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Adhering Characteristics of Diesel Spray Impinging to a Flat Wall
평판에 충돌하는 디젤분무의 부착특성

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Key Words : Diesel Spray(디젤분무), Fuel Film(연료액막), Impingement Spray(충돌분무), Adhered Fuel Ratio (부착연료비)

Abstract : 디젤분무가 연소실 벽에 충돌할 때의 연료부착특성을 파악하기 위하여 평판에 충돌하는 디젤분무의 부착특성을 실험적으로 연구하였다. 투명 아크릴판을 이용하여 연료액막과 충돌분무를 동시에 촬영하였고, 충돌분무의 성장에 따른 연료액막의 성장도 함께 측정되었다. 부착된 연료는 연료액막 및 부착액적들로 나누어서 측정할 수 있었으며 그 결과 연료액막 주변에 무수한 연료액적이 부착함을 알 수 있었다. 시간에 따른 부착연료비를 예측하기 위하여 몇 가지 가정이 사용되었다. 그 결과 시간경과에 따른 부착연료비를 충돌거리 10mm, 30mm, 50mm에 대하여 예측할 수 있었다.

1. INTRODUCTION

Although the diesel engine gives mankind lots of conveniences, the exhaust emission from it causes environmental problem such as global warming, acid rain and smog. Many research works have been conducted to solve the mechanism on the formation process of harmful exhaust emission. Modern diesel engines become high speed and smaller. Thus the impingement of a spray on a piston cavity wall can not be avoid in direct injection(D.I.) diesel engine due to short distance between a nozzle tip and the wall. As the spray impinges to the wall of combustion chamber, it is known that a liquid film is formed on the piston and cylinder wall. The liquid film is evaporated by surroundings and the wall surface heated, and it causes increment of smoke level[1]. Detailed spray-wall interaction and fuel film adhering on the wall surface is essential to better design of a diesel engine, efficient combustion and lower pollutant emission.

With regard to the impingement spray, Zurlo et al.[2] had taken a picture from underneath the plate under atmospheric conditions. By means of a modification of the polarization ratio technique, they measured droplet size instantaneously, and reported that the impingement spray was mainly re-atomized by breakup of ligaments which fuel film had at the edge. A laser reflection method using a prism enabled Saito et al.[3] to observe evaporation process of fuel film. They found out that the diameter of fuel film became smaller with an increase of temperature of the wall. As for the impingement of droplet to the liquid film, Stanton et al.[4,5] reported that when the wall temperature was lower than the liquid boiling temperature, the impingement of a drop on a liquid surface resulted in sticking, rebounding, spreading or splashing. Spray-wall interaction was also discussed by Ko et al.[6] They pointed out that spray concentration was much affected by the fuel adhering to the wall.

However the investigation on the characteristics of fuel film has been still insufficient compared with that on the impinging spray itself. In this work, the adhered fuel was measured by dividing into two types, that is, adhered fuel film and adhered fuel droplets. Especially, the adhering fuel to the total fuel ratio was predicted as a function of time on the basis of several assumptions.

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2. EXPERIMENTAL SETUP AND PROCEDURE

The experimental apparatus is shown in Fig. 1. In order to make a single injection, a single shot pulse generator, a solenoid valve and a dummy nozzle were used. A single-hole type diesel injection nozzle with the diameter of the nozzle hole of 0.24mm and the length-to-hole diameter ratio of 2.5 was used. The opening pressure of the nozzle was 19.0MPa. Diesel fuel (JIS No.2) was used as injection fuel. The pressure vessel was filled with nitrogen gas and the pressure was set at 1.0MPa at room temperature. The impingement distances from the nozzle tip to a wall were 10mm, 30mm, and 50mm.

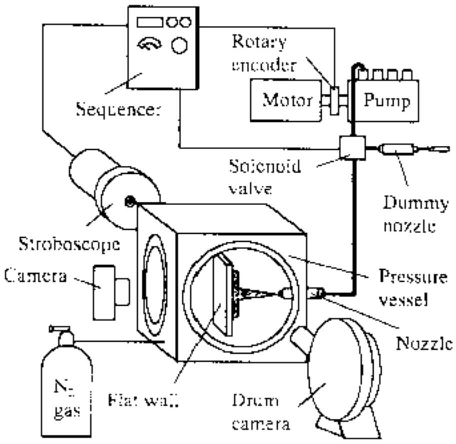


Fig. 1 Experimental set-up

Injection period was 1.8ms, and total injection quantity was 9.96mg/st. An aluminum circular wall with 95mm diameter and 2mm thickness was put on an impingement wall to catch the adhered fuel. Also the transparent acrylic wall was equipped into the pressure chamber in order to photograph the adhered fuel film. They were set vertically against the direction of spray axis. The shape of the fuel film after impingement was taken by a 36mm still camera, which was located at the rear of the transparent wall. Also, the behavior of the diesel spray with elapsed time was analyzed by the high speed photographs taken by a drum camera.

