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Study on Homogeneous Mixture Formation by High-Flow Hydrogen Jet

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In hydrogen engines for large commercial vehicles, which are typically based on diesel engines, the in-cylinder flow field is dominated by strong swirl, and as a result, turbulent diffusion contributing to mixture formation is suppressed, making it difficult to achieve sufficient mixing and leading to the formation of locally rich regions. As a potential solution to this issue, a jet roll-up concept, in which a hydrogen jet injected into the cylinder impinges on the piston wall and promotes mixing through roll-up motion, has been proposed. To realize this concept, a jet with sufficiently high penetration capability is required. Therefore, the objective of this study is to clarify the requirements for achieving high-penetration hydrogen jets necessary for homogeneous mixture formation by evaluating the behavior of high-flow-rate hydrogen jets using flow visualization techniques.

The jet penetration capability, defined as the jet tip penetration length at a given time, can be characterized by the mass flow rate and the nozzle exit velocity. Under choked flow conditions, the mass flow rate is determined by the supply pressure and the nozzle orifice area, while the jet velocity can be characterized by the pressure ratio between the supply gas pressure and the ambient pressure by treating the Mach disk location as a virtual nozzle exit. Accordingly, by varying the combination of supply pressure and nozzle orifice area, the effects of mass flow rate and jet velocity on jet penetration can be evaluated independently.

First, jet morphology and the internal hydrogen concentration distribution were measured in a constant-volume vessel using shadowgraph and negative laser-induced fluorescence (LIF) techniques. Under conditions of equal mass flow rate, increasing the pressure ratio resulted in only a slight increase in jet penetration length, with no significant difference observed in the penetration of the high-concentration hydrogen region. In contrast, under conditions of equal pressure ratio, increasing the nozzle orifice area led to a pronounced increase in jet penetration length and allowed the high-concentration hydrogen region to extend toward the jet tip.

Next, the relationship between the cumulative mass flow rate up to a given time, i.e., the injected mass, and the jet penetration length at that time was examined for each injection condition. Under identical injector geometry and ambient conditions, the jet penetration length was found to scale with the square root of the cumulative injected mass.

Based on these results, although jet penetration is governed by both jet velocity and mass flow rate, it can be concluded that increasing the mass flow rate is the most effective requirement for realizing high-penetration hydrogen jets necessary for homogeneous mixture formation.

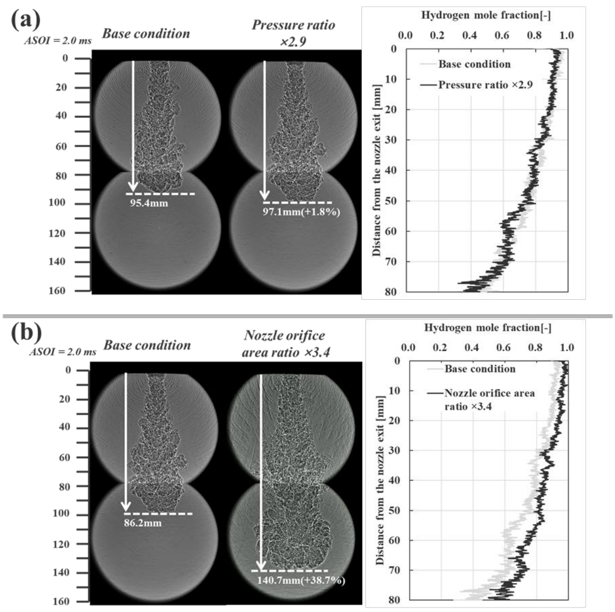

Fig.1 Comparison of shadowgraph images and hydrogen mole fraction distributions on jet cross sections

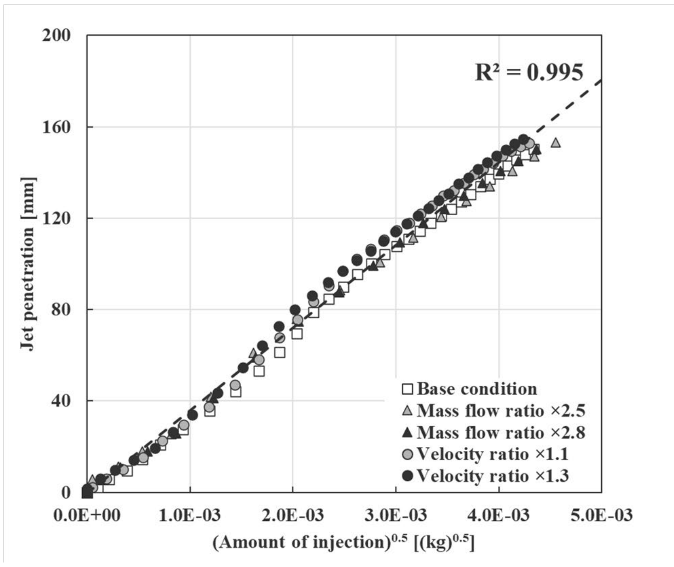

Fig.2 Amount of injection vs Jet penetration