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RADIAL FLOW AND DROPLETS SPLASH OBSERVED ON A WALL IMPINGEMENT JET
벽면 충돌분무의 반경방향 흐름과 액적 비산에 관한 고찰

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<요 약>

액체 분무가 벽면의 평평한 면에 충돌할 때의 거동에 대해 실험을 통하여 조사하였다. 각 분사노즐과 벽면까지의 거리 그리고 분사 속도에 있어서 충돌점에서의 액체 액막의 비산 거동과 평면에서의 액막의 흐름에 대하여 관찰하였다. 충돌점에서 비산하는 액적의 비산율을 정량적으로 측정하였다. 분사속도가 증가에 의해 충돌 거동은 5개의 영역으로 분류되며, 분사속도가 증가하면 비산율도 증가하게 된다. 또한, 충돌거리가 분무의 분열점보다 길 때의 액적은 분사량의 약 반정도가 비산하게 되는 결과가 얻어졌다.

Key words : Liquid jet, Wall impingement, splash, Break-up length, Hydraulic jump

1. INTRODUCTION

Wall impingement process of a liquid jet was often observed in many application systems of atomization and spray technology. In a manifold injection system of SI engine, a fuel jet injected through an EFI nozzle was impinged to an inner wall of the manifold or an upper surface of the intake valve. Some amount of injected fuel was scattered at the impingement point and resulted into a fine droplet spray. However, the rest of the injected fuel flowed along the wall. It formed a liquid film on the wall and caused harmful results in combustion [1]. In a Direct Injection SI Engine, fuel impingement on a piston surface caused more serious problems on combustion because it directly affects the flame propagation process near the piston surface [2,3]. In the combustion process DI diesel engine the diesel spray also impinges on a cavity wall of the combustion chamber and the heat release process in it was greatly affected by the wall impingement process of the spray [4]. Another examples of wall impingement were frequently found in liquid jet systems with painting, fire extinction, water jet cleaning and so on.

The fundamental approach to study impingement phenomena of liquid jet had been started from studies of a single droplet impingement [5,6] and liquid film flow process on a surface [7]. As for a single droplet impingement process a lot of experimental and theoretical works had revealed a deformation process of droplet at an instance of the impingement. Reflecting process of droplet was analyzed using the Weber number of a droplet [8]. Stability of liquid film on a wall surface had been

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studied with a hydraulic jump of thin water film [9] and the surface wave motion [10]. However, it needs more detail information to utilize effectively the wall impingement process.

In this study, to find out a relationship between liquid jet impinging on a wall surface and liquid droplets reflecting or scattering from the surface, fundamental behavior of liquid jet impingement process was experimentally investigated. Flow pattern of the liquid film on a surface was observed in detail. A splash ratio was defined as the ratio of the splashed liquid to the total injected liquid. Splash ratio was discussed with an impingement distance and impingement velocity of a liquid jet. And also, it was discussed with disintegration phenomena of jet

2. EXPERIMENTAL SETUP

Experimental set-up to investigate impingement behavior of a single laminar or turbulent jet on a smooth surface was explained as shown in Fig.1. Tap water was used as the test liquid. It was supplied from a pressurized water tank to a test nozzle. Flow rate was regulated by a valve and monitored by a flow meter and a pressure gauge. Test nozzle was made of straight pipe of Stainless steel. Its length was long enough to make a developed liquid flow inside a nozzle. A target surface for impingement was a smooth surface of Aluminum plate. Impingement behavior of a liquid jet was observed by a stroboscope and camera system. Thickness of a liquid film was detected by an electric resistance method using an electrode probe fixed on an X-Y stage.

The liquid film that was formed on a plate surface flowed and dripped down from the plate as shown in the figure. It was collected in a bottom of a plate holder and captured by a water trap to measure the mass of liquid that formed the liquid film. A splash ratio was obtained using a ratio of the measured mass of liquid film to the total injected mass of water. To capture the water dripping from the periphery of plate, a vacuum pump system was used. Figure 2 shows a detail construction of the target plate and plate holder. To enhance the smooth dripping of liquid films to the shows a detail construction of the target plate and plate holder. To enhance the smooth dripping of liquid film to the plate

