

Cooling Loss Reduction in a High-Compression-Ratio HD Diesel Engine with an Optimized Combustion Chamber and a High Flow Rate Nozzle

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For heavy-duty vehicles, diesel engines are considered as a suitable powertrain due to their superior fuel consumption. Therefore, it has been necessary to investigate into combustion phenomena and fuel spray characteristics aiming to achieve thermal efficiency improved commercial heavy-duty diesel engines. Nowadays, further improvements in thermal efficiency are required to achieve carbon neutral and reduce fuel consumption. Increasing the compression ratio is effective for improving thermal efficiency as state-of-the-art HD engines have been employed; however, it generally increases cooling loss and may deteriorate combustion. Therefore, it is necessary to design a combustion system that suppresses the increase in cooling loss while utilizing the benefit of a higher compression ratio. This study focuses on cooling loss reduction in a high-compression-ratio heavy-duty diesel engine by optimizing the combustion chamber geometry and applying a high flow rate nozzle. The effects of the proposed combustion concept were investigated by numerical simulation and single-cylinder engine experiments.

Figure 1 shows the cross-sectional shapes of the piston cavities investigated in this study. The ‘Previous’ chamber had been optimized for a compression ratio of 23.5 in a previous study. In the present study, the combustion chamber geometry was re-optimized from the Base chamber for application to a higher compression ratio. The chamber diameter, depth, and lip curvature were varied to obtain better performance at a compression ratio of 23.5 with the different concept from ‘Previous’. The design guideline was also applied to the chamber at a compression ratio of 26. In addition, a high flow rate nozzle was combined with the optimized high-compression-ratio chamber. Figure 2 shows the calculated gross indicated thermal efficiency. The final specification, Spec. ④, which combined the optimized chamber at a compression ratio of 26 with the high flow rate nozzle, showed the highest gross indicated thermal efficiency.

The proposed combustion concept was experimentally evaluated using a single-cylinder heavy-duty diesel engine with a bore of 135 mm and a stroke of 150 mm. The experiments were conducted at an engine speed of 1,200 rpm, a fuel injection quantity of 167.7 mg/st, and an excess air ratio of 2.66. Figure 3 shows the experimentally obtained heat balances of ‘Previous’, Spec. ③, and Spec. ④. Spec. ③, which combined with baseline nozzle, showed a higher cooling loss and a lower gross indicated thermal efficiency than ‘Previous’. By applying the high flow rate nozzle in Spec. ④, the cooling loss was significantly reduced, and the gross indicated thermal efficiency was increased. Although the cooling loss of Spec. ④ remained slightly higher than that of ‘Previous’, its gross indicated thermal efficiency exceeded that of ‘Previous’. These results demonstrate that the high flow rate nozzle can suppress the increase in cooling loss with higher compression ratio and can convert the excessive heat energy into an improvement in gross indicated thermal efficiency by means of the high-compression-ratio combustion chamber.

The key findings of this study are summarized as follows:

1. The combustion chamber design guideline numerically obtained at a compression ratio of 23.5 was successfully extended to an optimized combustion chamber design at a compression ratio of 26.
2. The high flow rate nozzle can suppress the increase in cooling loss with the new higher-compression-ratio chamber, which enabling the final specification to exceed the gross indicated thermal efficiency of the previously optimized specification.

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