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ECC Water Spreading Width for Flat Plate

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Abstract

To investigate the characteristics of water jet spreading width induced by Direct Vessel Injection(DVI), a steady state and separate effect test focusing on the effect of the downcomer curvature was performed using a rectangular flat-plate air-water open channel test facility. Comparative tests using various scaled diameter(D) of water jet nozzle, channel gap(W), water jet velocity(V_{JET}), and forced cross air-flow(V_C) on the water film are performed for the Korean Next Generation Reactor(KNGR) during the late reflood phase of LBLOCA. A simplified and visible thin acryl plates were used. The air-water channel has a nearly full height in height between DVI and coldleg. The channel gap and the diameter of water injection nozzle have scaled ratios of 1/50 ~ 1/10 by volume scaling method. The cross flow is introduced in the air-water channel to investigate the cross flow effects on the ECC water jet spreading width. The major parameters measured in the experiments are the film width of ECC water, the shifted degree of water film boundary by the cross air flow, and the attachment liquid fraction to total injected water in the region of front plate against water injected wall plate.

It was found out that (1) If the test scale is increased, for the typical film spreading width without any cross flow, the film width is linearly increased at the bottom of air-water channel except at the top of film. (2) If the cross flow is induced on the liquid film for the test scale of 1:51.68, the highly shifted film shape is formed (3) If the test scale and the water injection velocity are increased, the attachment ratio of liquid on the front plate is sharply increased. (4) The attachment ratio of liquid on the front plate is strongly increased by cross flow. In the case of 9.52 scaled test, the attachment ratio of liquid is affected by both the cross flow and the water injection velocity.

1. Introduction

It is known that the downcomer thermal behaviors are strongly dependent on DVI system from the recent studies of KNGR DVI features during LBLOCA(Kyoo H. Bae et. al., 2000). In each train of KNGR ECCS, a high pressure safety injection pump(HPSIP) and a Safety Injection Tank(SIT) are connected to the DVI nozzle located approximately 2.1 m above the centerline of coldlegs. The KNGR ECCS has a DVI configuration with four nozzles at the upper part of downcomer. Because the downcomer ECC thermal mixing behaviors are strongly governed by the location of ECC nozzle, the DVI system of PWR can be categorized in two group. One is a High Level DVI(H-DVI) system such as KNGR, the other is a low level DVI(L-DVI) system around coldleg. The thermal hydraulics in the downcomer is governed by steam coming from the intact coldleg and ECC liquid film during the late reflood phase of LBLOCA(Byung Jo Yun et. al.,2000; Kyoo H. Bae et. al., 2000). The steam-water interaction in that region may result in ECC bypass and ECC jet break-up around the coldleg elevation. If the ECC water is directly injected into the upper downcomer region, the steam coming from the intact coldlegs will interfere with the ECC water in the downcomer. The steam water interaction in the downcomer region may result in ECC bypass and break-up. Since the L-DVI is located around the coldleg, the ECC water jet is directly broken up by steam jet without wide spreading of liquid film shape around the core barrel wall. The cross flow effects of steam on L-DVI ECC film is more breakable when compared to that of H-DVI. Since the effective cross flow region of stream is concentrated at about coldleg elevation region, the spreading width of ECC water jet in the downcomer for the H-DVI becomes wider compared to that of L-DVI(Byung Jo Yun et al.,2000).

In this paper, the film width of 2-D ECC water jet is presented based on experimental observation using a flat plate air water open channel facility. The momentum of water jet and the gravitation head effects are considered on the film spreading width.

2. Experimental Method and Test Condition

2.1 Experimental Method

The experimental test facility consists of the flow channel width 2-D acryl flat plates, air supply blowers, and water supply pumps. Figure 1 shows a schematic diagram of test facility. The test section with variable gap widths is made of two acrylic plates for visualization. The water jet nozzle is mounted vertically onto the flat plate at the upper part of the front flat plate. The injection velocity of water jet is fixed at some reference points to equalize the momentum of water jet compare to that of reference plant HPSI condition. If the velocity of water jet is conserved, the radial impingement velocity distribution of the water jet near the stagnation point is also conserved. A forced cross air jet, which has a uniform distribution in vertical direction, is induced to investigate the effects of cross flow. The forced air-jet, as shown in Fig. 1, is injected from the right side to the left side of air-water channel. The velocity of air jet, however, is not fully modeled for the scaled range because of the capacity of blower since the blower was designed for the cylinderical test facility(1/50). Thus, the capacity of blower is not sufficient to cover the full range of cross flow velocity of interest. The maximum velocity of cross flow is 20m/sec for the gap size of 4.5cm. The cross flow velocity is reduced by the increase of channel gap width. Therefore, the maximum velocity of air flow is smaller compared to that of the gap size of 4.5cm. The major parameters tested are the gap size, water injection velocity, and cross flow air velocity. The major parameters measured in the experiments are the film width of ECC water, the shifted degree of water film boundary by the cross air flow, and the fraction of attachment liquid to the total injected water in the region of the front plate against water injected wall plate.

