

Visualization and Analysis of Formaldehyde Formation in Diesel Spray Combustion

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KEY WORDS: Heat Engine, Compression Ignition Engine, Measurement/Diagnosis/Evaluation, Combustion Analysis, Formaldehyde (HCHO), Chemiluminescence Imaging, Laser-Induced Fluorescence (LIF) (A1)

Formaldehyde (HCHO) is an important intermediate species in diesel combustion and is widely used as an indicator of low-temperature oxidation reactions. As fuel compositions become increasingly diversified, understanding the spatial and temporal behavior of HCHO is essential for clarifying combustion characteristics and validating combustion simulations. However, conventional optical diagnostics have primarily focused on either chemiluminescence imaging or laser-induced fluorescence (LIF), making it difficult to simultaneously investigate HCHO formation and residual distributions throughout the combustion process.

In this study, HCHO chemiluminescence imaging and LIF measurements were applied to a rapid compression and expansion machine (RCEM) based on a single-cylinder diesel engine. Experiments were conducted under high-EGR, low-load diesel combustion conditions. Continuous chemiluminescence imaging was performed at 20,000 fps to visualize the temporal evolution of HCHO formation. In addition, LIF measurements using a 355 nm Nd:YAG laser were performed to visualize HCHO distributions during the late stage of combustion. To extract HCHO chemiluminescence, broadband luminous flame emission was corrected using images obtained at 473 nm and subsequently removed through image-processing techniques.

Figure 1 shows the heat-release history and corresponding HCHO chemiluminescence images. HCHO chemiluminescence was mainly observed during the intermediate stage of combustion near the bowl lip and squish regions, where temperature rise was relatively limited compared with the central combustion zone. These observations suggest that HCHO consumption is suppressed in near-wall regions where the temperature rise is relatively limited, whereas HCHO is rapidly consumed in high-temperature reaction zones. As combustion progressed, HCHO chemiluminescence gradually disappeared, presumably due to the progress of oxidation reactions and the reduction of remaining intermediate species.

LIF measurements revealed residual HCHO distributions near the bowl lip and cylinder-wall regions during the late stage of combustion. These regions correspond to areas where reaction progress was relatively slow. Furthermore, qualitative comparisons with three-dimensional CFD simulations showed agreement in the spatial locations of HCHO distributions. This indicates qualitative consistency between the experimentally observed and CFD-predicted HCHO distributions.

The proposed diagnostic approach enables visualization of both HCHO formation and residual distributions during diesel combustion. Combining chemiluminescence imaging with LIF measurements provides a useful tool for understanding near-wall combustion phenomena and for qualitatively evaluating combustion simulations involving intermediate species.

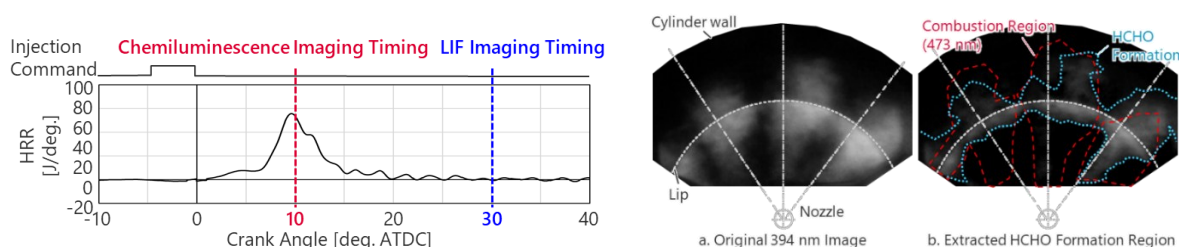


Figure 1. Heat release rate and extracted HCHO chemiluminescence images.

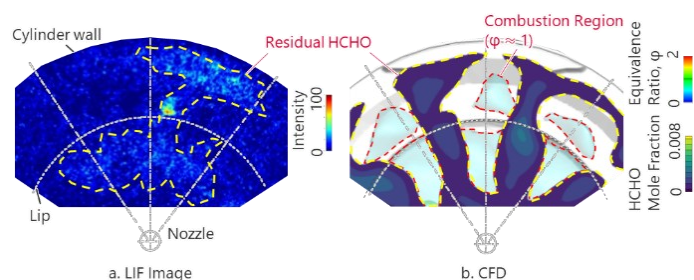


Figure 2. Comparison of HCHO distributions obtained by LIF measurements and CFD simulations.