論 文 の 要 旨

題 目　Characterization of Free and Wall-Impinging Fuel Spray under Cross-Flow Condition
（横風気流中での自由噴霧および壁面衝突噴霧の特性）

氏 名 張（ちょう） 更新（こうしん） (ZHANG GENGXIN)

Vehicle ownership and fossil fuel consumption are increasing annually worldwide. Meanwhile, emission regulations in various countries are becoming more stringent. Therefore, energy conservation and emission reduction have become important issues. Direct injection technology is widely used owing to its low fuel consumption and high thermal efficiency. The atomization, evaporation, and mixture formation of fuel spray significant affect the combustion and emissions of direct injection spark ignition (DISI) engines. However, the highly transient characteristics inside internal combustion engines (ICEs) can result in cycle-to-cycle variations (CCVs), which are reflected in various behaviors of fuel spray. All these CCVs are coupled with each other significantly during engine operation, and a significant CCV can results in low thermal efficiency, high fuel consumption, and exhaust emissions. It was discovered in a previous study that if most CCVs can be decreased, then the output power can be enhanced for the same amount of fuel consumed. Therefore, it is of great significance to investigate the spray CCVs inside the ICEs cylinder.

In addition, DISI engine has advantages such as good fuel economy and high thermal efficiency. However, it is known that a high fuel injection pressure and small cylinder volume result in the impingement of fuel spray on the surface of the piston and cylinder wall. Wall-impingement fuel spray usually affects atomization and combustion effectiveness, resulting in excessive hydrocarbons (HC) and soot emissions. It is difficult for DISI engines to satisfy future particle number (PN) requirements in this situation. ICEs have been developed to reduce pollutant emissions and fuel consumption. As various countries have recently pursued carbon neutrality targets, the mechanism behind the spray wall-impingement phenomenon and fuel adhesion characteristics requires further investigation.

Moreover, the airflow inside the cylinder has a direct impact on the fuel spray and in-cylinder combustion characteristics. The CCV characteristics and wall-impinging behaviors are inevitably affected by the in-cylinder airflow. Generally, cross-flow is applied to simulate the airflow movement in the cylinder. Therefore, it is necessary to study the cross-flow effect, which plays a significant role at the end of the exhaust period.

The novelty of this study is the characterization of free and wall-impinging fuel spray under cross-flow condition. At present, various research methods and evaluation principle, such as proper orthogonal decomposition (POD), presence probability image (PPI), intersection over union (IoU), and edge fluctuation lengths (EFL), have been applied to analyze spray CCVs in previous studies. However, there are few studies that have been performed to investigate the CCV of spray characteristics under cross-flow conditions so far. In addition, although several studies have been conducted on free spray under cross-flow conditions, but only a few studies have been conducted on wall-impingement spray, especially for the fuel adhesion characteristics. Meanwhile, there are no reports on the existence and propagation of the wall-jet vortex phenomenon at the wall-impinging spray tip region under cross-flow conditions. The experimental results can provide an insight into the operating conditions of air-flow inside the engine.

Spray images were obtained via high-speed photography using the diffused background illumination (DBI) method. The continuous wave (CW) laser sheet technology is used to perform high-speed photography on the vertical and horizontal planes to obtain wall-impingement spray images. Additionally, particle image velocimetry (PIV) technology was used to demonstrate the velocity distribution of wall-impingement spray. The sauter mean diameter (SMD) of spray droplets was obtained with laser diffraction spray analyzer (LDSA). The Mie scattering technique was used to perform high-speed photography on the vertical observation to obtain a side view of fuel spray. Meanwhile, the refractive index matching (RIM) technology was used for high-speed photography at the bottom of the observation section to obtain images of fuel adhesion. In addition, Numerical simulations are applied to investigate the characteristics of wall-impingement spray in a cross-flow flow field.

There are three main research part in the study. First is the CCV characteristics of free spray in the cross-flow flow field. The objectives include to quantitatively the CCV of spray characteristics, to observe droplet size distribution, and to clarify the effects of cross-flow/ injection and ambient pressure on the CCV of spray characteristics. Second is the characteristics of wall-impingement spray in the cross-flow flow field. The objectives include to quantitatively the wall-jet vortex characteristics, to evaluate the effects of cross-flow/ ambient pressure/ wall-impingement distance on the wall-jet vortex, and to clarify the effects of cross-flow and wall-impingement degree on the fuel adhesion characteristics. Third one is the computational fluid dynamics (CFD) simulation of wall-impingement spray in the cross-flow flow field. The objective is to validate the CFD results with the detailed measurements and then mainly consider the wall temperature effect.

In summary, the objective of the present study is to experimentally investigate the

CCV characteristics of free spray, structure of wall-impingement spray and the fuel adhesion characteristics of wall-impingement spray under cross-flow conditions, the results of which will provide data support to further improve the accuracy of empirical prediction equations and models.