The boundary line of liquid film is determined from the images recorded by digital video camera and image reproduction system. The thin grid film, which has a resolution of 10 mm vertically and horizontally, is attached at the outer surfaces of each acryl plate to measure the film width directly by the digital recorder. The red-aniline dye is used to enhance the visibility of the liquid boundary. In the case of the forced cross flow, however, the liquid film boundary at the downstream side of cross flow is not clear and very thin while the upstream side of cross flow is still thicker as shown in Fig. 2.

In the air-water chamber which has a vertically injected water nozzle, the film is formed at both plates. The liquid attachment fraction on the water injected plate(back plate) at the near region of injection nozzle is much higher compared to that of the opposite plate(front plate). However, the liquid attachment fraction of the front(opposite) plate is increased along the downward direction of liquid film because of the film breakup. To measure the attachment ratio of the liquid film and drop in the half region of the opposite plate against the water injected(back) plate, as shown in Fig. 1, a thin stainless steel plate is installed along the center line of the gap at the bottom of air-water chamber. The separated liquid is accumulated in the stand pipe of collection tank. The separation plate has a height of 170 mm from the bottom of effective region of the air-water chamber. The liquid attachment ratio in the front plate region at the bottom of air-water chamber can be calculated as follows:

$$Liquid\ Attachment\ Ratio = \frac{M_A}{M_T} \qquad (1)$$

where, M_T is the total amount of water injected, M_A is the total amount of water accumulated in the front plate region opposite to the water injected plate. The amount of accumulated water is determined by the measured water level of the collection pipe.

The technical specification of air supply blower and water supply pump are summarized in Table 1. The Instruments and its accuracy are also summarized in Table 2.

2.2 Test Conditions

The geometric test conditions such as diameters of water injection nozzles and gap sizes, as summarized in Table 3, are determined by the volume scaling method. Since it is required that the conservation of velocity scale to investigate the scaling effect on the film spreading width, so the velocity for the various nozzle and gap is not scaled down but fixed at 1.0, 1.5, 1.8, 2.0, 2.2, and 2.5 m/sec respectively. Since the air-water open channel is not allowed to have a pressurized condition, the system pressure is set at the atmospheric pressure in the channel. The temperature of liquid injected is about 18 ~20 ^{o}C. The liquid properties are not so much varied at the given temperature and pressure conditions.

3. Experimental Results

3.1 Film width

Figure 3 shows a typical film spreading width without cross flow. The injection velocity of water jet is 2.0 m/sec. If the gap width is increased, the film width is linearly increased at the bottom of air-water channel except at the top of film. Figure 4 to Figure 6 show the film shape with various cross flow under the fixed water jet velocity of 2.1 m/sec. Figure 4 shows, for scale of 1:51.68, the highly shifted film shape is formed by the forced cross flow when compared to that of scale 1/23 or scale 1/9.52. Figures 5 and 6 show the mitigation of film shifting by the cross flow with increasing gap(scale). In figures 5 and 6, the film shift is nearly equal for both scales of 1:23 and 1:9.52 if the cross flow is higher than 10 m/sec. However, if the forced cross flow velocity of air is increased to above 10 m/sec, the boundary line of the liquid film is more shifted to the downstream of the cross flow. If the forced cross flow is induced into the film flow, the right and left side of the liquid film show very different shapes as shown in Fig. 2. In the right side of Figures 4 and 6(upstream side or attack region of cross flow), the boundary line of liquid film is clear and shifted to the downstream of cross flow. The film thickness of the attack region is thicker compared to that of left side. In the left side of Figures 4 and 6(downstream side or wake region of cross flow), however, the boundary line of liquid film is not clear and broken up into small liquid drops. Therefore, if the forced cross flow is induced into the vertical liquid film, the shifted of film boundary is nearly close to each other above the test scale of 1:23.

In this experiment, however, the liquid drop size in the wake region was not measured. Thus, the effect of the cross flow on drop size could not be quantified.

