論文の要旨

題　目 Adhesion Characteristics of Fuel Spray Impinging on Flat Wall for Gasoline Engine
（平板壁面に衝突するガソリン噴霧の液膜形成に関する研究）

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In the current study, the impinging spray on the wall by single-hole gasoline injector under non-evaporation and evaporation conditions were investigated experimentally. The high-speed video observation method (Mie scattering) and Refractive Index Matching (RIM) were implemented under different engine dynamic operation to visualize the spray and fuel adhesion, respectively. The characteristics of spray morphology such as spray tip penetration, impinging spray height were compared during the injection process and the evolution of fuel adhesion such as mass, area and thickness were analyzed after the injection processes in detail. The effect of injection pressure (10, 20, 30 MPa) and ambient pressure (0.1, 0.5, 1.0 MPa) were paid attention to firstly, and then the surface roughness of the impinging wall (Ra 2.5, Ra7.7), and impingement distances (28 and 40 mm) were selected to acquire a better understanding about the impinging spray under non-evaporation conditions. Furthermore, the effect of ambient temperatures (298 and 433 K) on fuel adhesion was considered, along with the effect of hole diameter (0.135 and 0.155 mm). Moreover, droplets behaviors before and after impingement were discussed deeply by Particle Image Analysis (PIA) equipment. Additionally, the relationship between the fuel adhesion on the wall and the corresponding spray behaviors was investigated under the same conditions of the experiments as well. The main conclusions are summarized.

The motivation and significance of this study were introduced, and a review of the previous research in this field was conducted to give more background information of the current study in Chapter1. After that, the experimental approaches applied in this research were introduced in very detail in Chapter 2. The discussion and analysis about the results were in chapter 3-5. The main findings are classified as following.

1. The study on Non-evaporation Spray Evolution and Fuel Adhesion Formation (Chapter 3)

The characteristics of fuel spray and adhesion under different pressures, wall roughnesses and impingement distances were investigated experimentally under non-evaporation condition in chapter 3. The values of R_s, H_v, S, and H_i were acquired, and the fuel adhesion evolution was analyzed. Furthermore, the probabilities of adhesion and thickness distribution were discussed. The major conclusions are as follows:

The fuel adhesion tip is shorter than the spray tip because fuel droplets splash above the wall after impingement. Fuel droplets still exist in the air above the wall even after the end of injection. Owing to better atomization with high injection pressure, the fuel adhesion on the wall increases. An increase in ambient pressure improves the uniformity of the fuel adhesion.

An increase in wall roughness decreases the spray tip penetration and increases the impinging spray height. The fuel adhesion mass and area increase with time even after the end of injection. The fuel adhesion becomes slightly thicker in downstream for Ra2.5, whereas the thicker area moves upstream for Ra7.7. An increase in wall roughness increases the mass and area of the fuel adhesion. The ambient pressure decreases the differences between the two types of walls, whereas the injection pressure increases the differences. A higher roughness results in a higher maximum thickness of the fuel adhesion. An increase in roughness deteriorates the uniformity of the fuel adhesion. Wall roughness affects the fuel adhesion thickness along different lines.

For $x0$, the adhesion thickness for Ra7.7 is higher than that for Ra2.5 at the constant value stage, and the thickness uniformity for Ra7.7 is considerably inferior to that for Ra2.5. For y lines, the adhesion thickness for Ra7.7 is higher than that for Ra2.5 in the upstream region, and the thickness uniformity for Ra7.7 is poor compared to that for Ra2.5.

With a large impingement distance under ambient condition, the velocity of droplets decreases significantly, resulting in more droplets adhering to the wall instead of splashing out of the wall. As a result, R_s, H_v, and H_i decrease with an increase in impingement distance. However, after impingement, owing to the stronger drag force by the ambient gas and friction from the wall, S increases with the increase in impingement distance. Both the high injection pressure and large impingement distance increase the fuel adhesion mass and area, but the mechanisms are different. Owing to better atomization with high injection pressure, the fuel adhesion on the wall increases. At a large impingement distance, the lower velocity, bigger spray width, and better atomization are the main reasons for increased fuel adhesion on the wall after impingement. Under the large impingement distance condition, more fuel adheres on midstream and the thickness uniformity of fuel adhesion becomes worse. Moreover, the maximum thickness of fuel adhesion increases with a large impingement distance.

