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Differences in pool-fire induced soot production between subcooled spray and flash boiling spray in a DISI engine

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ABSTRACT

Pool fire and fuel-rich combustion have been considered the primary soot/particulate matter sources for gasoline direct injection (GDI) engines, which is a crucial issue for commercial and passenger vehicles. Flash boiling atomization, achieved by heating the fuel before injection, can notably improve spray atomization and reduce the occurrence of pool fire, thus reduce soot emission under extreme conditions. This investigation compared the performance of subcooled spray combustions and flash boiling spray combustions with the use of an optical engine facility. The optical engine was equipped with an optical liner so that side views of the combustion can be captured with a high-speed color camera. The high-speed measurement data from early injection conditions were then analyzed with the HSV color model to investigate the flame characteristics in the premixed, infrared, and diffusion flame regions. Indicated mean effective pressure (IMEP) and particulate number (PN) under different conditions were also analyzed under different conditions. It was found that the combustion performance using flash boiling sprays is superior to that using subcooled sprays, and the difference between the two combustion modes was discussed with the use of the flame model.

1. Introduction

Gasoline direction injection (GDI) engines have been considered as one of the primary techniques for passenger cars because of the advantages of improving fuel economy and combustion efficiency [1]. Meanwhile, it is still desirable to enhance the thermal efficiency further and reduce the particulate matter (PM) emissions for spark ignition GDI engines [2,3]. Fuel wall impingement and pool fire phenomenon can significantly worsen the combustion emission, which may be caused by improper injector design, unsuitable injection strategy, and extended spray penetration with downsized cylinder sizes, etc. [4–6]. Such pool fires are thought of as the primary reason for increased PM emissions and lower thermal efficiencies [7]. Besides, the remained footprints of the fuel spray on the cylinder wall can induce other critical challenges such as lubrication oil dilution, super knock, etc. [8,9]. Fuel film combustion can also be induced by tip wetting phenomenon, in which scenario fuel deposits on the fuel injector tip and is then ignited during engine combustion, leading to excessive soot formations near the injector tip or even coked injectors [10]. Techniques such as high-pressure injection and split/multiple fuel injectors can help soothe such deteriorated combustion phenomena [11,12], while cannot completely address the issues caused by pool fires and film combustion [13]. Furthermore, the use of alternative fuels or dual fuel systems on GDI engines can significantly improve thermal efficiency and reduce harmful engine emissions [14–16]. Recently some researches have been conducted and got good results, such as using the H_2 blended in the methanol to reduce the soot emission [17,18]. Some new techniques of in-cylinder soot concentration measurement have been developed, such as the Neural Network Two-Color technique [19].

Flash boiling atomizations for fuel spray applications have been considered as a promising approach in addressing the issues from high-pressure injections via fierce phase change of the fuel [20–25]. Typically, flash boiling atomization would rely on increasing the temperature of the fuel or reducing the ambient pressure, so that the saturated fuel pressure is higher than the local pressure, leading to evaporation/boiling of the fuel. The micro-explosion mechanisms would benefit the fuel atomization process by producing finer droplets and more fuel vapor, thus reducing the interaction between the liquid fuel and the cylinder wall [26–28]. In the previous studies, it has been demonstrated that flash boiling atomization can reduce PN emissions under cold start conditions of IC engines [29,30]. However, the mechanisms of such PN

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