論 文 の 要 旨

題 目　Characterization of Diesel Spray and Combustion Processes of Multi-Hole Injector with Micro-Hole under Ultra-High Injection Pressure
（微小噴孔の多噴孔インジェクタから超高圧で噴射したディーゼル噴霧と燃焼過程の特性に関する研究）

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Spray and combustion characteristic is regarded as the key to engine technology. Better spray and combustion technology can not only effectively improve the thermal efficiency of the engine, but also reduce fuel consumption and emission pollution. With the continuous advancement of human science technology, many advanced diesel engine technologies have been invented, such as high-pressure common-rail technology, exhaust gas recirculation (EGR) low-temperature combustion technology, and so on. The invention of high-pressure common rail technology has greatly improved engine efficiency and is regarded as a revolutionary technology for diesel engines. Meanwhile, the invention of high-pressure common rail technology-enabled precise control of diesel fuel injection and opened the door to diesel high-pressure injection systems. Previous studies have shown that the formation of combustion and pollutants largely depends on the turbulent mixing dynamics of spray and air. Higher injection pressure and smaller injector hole size directly affect the atomization and turbulent mixing performance of diesel. At the same time, under high load conditions, faster spray penetration can help air utilization and increase combustion speed.

Although many researchers have studied the spray characteristics under ultra-high injection pressure/micro-hole size conditions. However, previous studies on ultra-high injection pressure or small hole sizes have mostly focused on the study of single-hole injectors. Little or no significant fundamental research has been reported on multi-hole injectors. In fact, single-hole fuel injectors are generally only used for experimental research due to their convenience for experimental observation. In real engines, multi-hole fuel injectors (usually 8 to 10-hole fuel injectors) are often used. Because the internal structure of the multi-hole injector is different from that of the single-hole injector, the complexity of the internal flow of the injector is completely different. The inside of the multi-hole injector is often accompanied by extremely complicated turbulent flow and different kinds of cavitation. Therefore, studying the spray atomization, turbulent mixing mechanism and turbulent combustion characteristics of ultra-high injection pressure micro-hole injectors not only provides a technical basis for the optimization of the actual engine but also has important significance for the CFD numerical simulation of the engine.

In the dissertation, the fuel atomization and mixing process combustion process under the condition of small hole size and ultra-high injection pressure are investigated by experimental methods, including diffused background illumination, high-speed video observation, two-color pyrometry, and OH* chemiluminescence imaging. The main points and results obtained in this study are summarized as the follows:

In Chapter 1, introduced the energy and environmental issues. Meanwhile, a review of previous works on the development of diesel engine technology, spray and combustion process as well as experimental methods were presented.

In Chapter 2, the experimental apparatuses and investigation methods are introduced. The apparatuses include the constant volume chamber, injection systems, photograph systems o and

measurement system of injection rate. The principle of two-color pyrometry and the OH* chemiluminescence method have been described detailly. Meanwhile, the diffused background illumination used for high-speed observation is presented.

In Chapter 3, the non-evaporating spray characteristics of multi-hole injectors with different diameters were investigated under different injection pressures. The results show that the injector with a larger hole diameter has a larger injection delay and a longer injection rate rise and fall time. The injection pressure has a small effect on the injection delay. As the injection pressure increases, the injection rate rises and fall time decreases. Increasing the injection pressure and the hole diameter increases the instability of the spray. The penetration of the injectors with different hole diameters is similar in the initial stage of injection. The penetration increased with the increase of the injection pressure. However, the effect of the high injection pressure on the increase of the penetration becomes weak. The injectors with a larger nozzle hole diameter displayed a larger penetration, spray angle, spray cone angle, and spray area. The micro-hole injector under the ultra-high injection pressure, the expansion of the middle of the spray caused a larger spray angle and spray area. A larger nozzle hole diameter and injection pressure promotes an increase in the gas mass rate. But the injector with the micro-hole diameter has a better ratio and a lower average spray equivalent ratio under ultra-high injection pressure. Naber and Siebers' penetration model and Inagaki and Mizuta's spray angle model with modified parameters showed the better prediction effect under all experimental conditions.

