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Performance and emission characteristics of a spark ignition engine fuelled with butanol isomer-gasoline blends

M.N.A.M. Yusoff*, N.W.M. Zulkifli*, H.H. Masjuki, M.H. Harith, A.Z. Syahir, M.A. Kalam, M.F. Mansor, A. Azham, L.S. Khuong

Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

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ABSTRACT

The heavy reliance on petroleum-derived fuels such as gasoline in the transportation sector is one of the major causes of environmental pollution. For this reason, there is a critical need to develop cleaner alternative fuels. Butanol is an alcohol with four different isomers that can be blended with gasoline to produce cleaner alternative fuels because of their favourable physicochemical properties compared to ethanol. This study examined the effect of butanol isomer-gasoline blends on the performance and emission characteristics of a spark ignition engine. The butanol isomers; *n*-butanol, *sec*-butanol, *tert*-butanol and isobutanol are mixed with pure gasoline at a volume fraction of 20 vol%, and the physicochemical properties of these blends are measured. Tests are conducted on a SI engine at full throttle condition within an engine speed range of 1000–5000 rpm. The results show that there is a significant increase in the engine torque, brake power, brake specific fuel consumption and CO_2 emissions with respect to those for pure gasoline. The butanol isomers-gasoline blends give slightly higher brake thermal efficiency and exhaust gas temperature than pure gasoline at higher engine speeds. The iBu20 blend (20 vol% of isobutanol in gasoline) gives the highest engine torque, brake power and brake thermal efficiency among all of the blends tested in this study. The isobutanol and *n*-butanol blend results in the lowest CO and HC emissions, respectively. In addition, all of the butanol isomer-gasoline blends yield lower NO emissions except for the isobutanol-gasoline blend.

1. Introduction

Alcohols are often used as fuel additives in transportation fuels for internal combustion engines (Yusoff et al., 2015). Methanol and ethanol have been widely studied by scientists and researchers in order to improve the performance of vehicle engines. At present, the E10 blend, which contains 10 vol% of ethanol in gasoline, is commercialized on a large scale in the United States. In addition, the flex-fuel vehicles (FFVs) in Brazil is designed to run up to 85 vol% ethanol in gasoline blend (E85). Interestingly, butanol is perceived as a more competitive alternative fuel for use in gasoline engines due to its favourable properties, which are comparable to those for gasoline than ethanol.

Butanol (butyl alcohol) is a four-carbon alcohol exists in four different isomers: (1), *n*-butanol (1-butanol), (2) *sec*-butanol (2-butanol), (3) isobutanol (2-methyl-1-propanol), and (4) *tert*-butanol (2-methyl-2-propanol), as shown in Fig. 1. Even though these alcohols have the same energy content, their physical properties (*e.g.* density, viscosity, octane number and boiling point) are inherently different. Butanol is considerably toxic, less corrosive and easily biodegradable. More importantly butanol has more energy

* Corresponding authors.
E-mail addresses: ashraf.yusoff@siswa.um.edu.my (M.N.A.M. Yusoff), nurinmz@um.edu.my (N.W.M. Zulkifli).

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Nomenclature

SI	spark ignition engine
LHV	lower heating value
RON	research octane number
RVP	Reid vapour pressure
HoV	heat of vaporization
T	engine torque
BP	brake power
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
EGT	exhaust gas temperature
VE	volumetric efficiency
CO	carbon monoxide
CO_2	carbon dioxide
HC	hydrocarbon
NO	nitrogen monoxide or nitric oxide
nBu	*n*-butanol, 1-butanol
sBu	*sec*-butanol
tBu	*tert*-butanol
iBu	isobutanol
nBu20	blend containing 20 vol% of *n*-butanol in gasoline
sBu20	blend containing 20 vol% of *sec*-butanol in gasoline
tBu20	blend containing 20 vol% of *tert*-butanol in gasoline
iBu20	blend containing 20 vol% of isobutanol in gasoline
Bu0	pure gasoline

