Brief Report

Atomization Method Using Fuel/Cavitation Bubble Mixture Injection

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1. Introduction

In a direct injection (DI) gasoline engine, spray characteristics that achieve both better atomization and lower spray tip penetration are required to produce effective combustion and to prevent wall adhesion of the fuel. In conventional injection methods, a higher injection pressure yields better atomization, however it also results in higher spray tip penetration. To overcome this tradeoff, we devised a liquid fuel injection nozzle with a novel fuel atomization strategy that utilizes the effect of collapse of cavitation bubbles in the liquid jet (the cavitation nozzle). We first studied the feasibility of the cavitation nozzle and the conditions needed to implement it through computational fluid dynamics (CFD). A poppet type nozzle was designed based on the CFD results. The atomization mechanism and the spray characteristics of the nozzle were measured experimentally and compared with those of a conventional poppet type nozzle.

2. Liquid Fuel/Cavitation Bubble Mixture Injection Technique

The concept and configuration of the poppet type cavitation nozzle are shown in **Fig. 1**. The nozzle comprises two orifices and an intermediate cavity between the orifices. The role of the upstream orifice is to generate the cavitation bubbles at both the inlet and exit of the orifice. The intermediate cavity is placed to hold the cavitation bubbles within it. The role of the downstream orifice is to mix the cavitation bubbles and liquid fuel, and inject the mixture into the atmosphere. The collapse of the cavitation bubbles within the bubble/liquid mixture jet outside the nozzle increases turbulence and liquid surface area. Subsequently, these effects enhance the atomization of the liquid and decrease the breakup length; the improved atomization results in lower spray tip penetration.

The concept of the cavitation nozzle requires a number of conditions to be met. In a DI gasoline injection condition, the ratio of the effective area of the downstream orifice to the effective area of the upstream orifice should be greater than two to generate the cavitation bubbles at the first orifice. This condition can be derived from the cavitation number, which is defined as $CN=(P_1-P_2)/(P_2-P_v)$, and should generally be greater than three to generate bubbles at the exit of the orifice. Note that the cavitation bubbles generated at the exit of the upstream orifice distribute the circumference of the liquid jet in the intermediate cavity. Moreover, the generated bubbles can easily collapse and disappear when the local pressure exceeds the vapor pressure P_v of the fuel. It is important that the two orifices are offset to avoid bubble collapse caused by the pressure rise and to direct the portion of the

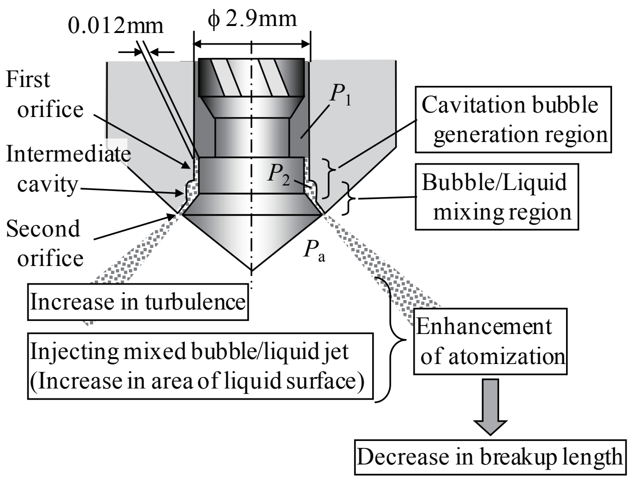

Fig. 1 Basic concept and configuration of the Cavitation nozzle.

mixture with the highest bubble volume fraction in the intermediate cavity into the second orifice smoothly. In this study, these conditions were elucidated through nozzle internal flow CFD, which employs a Eulerian three-fluid model (fuel liquid/vapor/air) with a cavitation model based on Rayleigh's equation.

A poppet type cavitation nozzle was designed through CFD. As shown in **Fig. 2**, while almost all of the jet in the exit area of a conventional nozzle (a) is liquid, the predicted volume fraction of bubbles at the exit of the cavitation nozzle (b) is 0.5. The observed spray pattern of the conventional nozzle is a streaky hollow cone. At the vicinity of the nozzle exit, relatively thick liquid columns are also formed. Subsequently the liquid columns are stretched and deformed, broken into ligaments, and finally divide again to form droplets. On the other hand, the spray pattern of the cavitation nozzle is a hollow cone spray which is homogeneously distributed in the circumferential direction. At the vicinity of the nozzle exit, a liquid sheet of fuel with a net-like structure is observed. This structure is stretched downward and partially broken into ligaments and multi-legged ligaments. The ligaments subsequently collapse to form droplets. The effects of the bubble/liquid mixture injection method achieve a mixture jet homogeneous in the circumferential direction and relatively small net-like liquid structures just downstream of the nozzle exit. A smaller droplet size and lower spray tip penetration are realized; in comparison with the conventional nozzle, the measured Sauter mean diameter is reduced from 21 mm to 19 mm and the spray length at 1 ms is reduced from 22 mm to 19 mm, at an injection pressure of 20 MPa and an ambient pressure of 800 kPa.

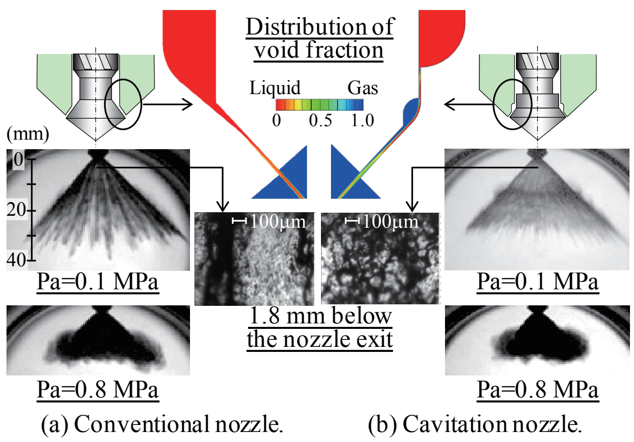

Fig. 2 Distribution of void fraction in the nozzle, spray pattern and close-up of liquid jet in the vicinity of the nozzle exit.

3. Conclusion

In this study, a liquid fuel injection nozzle with a novel fuel atomization strategy that utilizes the effect of collapse of cavitation bubbles in a liquid jet was proposed and investigated. The present nozzle achieves smaller droplet size and lower spray tip penetration than conventional nozzles.

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