2. The study on Evaporating Spray Evolution and Fuel Adhesion Formation (Chapter 4)

The aim of this study in chapter 4 was to investigate the effect of high temperature on fuel adhesion under gasoline engine conditions to understand its mechanism. For this, toluene was injected via a single-hole injector on the wall. Mie scattering and RIM methods were applied to observe the impinging spray structure and fuel adhesion on the wall. The spray tip penetration and impinging spray height were compared, and the evolution of fuel adhesion along with its mass, area, and thickness were studied. Finally, the mechanisms of fuel adhesion formation were established in regions I and II. Moreover, due to the importance in the design of the injector hole diameter, especially for the characteristics of atomization, the effect of hole diameter the fuel adhesion was checked. RIM experiment was done to measure the fuel adhesion under different hole diameters of gasoline injector. The main conclusions of this study are summarized as follows:

High ambient temperature has a significant impact on the impinging spray and fuel adhesion on the walls of the engine. A high ambient temperature favors the evaporation of fuel, thus decreasing the spray tip penetration and impinging spray height of liquid phase. Moreover, it decreases the mass, area, and maximum thickness of the fuel adhesion owing to the evaporation effect. Also, it increases the average thickness owing to the decrease in ratio of fuel adhesion area being faster than that of fuel adhesion mass. The fuel adhesion continues to increase even after the end of injection, because of droplets being re-deposited on the wall. However, under T_{amb} = 433 K, the adhered fuel evaporates from the periphery of the impingement region even where there are still some droplets being re-deposited on the wall, but the increased adhesion can only be observed in region I. By comparing the evolution of fuel adhesion under different ambient temperatures, it can be concluded that high ambient temperatures lead to more uniform fuel adhesion on the wall.

The distributions of adhesion mass were studied in regions I and II. Similar curves were observed in region I under different ambient temperatures, whereas there was great variation in region II. Based on these results, different mechanisms were described for the formation of fuel adhesion during and after injection. The primary spray impinging on the wall contributed to the formation of fuel adhesion in region I, known as the primary impingement region. The splashing droplets impinging next on the wall contributed to the formation of fuel adhesion in region II, known as the secondary impingement region. Furthermore, high ambient temperature exerts more influence on the fuel adhesion formation in region II when compared to region I.

Decreasing the nozzle hole diameter can reduce the fuel adhesion mass, area, average thickness and maximum thickness owing to the better atomization. However, the large hole diameter improves the uniformity of the thickness under both non-evaporation and evaporation conditions.

3. The study on Microscopic Spray Behaviors (Chapter 5)

The microscopic characteristics of impinging spray under gasoline conditions were studied in chapter 5. PIA was applied to observe the microscopic spray structure, and droplets were detected by refined criteria. The droplet size distributions and SMD were calculated and compared under various injection and ambient pressures. Furthermore, the correlation between droplets behaviors and fuel adhesion on the wall was discussed in this chapter, too. The main conclusions of this study are drawn as follows:

Before impingement, large droplets and ligaments can be observed. Both injection and ambient pressures increase the droplet density by promoting the breakup process. However, under high injection and ambient pressures, the spray droplets are dense, and it is difficult to observe the ligaments and large droplets. Moreover, after impingement, the near-wall region becomes very dense as many droplets accumulate, whereas the droplets far away from the wall are clear and easily observed. Before impingement, injection pressure has a more positive effect on the distribution of small droplets, and ambient pressure favors the breakup of large droplets. Furthermore, after impingement, the probability of small droplets under P_{inj} = 20 MPa, P_{amb} = 0.1 MPa is higher than that under P_{inj} = 20 MPa, P_{amb} = 0.5 MPa. And the probability of large droplets under P_{inj} = 10 MPa, P_{amb} = 0.5 MPa is higher than that under P_{inj} = 10 MPa, P_{amb} = 0.1 MPa, which demonstrates the coalescence effect of ambient pressure.

Before impingement, the probability distribution of droplet number along the radial distance from the spray axis shows “M”-type curve. And the SMD distribution along the radial distance shows “∧”-type curve. After impingement, the probability distribution of droplet number along the vertical distance shows similar “>”-type curve. The SMD decreases from the near-wall region to the periphery under P_{amb} = 0.1 MPa, whereas a reversal phenomenon can be observed under P_{amb} = 0.5 MPa. Both the breakup and coalescence behaviors of droplets occur during the impinging spray. At low velocity, the coalescence phenomenon is more obvious at the periphery of spray under high ambient pressure. However, it weakens at increased droplet velocity.

Key factor governing the spray-wall impingement behavior were found. The adhered fuel adhesion mass increase with smaller *Re*, *We*, and *K* numbers. Although combination with the fuel adhesion mass and droplets behavior has been done to find some partial conclusion, the gasoline spray-wall is totally complicated and need more investigation have to be taken to identify the fuel adhesion formation and impingement process.