Fuel 176 (2016) 209–215

Contents lists available at ScienceDirect

Fuel

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

Comparative analyses of diesel–waste oil biodiesel and propanol, n-butanol or 1-pentanol blends in a diesel engine

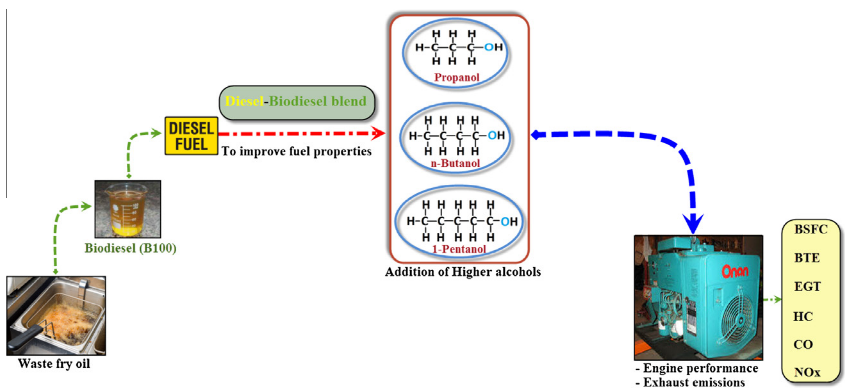
Alpaslan Atmanli *

Turkish Land Forces NCO Vocational College, Automotive Sciences Department, 10110 Balikesir, Turkey

HIGHLIGHTS

- Propanol, n-butanol and 1-pentanol were added diesel–biodiesel blends.
- Cold flow properties of the diesel–biodiesel blends were improved by adding higher alcohols.
- Engine characteristics of higher alcohol blends were reported and compared to diesel–biodiesel blend.
- There were different results in terms of HC emissions as a result of higher alcohol addition to diesel–biodiesel.
- All higher alcohol blends increased CO emissions, while they reduced NO_x emissions as compared to diesel–biodiesel blend.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form 24 February 2016
Accepted 25 February 2016
Available online 5 March 2016

Keywords:
Waste oil biodiesel
Higher alcohols
Fuel properties
Engine performance
Exhaust emission
Diesel engine

ABSTRACT

Higher alcohols are important alternative fuel resources for use in internal combustion engines promising positive economical and environmental outcomes. Moreover, higher alcohols are advantageous over lower alcohols due to their better blending capabilities, hydrophobic properties, higher cetane numbers and calorific value. The aim of this work is to investigate and compare the basic fuel properties of the ternary blends of diesel (D), waste oil methyl ester (biodiesel (B)) and the higher alcohols of propanol (Pro), n-butanol (nB) and 1-pentanol (Pn), and their effects on engine performance and exhaust emissions of a diesel engine. As test fuels four different blends were prepared by volume: 50%D–50%B (D50B50), 40%D–40%B–20%Pro (D40B40Pro20), 20%nB (D40B40nB20) and 20%Pn (D40B40Pn20). Addition of higher alcohols to diesel–biodiesel blend improved especially the cloud point (CP) and cold filter plugging point (CFPP), while slightly decreased density, lower heating value, kinematic viscosity, cetane number and flash point. In order to determine engine performance and exhaust emissions, tests were performed at four engine loads (1, 3, 6, 9 kW) with a constant engine speed (1800 rpm). Based on the engine performance and exhaust emissions, D40B40Pro20 had higher brake specific fuel consumption (BSFC) values than the ternary blends of D40B40nB20 and D40B40Pn20 at all engine loads. The exhaust gas temperatures (EGT) of D40B40Pro20, D40B40nB20 and D40B40Pn20 were higher than that of the diesel–biodiesel blend. All blends of the higher alcohols reduced oxides of nitrogen (NO_x) emissions as 1-pentanol, n-butanol and propanol were the most to least effective alcohols respectively. However, carbon monoxide (CO) emissions were increased with the addition of the alcohols to the blends. When the effects of higher alcohols on hydrocarbon (HC) emissions are compared in terms of emission reduction, the order from best to worst was as follows: D40B40Pn20, D40B40nB20.

* Tel.: +90 266 2212350x4451; fax: +90 266 2212358.
E-mail address: aatmanli@hotmail.com

http://dx.doi.org/10.1016/j.fuel.2016.02.076

1. Introduction

Diesel engines are extensively used for heavy machinery for power generation, generators and industrial purposes. Pollutants spread all over the world due to production and consumption of fossil fuels in vehicles. Most of the pollutants are produced due to the use of diesel fuel. With respect to the increase of diesel engine based vehicles, the share of pollutants in total atmospheric pollution caused by these vehicles is increasing as well [1,2]. Many countries have come up with new energy policies due to numerous problems in finding oil supplies, instability in oil costs, decreasing fossil fuel reserves and global warming as a result of the increase in carbon dioxide (CO_2) emissions. The oil crisis in early 1970's followed by oil embargos forced those developed countries to take immediate actions on new initiatives. One of these actions was to come up with new alternative fuel resources that are renewable, economical and environmentally conscious, and that can be used in the transportation sector which has the highest demand for petroleum fuels [3].

Renewable biofuels are important energy resources for reduction of green house gases, better air quality, less dependency on oil imports, and new jobs and markets. Biodiesel and alcohols are forefront alternatives in countries that have high potentials of biomass [4,5]. Direct use of biodiesel or its blends with diesel has a negative impact on cold flow properties under 0 °C and increases NO_x emissions as compared to diesel [6,7]. Moreover, alcohols have several important disadvantages such as low cetane numbers and high latent heat of evaporations, and cannot be directly used in diesel engines [8,9].