3.2 Liquid Attachment Rate in the Front Plate Region

Figure. 7 shows the liquid attachment rate in the front plate region which is located on the opposite side of the water injected plate. The liquid attachment on the front plate is driven by the breakup mechanism of liquid film and by cross flow. Figure 7 shows that the liquid attachment rate on the front plate is driven by the self-breakup mechanism of liquid film because no cross flow. In fig. 7, the attachment rate is increased sharply with the test scale of test facility. It means that the direct breakup or rolling breakup at the top of film is highly occurred because the liquid film is thicker compared to that of small test scale less than 1:23. As shown in fig. 3, the film width may not be increased by the test scale, and it means that the thickness and stagnation of film at the top of the film will be increased. Thus, the rolling and breakup of liquid film at the top is increased in the lager scale tests when compared to that of small scale test.

S.A Ashforth et.al(Nottingham, UK) investigated the spreading velocity of free and confined jets. The degradation of center line velocity of free and confined jets is negligibly small to Gap/Nozzle< 4.0, and the ratio of spreading velocity to jet injection velocity is nearly 0.95 at the boundary of jet. Therefore, the spreading velocity is equal to the jet injection velocity multiplied by 0.95. The top stagnation point of jet film, H, is simplified by kinetic relation as follows;

$$H = 0.98 * V_{DVI} * t - \frac{1}{2} g t^2 \quad (2)$$

$where \ \ t = 0.98 * V_{DVI} \ / \ g$.

The stagnation height, H, is about 0.207 m above from the center line of the injection nozzle. Figure 3 may confirm the predictability of kinetic relation for the stagnation point of vertical film. The stagnation height(H) is about 0.2 m for all test scales as shown in Fig. 3. Therefore, if the water jets with equal injection velocity are induced on a vertical plate, the film thickness above the injection nozzle will be increased by the film stagnation(see Fig. 2). It means that the rolling and break up of liquid film is increased by the stagnation of film at the region above nozzle.

4. Summary and Conclusion

Experimental investigations on the film width of ECC water injected horizontally on the 2-dimensional flat plate have been performed with a variable water jet velocity, cross flow velocity, and scaled gap width. The major observations include (1) If the test scale is increased, for the typical film spreading width without any cross flow, the film width is linearly increased at the bottom of air-water channel except at the top of film. (2) If the cross flow is induced on the liquid film for the test scale of 1:51.68, the highly shifted film shape is founded. (3) If the test scale and the water injection velocity are increased, the attachment ratio of liquid on the front plate is sharply increased. (4) The attachment ratio of liquid on the front plate is strongly increased by cross flow of 10 m/sec. In the case of 9.52 test scale, the attachment ratio of liquid is affected by both the cross flow and the water injection velocity.

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Table. 1 Major Components of the Test Facility

Components	Capacity	Model or Spec.
Air Blower	30 m^3/min	Turbine Blade Type
Air Flow Meter	0.25 m^3/min at H=20m	Centrifugal type

Table. 2 Instrumentation

Instrument	Model or Spec.	Capacity	Accuracy
Air Flow Meter	Oval Vortex Flow Meter Model: VAW1150-C1C1-1511	230~4000 m^3/hr	± 1 %
Water Flow Meter	Sponsler Turbine Flow Meter Model : SP712-2	1 ~ 13.6 m^3/hr	± 0.25 %
Temperature sensor	PT-100Ω	1 ~ 100 °C	± 0.5 %
Pressure sensor	Rosemount Smart Type Model : 3051C	0 ~ 200 kPa	± 1 %
Differential Pressure sensor	Rosemount Smart Type Model : 3051C	0 ~ 200 kPa	± 1 %

Table. 3 The Technical Specification of the Test Section

Parameter	KNGR	Scale	Values
D/C Gap Width	25.4 cm	1/4.66	11.76 cm
		1/9.52	8.23 cm
		1/23.0	5.29 cm
		1/51.68	3.53 cm
Water Injection Velocity	about 1.8 ~2.2 m/s (HPSI Mode)	1:1	2.5 m/sec
			2.2 m/sec
			2.0 m/sec
			1.8 m/sec
			1.5 m/sec
			1.0 m/sec
DVI Nozzle Diameter	8.5"(21.6 cm)	1/4.66	10.00 cm
		1/9.52	7.00 cm
		1/23.0	4.50 cm
		1/51.68	3.00 cm
DVI Elevation (from C.L of Coldleg)	82.78"(210cm)	1/1	210 cm

