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Full Length Article

Comparison of spray collapses at elevated ambient pressure and flash boiling conditions using multi-hole gasoline direct injector

Hengjie Guo [a], Haichun Ding [a], Yanfei Li [a,*], Xiao Ma [a], Zhi Wang [a,b], Hongming Xu [a], Jianxin Wang [a]

[a] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
[b] Center for Combustion Energy, Tsinghua University, Beijing 100084, China

HIGHLIGHTS

- Spray collapse occurred in near field at elevated P_{amb} and in far field in flash boiling conditions.
- The characteristics of the two collapse modes were fully discussed.
- Jet-air interaction caused the near field spray collapse at elevated P_{amb}.
- Vapor condensation caused the far field spray collapse under flash boiling conditions.

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ABSTRACT

In this study, the spray characteristics of a five-hole gasoline direct injector were investigated in a constant volume vessel. The absolute ambient pressure ranged from 0.5 to 10.0 bar, and the fuel temperatures were 20 °C and 80 °C. High-speed imaging and phase Doppler measurement technique were utilized to investigate the spray morphology and the droplet dynamics, respectively. Spray collapses were observed in the near field under the elevated ambient pressure (higher than 1.0 bar) conditions and in the far field under the flash boiling conditions in both macroscopic and microscopic levels. In addition, under the elevated ambient pressure conditions, the droplets at the inner side of the target jet were larger than those at the outer side, due to the increased probability of droplet coalescence as a result of spray collapse. Whilst, slight increase in droplet diameter in the inner side of the target jet was also found under the flash boiling conditions. Furthermore, the near-field collapse at the elevated ambient pressure conditions was attributed to the jet-air interaction, termed as jet-induced spray collapse; and the far-field collapse under the flash boiling conditions was attributed to the dramatic temperature drop and the resultant vapor condensation, termed as condensation-induced spray collapse.

1. Introduction

Nowadays, multi-hole injectors have been widely used in gasoline direct injection (GDI) engines due to their flexibility in controlling jet targeting and fuel distribution, which can be designed to transport the fuel to where it is needed, e.g. towards the spark plug. However, the thermal conditions inside the combustion chamber are complicated. The absolute ambient pressure varies from 0.2 to 5 bar, and can be even higher in turbo-charged engines, while the fuel temperature varies from below 0 °C at cold-start conditions to 150 °C at high loads [1]. Different spray behaviors, such as flash boiling [2], can be observed with the combination effects of the thermal atmosphere and fuel properties.

Flash boiling is the rapid phase transition from liquid to vapor when the liquid is injected into a chamber with the ambient pressure lower than the saturation pressure. Brown et al. [3] studied the spray formed by flashing liquid jet, and found that flash boiling could improve the atomization quality. Reitz et al. [4] investigated the mechanism of flash boiling atomization, and ascribed it to unstable bubble growth within the bubbly jet as it leaves the nozzle. Kim et al. [5] investigated flash boiling injection in a spark-ignition engine and found the improved thermal efficiency at partial load. Senda et al. [6] applied flash boiling to diesel spray process and proposed a fuel design concept based on the use of both high and low volatility fuels. Besides, it has been reported that up to 99% of the injections during the 'New European Driving Cycle' and 95% during 'Real Driving Emissions' tests are superheated in mid-range cars [7]. Therefore, the flashing spray should be studied not only because of its potential to improve the atomization

* Corresponding author.
E-mail address: liyanfei1@tsinghua.edu.cn (Y. Li).

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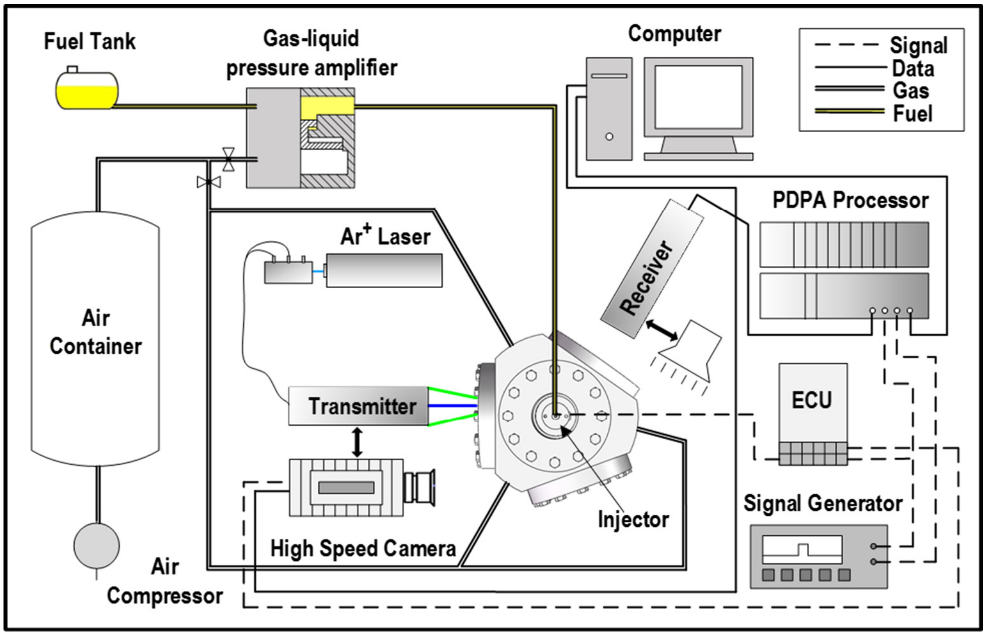