content than ethanol and it is comparable to gasoline (Patakova et al., 2011). In addition, *n*-butanol and isobutanol have lower water solubility, which makes these butanol isomers suitable for engines. Sec-butanol has higher water solubility whereas *tert*-butanol is fully miscible with water but less soluble than ethanol. The highly hydrophobic characteristic of *n*-butanol and isobutanol helps reduce water contamination, which can damage the fuel system of the engine. However, it shall be noted that there are standard limitations for blending fuels. It is highly recommended that fuel blends should contain 3.7 wt% of oxygen for use in conventional vehicle engines. This is equivalent to 10 vol% ethanol in gasoline (E10) or 16 vol% of butanol in gasoline (Bu16). Fuel blends containing high concentrations of butanol can be used in existing engines without failure, unlike fuel blends containing high concentrations of bioethanol. Bioethanol is highly corrosive, which can cause severe wear of engine components, as reported in previous studies (Coordinating Research Council, 2012; Hilbert, 2011; Khuong et al., 2016).

Numerous researchers have conducted comparative studies on the effect of alcohol-gasoline blends on engine performance. Masum et al. (2014a) examined the effect of various alcohol blends (M20, E20, Pr20 and Bu20 containing 20 vol% of methanol, ethanol, propanol and butanol in gasoline, respectively) on a multi-point fuel injection-spark ignition (MPFI-SI) engine at full throttle condition and various engine speeds. The results showed that the alcohol-gasoline blends result in higher engine torque (T) and brake thermal efficiency (BTE) compared to pure gasoline. However, the brake specific fuel consumption (BSFC) of the alcohol-gasoline blends is significantly higher than that for pure gasoline due to the lower energy content of the alcohols. The BSFC of the Bu20 blend is significantly lower than that for E20, with a value of 1.95 and 5.17%, respectively, relative to the pure gasoline. Xialong et al. (2009) performed a dyno-experiment test of an SI engine fuelled with Bu30 blend (30 vol% of butanol in gasoline) as well as pure gasoline. They observed that the T and brake power (BP) of the Bu30 blend are comparable to those for pure gasoline at lower engine speeds. However, the T and BP of this blend decreases at higher engine speeds due to the improved volumetric efficiency (VE) and longer combustion delay caused by the higher heat of vaporization (HoV). Thus, the T and BP can be recovered by the optimum spark ignition timing.

Elfasakhany (2015) studied the effect of isobutanol-gasoline blends on the performance of an SI engine. The results showed that the BP, T, VE, exhaust gas temperature (EGT) and in-cylinder pressure are lower for these blends (containing 3, 7 and 10 vol% of isobutanol in gasoline) compared to those for pure gasoline without engine optimization. Elfasakhany (2016) also compared the effect of dual butanol blends (*n*-butanol and isobutanol in gasoline) and single butanol blends (isobutanol or *n*-butanol in gasoline) on the performance of an SI engine at different engine conditions. The volume fraction of the alcohols was varied from 3 to 10 vol% and the results were compared with those for pure gasoline. The results showed that the niBu10 blend (10 vol% of *n*-butanol and isobutanol in gasoline) gives the best engine performance among all of the fuel blends tested in their study. However, the dual alcohol blends resulted in lower VE, BP, T and EGT compared to pure gasoline.

Furthermore, many experiments have been carried out to examine the emission characteristics of the butanol in gasoline blends. Feng et al. (2015) studied the effect of *n*-butanol-gasoline blends on a single cylinder SI motorcycle engine running at a speed of 6500

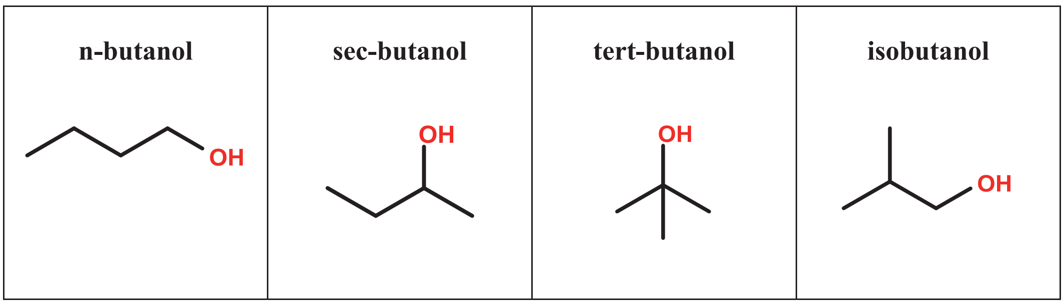

Fig. 1. Structural formula of butanol isomers.