ARTICLE IN PRESS

Engineering Science and Technology, an International Journal xxx (2018) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

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

Full Length Article

An experimental study on using diethyl ether in a diesel engine operated with diesel-biodiesel fuel blend

Amr Ibrahim

Mechanical Engineering Department, Beirut Arab University, 11 5020 Beirut, Lebanon

ARTICLE INFO

Article history:
Received 20 December 2017
Revised 25 June 2018
Accepted 8 July 2018
Available online xxxx

Keywords:
Diesel
Biodiesel
Diethyl ether
Engine
Combustion

ABSTRACT

Although biodiesel has a promising potential to be used as an alternative fuel for compression-ignition engines, its use may deteriorate engine performance. The objective of the current study was to enhance the performance of a compression-ignition engine operated with a diesel-biodiesel blend using diethyl ether (DEE). Four fuels were examined in a diesel engine to assess its performance and analyze the combustion process. These fuels were diesel, biodiesel-diesel mixture, and two mixtures of biodiesel-diesel-DEE with DEE proportions of 5% and 10% by volume. It was found that using diesel-biodiesel blend increased the minimum brake specific fuel consumption (bsfc) and reduced the maximum thermal efficiency by 8.1% and 6.8%, respectively, compared to diesel fuel. However, employing 5% DEE in the diesel-biodiesel mixture improved engine performance considerably for most engine loads in comparison with all fuels. Altering the fuel type had no significant impact on combustion start instant. However, the heat release rate was lower and combustion duration was longer for diesel compared to other fuels at higher engine loads. Using DEE did not significantly affect engine stability.

1. Introduction

The use of alternative renewable fuels for diesel engines has been recommended worldwide due to fossil fuel depletion and the harmful impact of petroleum fuel combustion on the environment [1–8]. Also, using renewable fuels can give the chance for many countries to reduce their dependence on imported oil [9].

Biodiesel is one of the most promising renewable fuels which can be used for diesel engines without engine modification [10,11]. Biodiesel has the potential to improve the combustion efficiency and decrease engine emissions because it is an oxygenated fuel. However, most studies [12] showed that using biodiesel as an alternative to diesel fuel in diesel engines without engine modification can result in some deterioration in engine performance such as a reduction in power and thermal efficiency because biodiesel properties such as viscosity, density, calorific value, etc differ from the corresponding diesel properties. Therefore, biodiesel is usually mixed with diesel in different ratios so that the fuel blend properties are more comparable to diesel fuel properties. Also, fuel additives can be added to biodiesel to make its properties more comparable to diesel properties. For example, biodiesel viscosity is slightly higher compared to the viscosity of diesel. Increasing the fuel viscosity can increase the atomized fuel droplet diameter during fuel injection leading to a decrease in combustion efficiency. On the other hand, alcohols have low viscosity. Therefore, alcohols are added to diesel-biodiesel blends to reduce the fuel blend viscosity to become more comparable to diesel viscosity. Alcohols are oxygenated renewable fuels, which can be produced from biomass. Alcohol based fuels include methanol, ethanol, butanol, diethyl ether (DEE), etc. Table 1 compares the properties of different alcohol based fuels with the relevant properties of diesel and biodiesel fuels. Although most of the previous investigations found in the literature studied using either butanol or ethanol as alcohol additives for diesel engines, Table 1 indicates that the DEE has the potential to be the most suitable fuel supplement for compression ignition engines because its cetane number and heating value are higher compared to ethanol and butanol. Also, DEE is miscible with diesel and biodiesel fuels [13]. The composition of DEE is $C_4H_{10}O$, making its oxygen content 21.6% by mass. Using DEE as a fuel additive was investigated in only limited number of studies. Kaimal and Vijayabalan [14] found that blending the DEE with waste plastic oil with different proportions up to 15% increased the thermal efficiency. Also, soot and nitrogen oxides (NOx) emissions were significantly reduced. Venu and Madhavan [15] studied adding DEE (up to 10%) to diesel-biodiesel-ethanol and diesel-biodiesel-methanol blends. The results showed that the addition of DEE to diesel-biodiesel-ethanol blend increased the combustion duration, cylinder pressure, and brake specific fuel consumption (bsfc) and

E-mail address: amralihi@yahoo.com.

Peer review under responsibility of Karabuk University.

https://doi.org/10.1016/j.jestch.2018.07.004
2215-0986/© 2018 Karabuk University. Publishing services by Elsevier B.V.

Table 1
Fuel properties [16,17].