Fig. 2 shows the measurement method of the adhered fuel mass and fuel film. The wall was set at perpendicular in order to minimize the re-attachment effect of the droplets after impingement. The real adhered fuel mass could be obtained by this method. After the spray was impinged to the aluminum circular wall, which was the same material as those of a piston in practical diesel engine, the weight of the wall with adhered fuel was measured using a precision balance, whose sensitivity is 0.01mg. And then, since the sparsely adhered fuel encircling with the fuel film could not be neglected, the adhered fuel mass on the wall was analyzed by means of dividing into two types; the fuel film itself and the sparsely adhered fuel droplets encircling with the film.

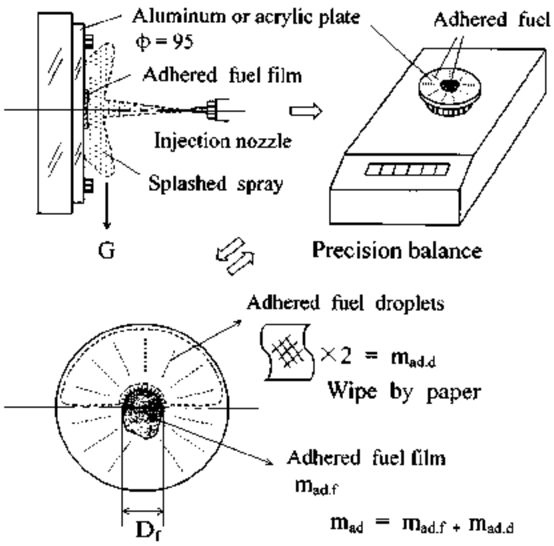


Fig. 2 Measurement method of adhered fuel mass

However because of the gravity effect, the fuel film slid down along the wall. So, we wiped sparsely adhered droplets on the upper half area of the circular wall with a paper, and measured again the mass of the wall with adhered fuel remained on that. Taking twice of the mass of wiped fuel, we could obtain the real value as surrounding adhered droplets. Then, the fuel film mass was obtained from total the adhered fuel mass and the surrounding one. In more detail, the total adhered fuel mass m_{ad} was expressed by;

$$m_{ad} = m_{adf} + m_{add} \quad (1)$$

where, m_{adf} is the fuel film mass, and m_{add} is the sparsely adhered fuel droplets encircling the film.

3. EXPERIMENTAL RESULTS

Adhered fuel ratio α_{ad} is defined as follows.

$$\alpha_{ad} = \frac{\text{adhered fuel mass}}{\text{total injection mass}} \quad (2)$$

Fig. 3 shows adhered fuel ratios at various distances. This figure indicated that the adhered fuel ratio on the dry surface wall was from 0.3 to 0.7. The adhered fuel ratio was linearly increased with increase of the wall distance L_w. Since this figure represented the adhered fuel ratio after fuel injection perfectly finished, we could not obtain the adhering fuel ratio according to time after impingement.

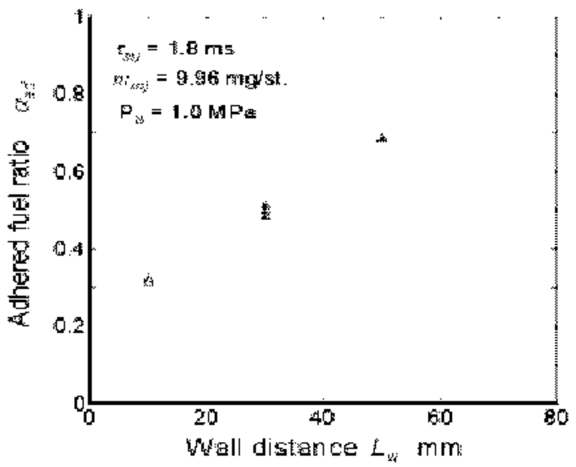
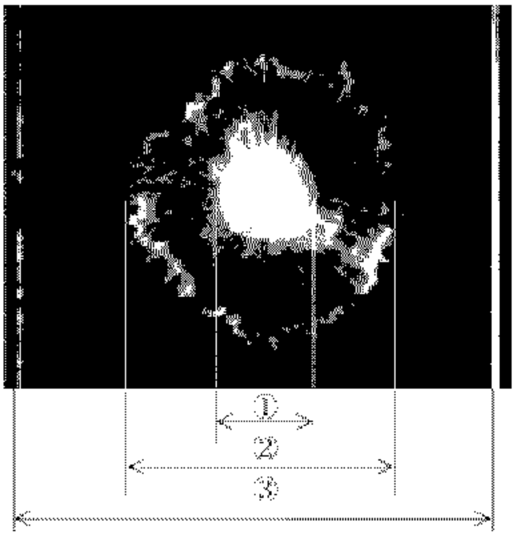


