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Analysis of Hydrogen Jet Characteristics and Concentration Distribution by Simultaneous LIF and Schlieren Method Measurements in a Constant Volume Chamber

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ABSTRACT: This study quantitatively investigates hydrogen-jet shape and mole fraction distribution using a simultaneous acetone laser-induced fluorescence (LIF) and schlieren imaging technique. Experiments were conducted in a constant-volume chamber(CVC) with injection pressures of 2, 6, 9 MPa and ambient pressures of 0.15, 0.4, 0.6 MPa. After applying image corrections for optical interference and laser non-uniformity, inverse-LIF analysis revealed that higher injection pressure sustains higher hydrogen mole fractions farther downstream, whereas increased ambient pressure narrows the jet core and accelerates downstream dilution. These results clarify the combined influence of injection and ambient pressures on hydrogen-jet structure and mixing behavior.

Hydrogen is a promising carbon-free fuel for internal combustion engines due to its wide flammability range and zero CO_2 emissions at the point of use. However, its higher adiabatic flame temperature than those of hydrocarbon fuels can increase NO_X emission. And, abnormal combustion phenomena—such as knock, flashback, and pre-ignition—may occur. Therefore, accurate characterization of hydrogen-jet structure and concentration fields under engine-relevant conditions is critical. This study develops a simultaneous LIF–schlieren methodology to quantitatively evaluate hydrogen-jet behavior in a constant-volume chamber.

Experiments were conducted in a CVC equipped with a hydrogen injector and optical access windows. Acetone was employed as a fluorescent tracer for inverse-LIF measurements, while schlieren imaging was simultaneously used to extract jet shape information. Injection pressure ranged from 2 to 9 MPa and ambient pressure from 0.15 to 0.6 MPa at room temperature. Image corrections were applied to account for background illumination, laser energy fluctuation, and laser-sheet intensity non-uniformity, enabling quantitative evaluation of hydrogen mole fraction distributions.

The hydrogen-jet characteristics and mole fraction distributions were analyzed under varying injection and ambient pressure conditions using averaged LIF and schlieren measurements. Increasing the injection pressure resulted in a wider jet core angle and a more gradual downstream decay of hydrogen mole fraction. This behavior indicates enhanced jet momentum, allowing a greater portion of injected hydrogen to penetrate further downstream while maintaining relatively high core concentrations. Radial mole fraction profiles further showed that higher injection pressure led to broader regions of elevated hydrogen concentration, especially in the downstream region.

In contrast, ambient pressure exhibited a suppressive effect on jet expansion. As the ambient pressure increased, the hydrogen-jet core angle decreased and downstream mole fraction attenuation became more pronounced. This can be attributed to the suppression of gas expansion under higher surrounding pressure, which constrained radial spreading and promoted faster dilution along the jet axis. The cross-sectional mole fraction distributions confirmed that lower ambient pressure conditions preserved wider hydrogen-rich regions, whereas higher ambient pressure cases resulted in narrower and more rapidly diluted jets.

Normalized radial mole fraction profiles revealed near self-similar behavior in the upstream region for both injection and ambient pressure variations. However, deviations from self-similarity increased farther downstream, particularly under low ambient pressure conditions. This suggests that quasi-steady jet behavior becomes increasingly sensitive to surrounding flow conditions downstream, where momentum exchange between the jet and ambient gas plays a more dominant role.

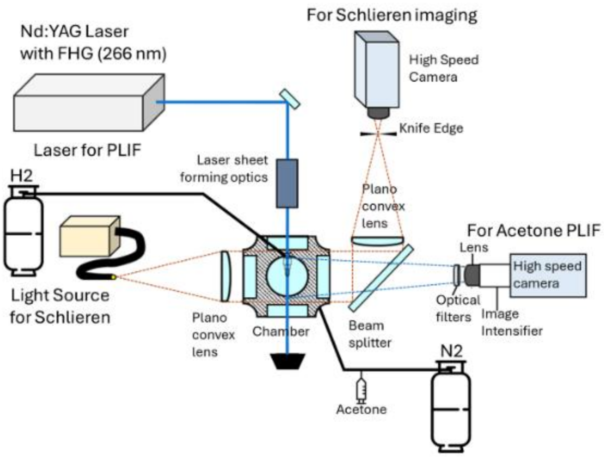

Fig. 1 Schematic of Experimental apparatus