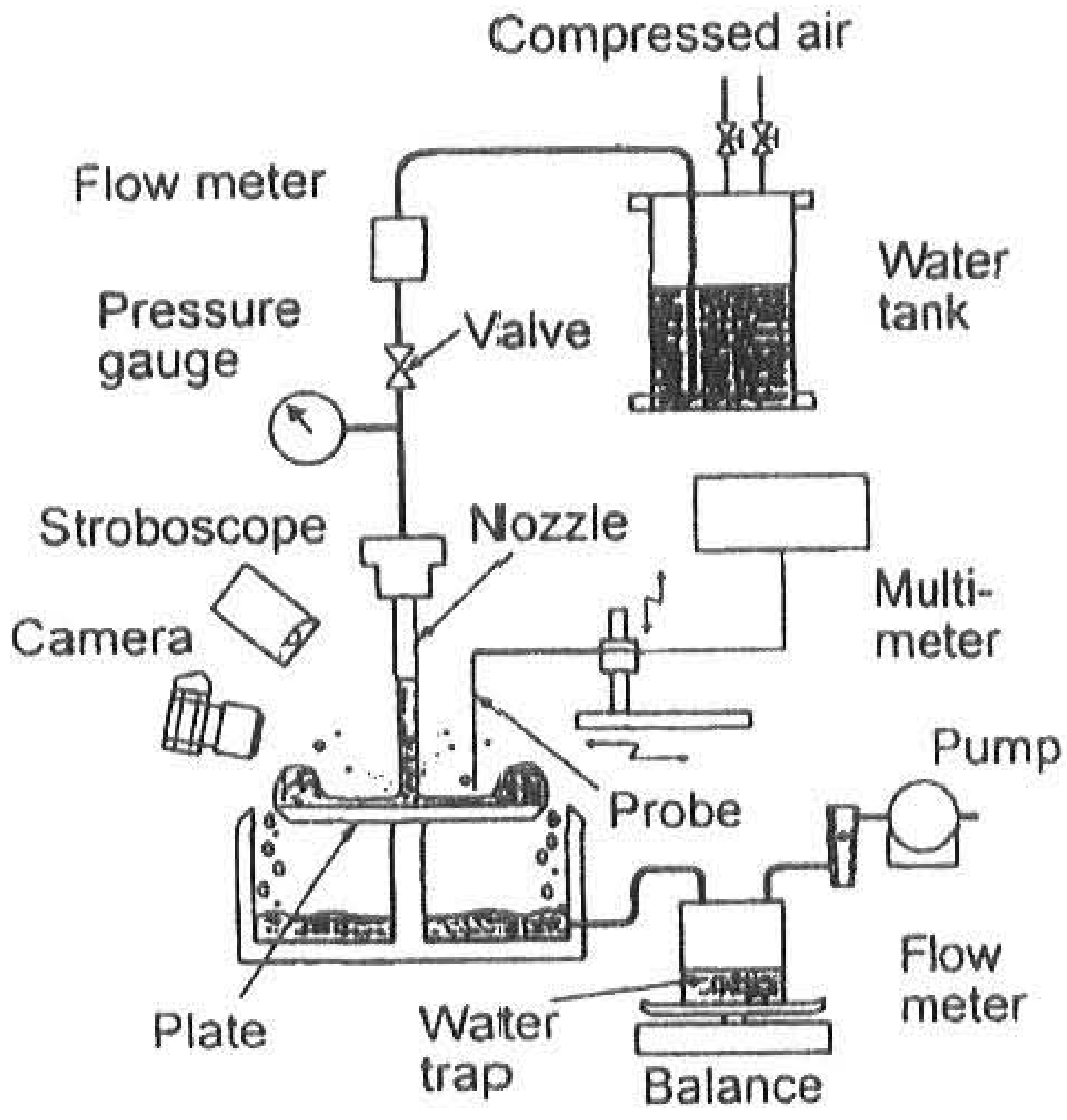

Fig.1 Experimental set

holder, annular distance between the plate and plate holder and the edge angels of plate and holder were designed according to the results of preliminary. According photographic observation of the dripping phenomena of liquid, the annular distance of 3mm and the edge angles of 30 degree were enough for effective capture of film water on the impingement surface.

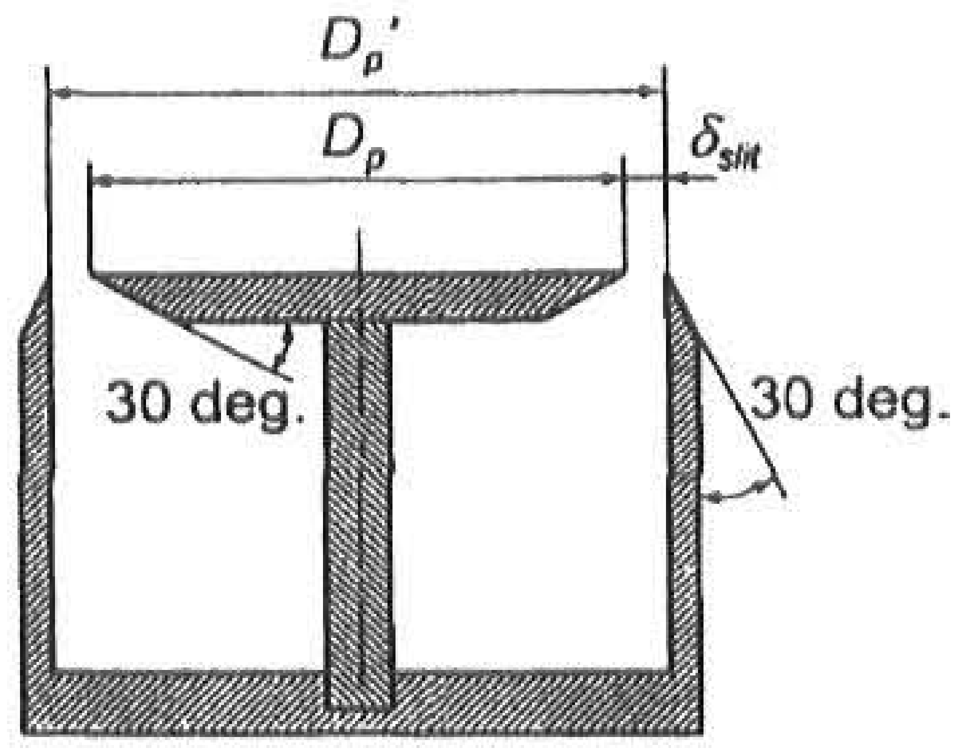

Fig.2 Impingement plate and plate holder

Flow patterns were basically classified into two groups according the flow modes on the surface. Figure 3 shows these two modes and the pattern parameters to characterize the flow modes. One mode was a relatively thick water layer and the other was a thin water film with hydraulic jump or water rim.