Fig. 3 Adhered fuel ratios at various distances

Photograph of the impingement spray taken from bottom view from the transparent wall is shown in Fig. 4. This photograph was taken at wall distance of 30mm after 0.5ms from the wall impingement. The circular fuel film is observed clearly in the center region, and is adhered on the transparent wall. The post-impingement spray is also observed in the photograph, but it is not entirely adhered on the transparent wall. Large number of ligaments and droplets are broken up from boundary layer of the fuel film. Accordingly, it is clear that the post-impingement spray is re-atomization by the breakup of the liquid film, as reported by Zurlo et al.[2] From such photographs as this, both the spray diameter and the fuel film diameter after the impingement were obtained at all wall distances.



① Fuel film diameter ② Spray diameter
③ Impingement wall width (60mm)

Fig. 4 Photograph of the impingement spray taken from bottom view through the transparent wall (Lw = 30mm, Pa = 1.0MPa, timp = 0.5ms)

Fig. 5 represents comparison of the spray diameter and the adhering fuel film diameter at various timings. The experimental condition is the wall distance of 30mm and the ambient pressure of 1.0MPa. The diameter of spray impinged after about 0.3ms from injection start increased up to 3ms, and then stagnation occurred. However, the fuel film diameter increased up to only 1ms. After that time, the fuel film diameter rarely grew up regardless of continued injection. That is to say, the period forming the fuel film was no more than 1ms from the wall impingement. The fuel adhering on the wall could be measured by means of dividing into two zone; film zone and droplets zone, as shown in the figure.

Maximum values of the fuel film diameter at various wall distances are shown in Fig. 6. As the wall distance increases, the fuel film diameter becomes larger.

As for fuel mass, adhered fuel droplets to fuel film ratios are shown in Fig. 7. With increase of the wall distance, the droplets to film ratio decreases. At the wall distance of 10mm and 30mm, the droplets to film ratio is more than 1. In other words, the fuel droplet more than 50% of the adhered fuel mass is stuck in the vicinity of the fuel film. Although it was not unusual compared with fuel film, these adhered droplets should not be neglected for more precise measurement of adhering fuel mass.

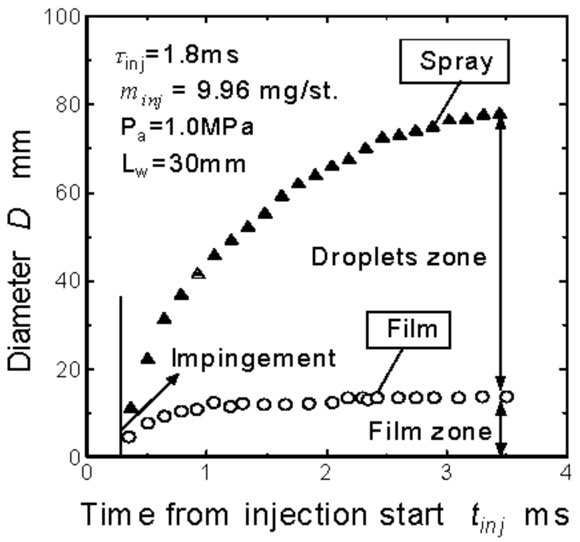


Fig. 5 Comparison of the spray diameter and the adhering fuel film diameter at various timings

