but crude jatropha oil required both steps because the acid value was greater than 4 mg KOH/gm. Methanol was used as solvent with H_2SO_4 and KOH for the first and second process, respectively. Using acid catalyst, free fatty acid (FFA) level of crude jatropha oil was reduced about 1–2%. A Favorit jacket reactor of 1 l capacity was used with IKA Eurostar digital stirrer and Wiscircu water bath arrangement. One liter crude oil, 200 ml methanol, and 0.5%·H_2SO_4 (v/v) were mixed in a flask for acid-catalysed esterification. The mixture was constantly stirred at 700·RPM, 50 °C to 60 °C temperature, and maintained at atmospheric pressure by circulating hot water through the jacket. A sample of 5 ml was taken from the flask at 10 min intervals to determine the FFA level. After completing the acid esterification process, the product was poured into a separating funnel where H_2SO_4 and excess alcohol including impurities were moved to the top. Then the top layer was separated and the lower layer was collected for base trans-esterification. The same experimental setup was used for the alkaline-catalysed trans-esterification process. Meanwhile, 1% KOH (w/w) dissolved in 25%·methanol (v/v) was poured into the flask. Then the mixture was stirred at 700 RPM and at 70 °C temperature. The mixture was heated and stirred for 3 h and again poured into a separating funnel where it formed two layers. The lower layer contained glycerol and impurities, and the upper layer was methyl ester of crude vegetable oil. The lower layer was discarded and the yellow upper layer was washed with hot distilled water (100%·v/v) and stirred gently to remove the remaining impurities and glycerol. Then the biodiesel was taken in an IKA RV10 rotary evaporator to reduce the moisture content. Finally, moisture was absorbed using sodium sulphate and the final product was collected after filtration.

2.2. Fatty acid (FA) composition

The fatty acid compositions of palm and jatropha biodiesel were tested using the MPOB test method (Malaysian Palm Oil Board (MPOB), 2005). A specified amount (0.02 g) of biodiesel was diluted with 1.5 ml hexane in a small vial. A Perkin-Elmer GC equipped with a flame ionisation detector (FID) was charged with 2 μl of diluted sample for FAC analysis. Identification of each peak was done by