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Study of flash boiling combustion with different fuel injection timings in an optical engine using digital image processing diagnostics

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ABSTRACT

Flash boiling atomization is considered a potential solution to multiple issues encountered in fuel atomization for internal combustion engine applications. It has been demonstrated that flash boiling combustion can reduce soot emission under cold-start conditions, while the analysis was still preliminary and limited to engine cold-start conditions. This work investigates the performance of flash boiling combustion in comparison to sub-cooled spray combustions realized with the variation of injection timing. An optical engine facility was used to capture the combustion characteristics with a high-speed color camera, with the temperature of the engine coolant maintained at 60 °C. HSV color model and modified digital CH^*/C_2^* ratio (excess air intensity) to study different flame regions and local combustion richness in the optical engine. The results show that under the conditions tested, flash boiling can improve the efficiency of the engine while reducing the PN emission simultaneously. Furthermore, it was seen that flash boiling combustion could yield a faster flame speed, uniform distribution of flames and less rich mixtures. Finally, color model analysis for transient and averaged flame images is also in good agreement with actual engine performance.

1. Introduction

Flash boiling atomization is potentially an alternative for the current high injection pressure sprays for gasoline direct injection (GDI) internal combustion engine (ICE) applications because of its capacity in creating finer droplets and stronger evaporations under low injection pressures [1–3]. Flash boiling phenomenon is enabled as the ambient pressure is lower than the saturation pressure of the injected fuel, thus usually flash boiling spray is achieved by increasing the fuel temperature or decreasing the ambient pressure inside the chamber. The fuel injector phase changing flow has been studied systematically to understand the flash boiling phenomenon near the nozzle [4]. The Flash boiling sprays have been widely studied in non-reactive constant volume chambers [5–7], and it has been shown that flash boiling sprays have desirable features for combustion, although there has been concern about targeting change and plume collapse under flash boiling conditions. Correlational researches about the dual fuel system for flash boiling spray [8] and the impingement film break up process [9] have been conducted in recent years. In comparison, ICE related studies using flash boiling sprays are still limited relatively.

With the existing studies, it has been shown that flash boiling combustion can indeed improve combustion efficiency and reduce harmful emissions under some engine conditions. Under flash boiling conditions, each single spray plume would expand radially [10], and thus enabled an enhanced fuel–air mixing process and a faster fuel evaporation rate [11,12]. The fuel–air mixing process inside the cylinder is further improved because of enhanced plume-to-plume interaction as well as plume-air interaction [13,14], and the fuel distribution is considered to be more uniform consequently. Furthermore, flash boiling is considered capable of eliminating the fuel film that forms during the combustion of the premixed charge ignite to create piston-top pool fires. With different injection timing, the film mass and corresponding pool fire vary, which is affected by the different spray plume-wall interaction [15,16]. While since a greater vapor phase concentration will be produced under flash boiling conditions, the amount of spray impingement film is also expected to be less [17].

In the previous work of the authors [18–21], it has been demonstrated that flash boiling atomization both increased the brake thermal efficiency (indicated mean effective pressure-gross) and reduced the soot emission under cold start conditions. The previous study showed that flash boiling sprays reduced the amount of yellowish flame, which is suspected to lead to the final production of soot. Besides, the impact

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