Fuel	Lower heating value (MJ/kg)	Density @20 °C (kg/m^3)	Viscosity @40 °C (mPa s)	Flash point (°C)	Cetane number
Diesel	44.8	815	2.95	70	52
Vegetable oil	40.4	916	34.2	274	37
Biodiesel	40.5	855	4.57	126	52
DEE	33.9	714	0.22	-45	125
Butanol	33.1	808	2.63	35	25
Ethanol	28.6	790	1.1	13	6
Methanol	19.8	792	0.59	11	<5

decreased NOx and smoke emissions. On the other hand, adding the DEE to diesel-biodiesel-methanol blend decreased the bsfc, cylinder pressure, and combustion duration. However, smoke emissions increased. Lee and Kim [16] demonstrated that adding the DEE to diesel in different ratios (up to 50% by mass) did not significantly change the engine thermal efficiency. It was also shown that both hydrocarbon (HC) and carbon monoxide (CO) emissions decreased while NOx emissions increased. Patil and Thipse [13] investigated the addition of DEE to diesel in different ratios ranging from 2% to 25% by volume. It was found that the optimum proportion was 15% as it resulted in optimum engine performance. It was also shown that using the DEE reduced the trade-off between particulate matter (PM) and NOx emissions. The DEE was also used as a supplement (up to 4%) to a mixture of tire derived fuel (40%) and diesel (60%) by Tudu and coworkers [17]. It was shown that the bsfc decreased by 6% and NO emission decreased by 25% compared to diesel operation at engine full load condition. Barik and Murugan [18] investigated improving the performance of a diesel engine fuelled by biodiesel-biogas by utilizing the DEE as a supplement (up to 6%). The authors showed that using the DEE increased the thermal efficiency by 2.3% and reduced bsfc by 5.8% in comparison with dual fuel operation at full load condition. It was also shown that CO, HC, and smoke emissions decreased by 12.2%, 10.6%, and 5.7%, respectively, while NO emission increased by 12.7%. Devaraj and coworkers [19] showed that utilizing the DEE (up to 10%) as a supplement for a diesel engine fuelled by waste plastic oil increased the thermal efficiency from 28% to 29% at engine high load condition and decreased NOx emissions.

Although most of previous studies showed that using DEE as a supplement for diesel engines had a great potential to enhance engine performance and decrease emissions, there is only limited number of studies that investigated using DEE in diesel engines fuelled with diesel-biodiesel blends. These studies are not sufficient to build a solid conclusion regarding the effect of using DEE on diesel engine performance, emissions, and combustion characteristics. Further studies need to be conducted to investigate wide range of engine design parameters and operating conditions.

This research paper aimed to compare engine performance and combustion parameters for four different fuels as summarized in Table 2. Engine speed was fixed to 1500 rpm while engine load changed from small to full-load operating mode.

2. Test bed

A single-cylinder, direct- injection, four-stroke, TecQuipment TD212 compression-ignition engine was used to conduct all tests. The engine cylinder head was fitted by a pressure sensor. The inlet air was supplied to engine cylinder at ambient conditions. Engine specifications are indicated in Table 3. The test bed contained a hydraulic dynamometer as shown in Fig. 1. The DVF1 volumetric fuel sensor was employed to detect the fuel flow rate and an orifice plate was used to measure the inlet air flow rate. Temperature and pressure of air flowing through the orifice were measured using a thermocouple and a pressure sensor, respectively. A load cell was used to detect the engine torque. An optical rpm transducer was supplied to detect the crankshaft revolutions. Instrument modules were provided to digitally display measured parameters such as flow rates, speed, torque, etc. Also, all the measured data were accurately monitored and recorded on a computer by the TecQuipment Versatile Data Acquisition System (VDAS). Both the engine load and speed were controlled via mechanical governors.

The cylinder pressure and engine crankangle were measured simultaneously using a piezoelectric pressure sensor (ECA 101) and a shaft encoder (ECA 102), respectively as indicated in Fig. 1. The cycle analyzer (ECA 100) was supplied by TecQuipment in order to display and record the cylinder pressure data. The ECA 100 was a two-part product, which were interface and software. The ECA 100 interface was connected to pressure sensor, TDC position sensor and shaft encoder. The TDC position sensor produced a signal each time the piston reached the TDC; the crankangle was assigned with zero value at this instant. The interface, which contained charge amplifier and signal conditioning circuits, converted the sensor signals to a format that suited the ECA 100 software. This software did several jobs which included displaying pressure crankangle and pressure volume diagrams, and calculating the indicated power and indicated mean effective pressure. The ECA 100 software was also capable of using the test results and a user controlled animation to visually simulate the engine thermodynamic cycle and the relative position of engine crank, piston, and valves. The software calculated the cylinder volume as a function of measured crankangle using the following equation:

$$V = V_c + \frac{\pi}{4} B^2 y \quad (1)$$

where B is cylinder bore, V_c is clearance volume, and y was calculated as follows:

$$y = a + l - \left(a \cos\theta + \sqrt{l^2 - a^2 \sin^2\theta}\right) \quad (2)$$

Table 2
Examined fuel types.

Fuel	Acronym
Diesel	D100
70% diesel + 30% biodiesel (% by volume)	D70B30
70% diesel + 25% biodiesel + 5% DEE (% by volume)	D70B25DEE5
70% diesel + 20% biodiesel + 10% DEE (% by volume)	D70B20DEE10

Table 3
Engine specifications.

Item	Value
No. of cylinders	1
Maximum power, kW	3.5 at 3600 rpm
Compression ratio	22
Bore, mm	69
Stroke, mm	62
Connecting rod length, mm	104
Engine capacity, cm^3	232
Injection timing, degrees bTDC	10

Please cite this article in press as: A. Ibrahim, An experimental study on using diethyl ether in a diesel engine operated with diesel-biodiesel fuel blend, Eng. Sci. Tech., Int. J. (2018), https://doi.org/10.1016/j.jestch.2018.07.004