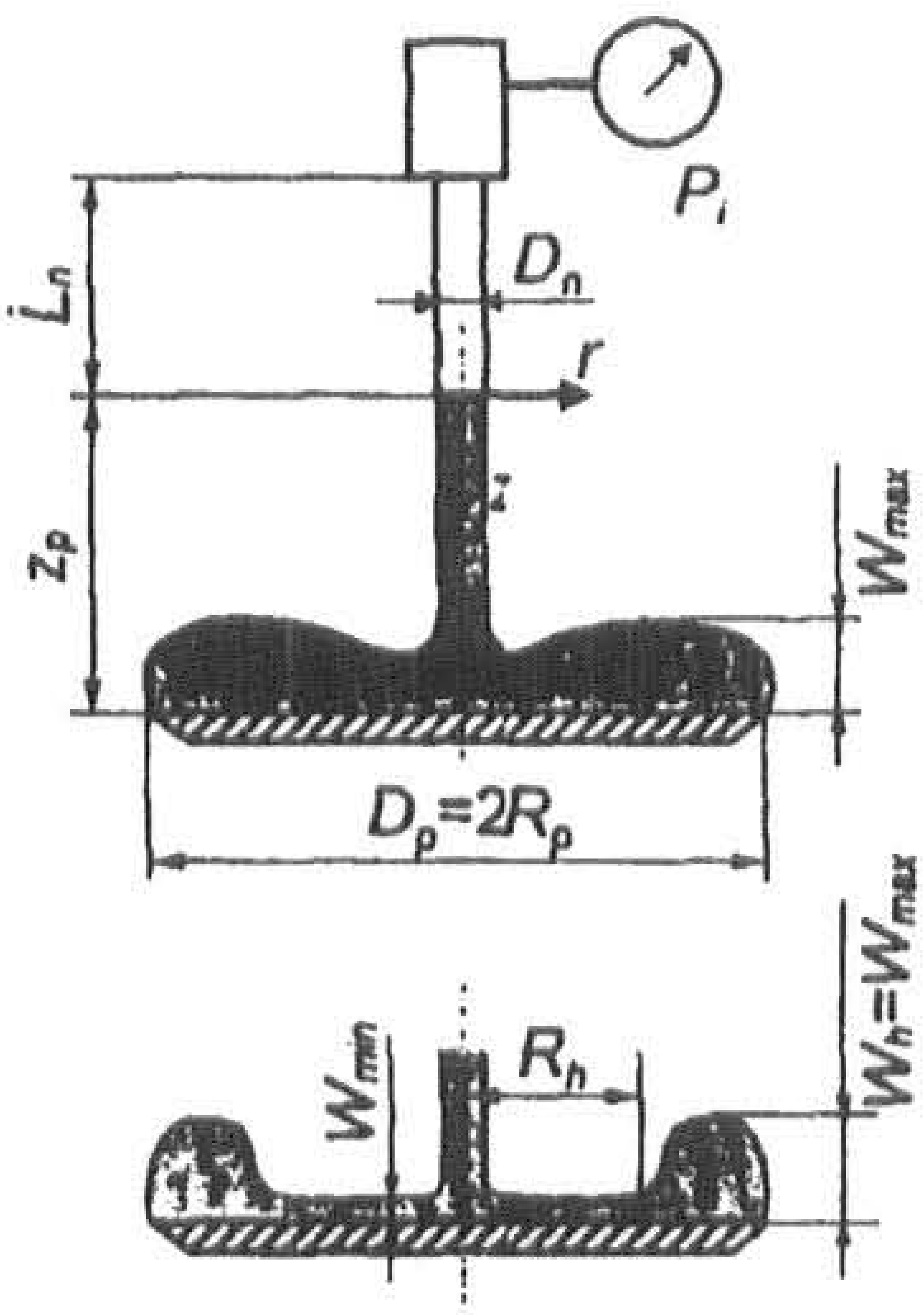

Fig.3 Impingement models and their parameters

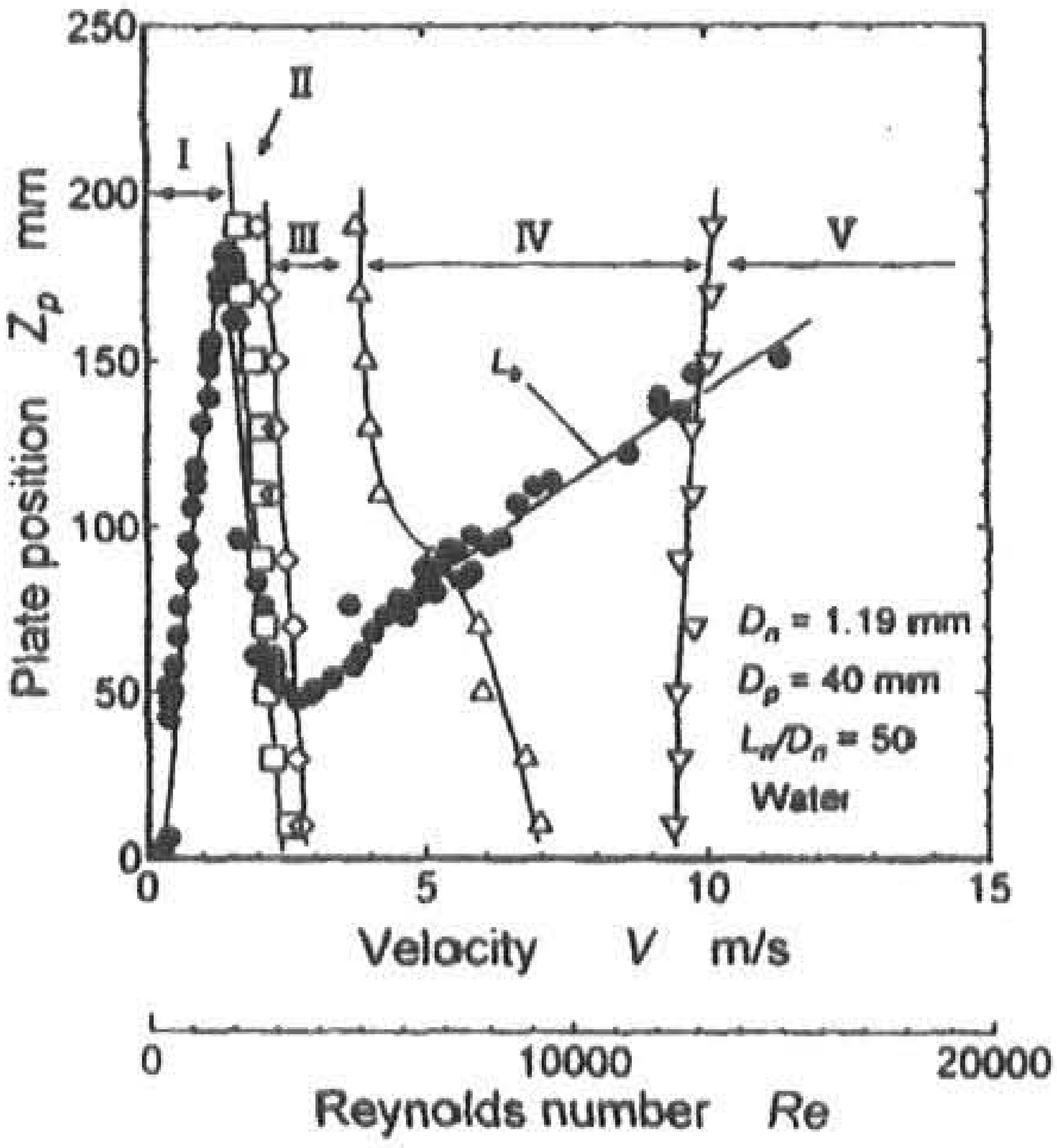

Fig.4 Break-up length and impingement behavior

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Flow patterns of impinged jets

Liquid jet injected from a nozzle was characterized by the flow state in the nozzle. The laminar flow usually made a smooth jet and the turbulent flow resulted in a wavy jet. Liquid jet was characterized by these states and a distance from nozzle. A liquid jet that was observed near the nozzle exit was continuous liquid jet. However the liquid jet which was observed far down stream of its break-up length was droplets array or spray. Then the impingement phenomena of a jet had to be discussed with the characteristics of jet and with the distance from a nozzle to a target plate. To discuss them, the break-up length and impingement behavior was summarized and shows in Fig.4. The typical break-up length from laminar to turbulent jet was observed on the jet. The classifications indicated by I-V were corresponding to the flow patterns shown in Fig.5.

