

Optimization of Combustion Chamber Geometry Using Machine Learning Based on Numerical Analysis of Mixture Formation in Direct Injection Hydrogen Engines

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Optimizing mixture formation is essential for improving thermal efficiency and reducing NOx emissions in direct-injection hydrogen engines. The Plume Ignition and Combustion Concept (PCC) has been proposed in previous studies to achieve near-zero NOx emissions while maintaining high thermal efficiency. In this study, a machine-learning-based method was developed to optimize combustion chamber geometry based on a quantitative evaluation of mixture formation characteristics required for PCC combustion.

Mixture formation obtained from CFD simulations, validated against experimental data, was quantitatively assessed using objective functions that represent the target mixture characteristics. Machine learning models were then constructed to describe the relationship between the objective functions and combustion chamber geometry. Using these models, combustion chamber geometries were iteratively generated and evaluated, and an optimized design was selected after confirming convergence trends in the objective functions.

Figure 1 shows the distribution of the combustion chamber geometries generated during the optimization workflow. The highlighted region represents geometries that improve mixture homogeneity while maintaining favorable plume concentration and spatial distribution characteristics. Based on these results, an optimized combustion chamber geometry was selected for experimental evaluation.

Figure 2 presents the engine performance of the optimized combustion chamber under high-load operating conditions. The optimized geometry significantly reduced NOx emissions while maintaining a gross IMEP above 2,000 kPa and preserving thermal efficiency. These results demonstrate the effectiveness of the proposed optimization workflow for combustion chamber design based on quantitative mixture formation analysis and highlight its potential to provide practical design guidelines for direct-injection hydrogen engines.

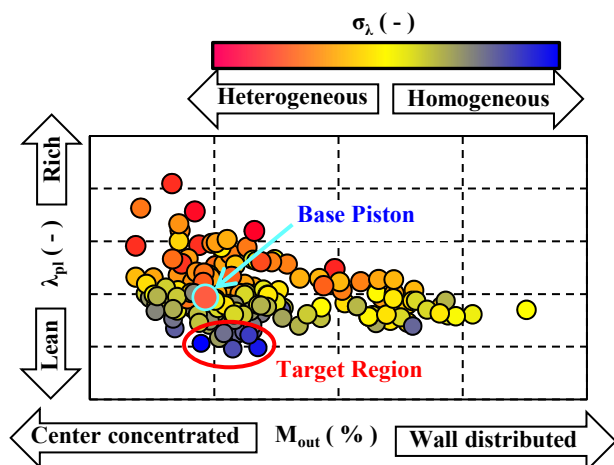


Fig. 1 Distribution of Optimized Combustion Chamber Geometries

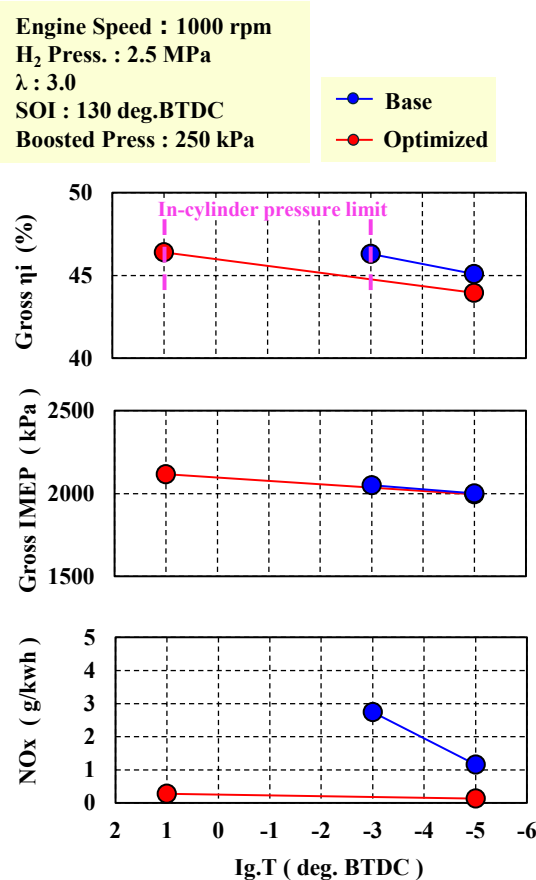


Fig. 2 Effect of Optimized Combustion Chamber on Engine Performance