Fig. 1. Schematic of the experiment set-up.

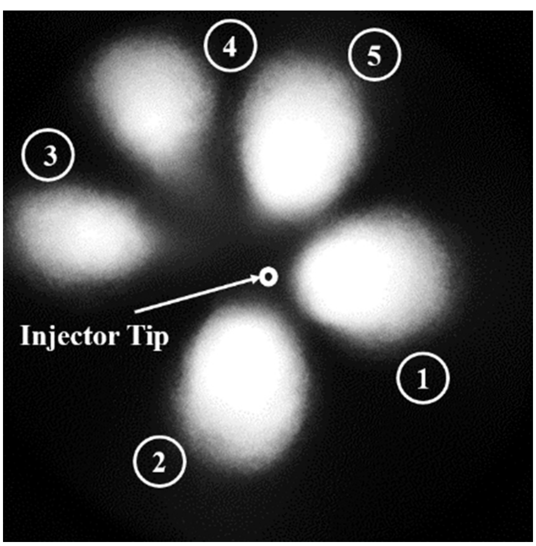

Fig. 2. Spray footprint of the tested injector.

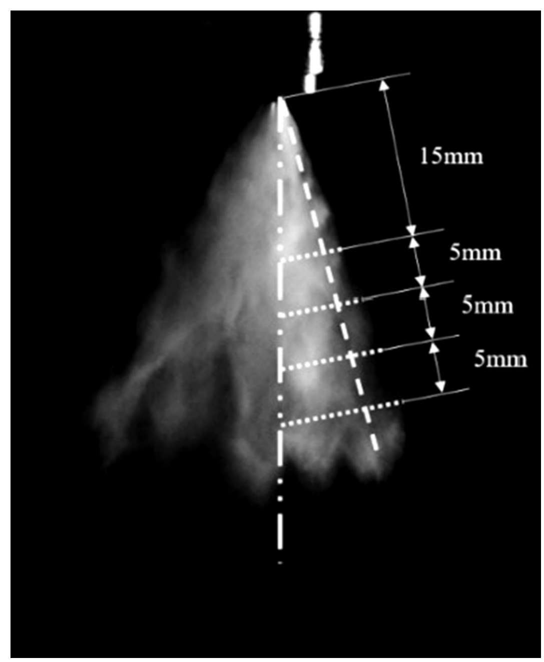

Fig. 3. PDPA measurement positions.

quality, but also due to its frequent appearance during engine operations.

One noticeable feature for flash boiling when using multi-hole injectors is the spray collapse [8–10]. The influencing factors and the cause of spray collapse have been widely studied. Mojtabi et al. [11] revealed that the superheated degree and nozzle hole configuration are the two key factors affecting spray collapse. Aori et al. [12] investigated the effect of nozzle hole configuration on the macroscopic characteristics of flash boiling sprays and indicated that the spray collapse was enhanced for nozzles with more holes and a symmetrical configuration. Yang et al. [13] suggested that the spray collapse in flash boiling conditions was caused by the joint effect of the low-pressure core and the overlap of spray plumes.

Recently, spray collapse has also been reported under non-flash boiling conditions, especially with compact asymmetrical nozzle configurations [14,15]. Nishida et al. [16] studied the effect of the hole-axis-angle of two-hole nozzles on the liquid and vapor distributions at the ambient pressure of 10.0 bar and the ambient temperature of 500 K. The results showed that the jets moved towards each other as the hole-axis-angle decreased because of the pressure difference between the center and the periphery of the spray. Malaguti et al. [17] investigated the spray development of a six-hole injector experimentally and numerically under atmospheric conditions, and found the outer jets were defected inwards due to the low-pressure zone inside the spray. Rontondi et al. [18] investigated the droplet dynamics of multi-hole GDI sprays under atmospheric conditions and found that the low-pressure area between the jets was filled with small droplets. Li et al. [19] reported that the spray collapse became obvious as the ambient