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Experimental investigation on SI engine using gasoline and a hybrid iso-butanol/gasoline fuel

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ABSTRACT

Experimental investigation on pollutant emissions and performance of SI engine fueled with gasoline and iso-butanol–gasoline blends is carried out. Engine was operated at speed range of 2600–3400 r/min for each blend (3, 7 and 10 vol.% iso-butanol) and neat gasoline. Results declare that the CO and UHC emissions of neat gasoline are higher than those of the blended fuels for speeds less than or equal to 2900 r/min; however, for speeds higher than 2900 r/min, we have an opposite impact where the blended fuels produce higher level of CO and UHC emissions than the gasoline fuel. The CO_2 emission at using iso-butanol–gasoline blends is always lower than the neat gasoline at all speeds by up to 43%. The engine performance results demonstrate that using iso-butanol–gasoline blends in SI engine without any engine tuning lead to a drop in engine performance within all speed range. Without modifying the engine system, overall fuel combustion of iso-butanol–gasoline blends was quasi-complete. However, when engine system is optimized for blended fuels, iso-butanol has significant oxygen content and that can lead to a leaner combustion, which improves the completeness of combustion and therefore high performance and less emissions would be obtained. Finally, the performance and emissions of iso-butanol–gasoline blends are compared with those of n-butanol–gasoline blends at similar blended rates and engine working conditions. Such comparison is directed to evaluate the combustion dissimilarity of the two butanol isomers and also to emphasize which isomer is a superior fuel for SI engines.

1. Introduction

Due to limited fossil-fuel resources and increasing concentrations of greenhouse gases in the atmosphere, renewable energy must be used instead. Biomass is one of the promising renewable energy sources [1–5]. It is carbon neutral resource over its life cycle and, hence, it significantly reduces net carbon dioxide concentration in the atmosphere [6–9]. Currently, biomass is classified as the fourth largest source of energy in the world after coal, petroleum and natural gas. Biomass, as a raw material, is a source of many friendly fuels as ethanol, methanol, butanol, and so on.

Ethanol is produced by alcoholic fermentation of sugar from vegetable biomass materials, such as corn, sugar cane, sugar beets, barley, sweet sorghum and agricultural residues [10–12]. But methanol is rarely produced from biomass and it is mainly produced from coal or petrol based fuels. Therefore, ethanol is superior on methanol due to its renewability and, in turn, ethanol is widely used as alternative fuel in many countries, such as the United States, Brazil and China. Ethanol and methanol (renewable based) are considered as alternative fuels for internal combustion engines within the past decades [13–17]. However, there are problems with the use of ethanol and methanol as an engine fuels [12,18–20]. They are corrosive to the engine systems through general corrosion, dry corrosion and wet corrosion; detailed effects of corrosiveness have been reviewed by Hansen et al. [10]. In addition, the energy-intensive ethanol and methanol processes still have not solved our fuel, power or clean air requirements within the past 30 years [21]. Therefore, butanol is examined as alternative source of energy in many countries. Butanol has received increasing attention in recent years after being identified as a feasible alternative for diesel fuel in internal combustion (IC) engines and its related advantages [22–26]. Butanol has advantages over ethanol and methanol, such as higher energy content, lower water absorption and better blending ability. However, the butanol toxicity and cost of substrates are still the main obstacles at making butanol commercially feasible fuel [27]. Besides, one of the main disadvantages of butanol is its quite low production quantity. Comparing butanol yields from acetone butanol ethanol (ABE) fermentation to that of the ethanol fermentation process, the ethanol yields about 10–30 times higher production rate than ABE. This is the reason of chosen ethanol as an alternative fuel source over butanol during the oil crisis in the 1970s and 1980s.

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However, with the development of butanol fermentation process, a higher butanol production rate has become possible. Various methods for increasing the production of butanol are recently introduced, see e.g., Chao et al. [21]. Researchers expected that butanol will become an attractive, economic and sustainable fuel as petroleum oil nearly and that may explain the increasing studies on butanol in recent years.

Butanol (CH3(CH2)3OH) has four different structures based on the location of the hydroxyl group (OH) and carbon chain construction. Such four structures are named as 1-butanol, 2-butanol, iso-butanol and tert-butanol. 1-Butanol, also known as n-butanol (normal butanol), has a straight-chain structure with the hydroxyl group (OH) at the terminal carbon. 2-Butanol (sec-butanol) is also a straight-chain structure like n-butanol but with the OH group at the internal carbon. Both iso-butanol and tert-butanol have branched-chain structure with the OH group at the terminal carbon (for iso-butanol) or internal carbon (for tert-butanol). All butanol structures contain about the same energy, but have different physical properties [28]. Jin et al. [29] summarized such different physical properties, which include density, octane number, boiling point, viscosity, etc. Thus, combustion characteristics of the all four butanol structures need to be investigated, e.g., one structure may not present correct indication about the others; such combustion characteristics are highly needed, since all of them can be used as fuels in engines either at present or in the near future.