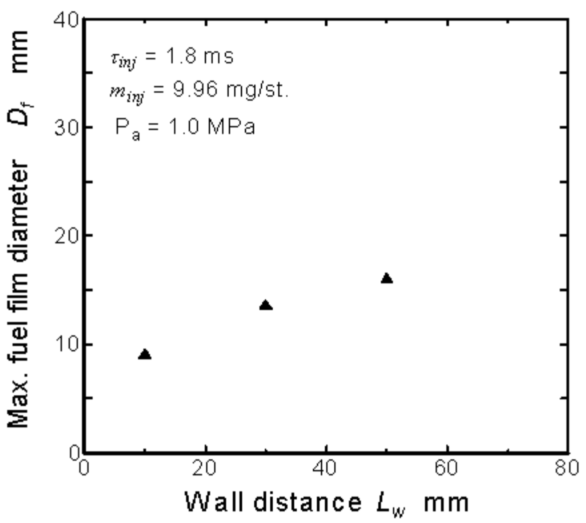


Fig. 6 Maximum value of the fuel film diameter at various wall distances

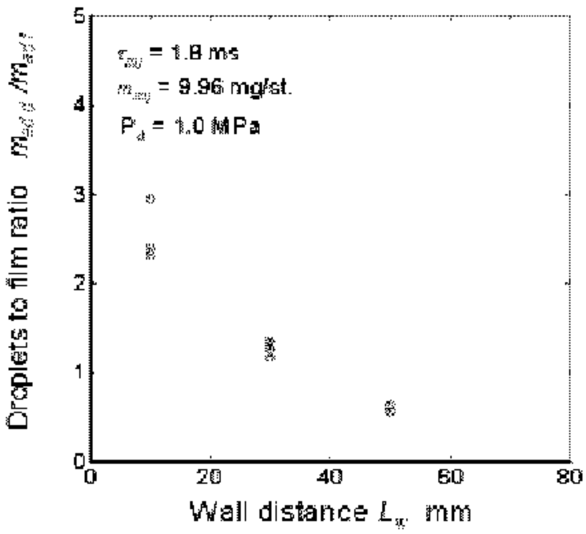


Fig. 7 Adhered fuel droplets to fuel film ratios at various distances

The adhering fuel mass changes as time progresses. It is impossible to measure the variation of the adhering fuel ratio with elapsing time. However several assumptions make it possible to calculate the adhering fuel mass with elapsing time. That is, it was assumed that fuel film has the same thickness in film zone, and the fuel droplets adheres equally through droplets zone. The last assumption is that the growth of fuel film is two-thirds less than that of the post-impingement spray until the film diameter becomes constant, as shown in Fig. 5. Based on these three assumptions, the adhering fuel ratio was obtained with elapsing time at various wall distances. The results are shown in Fig. 8. Here, adhering fuel ratio α_{time} is defined as follows.

$$\alpha_{time} = \frac{\text{adhering fuel mass with elapsing time}}{\text{total injection mass}} \quad (3)$$

The adhering fuel ratios increased with elapsing time at all the wall distances. Finally, they became about 30%, 50% and 70% for L_w = 10mm, 30mm and 50mm, respectively.

The adhering fuel ratio increased steeply up to 0.4ms, 0.8ms and 1.9ms from start of the impingement for L_w = 10mm, 30mm and 50mm, respectively. And then, it increased slowly. The changing point corresponded to the time that growth of the fuel film finished. In other words, diesel spray after impingement was adhered within a growing period of the fuel film much more than after that period. In the case of L_w = 50mm, the adhering fuel ratio rarely increased after 1.9ms from the impingement. This means the post-impingement spray rarely expanded along the wall after that time.

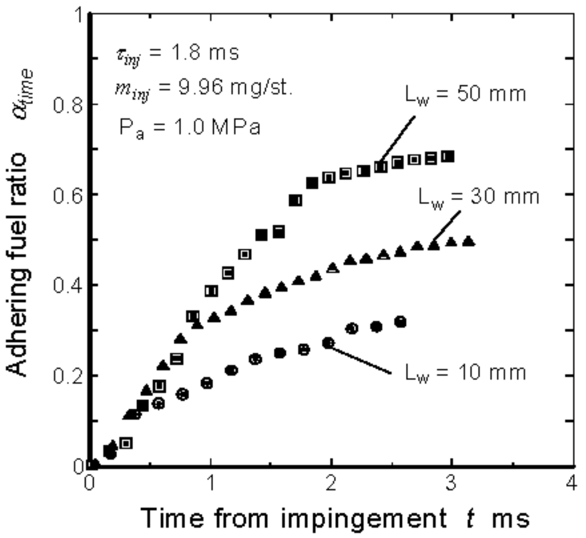


Fig. 8 Temporal change in adhering fuel ratio at various wall distances

4. CONCLUSIONS

Although adhering fuel affects on smoke level in D.I. diesel engines, its investigation has been insufficient compared with the impinging spray. So, this work focused on diesel fuel adhering with impingement to a flat wall. Adhered fuel mass after the impingement was measured by dividing into fuel film and fuel droplets encircling with the film. Also, the photograph of both fuel film and post-impingement spray was taken clearly. From the photograph, we could obtain the growing process of the fuel film as well as that of the post-impingement spray. Furthermore, though it is not possible to measure the variation of the adhering fuel ratio with elapsing time, it could be predicted on the basis of some assumptions. The results are as follows.

1. The period forming the fuel film was no more than 1ms from the wall impingement.
2. The adhering droplets should not be neglected for more precise measurement of adhering fuel mass.
3. Diesel spray after impingement was adhered within a growing period of the fuel film much more than after that period.

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