Proceedings of the 9th World Congress on Momentum, Heat and Mass Transfer (MHMT'23)
London, United Kingdom – April, 2024
Paper No. CSP104
DOI: 10.11159/csp24.104

The Effect of Ballistic Characteristics and Fuel Temperature on GDI Injector Behavior with 1-D simulation using AMESim

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Extended Abstract

The research on thermal efficiency improvement of gasoline engine, say, GDI, gasoline hybrid and so on is still significantly meaningful to meet the stringent air quality regulation. Especially, Euro7 regulation imposed PM and PN_{10} limit over various temperature range including 10 degrees below zero. Under cold environment, the fuel injection during the compression stroke causes the severe spray wall impingement due to the insufficient time for fuel–air mixing time. As a result, PM emission can increase, which has been raised as one of the critical problems of GDI combustion. Multiple injection strategies with short individual injections have been applied in cold-start and stratified-charge of GDI engines because it can improve the fuel–air mixing and suppress the spray tip penetration. However, very short injection duration encounters the ballistic injection region, which injection quantity does not increase linearly with injection duration.

Precise injection quantity control is essential to achieve the combustion optimization with multi-injection, which implies that the deep investigation for the ballistic region is necessary. It has been known that the ballistic injection characteristics is generally dependent on injector needle dynamics, electro-magnetic force and frictional force. However, most researches have focused on the analysis of the relationship between injection current signal and injection rate and the methodology development of controlling the injection quantity with real time closed-loop.

To analyze the effect of these parameters on ballistic characteristics, conducting 1-D simulation is more favorable than experiment considering the time, cost and so on, for which commercial program such as AMESim and GT-Suite is generally used to predict injection rate. Therefore, numerical studies were conducted to reveal the inner dynamics of injector under ballistic region with 1-D injector model established with AMESim, the effect of injector design parameters on injection quantity quantitatively and finally provide the considerations for the optimization of multiple injection with fuel temperature.

Injection rate and injection quantity were compared with experiment to validate the established model with the help of actual measurement of injector needle motion using x-ray at Argonne Nat. Lab., which showed the accuracy within 10% error. The model revealed that the tendency of ballistic region coincides with the needle motion behavior. The result showed that those parameters clearly changed the ballistic region characteristics, however, the impact became insignificant for outside of ballistic region, which means that the ballistic injection is mainly influenced by initial motion of injector needle. Injection rate experiment showed that injection quantity was decreased up to 20% when applying the same injection duration signal comparing ±20 Celsius degree fuel temperature conditions, which was confirmed from the simulation result that the increase of effective discharge coefficient of injector nozzle hole due to lowered vapor pressure was the main reason. Multi-injection including two and five times injection with fuel temperature variation showed not only increase of injection quantity but also abnormal injector needle behavior, which implied that careful injection control is essential to have full benefit with PM reduction.