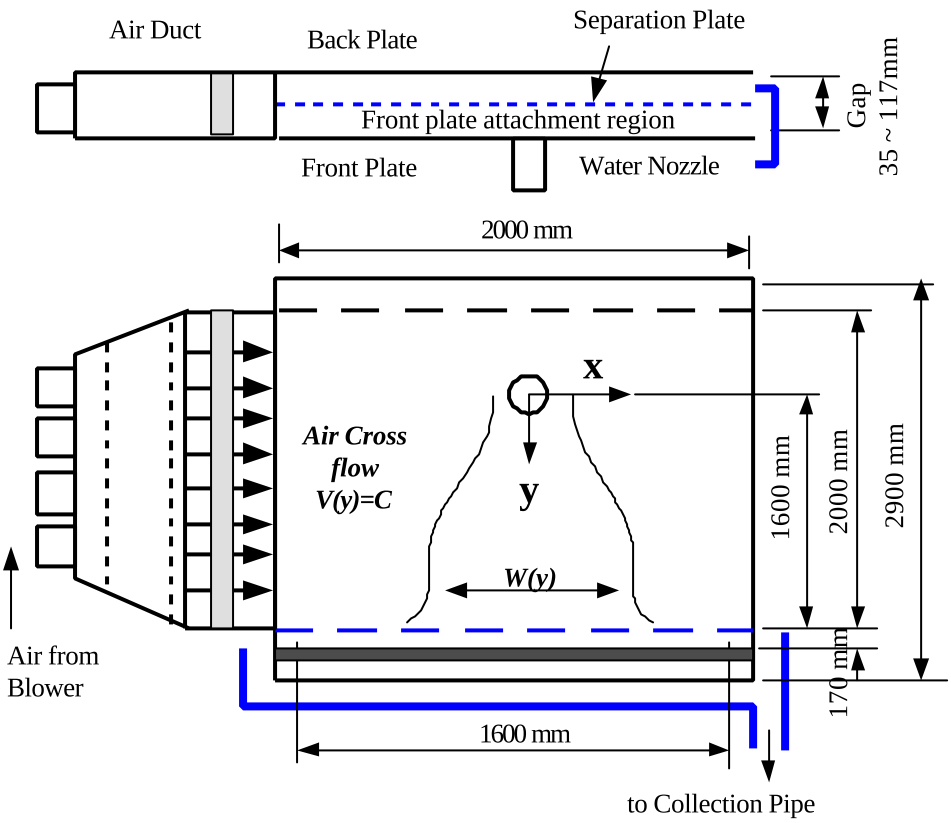

Fig. 1 Schematic diagram of the Air-water 2-D Flat Plate Test Facility

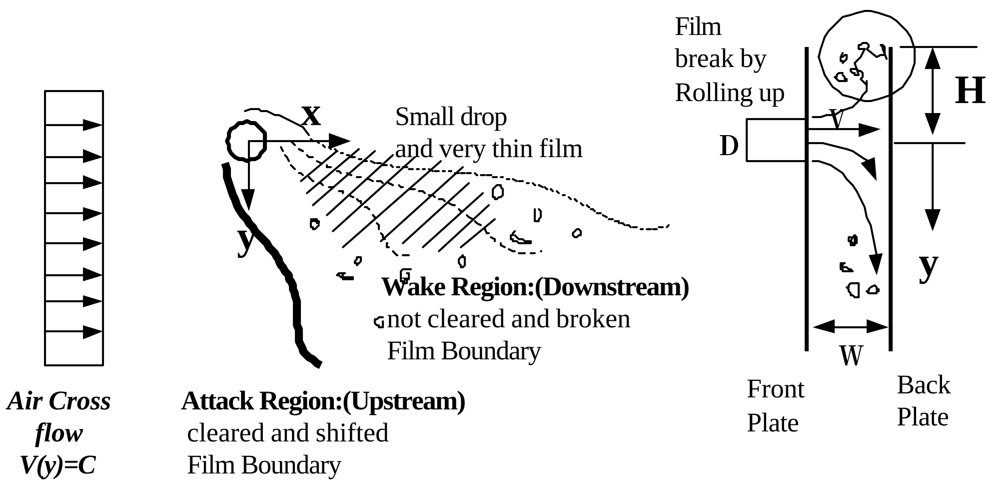

Fig. 2 Sketch of the Film Boundary by Forced Cross Flow Induced

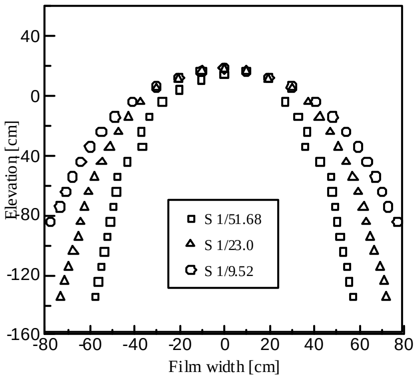

Fig. 3 Film width for V_{Jet} =0 m/sec

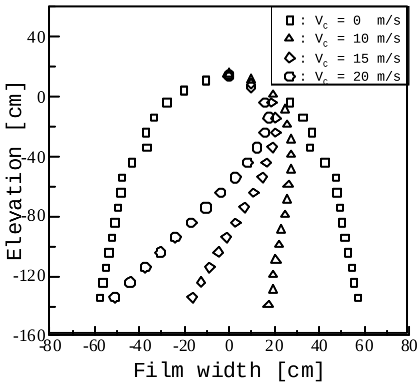

Fig. 4 Film width for 1/51.68 Scale

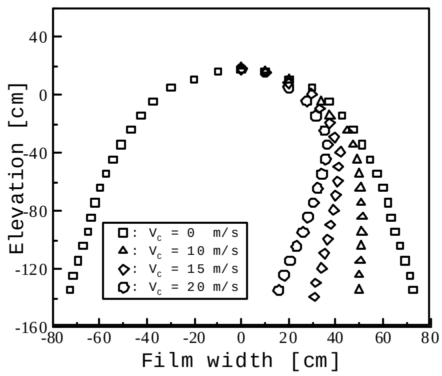