When the liquid velocity was low and the jet was laminar, a smooth liquid surface indicated by Region I was observed on the plate. The flow pattern on the plate was not affected by the position of plate. Even if the plate was far away from the nozzle and droplets array was impinged, the flow indicated by Regions II and III. Flow pattern of Region II was characterized by a smooth surface with bubble containing flow. A hydraulic jump and a little amount of

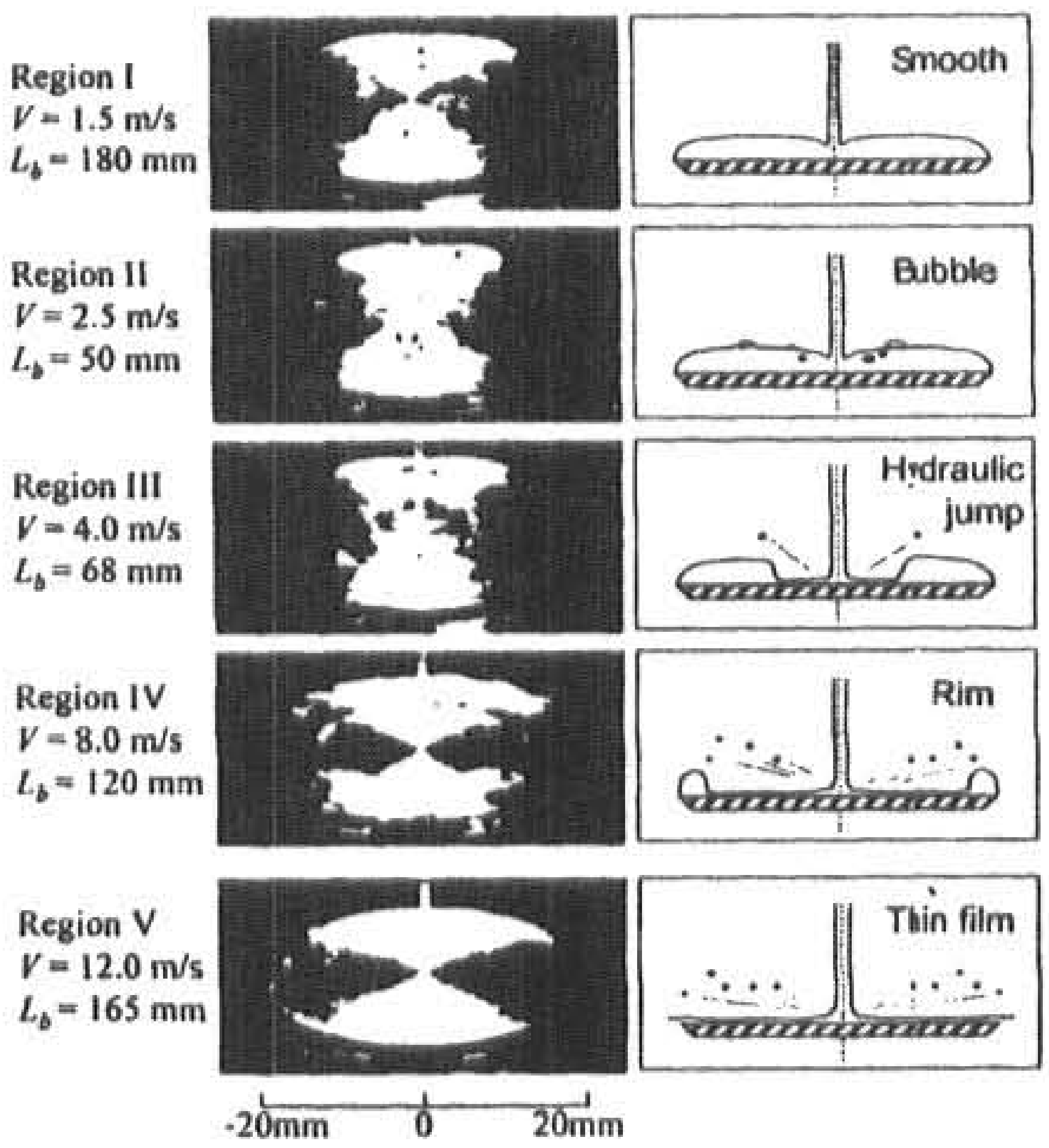

Fig.5 Photographs and sketches of impingement jets at Zp=30mm
(Dn=1.19mm, Ln/Dn=50, Dp=40mm)

splashed droplets were the special feature of the state of Region III. Impingement pattern of the turbulent jet was characterized by the thin film and splashed droplets. The flow in Region IV was modeled by a film flow with water rim and splash of droplets. When the velocity of the jet was too high to make the rim on the periphery of the plate, flow pattern was changed to Region V that was simply characterized by a thin film with splash of droplets.

