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Engine performance and emissions characteristics of a diesel engine fueled with diesel-biodiesel-bioethanol emulsions

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ABSTRACT

In this research work, the experimental investigation of the effect of diesel-biodiesel-bioethanol emulsion fuels on combustion, performance and emission of a direct injection (DI) diesel engine are reported. Four kind of emulsion fuels were employed: B (diesel-80%, biodiesel-20% by volume), C (diesel-80%, biodiesel-15%, bioethanol-5%), D (diesel-80%, biodiesel-10%, bioethanol-10%) and E (diesel-80%, biodiesel-5%, bioethanol-15%) to compare its' performance with the conventional diesel, A. These emulsion fuels were prepared by mechanical homogenizer machine with the help of Tween 80 (1% v/v) and Span 80 (0.5% v/v) as surfactants. The emulsion characteristics were determined by optical electron microscope, emulsification stability test, FTIR, and the physiochemical properties of the emulsion fuels which were all done by following ASTM test methods. The prepared emulsion fuels were then tested in diesel engine test bed to obtain engine performance and exhaust emissions. All the engine experiments were conducted with engine speeds varying from 1600 to 2400 rpm. The results showed the heating value and density of the emulsion fuels decrease as the bioethanol content in the blend increases. The total heating value of the diesel-biodiesel-bioethanol fuels were averagely 21% higher than the total heating value of the pure biodiesel and slightly lower (2%) than diesel fuel. The engine power, torque and exhaust gas temperature were reduced when using emulsion fuels. The brake specific fuel consumption (BSFC) for the emulsion fuels were observed to be higher in comparison to diesel, A. The CO_2 (carbon dioxide) and CO (carbon monoxide) emissions were reported to be lower than diesel oil. The effect of using emulsion fuels decreased the NOx (nitrogen oxides) emissions at medium engine speeds, i.e. approximately 30.0%. Lesser NOx emission was attributed by the reduction of cetane number of the diesel-biodiesel-bioethanol emulsion fuels' cetane number as the amount of bioethanol increases. However, the emissions of NOx were found to increase gradually at low speed (~1600 rpm), high load; high speed (~2400 rpm), medium load conditions. It was found that the combustion performance and emissions of the diesel engine very much depend on the fuel, its emulsion combination types and engine operating conditions.

1. Introduction

Generally, diesel engines operate with a better fuel efficiency and produce a higher power torque than a conventional spark ignition (gasoline) engine diesel engines. This advantages help to make the internal combustion diesel engine ideal for use in the heavy haul industry as well as automotive industry. Nevertheless, several emissions and waste products are released when diesel fuels burn in particular nitrogen oxides (NOx), suspended particulates matter (PM), sulfur dioxide (SO_2) and hydrocarbons. These unwanted emissions not easily disappear and they can harm the environment for instance by contributing to global warming, global dimming

Abbreviations: %v/v, blending percentage per volume of diesel; A, diesel; ASTM, American society for testing and materials; B, 80% diesel + 20% biodiesel; BSFC, brake specific fuel consumption; BTE, brake thermal efficiency; C, 80% diesel + 15% biodiesel + 5% bioethanol; cc, cubic centimeter; CO, carbon monoxide; CO_2, carbon dioxide; D, 80% diesel + 10% biodiesel + 10% bioethanol; D2, conventional diesel fuel; DI, direct injection; E, 80% diesel + 5% biodiesel + 15% bioethanol; E10, 10% of water + 90% of diesel; E20, 20% of water + 80% of diesel; ED10, 10% water emulsion diesel; H_2O, water; HLB, hydrophilic-lipophilic balance; kW, Kilowatt; LSS, liquefied sago starch; MJ/kg, mega joule per kilogram; ml, milliliter; mm, millimeter; Nm, Netwon.meter; NO, nitric oxide; NOx, nitrogen oxides; O/W/O, oil-wateroil; PM, particulate matter; rpm, revolution per minute; SO_2, sulfur dioxide; WHO, World Health Organization.

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and acid rain. The levels of NOx, PM, SO_2 and soot increases over the period of time. The World Health Organization (WHO) has reported air pollution has risen by 8% globally in the past five years (2008–2013) and environment experts have warned that this situation is only going to get worse in the future. The continuous emission of pollutant gases into the atmosphere will lead to public health crisis [1].

Millions of lives could possibly be saved if a concerted effort to provide cleaner energy, better technologies and emissions controls. Thus, in this works, researchers have responded to the issues by investigating biofuel and emulsion diesel as an alternative fuels designed to reduce the air pollution as well as other adverse environmental impacts. The development of a new kind of diesel-water fuel emulsion has greatly attracted the attention of researchers as it has exhibit a lower engine emission, especially in NOx, PM and soot emissions. Besides, the diesel-water fuel emulsion shows a better engine performance in term of fuel consumption [2]. Thus, the blend of water with conventional diesel can be considered as promising alternative fuels which have the potential to serve as full or partial alternatives to diesel [3].

