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A Study on Cold Emission Reduction of Direct-Injection Gasoline Engine by Controlling the In-cylinder Gas Properties (First Report)

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The unburned components that do not contribute to combustion exhausted from internal combustion engines should be significantly reduced. During the cold start of a direct-injection gasoline engine, some of the fuel injected into the cylinder adheres to the top of the piston and cylinder wall, forming a liquid film due to insufficient vaporization of the fuel. The unburned mixture on the wall quench layer and the fuel trapped in the piston crevice are exhausted as unburned hydrocarbons after avoiding combustion, and particulate matter, mainly soot, is formed in the fuel-rich region due to the inhomogeneous diffusion flame in the vicinity of the liquid film.

In this study, in order to significantly reduce unburned hydrocarbons (THC) and particulate number (PN) emissions, enhancement of fuel evaporation under cold conditions was investigated by controlling the in-cylinder gas properties of a direct-injection gasoline engine equipped with a variable valve system. The in-cylinder gas properties can be controlled relatively easily by operating the intake and exhaust valve timing. Late intake valve opening (LIVO) creates a negative pressure inside the cylinder, while negative valve overlap (NVO) recompresses the hot internal EGR remaining in the cylinder.

Experimental results with a single-cylinder engine showed that LIVO and NVO reduced THC and PN, and could be improved to hot condition levels. The results of the in-cylinder gas temperature and internal EGR rate using the Three Pressure Analysis (TPA) in the one-dimensional cycle simulation software GT-POWER showed that the introduction of internal EGR by NVO resulted in a higher temperature of the in-cylinder gas, as expected. However, LIVO with no change in the internal EGR rate also showed a temperature increase similar to that of NVO. It was found that more flow work of the intake air flowing into the cylinder to equilibrate the pressure increases the internal energy of the in-cylinder gas, which increases the temperature of the charged gas. The temperature and pressure obtained from TPA were used to evaluate the average degree of superheat of the in-cylinder gas relative to the liquid fuel. The degree of superheat is expressed as the difference $(T - T_s)$ between the superheated steam at temperature T and the saturation temperature T_s under the same pressure, and the "average degree of superheat" was defined as the time average from the start of injection to before ignition timing. T_s was obtained assuming that the gasoline fuel used in the experiment consisted of 12 pure components $(\mathrm{C_4} \sim \mathrm{C_{10}})$.

As shown in Fig.1 and Fig.2, it was confirmed by controlling the degree of superheat for liquid fuels allows the reduction of unburned hydrocarbons and particulate numbers in cold conditions. In particular, LIVO has superior combustion stability even when cold conditions, and reduced cold emissions by increasing the degree of superheat synergistically due to the lower saturation temperature caused by decompression and the higher temperature of the charged gas. In addition, spray observations in an optical engine also showed that the strong intake air flow into the cylinder due to the lower pressure resulted in reduced fuel adhesion to the cylinder walls.

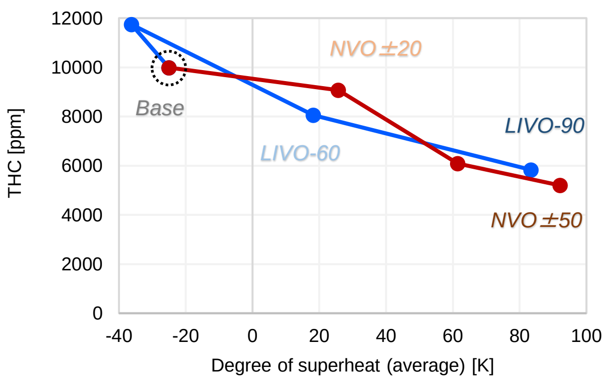

Fig. 1 Relationship between degree of superheat and THC

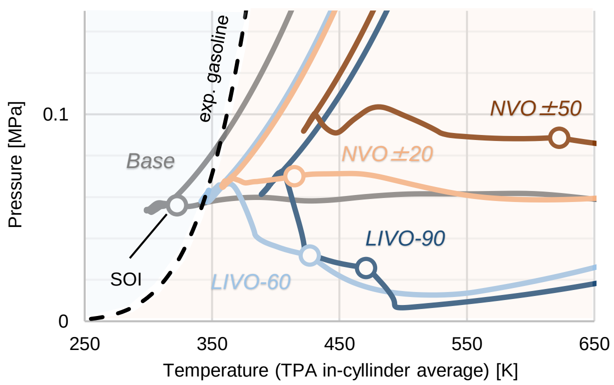

Fig. 2 P-T diagram of LIVO and NVO