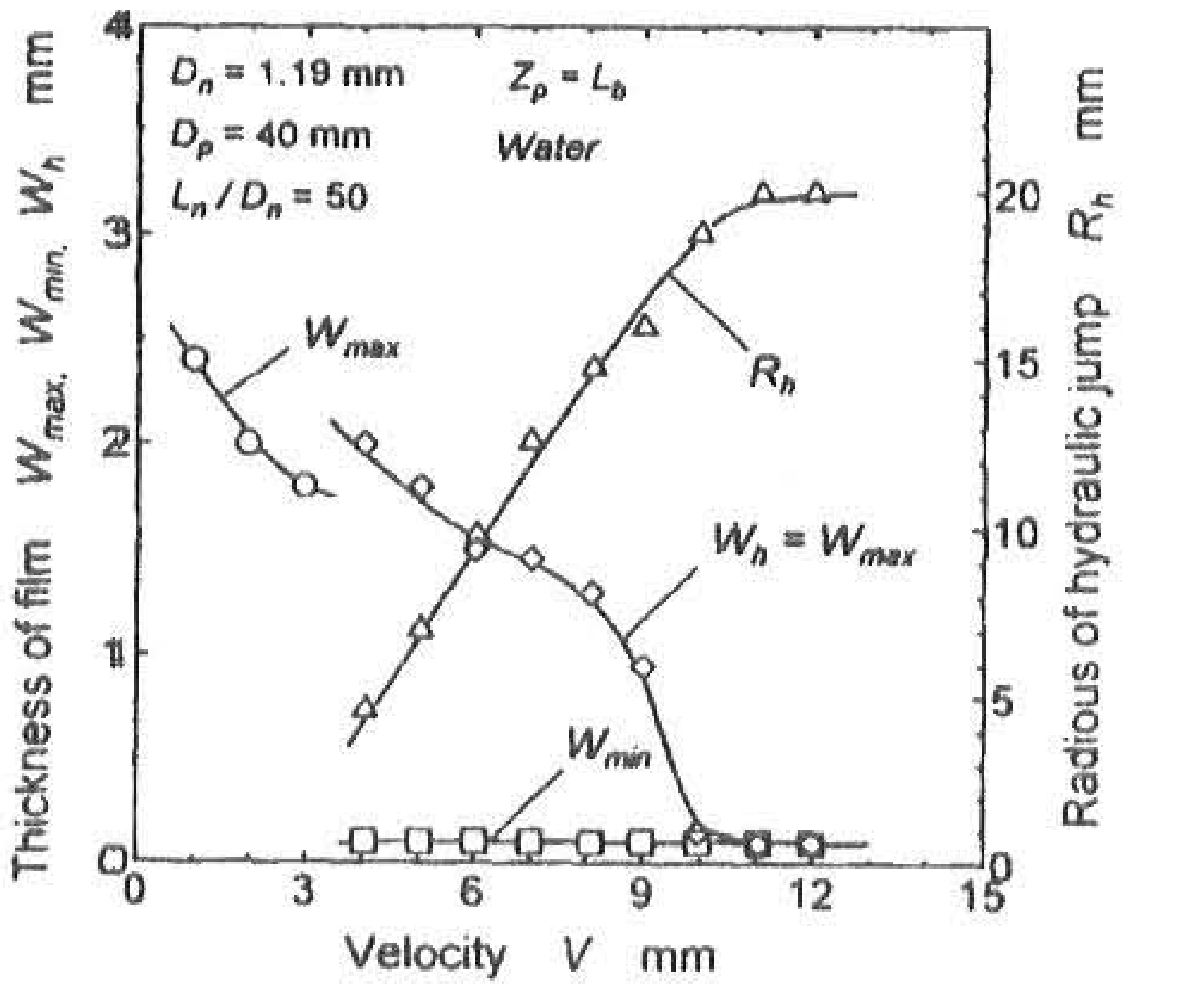

Fig.6 Thickness of film and radius of hydraulic jump at Zp=Lb

The surface pattern of the flow and thickness of the film on the target plate were measured by the electrode probe. The feature of the surface was indicated by the parameters shown in Fig.3. The results measured at the impingement distances which were summarized as shown in Fig.6. When the injection velocity was low and flow state was laminar, very thick water film was observed on the plate. After a hydraulic jump being developed onset on the plate, a very thin water film was observed inside the area of hydraulic jump. As increasing the injection velocity, the radius Rh that meant the onset location of a hydraulic jump increased and the height of the rim W_h decreased.

3.2 Impingement distance and flow pattern

The flow pattern on the plate was also changed by position of the plate. The photographs previously shown in Fig.5 was the impingement phenomena observed at Z_p=30mm. The distance changed the boundaries of the regions explained above between the nozzle and impingement plate as shown in Fig.4.

Effects of impingement distance on the flow pattern are shown in Fig.7. The impingement conditions were D_n=1.19mm, D_p=40mm and V=6m/s. The impinging jet was a turbulent jet and its average break-up length L_b was continuous turbulent jet. The flow patters of Region III, in other words, a rim of smooth surfaces and a few splashing droplets were observed there. Z_p=75mm was the case of impingement at the location of break-up point of the jet. After passing the break-up point of the jet, the jet was broken-up to droplets. Then, the impingement conditions of Z_p=100mm and 150mm were the impingement systems of droplets arrays. The flow patterns in these conditions were changed from Region III to Region IV as indicated in Fig.4. The water rim with high turbulent surface and splashing droplets were the main feature of these impingement systems.

The critical velocity of the onset of hydraulic jump was mainly dependent on the diameter of the impinging jet, the velocity of impinging jet and hydrodynamic properties of liquid. However, preliminary experiments which were conducted with the different sizes of nozzles and target plates, showed that the transition from laminar jet to turbulent jet could also give a change of

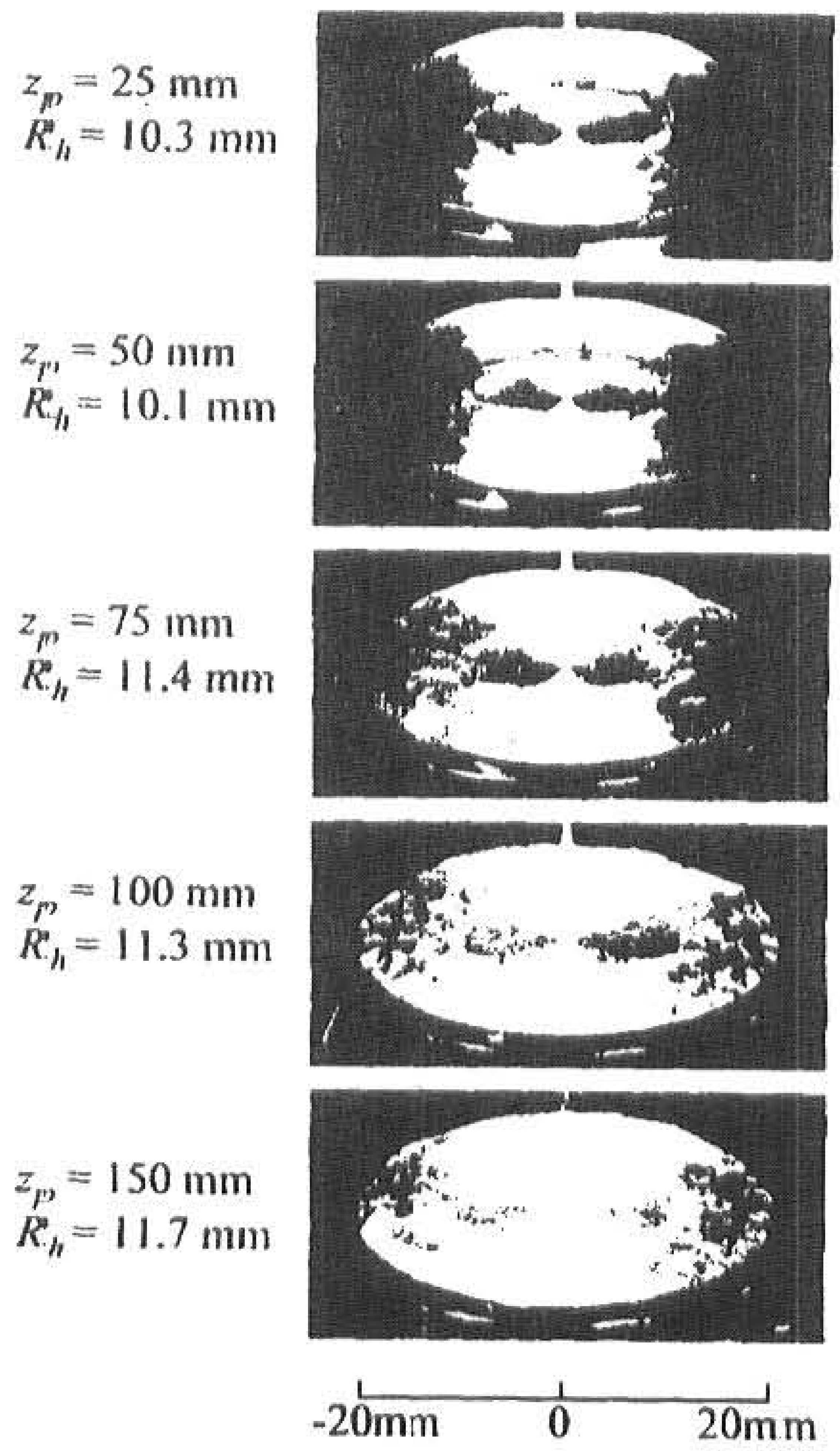

Fig.7 Impingement jets at various position (Dn=1.19mm, Ln/Dn=50,Dp=40mm, V=6m/s, Lb=76mm)

the critical velocity but the impingement distance did not affect the onset velocity of hydraulic jump. To make more detail discussion about the onset of hydraulic jump, it was considered that the more detail experimental and theoretical studies were needed.

