



Full Length Article

Combustion and emissions of isomeric butanol/gasoline surrogates blends on an optical GDI engine

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ABSTRACT

The combination of distinctive physicochemical properties of biofuels and recent engine technologies offer benefits in terms of efficiency improvement and emissions reduction. The recent development in butanol bio-based production pathways encourage researchers to study their combustion characteristics. This paper experimentally evaluates the combustion and emissions of a gasoline direct injection (GDI) engine fueled with the butanol isomer/gasoline surrogate blends, in which primary reference fuel (PRF) and toluene primary reference fuel (TPRF) are selected as the gasoline surrogates, respectively. The flame propagation behaviors, in-cylinder pressure, apparent heat release rate, along with PN emissions from this optical GDI engine are discussed. First, butanol addition to the gasoline surrogates is found to slow down flame propagation, reduce peak cylinder pressure and heat release rate, and extend ignition delay and combustion duration. Further, among the four butanol isomers, n-butanol and *tert*-butanol are the most and least reactive fuels, respectively, whereas *iso*-butanol and *sec*-butanol show reactivities in between, as supported by the measured flame propagation and pressure traces, calculated heat release rates, as well as time scales describing the combustion progress, e.g. ignition delay and combustion duration. Finally, butanol addition reduces the PN emissions from the GDI engine, and the PN emissions reduction capacity of the four butanol isomers ranks as *sec*-butanol > *iso*-butanol > n-butanol > *tert*-butanol. Also, compared to the PRF/butanol blends, the PN emissions are reduced to a less extent when butanol is blended with TPRF.

1. Introduction

The increasing utilization of gasoline direct injection (GDI) engines in passenger cars is attributed to such advantages as lower fuel consumption, precise transient response, better knock resistance, and improved combustion efficiency. However, increased PM emissions is one drawback of GDI engines [1]. The primary reason for the higher PM in GDI engines is spray-wall (piston, cylinder, and valve) interaction, which leads to lower fuel vaporization rates and pool fires [2]. Consequently, more locally fuel-rich zones are formed within the flame area and promote soot formation. Various methods have been adopted to solve this problem. One of them is to utilize oxygenated fuels, such as alcohols, and their physicochemical characteristics to enhance in-cylinder combustion and soot oxidation [3–5].

Alcohols have been investigated during the last few decades as an alternative fuel for SI engines [6–8]. Many researchers studied methanol and ethanol and their effects on SI engine combustions and

emissions [9–13]. Methanol and ethanol have the advantages of high oxygen contents and sustainable production methods from renewable resources [6,8]. Nevertheless, methanol and ethanol have low energy densities, high fuel consumption, low water tolerances, and high corrosion rates.

Butanol is another alcohol fuel of interests. Compared to ethanol and methanol, butanol demonstrates a higher calorific value and a lower corrosion rate [6]. Butanol has four different molecular structures, denoted as n-butanol, *sec*-butanol, *tert*-butanol, and *iso*-butanol, as shown in Fig. 1. Different molecular structures (straight or branched) and their OH locations are expected to affect the combustion and emissions formation in internal combustion engines [14–16]. Specifically, *tert*-butanol, *iso*-butanol and *sec*-butanol reveal a higher octane index but reduced flame velocity compared to n-butanol [14,17,18]. Fan et al. [14] reported that the RON of PRF increased with butanol isomers addition in the following order: *iso*-butanol > *sec*-butanol > n-butanol > *tert*-butanol. They pointed that the RON of TPRF

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