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Combustion and emissions study on motorcycle engine fueled with butanol-gasoline blend

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A B S T R A C T

In this paper, experimental studies were conducted on a single cylinder high speed spark ignition (SI) motorcycle engine under both full load and partial load at 6500 and 8500 rpm with pure gasoline, 30% and 35% volume butanol-gasoline blends. This study is trying to find out the influence on combustion heat release of high speed SI engine by variables including ignition timing, butanol blend ratio and engine load. The results show that butanol-gasoline blend provides higher knocking resistance by allowing advance ignition timing in SI engines, which leads to more efficient combustion. With butanol blend ratio increases, more complete combustion process will achieve with the optimum operating parameters. With engine load increases, the rates of heat release become faster and ascend in peak value for both pure gasoline and butanol-gasoline blends. Furthermore, engine performance parameters such as power, fuel economy and emissions have been compared and analyzed. The results also show that engine power, torque, brake specific energy consumption, HC, CO and O_2 emissions are better than those of pure gasoline at full load with 35% volume butanol addition, combined with ignition timing optimization. But NOx and CO_2 emissions are higher than those of the original level of pure gasoline.

1. Introduction

In the 21st century, energy crisis and environmental protection are two of the biggest challenges [1,2]. Due to the shortage of oil resources and the increasing oil price, it is very important to seek alternative fuels for internal combustion engine [3]. Biofuels can be made from agricultural products [4]. Biofuels have been considered as the alternative fuels in some ways [5]. At present, common biofuels include methanol, ethanol, butanol, biodiesel, biogas and biohydrogen [6]. Butanol has been suggested as a future fuel bio-component [7]. Compared with conventional fuels, butanol has more excellent fuel properties and environment performance, such as wildly production sources, more oxygen content and higher heat of evaporation [8]. As automotive fuel, butanol has more advantages compared to methanol and ethanol, including lower volatility, higher heating value, higher viscosity, less corrosive and lower auto-ignition temperature [9]. Furthermore, butanol can be extracted from renewable resources, such as corn fiber [10], wheat straw [11], distillers dry grains and solubles (DDGS) [12], corn stover [13], switchgrass, barley straw [14] and other plant materials [15]. Due to its superior physical and chemical properties, butanol has become a very competitive biomass-based renewable fuel for internal combustion engines to substitute or supplement gasoline [16,17]. Typical properties of gasoline, methanol, ethanol and butanol [18–22] are shown in Table 1.

There are many researches in butanol utilizations on conventional spark ignition (SI) gasoline engines. Some of them focused on engine performance, fuel economy and emission characteristics. Alasfour [23–26] has conducted the pioneer work to study performance and emissions on a single cylinder engine with 30% volume butanol gasoline blend. Williams et al. [27] studied the impact of butanol and other bio-components on thermal efficiency of prototype and conventional engines. It was found that butanol blends offered measurable gains in thermal efficiency in line with the relative octane lift over base gasoline. And butanol blends

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Table 1
Typical properties of gasoline, methanol, ethanol and n-butanol.

Property	Gasoline	Methanol	Ethanol	n-Butanol
Chemical formula	C_4–C_{12}	CH_3OH	C_2H_5OH	C_4H_9OH
Molecular weight (g/mol)	100–105	32	46	74
Composition (C, H, O) (mass%)	86, 14, 0	37.5, 12.5, 50	52, 13, 35	65, 13.5, 21.5
Lower heating value (MJ/kg)	42.9	20.1	26.8	33.1
Density (kg/m^3 at 20 °C)	720–760	792	790	810
Octane number (R + M)/2	86–94	98.6	99.1	89
Boiling temperature (°C)	25–275	64.5	78.3	118
Latent heat of vaporization (25° kJ/kg)	380–500	1178	904	716
Auto-ignition temperature (°C)	257	465	422	343
Stoichiometric air/fuel ratio	14.7	6.4	9.0	11.2
Laminar flame speed (cm/s)[a,b]	51	68	63	58.5
Adiabatic flame temperature (K)	2370	1890	2310	2340

[a] T = 325 K and P = 100 kPa, at stoichiometric mixture.
[b] The gasoline was represented by iso-octane here.