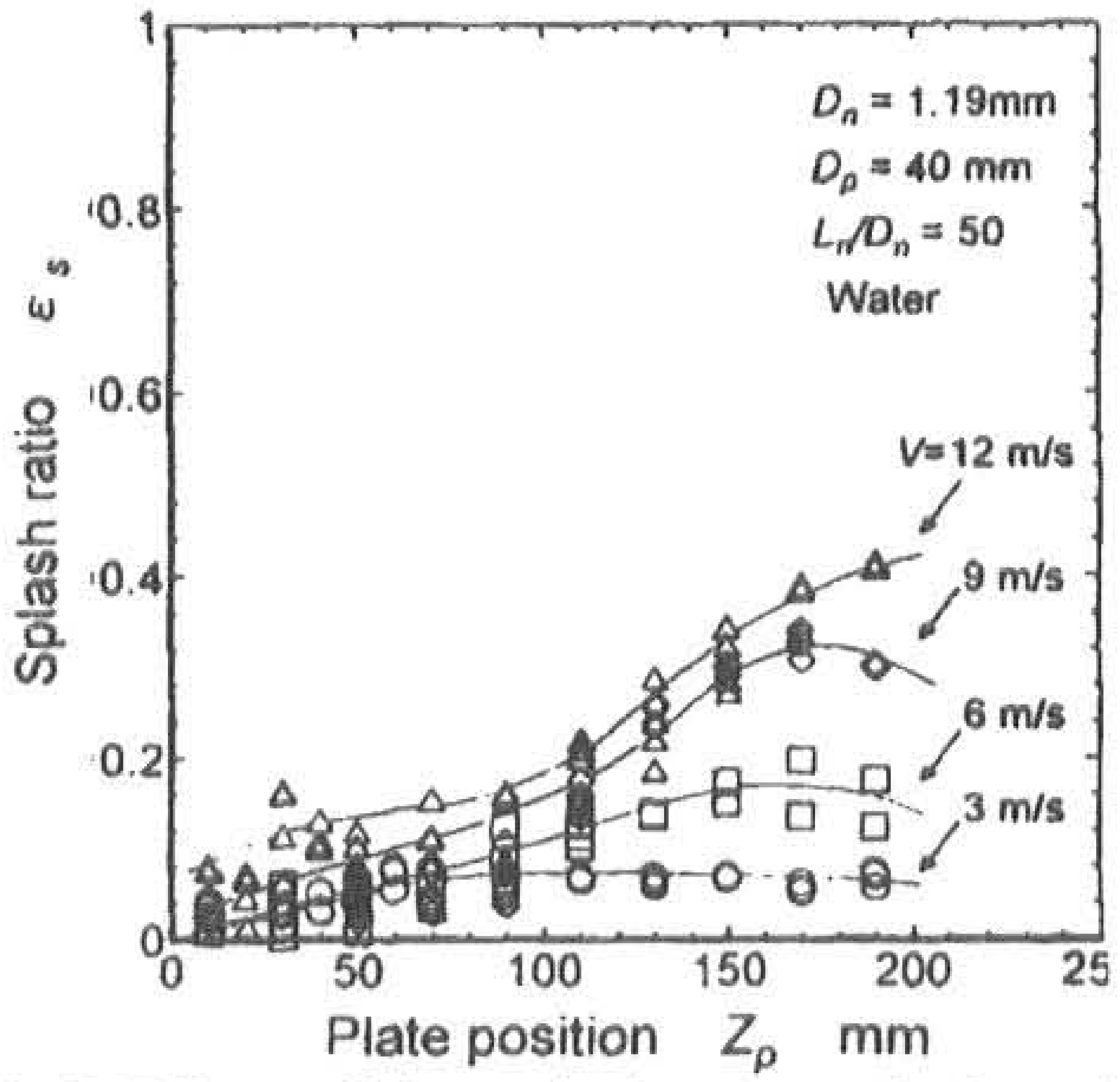

Fig.8 Effect of jet velocity on splash ratio (D_p=40mm)

