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Effects of fusel oil water content reduction on fuel properties, performance and emissions of SI engine fueled with gasoline -fusel oil blends

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ABSTRACT

This study sets out to determine the effects of water reduction on the properties characteristic of fusel oil-gasoline blends, also to study the effects of this reduction on the performance and emissions of an SI engine. The experiments were performed on a SI engine under 4500 rpm speed, different open throttle valve position (% of WOT) as engine loads. As a result of the reduced water contentfrom 13.5% to 6.5%, the heating value and carbon content improved by 13% and 7.9% respectively. While the oxygen content reduced by 14%. The brake power was slightly increased than that of gasoline for most fusel oil–gasoline blends. Furthermore, it was observed that the fusel oil after water extraction (FAWE10 and FAWE20), the fusel oil had slightly higher power compared to the fusel oil before water extraction (FBWE10 and FBWE20). Moreover, brake-specific fuel consumption (BSFC) and brake thermal efficiency (BTE) improved by reducing the water content. The engine emissions were also slightly increased with the reduction of water content.

1. Introduction

The transportation sector is growing at a faster rate than reserves due to rapid technological development in the automotive industry and an increase in the use of personal vehicles in developed and developing countries. Thus the demand for petroleum accelerates the crude oil petroleum production peaks as well as its cost. One of the main issues involved with petroleum fuels are the environmental impacts that occur from their use thereby it seems that the use of alternative fuels in the future is inevitable [1–3]. Alternative fuels are obtained from resources other than fossil fuel. Advantages of alternative fuels are they emit less engine emissions compared to fossil fuels, whereby most of them are more economically useful as well as they are also renewable. Alternative fuels for transport, including ethanol, biodiesel, and many other liquid fuels, have the potential to compensate or replace an amount of fossil fuels worldwide over the ensuing few decades and a clear trend in that way has started [4–6]. The first-generation alcoholic fuel based as alternative fuels for spark ignition (SI) applications have so far largely been based on gasoline-ethanol blends, where current fuel quality standards typically allow between 5 and 10% inclusions of ethanol within an existing gasoline pool. Conventional fuels that have been utilized as alternative fuels are alcoholic fuels [7–10]. Alcohol based fuel targets to compensate the reduction in fossil fuels as well as to improve the performance of a SI engine [11–14]. Furthermore, alcohol (ethanol, butanol, and methanol)-gasoline blends have a significant effect on fuel properties, thereby improving the performance and emissions of a SI engine [15]. Physicochemical properties refer to the quality of fuel to be combusted in an engine. There are numerous fuel properties such as octane number, heating value, density, viscosity, oxygen content carbon content and latent heat of vaporization which are important

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for gasoline-alcohol blends in a SI engine. Adding alcoholic fuel into gasoline influences certain key properties with particular reference to blending density,viscosity, octane number, and heating value. There are a large number of published studies that show the heating value of the blends fuel decreased with the increasing the fraction of alcoholic fuels into gasoline, while the density and viscosity are increasing [16–22]. Furthermore, the octane number enhanced in all blending fuels compared with gasoline except butanol [22]. Some alcohols such as hydro-ethanol and fusel oil have high water content that also considered as one of the important properties. The water content of any fuel imparts its combustibility characteristic; for instance, the water content of fusel oil causes a dramatic decrease of in-cylinder temperatures and heat release rates [23–26]. However, high water and ash contents in biofuel can cause ignition and combustion problems [27]. Also, the water content of biofuel generally decreases its heating value. Solmaz [28] informed that the torque of SI engine decreased averagely at 6% and 2% respectively when pure and 50% of fusel oil were used while the BSFC increased. He also declared that the increase in HC and CO emissions were up to 21% and 25% respectively when utilizing fusel oil, while the NO_x emissions decreased up to 31%. The engine torque, brake thermal efficiency and emission decreased due to lower heating value and higher water content of fusel oil thereby the BSFC increased. The research study by Omar et al. [29] also found that the engine power and torque for F20 (20% fusel oil −80% diesel) had slightly dropped compared to those with pure diesel while the fuel consumption increased. In fact, the amount of water content in fusel oil should be driven off before it is utilized as fuel [28].

The heating value of any fuels or alcohols is affected by several factors such as water, oxygen, hydrogen, carbon and ash content of the fuel [29–31]. Furthermore, some researchers linked the relationship between the fuel properties such as density, viscosity and the heating value [32–34]. Demibras [35] reported that the heating value of fuel was associated with its oxygen content and the lower heating value (LHV) of fuel reduced with increasing the oxygen and water content while increased by increasing hydrogen. The carbon content is the most significant parameter that leads to the increase in the LHV according to the release of CO_2 after combustion. Therefore, the concentration of carbon (C) is positively related to the heating value of the fuel, thus explaining why fossil fuels have higher heating value than biofuel [36–38]. Demibras [32] in another work he indicated that the water content in a fuel reduced its higher heating value.