Although there are increasing studies on butanol in recent years, most of studies focus on using n-butanol–gasoline blends in SI engines, see e.g. [29–38]. However, similar studies on iso-butanol–gasoline blends in SI engine are very scarcely found in the literature; only six publications are found according to the best of our knowledge, see e.g. [39–44]. Within such very few studies, Irimescu [39] applied iso-butanol–gasoline blend of 50 vol.% of iso-butanol and 50 vol.% of gasoline; fuel conversion efficiency showed a slight improvement of up to 6% when the engine was operated using iso-butanol–gasoline blend. Studies by Alasfour [40], Bata et al. [41] and Kelkar et al. [42] showed that using iso-butanol blends of about 30 vol.% gave reductions in power, exhaust temperature and thermal efficiency compared to pure gasoline. The experimental work by Alasfour [43] investigated the NOx emission from a spark ignition engine using 30 vol.% iso-butanol blend. Results indicated that NOx emission is reduced by 9% compared to neat gasoline. Another study by Alasfour [44] investigated the effect of using 30 vol.% iso-butanol blend on hydrocarbon (HC) emission and found that HC emission reduced by 12%. Nevertheless, none of the early studies presents direct evaluation of the combustion characteristics of iso-butanol blends via measurements [39].

From the above literatures review, it is made obvious that a major gap exists for the performance and environmental behavior of the iso-butanol–gasoline blends in SI engines, especially with low blended ratios, e.g., less than 10 vol.% of iso-butanol. In the current study, we aim to fill this gap; detailed descriptions of engine performance (output power, in cylinder pressure, exhaust gas temperature, torque and volumetric efficiency) and pollutant emissions (CO, CO_2 and UHC) are investigated in low blend rates (10, 7 and 3 vol.% iso-butanol). The low rates of iso-butanol were recommended in this study for couple of reasons; firstly, small rates of iso-butanol (up to 10 vol.%) can be mixed with gasoline without any needs for engine modifications, e.g., no extra costs to modify engines and their related industries; secondly, iso-butanol is still more expensive and less productivity than gasoline. Results of iso-butanol blends were compared with those of n-butanol–gasoline blends at same blended rates and working conditions. Such comparison can guide to evaluate the combustion dissimilarity of the two different butanol structures and also to emphasize which butanol structure is a superior fuel for SI engines.

2. Experimental

The gasoline engine used in this work is an air-cooled, carbureted fuel system, single-cylinder, natural intake and four-stroke SI engine with a cylinder bore of 65.1 mm and stroke of 44.4 mm, as shown in Table 1. The power generator has a 200/220 V (50/60 Hz) AC input (three-phase and five-wire type) with a maximum output of 1.5 kW. The engine exhaust was discharged directly to a stainless steel tail pipe without any dilution. For each combination of measured parameters, the experiment was performed three times (each sampling time about 15 min). Sampling data were collected after the engine had been running for at least 10 min. The experiment scenario is performed as three steps: firstly, preparing the fuels with the different blends, secondly, measuring engine performance, and finally measuring emissions, as explained below in details.

2.1. Fuel preparations

Premium gasoline fuel used in this study was obtained from the Saudi Petroleum Corporation in KSA, while the iso-butanol fuel was manufactured by the Mumbai, India Corp. The properties of gasoline and iso-butanol are summarized in Table 2. Various blend rates of iso-butanol–gasoline fuels (3, 7 and 10 vol.% iso-butanol) have been prepared and then inserted into intake system of SI engine for the experiments.

2.2. Performance measurements

Engine control and monitoring was performed using a target-based rapid-system with electronic sensors and actuators installed with the engine. A real-time combustion analysis system was applied for data acquisition and online analysis of combustion quantities. The engine performance measurements (torque, brake power, volumetric efficiency, in-cylinder pressure and exhaust gas temperatures) were calculated and recorded online using personal computer (PC), which is connected with the engine via data transfer unit.

2.3. Emission measurements

The engine pollutant emissions were analyzed using an exhaust gas analyzer. The gas analyzer (its details are presented in Table 3) was equipped with online measuring cells for analyzing different gases as carbon monoxide (CO), carbon dioxide (CO_2) and unburnt hydrocarbons (UHC). The H_2O in the exhaust gases was separated using a draining device and the CO_2, CO and UHC contents were determined using a non-dispersive infrared (NDIR). The data processing and calculations were conducted by the analyzer systems to determine the percentage and/or ppm (part per million) of examined gases in each sample. Further descriptions and details

Table 1
Engine specifications.

Engine	Main parameters
Engine type	1 Cylinder, 2 valves, air cooled, carbureted
Bore/stroke	65.1 mm/44.4 mm
Displacement	0.147 L
Rated speed	2200 r/min
Connecting rod length	79.5 mm
Compression ratio	7:1
Sensor measuring ranges	Ambient temp.: 0–100 °C Fuel temp.: 0–100 °C Exhaust-gas temp.: 0–1000 °C Accuracy ±1 °C