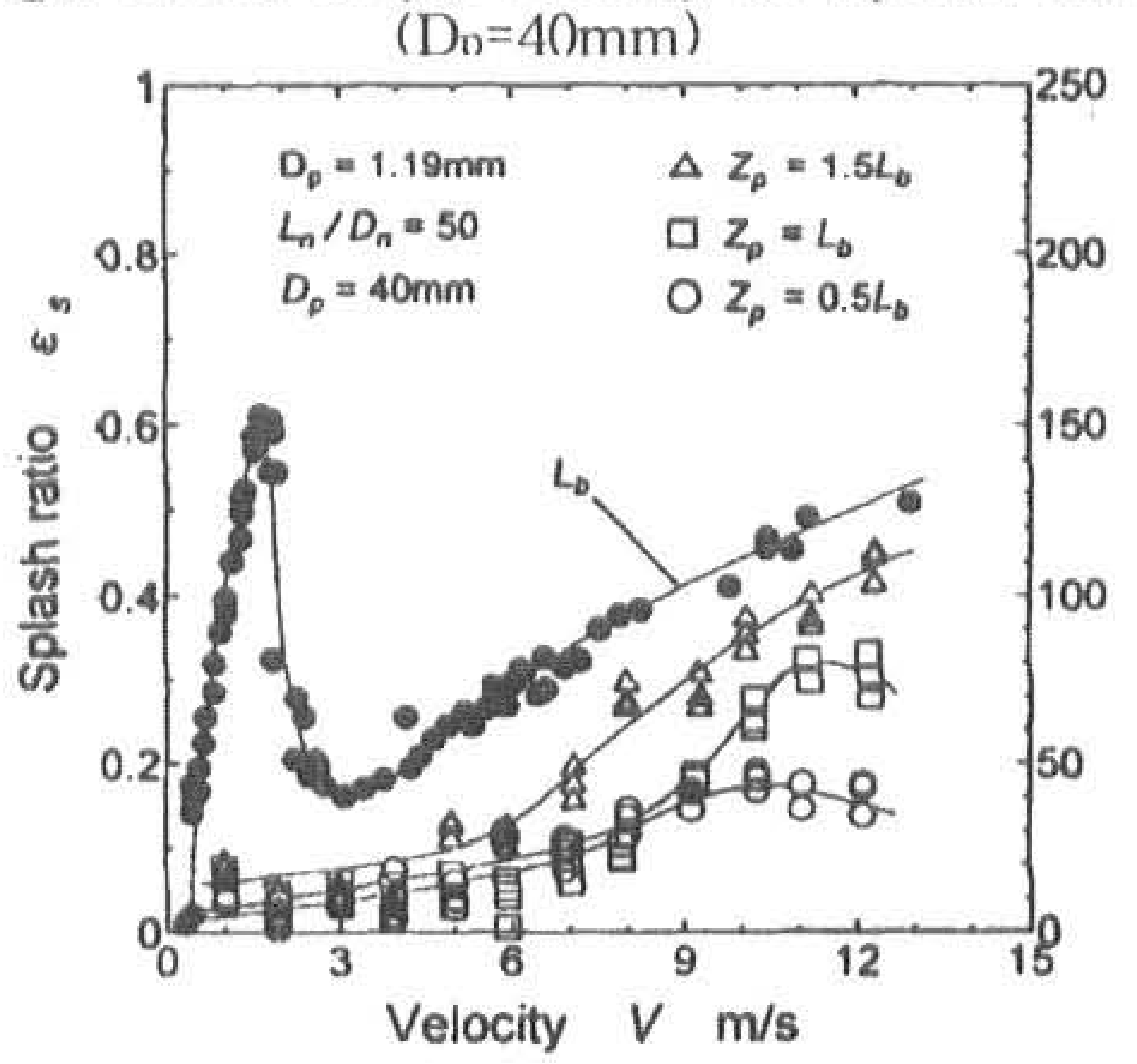

Fig.9 Relation between break-up length and splash ratio

3.3 Splash ratio of droplets

A liquid jet impinging on the impingement plate was divided into droplets and liquid falling in to the vessel after forming a liquid film. A splash ratio of droplets was defined by the ratio of splashed liquid mass to the total injected liquid mass. It was obtained from total of injected liquid and amount of liquid captured in the vessel by using the following formula;

$$Q_s = \frac{Q_{splash}}{Q_{total}} = \frac{Q_{total} - Q_{film}}{Q_{total}}$$

where ε_s is splash ratio, Q_{total} is the amount of total injection, Q_{film} is the amount of collected liquid and Q_{splash} is the amount of splash.

The splash ratio of droplets was measured on the impingement systems of various impingement distances and injection velocities. Effects of the jet velocities on the splash ratio of different impingement positions are shown in Fig.8. When the jet velocity was 3m/s, the splash ratio was not changed by the impingement distance of the jet. However, as increasing the velocity, the splash ratio became increase with an increase of the impingement distance. Turbulence on the liquid jet surface and deformation level of the jet was enhanced with an increase of the distance from the nozzle. Then the splash ratio was considered to be affected by the turbulence or disintegration level of the liquid jet.

The relation between splash ratio of droplets and break-up length of the jet could be discussed using the results shown in Fig.9. The splash ratios in this figure were measured at Z_p=0.5L_b, Z_p=L_b(break-up position), Z_p=1.5L_b for every impinging jet. The splash ratio increased with an increase of injection velocity and with an increase of impingement position of the jet. However, the increment of the splash ratio was obvious in the turbulent jet region. It was considered that the disintegrated liquid jet or droplets array formed from a turbulent jet gave stronger impact force to the impingement point than the other conditions and this impact force caused the splashing of droplets.

Figure 10 shows the effect of the impingement position on the splash ratio at the condition of V=6m/s. In this condition, the break-up length of the jet was 76mm and the splash ratio measured at far down stream of the break-up position was higher than that at break-up position. It took the maximum at Z_p=170mm and had a decreasing tendency with a further increase of the position. The splash of droplets was strongly enhanced at the location where the jet or disintegrated jet gave the strong impact force to the target plate or to the water film on the target plate.

Then, the result indicated the strongest impact force was given by the impingement