In Chapter 4, Ultra-high injection pressure and reduction of nozzle hole diameter are the development direction of future diesel engines. In this report, spray characteristics under the evaporating condition are described. The results demonstrate that the increase in ambient temperature causes the spray near the nozzle to become wider. As the distance to the nozzle increases, the width of the spray tail near the nozzle tip slowly increases or remained basically unchanged. Under the evaporating condition, the spray head expands and assumes the shape of a mushroom head at the initial stage of injection. The spray of the micro-hole injector may be deflected to form a larger spray head under ultra-high injection pressure. Spray-tip penetration of injectors with different hole diameters is similar at the initial stage of injection. However, the increase in ambient temperature significantly reduces the time of similarity. The spray cone angle of micro-hole injectors under the evaporating condition is larger than that under the non-evaporating condition. But, the cone angle of a large-hole injector under the non-evaporating condition is larger than that under the evaporating condition. Increases in ambient temperature only slightly affect the spray angle under different conditions. The spray evaporation results in a clear upward trend in the spray angle under 100 MPa conditions. However, under 300 MPa conditions, the spray angle does not increase because of the higher velocity. The spray evaporation effect of the micro-hole injector under a 300 MPa condition per unit mass is most favorable. The liquid length of the spray increases with the increase in the hole diameter, and a linear relationship exists between the liquid length and hole diameter of the injector. The liquid length of the spray is less affected by the injection pressure. F. Dos Santos' and Higgins's models can better predict the liquid length under different conditions.

In Chapter 5, the characteristics of the natural flame and combustion processes were studied using the direct photograph method and OH* chemiluminescence imaging. The results show that increasing the injection pressure and reducing the hole diameter can reduce soot generation per unit fuel mass. Compared with the use of the micro-hole diameter (D = 0.07 mm, Pinj = 100 MPa), increasing the injection pressure to 300 MPa (D = 0.133 mm, Pinj = 300 MPa) can suppress soot generation per unit fuel mass more effectively. The strong oxidation reaction was distributed both in the upstream and downstream areas of the flame only when the micro-hole injector was used under ultra-high injection pressure. The increase in the injection pressure and decrease in the hole diameter shorten the ignition delay. As the combustion proceeds, the LOL is shortened under all conditions. The increase in injection pressure increases the flame LOL, and the change in hole diameter has a slight effect on the flame LOL.

In Chapter 6, the effects of increasing the injection pressure to 300 MPa and reducing the injector diameter to micro-hole (0.07 mm) on the characteristics of combustion are investigated. The results show that the flame temperature distribution of a micro-hole injector is dispersed, whereas that of a large-hole injector is concentrated. Although the flame temperature distributions of the micro-hole injector and ultra-high injection pressure condition shift to the low-temperature region, the flame temperature of the micro-hole injector under a low injection pressure (Pinj = 100 MPa, D = 0.07 mm) encompasses a higher-temperature range and has a higher percentage in this range. Soot generation during combustion is evaluated based on the ratio of the integrated KL to the intensity of OH* chemiluminescence. Reducing the hole diameter and increasing the injection pressure can reduce I_{KL}/I_{OH*}. The I_{KL}/I_{OH*} value of the large-hole injector under an ultra-high injection pressure (Pinj = 300 MPa, D = 0.133 mm) is slightly smaller than that of the micro-hole injector (Pinj = 100 MPa, D = 0.07 mm), which indicates that it can inhibit soot generation slightly more effectively.

In Chapter 7, we have combined the results of the previous chapters to discuss the relationship between the liquid length, the flame lift-off length, and the soot amount. The results show that the boundaries of the evaporating spray, OH* chemiluminescence images, and natural flame images basically coincide at the top. The formation of soot is related to the liquid and lift-off lengths. When the liquid length is less than the lift-off length, the formation of soot is reduced. However, when the liquid length is longer than the lift-off length, the formation of soot is increased. According to the intersection of the liquid length and flame LOL trend line, it is estimated that the range of the liquid length is less than the flame LOL under different conditions. The determination of this range provides guidance and suggestions for the selection of the hole diameters of injectors and injection pressure for diesel engines