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Full Length Article

Flash boiling combustion of isomeric butanol and gasoline surrogate blends using constant volume spray chamber and GDI optical engine

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ABSTRACT

Flash boiling spray has been regarded as a promising fuel injection technology. Many investigations have been focused on spray physics and mechanisms of flash boiling spray, but information on flash boiling of alcohols in GDI engines is very limited. In this paper, the spray characteristics, flame propagation, combustion analysis, and PN emissions of butanol isomers under flash boiling spray have been studied. A constant volume chamber with a high-speed camera used to investigate the flash boiling spray of butanol isomers and gasoline surrogate blends. The flash boiling spray was tested at 180 °C and compared to subcooled spray at 25 °C. The tested gasoline surrogates are primary reference fuel (PRF) and toluene primary reference fuel (TPRF). The flash boiling leads to the collapse of the spray six plumes into a single extended spray plume with longer spray penetration compared to subcooled injection. The spray study then extended to study the effects of flash boiling injection on flame development and PN emissions of the GDI optical engine. The results reveal that flash boiling injection leads to lower apparent flame speed and flame area compared to subcooled injection due to the lean-like burn condition, and yellow flame spots are diminished. The peak in-cylinder pressure and apparent heat release rate are reduced with longer ignition delay when the flash boiling injection is applied. The flame lasted longer under flash boiling conditions with improved late combustion phase, which results in higher heat released. The PN emissions reduced with flash boiling spray compared to subcooled conditions.

1. Introduction

Gasoline direct injection (GDI) engines have been used in light-duty vehicles because of its advantages of better transient controls, lower fuel consumption, lower knock tendency, and higher combustion efficiency. Meanwhile, the challenges of GDI engines include higher particulate emissions and improper mixture preparation [1]. This is partially attributed to the occurrence of impinging fuel film due to spray-wall interaction, a shorter duration for spray-air interaction, and more significant cyclic variations [2]. Such challenges can be even more pronounced with alternative fuels, for instance, butanol, because of their reduced evaporation rates. As representative alcoholic alternative fuels, butanol isomers and ethanol are frequently studied alcohols for GDI engine applications. Butanol isomers have many advantages over ethanol due to higher heating value, higher blending fraction in gasoline with better stability, lower volatility, lower corrosion, and production through various conventional and renewable biological methods [3–5]. However, due to the higher boiling point and higher viscosity of butanol, butanol fuels can suffer from deteriorated atomization under cold-start conditions [6,7].

Several studies have investigated the effects of using sub-cooled butanol isomers on combustion, flame propagation, and emissions of GDI engines [6,8–11]. For instance, Han et al. [8] reported that butanol addition into the gasoline surrogates led to a slower flame propagation speed, reduced peak cylinder pressure and heat release rate, and extended ignition delay and combustion duration. They also found that n-butanol yielded the best engine performance while *tert*-butanol the worst, with isobutanol and secbutanol are in-between. Li et al. [9] reported that all butanol isomers promote flame speed with shorter burning durations except for *tert*-butanol. They found that the use of butanol isomers reduced CO, UHC, and PN emissions. They recommended n-butanol and secbutanol as alternative fuels to achieve higher engine efficiencies and lower emissions. Yusoff et al. [10] reported that isobutanol gave the highest brake thermal efficiency compared to other isomers. All butanol isomers reduced the NO_x, CO, and UHC emissions. Lattimore et al. [11] reported that the addition of n-butanol to gasoline advanced the combustion phasing and shortened the combustion

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