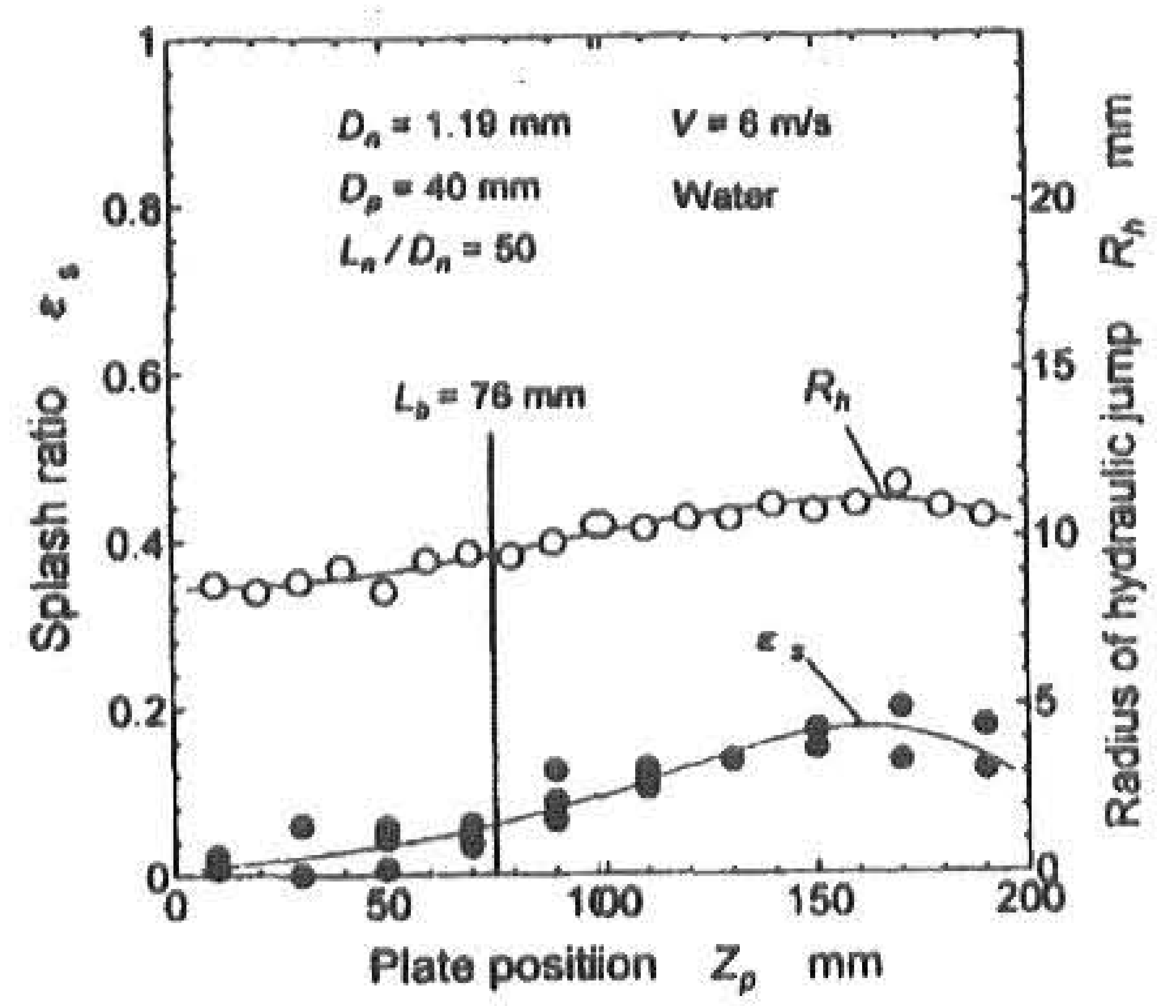

Fig.10 Splash ratio and hydraulic jump at various positions (V=6m/s)

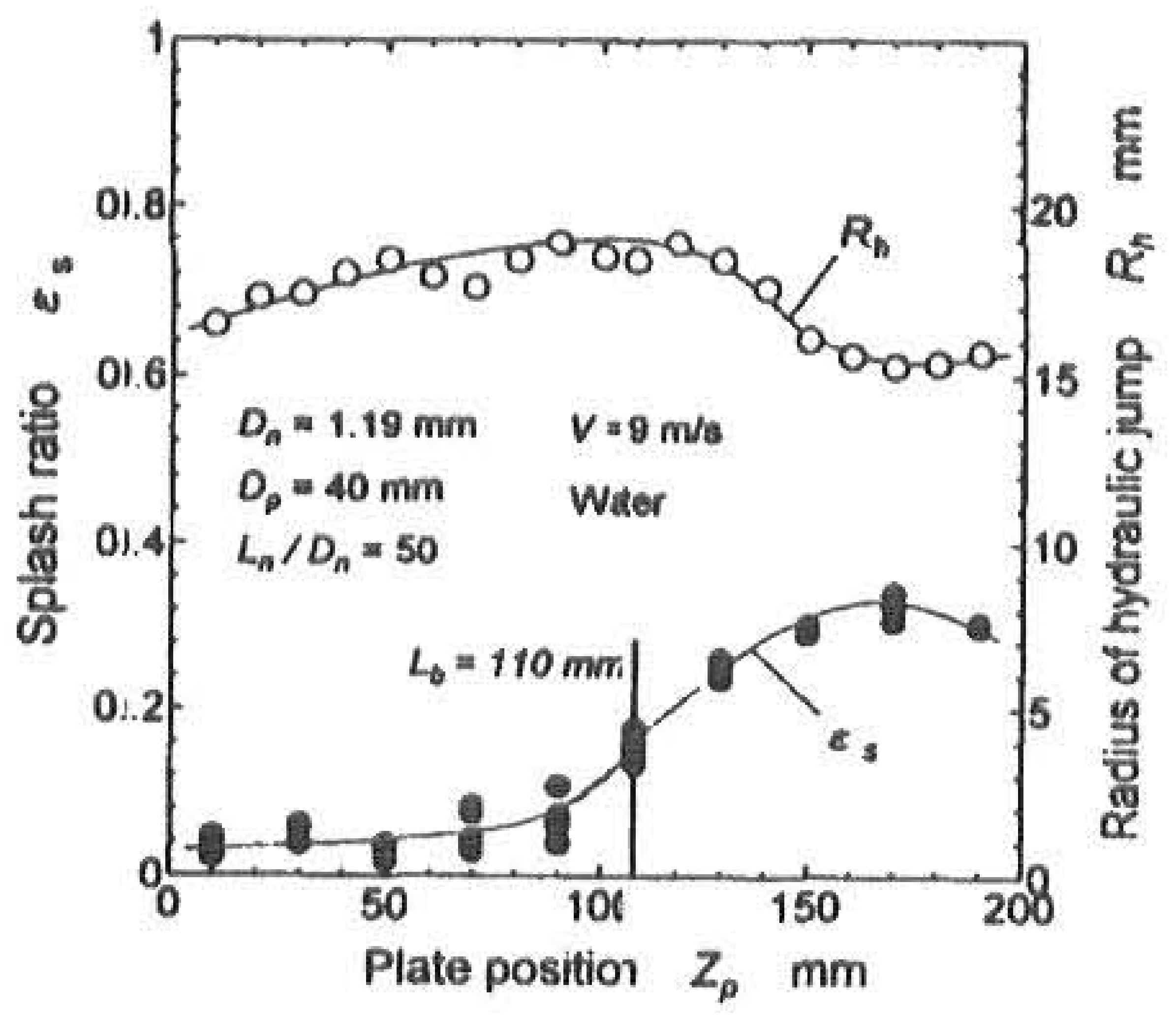

Fig.11 Splash ratio and hydraulic jump at various positions (V=9m/s)

system of Z_p=170mm. Almost same but clearer tendency of the splash ratio was shown in Fig.11. In this case, the jet velocity was 9m/s and the break-up length was 110mm. Since the large mass of liquid was splashed away, the radius of hydraulic jump location tended to decrease at the position where the maximum splash ratio was observed.

4. CONCLUSIONS

The fundamental study on wall impingement phenomena of a liquid jet was performed. The splash ratio of droplets was introduced as the impingement characteristics of the jet. Then, the following results were obtained.

(1) Impingement phenomena were classified into following five categories.

(a) smooth surface, (b) bubble containing flow, (c) flow with hydraulic jump, (d) film flow with rim and droplet splash, and (e) thin film with droplets splash.

(2) The impingement distance between the nozzle and the plate gave some influence on the flow pattern on the plate.

(3) The splash ratio of droplets was greatly controlled by turbulent level and impingement velocity of the jet.

(4) The splash ratio of droplets from a turbulent jet was higher than that from a laminar jet.

(5) The splash ratio of droplets took the maximum at impingement distance longer than the break-up length.

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