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Title: Application of LPG to SI engines – Lean Stratified Combustion

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Abstract: The emission regulations such as European emission standards have become stringent more and more. Direct injection (DI) technology is one of the technologies which improves not only fuel economy but also performance of spark ignition (SI) engines. With DI of fuel, the evaporation latent heat of fuel can effectively reduce the in-cylinder temperature, which is a charge cooling effect, and it gives help to advance ignition timing for better fuel economy. However, the reduction level of fuel consumption with DI was just up to 10 %. This is due to that fuel is injected during intake stroke and forms stoichiometric homogeneous mixture, which is same as mixture of conventional port fuel injection SI engines. Therefore, stratified combustion operation was suggested to improve better fuel economy. In a stratified combustion mode, fuel is directly injected into the cylinders, but injection takes place during end of compression stroke. In addition, engine is operated under globally lean condition, not stoichiometric condition. Therefore, heat transfer and pumping losses are much reduced, which leads to lower fuel consumption compared to homogeneous combustion mode. However, given time for mixture formation is much shorter than that of homogeneous mode due to late injection timing. Due to the short time, locally rich mixture region was formed leading diffusion controlled combustion, which led to high smoke emission. Fast combustion speed is also the main reason of high nitrogen oxides (NOx) emissions. Unlike gasoline, gaseous fuel like LPG was regarded to have shorter required time for stratified mixture formation; therefore, LPG is regarded clean fuel in terms of NOx and smoke emissions. However, researches and attempts using evaporative alternative fuels including liquefied petroleum gas (LPG) have been rare conducted under lean stratified combustion condition.

In this presentation, the combustion and emission characteristics of LPG and gasoline were investigated in a single cylinder spray-guided DISI engine under lean stratified conditions. Firstly, the

basic spray characteristics investigation was conducted in a constant volume chamber with Mie scattering and shadowgraph techniques. As characteristics of LPG spray compared to gasoline, LPG spray showed shorter liquid penetration and wider spray angle due to better evaporation characteristics. Also, time for mixture formation of LPG spray seemed to be shorter than that of gasoline with shadowgraph technique. In addition, leading edge vortex, which is sweet spot stable ignition was widely formed in LPG case. Consequently, LPG fuel was expected that LPG has better ignition stability and less piston wetting. However, structure of LPG spray was collapsed and became narrower unlikely gasoline cased under high injection pressure condition.

In metal engine test, LPG fuel showed better combustion stability but lower indicated mean effective pressure (IMEP) compared to gasoline. These results were due to that better evaporation characteristics of LPG. With results of basic spray experiment, LPG spray showed the larger leading edge vortex leading to ignition stability and higher local homogeneity of mixture causing slow combustion speed. As emissions characteristics, both lower NOx and smoke emissions were achieved due to slower combustion speed and better local mixture homogeneity, respectively.

To analyze combustion process and emission characteristics in detail, flame visualization experiment was conducted with both fuels in an optical engine. In gasoline case, after ignition non-luminous blue flame and luminous yellowish flame coincided and propagated toward to boundaries of quartz window. This meant that locally rich mixture was formed and combusted. As injection timing was retarded, the intensity and region of luminous yellowish flame became strong and larger. In other hand, intensity of non-luminous blue flame in case of n-butane was lower than those of gasoline due to slower combustion speed of n-butane. However, luminous yellowish flame can be easily captured even though the intensity of luminous flame was lower than that of gasoline. It meant that diffusion controlled rich combustion leading to high smoke emissions less occurred.