In recent years many researchers have reported that the diesel-water fuel emulsion in DI (direct injection) diesel engines were altered through different preparation methods, such as single step emulsification, two step emulsification, ultrasonic or microwave method and use of different types of surfactants to study the engine behavior in terms of performance and emissions. Recently, Hasannuddin et al. [4] prepared two types of emulsion fuel which are E10 (10% of water and 90% of diesel) and E20 (20% of water and 80% of diesel). Both E10 and E20 emulsion fuel have reduced the combustion temperature and decreased the rate of formation of PM and NOx in diesel engines. Seifi et al. [5] employed 2% water to neat diesel fuel and resulted in better engine power performance. However, a significant decrease in engine power was observed when the water content in the mixture was increased. Wamankar et al. [6] performed experiments using 10% emulsion, 2% water, 85% diesel and 3% surfactant which was denoted as CBWD10. They found that CO, HC and smoke emissions were reduced by about 23.5%, 7.2%, and 5.2%, respectively while the NO emission was increased by about 6%. Ogunkoya et al. [7] evaluated the emissions of diesel emulsion, biodiesel emulsion, jet fuel emulsion with water-to-oil ratio of 30:70 by mass in diesel engine. At high loads, NOx emission was lower for all of the emulsions but CO emission was higher. At low engine loads, these emulsion fuels have higher NOx emission but lower CO emission. As for HC emission, it has increased for all of the fuel emulsions as higher loads were applied to the engine. Fahd et al. [8] used 10% water emulsion diesel (ED10) fuel to perform emission test. They have reported that ED10 produces slightly less engine power output and engine efficiency with higher brake specific fuel consumption (BSFC) as compared to neat diesel fuel. Lower exhaust gas temperature and lower NO emission at all load and engine speed was reported. At low speed and load, higher CO emission was observed but it was reduced dramatically at higher engine speed. Yang et al. [9] used an emulsion of diesel, water, organic oxygenated additives and NP-9 surfactant in the diesel engine test. Brake thermal efficiency, BTE was improved and NOx emission was reduced. Chang et al. [10] employed acetone, butanol, ethanol and diesel fuel with water content to form emulsion fuel without adding any surfactant. They reported this kind of fuel increased the BTE value and lower the PM and NOx emissions. Debnath et al. [11] explored the emulsified biodiesel, i.e. water in palm oil biodiesel emulsion in a diesel engine. Water in palm oil methyl ester emulsions improved the BTE than diesel. The water in palm oil methyl ester emulsions emitted lower exhaust NOx and CO than palm oil methyl ester. Alahmer et al. [12] prepared the emulsified diesel fuels with different water content in the range of 0–30% by volume. They discovered that the torque, brake power and BTE are maximum when 5% water emulsion is used. The emission CO_2 was found to be increasing at increased engine speed and decreased water content. NOx emissions from emulsified fuel is significantly less than diesel under the same operating conditions. Research work in Refs. [4–12] have showed a reduction in NOx, PM and CO emissions with a better combustion efficiency for diesel-water emulsions.

Several researchers have looked into the combination of water-diesel emulsion fuels i.e. [4–12]. However, combination of tri-phases i.e. diesel-biodiesel-bioethanol emulsion fuel, whereby the bioethanol contains ~5% of water has not been explored and studied. Thus in the present study, the authors have made an attempt to improve the engine performance and reduce the engine emissions by introducing the diesel-biodiesel-bioethanol emulsion fuel. The incorporation of bioethanol and biodiesel in diesel emulsion may have the potential to reduce gas emissions that cause gas pollution such as NOx, CO and unburned hydrocarbon compounds by increasing the combustion efficiency in diesel engine. Therefore, the introduction of this diesel-biodiesel-bioethanol emulsion fuel could provide an optimized fuel source for better efficient in diesel engines.

Both biodiesel and bioethanol are generally under the category of renewable energy which can be synthesized from crops, plants or recycled industrial waste. Biodiesel is an alternative fuel which can be synthesized from vegetable oils or animal fats, including the waste cooking oils from restaurants. It is to be noted that existing vehicle engines can be modified and converted to burn pure biodiesel (100%) but it is not considered in this study. Also, biodiesel can be blended with petroleum diesel (0–20%) and used in standard diesel engines without any engine modification [9]. Unlike biodiesel, bioethanol is an alcohol-based alternative fuel which is mainly produced by the sugar fermentation process and distilling the agricultural crops such as sago starch, hemp, sugarcane, potato, corn, cassava, barley or wheat [10]. The combination of petro-diesel and bioethanol may result in the reduction of emissions because ethanol is a kind of oxygenation additive when it is blended with gasoline, and it helps increase the octane number of the fuel which may result in better combustion efficiency [13]. Additionally, the diesel-biodiesel-bioethanol emulsion fuel has potential to overcome the disadvantages of conventional diesel petrol, in particular from the sustainability standpoints, i.e. they are renewable, biodegradable, low in toxicity and improve engine emissions quality by reducing air pollutants such as particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx) and soot [14]. Thus, in the present work, investigations related to the combination of biofuel (biodiesel and bioethanol) and diesel in the diesel engine were first carried out- to the best knowledge of authors.

This paper focuses on investigating the emulsion characteristics, engine performance and gas emissions of water cooled, four strokes, single cylinder and direct- injection diesel engine when using the diesel-biodiesel-bioethanol emulsion fuels. The effects of different bioethanol and biodiesel ratio content in the emulsion fuels were investigated. The experimental results were then compared with the conventional diesel operation. Further, the feasibility of diesel-biodiesel-bioethanol emulsion as alternative fuels for diesel engine was studied.

2. Material and methods

2.1. Emulsion preparation

In order to prepare the fuel blends the following components were used: Malaysian (Petronas) conventional diesel fuel (D2), biodiesel obtained from waste cooking oil [14] and bioethanol (95.0%