In order to use biofuels or biofuel blends in diesel engines, fuel properties of the biofuels must be improved. Such investigations can be seen in literature, where focus has recently been on biodiesel/diesel blends and the addition of certain alcohols into those blends. In those studies, biodiesel made of edible vegetable oils and ethanol (C_2H_5OH) are the most commonly used alternatives [10,11]. However, it is important to make biodiesel from non-edible oils to conserve the availability of food production resources. Waste vegetable oils left over in restaurants or in food industry are used to solve some of the biodiesel production issues.

Ethanol causes phase separation under 10 °C if it is blended with diesel or biodiesel for the use in diesel engines. In addition to that, it cannot be mixed with diesel fuel with high blend ratios because of its low cetane number which causes ignition delay, low calorific value and poor lubricity [12,13]. As the number of carbons in alcohols increases, they can be more easily blended with diesel and biodiesel. With the increase of carbons in alcohols, the mass percent of oxygen decreases while cetane number, density and calorific value increase. With respect to the number of carbons in atomic structures of higher alcohols, propanol (C_3H_7OH), n-butanol (C_4H_9OH) and 1-pentanol ($C_5H_{11}OH$) have higher cetane numbers, calorific values, viscosities, flame speeds while having lower latent heat of evaporations, ignition temperatures and corrosion risks. Moreover, because these higher alcohols have good solvent capabilities, they can easily be blended with diesel and biodiesel [9,14]. Overall literature does not show any study with regards to the examination of biodiesel/propanol blends in diesel engines [14]. Recent literature shows n-butanol in use as a blended fuel with diesel, biodiesel and vegetable oil [2,15–24]. The studies that use pentanol in diesel or biodiesel blends in literature are few include Li et al. [25,26], Campos-Fernández et al. [27,28], Wei et al. [29] and Zhang et al. [30].

According to studies mentioned above, n-butanol and pentanol can be used as fuel additives in diesel fuel and diesel–biodiesel blends without any engine modification. Besides, these investigations have proven that higher alcohols such as n-butanol and n-pentanol are more effective than lower alcohols in improving biodiesel fuel properties, and therefore, having more potential in being the next generation biofuels. Although there are some studies with some of the higher alcohols, there is no study in literature for the evaluation of propanol, n-butanol, and 1-pentanol in the same engine. Meanwhile, currently published work in this field shows limited results on the effects of biodiesel and higher alcohols on engine performance and exhaust emissions. Thus, it is important to identify such effects in order to aid in future engine design and understanding the reliability of potential alternatives.

In this work, as next generation alternative fuels, the higher alcohols of propanol, n-butanol and 1-pentanol were blended with diesel and waste oil biodiesel, and evaluated in a diesel engine to investigate the engine performance and exhaust emission characteristics. With that purpose, 20% (by volume) of propanol, n-butanol and 1-pentanol was added to diesel and waste oil biodiesel to make D40B40Pro20, D40B40nB20 and D40B40Pn20. These blends were used in a diesel engine and the performance of the higher alcohol-blended fuels was compared to the baseline fuels that are diesel–biodiesel blend (D50B50), and diesel.

2. Experimental procedure and specifications

The experiments were performed on an Onan DJC type, indirect injected, four-cylinder diesel engine generator. The schematic view of the engine test setup is given in Fig. 1. The test engine specifications are presented in Table 1. The exhaust emissions were measured using an EMS 5002 exhaust gas analyzer. The analyzer provided a HC measurement range of 0–2000 ppm with a resolution of 1 ppm, CO range of 0–10 vol.% with a resolution of 0.01 vol.%, CO_2 range of 0–20 vol.% with a resolution of 0.1 vol.%, O_2 range of 0–25 vol.% with a resolution of 0.01 vol.% and NO range of 0–5000 ppm with a resolution of 1 ppm. In order to perform EMS 5002 exhaust gas analyzer calibration procedure, BAR 97 Low gas used. The calibration process was repeated regularly for the engine tests. EN ISO 8178-6 test standards [31] were followed for exhaust emission tests. The fuel mass consumption was measured by comparison of the mass of fuel before and after each 15 min trial time for each fuel at each load. In order to measure exhaust gas temperature a K-type thermocouple was used. Engine performance and exhaust emission tests were carried out at fixed engine speed of 1800 rpm and four loads 1, 3, 6 and 9 kW supplied by a series of electrical resistance elements, two Holmes 1000/1500 watt electric heaters, and one Dayton 2500/5000 watt heater, without any modification in the engine. Engine performance values and exhaust emissions were determined after the engine speed reached a steady-state conditions. Experiments were repeated three times in order to increase confidence in measurements of engine performance parameters and exhaust gas emissions and averaged values were reported in this work.

3. Test fuels

In this work, commercial waste oil (fry oil) biodiesel (B100), which is certified ASTM D6751-compliant, was obtained from Core Biofuels (NM, USA). Agilent Technologies 6890 Network GC System was used to measure the fatty acid compositions of the waste oil biodiesel according to the test method EN 15779 [32]. DB-225 column (30 m long, 0.25 mm diameter and 0.2 μm film thickness) was used. Waste oil biodiesel consisted of 12.99% saturated and 82.87% unsaturated fatty acid methyl esters (FAME). The measured FAME compositions (%) are given in Table 2. Propanol, n-butanol and 1-pentanol of the technical grade (99.9% purity) were purchased from Univar Chemistry and low sulfur No:2 diesel fuel was