Fusel oil is a by-product of alcohol production after fermentation during the distillation process [39–41]. It consists of ethyl alcohol, methyl alcohol, amyl alcohol, isobutyl alcohol, and n-propyl [16,42]. Higher research and motor octane number (RON 106 and MON 103), high oxygen content (30.23 % wt) and single boiling point of fusel oil indicated that it could be used as an additive to fuel in spark ignition engine [17,18,28]. On the other hand, the higher water content of fusel oil that around (10–20%) leads to a low heating value of fusel oil (30 MJ/kg) compared to gasoline (43 MJ/kg). Also, the higher water content of fusel oil lead to an adverse effect on the combustion efficiency, thereby engine performance dropped [28].

The specific objectives of this work are to study the effects of water reduction on the properties of fusel oil-gasoline blends, as well as to study the effects of the reduction on the performance and missions of a SI engine. The experiments were performed on an SI engine operating under 4500 rpm, with different open throttle valve position as engine loads and the different blending ratio of gasoline-fusel oil (G100, FBWE10, FBWE20, FAWE10, and FAWE20). In addition, the effects of test fuels upon brake power (BP), brake thermal efficiency (BTE),brake-specific fuel consumption (BSFC), maximum in-cylinder pressures (MCP), and emissions (NO_x, HC, CO, and CO_2) were examined.

2. Methodology

2.1. Material

Experimental test were conducted with pure gasoline (G100) and fusel oil -gasoline blends. The fusel oil was supplied from the Eskişehir sugar refinery, which produced ethyl alcohol with 99.5% purity. Meanwhile, the gasoline fuel with octane number 95 was provided by Shell petrol stations in Pahang- Malaysia. Fusel oil – gasoline blends were prepared by mixing (based on volume) FBEW10 (90% gasoline and 10% fusel oil by volume) and FBEW 20 (80% gasoline and 20% fusel oil by volume), and the fusel oil – gasoline blends after the extraction of water content were prepared by mixing FAEW10 (90% gasoline and 10% fusel oil by volume) and FAEW 20 (80% gasoline and 20% fusel oil by volume). After that, the fuel properties of blends were measured using ASTM standards (higher heating value ASTM D240, Density ASTM D4052, viscosity ASTM 445-01, carbon content ASTM D5291, hydrogen content ASTM D5291, nitrogen content ASTM D5291 and sulphur content ASTM D1552).

2.2. Water reduction

The water content of fusel oil was reduced (extracted) using a rotary evaporator (Buchi R-210, Switzerland). The fusel oil was decanted into a 250 mL round bottom flask, and the content was evaporated to using the rotary evaporator at 100 °C under vacuum. The water (moisture) content of fusel oil for all test samples was determined according to the ASTM D6304 standard test method using a Karl Fischer Titration 870 in the central laboratory of University Malaysia Pahang (UMP).

2.3. Fuel properties measurement

The physical and chemical properties of test fuels such as higher heating value (HHV), density, the viscosity, oxygen, carbon, hydrogen, and sulphur were measured according to the ASTM methods. Each test was performed three times and the average test results were presented in this study. HHV was determined by a Parr 6200 oxygen bomb calorimeter (Parr Instrument Co., Moline, IL) according to ASTM D240 method. The density of the fuel samples measured at 15 °C according to the ASTM D4052 using a Density Meter, model DA-640. The dynamic viscosities of the fuel samples were determined according to the ASTM 445-01 fuel standards by using a Brookfield DV-II+Viscometer, and the kinematic viscosity was calculated. Oxygen, carbon, hydrogen, and sulphur were measured in the Intertek laboratories in Kuala Lumper –Malaysia. Carbon, hydrogen, nitrogen, and sulphur were measured according to the ASTM D5291, ASTM D5291, ASTM D5291 and ASTM D1552 respectively. All fusel oil -gasoline blends, pure fusel oil and pure gasoline are listed in Table 1.

2.4. Engine set up

The tests were done on a Mitsubishi 4G93 SOHC 4-cylinder PFI with a naturally aspirated SI engine. The engine specifications are provided in Table 2. Fig. 1 shows a layout of the experimental setup engine. A 100-kW eddy current dynamometer was utilized in the tests. Fuel consumption was measured using an AIC fuel flow meter with an accuracy of 1%. Furthermore, the engine emissions and air-fuel ratio were measured by using an AUTOMOTIVE EMISSION ANALYZER QRO - 401. The emission analyzer determined the