Fig. 5 Film width for 1/23.0 Scale

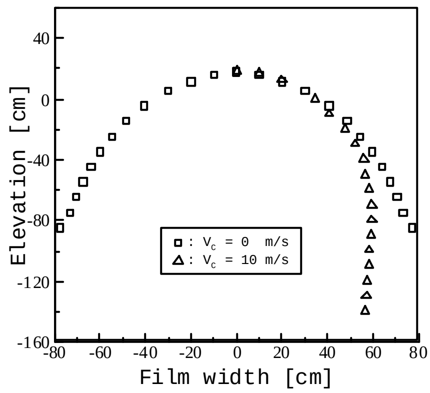

Fig .6 Film width for 1/9.52 Scale

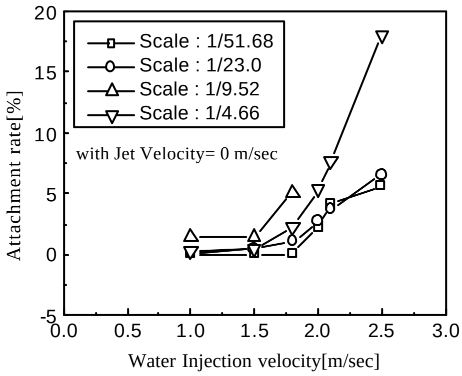

Fig. 7 Attachment ratio for V_{Jet} =0 m/sec

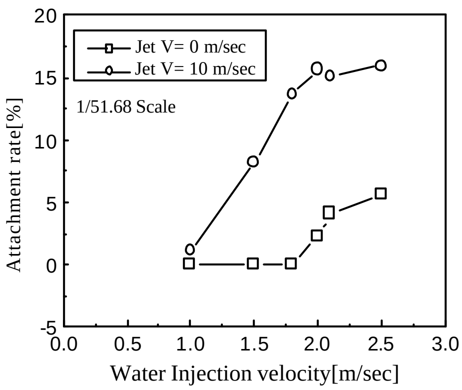

Fig. 8 Attachment ratio for 1/51.68 scale

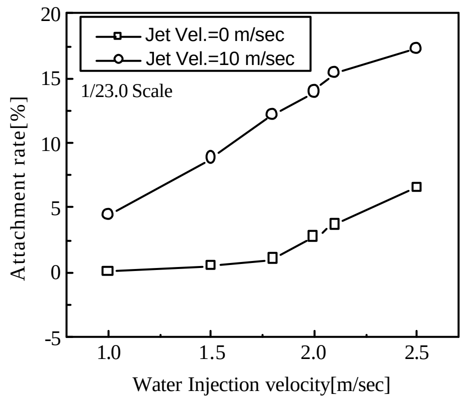

Fig. 9 Attachment ratio for 1/23 scale

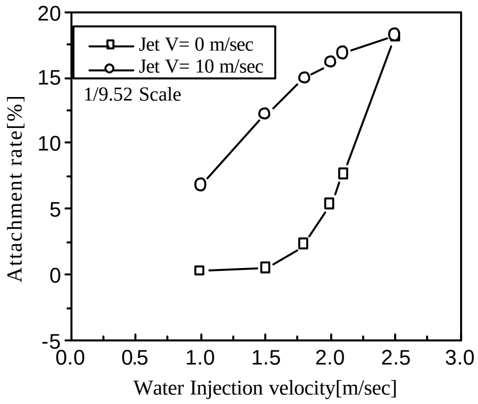

Fig. 10 Attachment ratio for 1/9.52 scale