allowed the greatest volume of crude derived gasoline displacement at fixed fuel oxygen content. Gu et al. [28] measured the speeds of laminar flame of tert-butanol-air premixed mixtures and got the results that laminar burning velocity of tert-butanol-air mixtures increase with the increase of initial temperature and decrease with the increase of initial pressure. Gu et al. [22] also conducted an experiment on a port-fuel injection SI engine fueled with blends of gasoline and n-butanol at different spark timings and exhaust gas recycling (EGR) rates. It was found that advancing spark timing increases engine specific HC and NOx emissions and particle number concentration while it decreases engine specific CO emissions. EGR can reduce engine specific NOx emissions and particle number concentration simultaneously on SI engine fueled with gasoline and n-butanol blends. These tendencies were similar to Ref. [29]. Venugopal and Ramesh [30] studied the effect of injection timing on a SI engine using dual injection of n-butanol and gasoline at the intake port. The results showed that with dual injection, n-butanol has to be used at higher throttle positions for good performance and low emissions. Injection timing mainly influences HC emission, and injection phasing has a small influence on emissions. Mittal et al. [31] studied two different fuel blends containing 10% and 15% of butanol in Gasoline by volume, which are tested on an engine dynamometer using the uncoated and ceramic coated engines. The results strongly indicated that combination of ceramic coated engine and butanol gasoline blended fuel has potential to improve engine performance. Besides the regulated emissions, Broustail et al. [32] studied the non-regulated pollutants (methane, acetylene, ethylene, benzene, acetaldehyde and formaldehyde) on a single-cylinder port-fuel injection SI engine, and comparisons have been made between iso-octane butanol blends and iso-octane ethanol blends. The results showed that ethanol has a superior emission performance relative to butanol and they are both better than iso-octane.

As the very important research factor and direction, the studies about engine combustion heat release of butanol-gasoline blend also have been carried out. Dagaut and Togbe [33] examined theoretical and experimental analyses of combustion mechanism of n-butanol-gasoline mixtures and studied oxidation mechanism using a jet stirred reactor. They reported good agreement between experimental results and the computations of detailed chemical kinetic scheme for n-butanol-gasoline blend. Furthermore, combustion processes of SI engine fueled with butanol-gasoline blend or neat butanol were investigated. Yang et al. [34] and Deng et al. [35] achieved the combustion efficiency increasing by adjusting ignition timing on a SI engine fueled with butanol-gasoline blend. Serras-Pereira et al. [36] studied combustion processes of SI engine fueled with butanol-gasoline blend or neat butanol, and Tornatore et al. [37] investigated the effect on the spark ignition combustion process of 40% of n-butanol blended in volume with 60% pure gasoline through cycle resolved visualization applied in a single cylinder SI engine working at low speed, medium boosting and wide open throttle. The results showed that laminar burning velocity is faster with butanol addition and similar results were found in research of Ref. [38].

However, only a few studies for SI engine combustion heat release analysis, performance, economy and emissions with the butanol blend at the same time, especially for the very high speed gasoline engines. Furthermore, many studies just focused on conventional harmful exhaust emissions (CO, HC and NOx) when use butanol as SI engine fuel. Although CO_2 is a non-toxic gas, which is not classified as an engine pollutant, it is one of the substances responsible for global temperature rises through the greenhouse effect [39,40], and CO_2 emission has not been usually taken into account in many studies. Moreover, Oxygen (O_2) emission can reflect some situations of other emissions but it was rarely concerned by investigators. Based on authors' previous studies [34,35,41,42], the objectives of this study will be find out common principles about the influence on combustion heat release, performance, fuel economy and the exhaust emissions of SI engine for variables such as ignition timing, engine load and butanol blend ratio. In this study, experiments were conducted on a single cylinder high speed SI motorcycle engine for two operating modes of full load and partial load at 6500 and 8500 rpm with pure gasoline, 30% and 35% volume butanol-gasoline blends. Engine performance, fuel economy and exhaust (HC, CO, CO_2, NOx and O_2) emissions have been tested and analyzed among pure gasoline, 30% and 35% volume butanol-gasoline blend.

2. Experimental setup

The engine used in this study is a single cylinder, four-stroke, 2-valve, air-cooling SI motorcycle engine with compression ratio of 9.2. The specifications of this engine are listed in Table 2.

In this study, three fuels were tested, including pure commercial 90# gasoline (PGS) which is used as the base fuel, two n-butanol and gasoline blends denoted as Bu30 and Bu35 (Bux means the volume fraction of n-butanol in the blend is x). Table 1 showed main properties of gasoline and butanol.

Experiments were conducted on a fully warmed engine. Engine was tested on full load from 3000 to 8500 rpm with an interval of 500 rpm. The partial loads were conducted at 6500 and 8500 rpm. Firstly, air/fuel ratio (AFR) was adjusted for adapting the 30% and