Development of Sweepout Model for the APR1400 Downcomer

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1. Introduction

According to the experiments of Upper Plenum Test Facility (UPTF)[1] and the those related to the multi-dimensional phenomena in the Advanced Power Reactor 1400MWe (APR1400) downcomer[2], the sweepout has been identified to play an important role in depleting the coolant inventory in the reflood and the long term cooling phase of Large-Break Loss-of-Coolant Accident (LBLOCA).

Thus, the sweepout separate effect test was performed to investigate the mechanism and to estimate the amount of the coolant discharged by sweepout. Deriving the non-dimensional parameters by analytic study, the results of experiment were correlated to devise the sweepout model, which calculates the critical void height and the flow quality at the break. The developed model was validated with the results of counter-part experiments performed in KAERI and SNU.

2. Experimental Results

The test apparatus has been scaled down to 1/5 of the APR1400 downcomer. The test section was constructed as a slab type with air and water as working fluids. The test matrix includes the individual parameter relevant to sweepout, such as the gas flow rate, void height, distance between intact and broken cold legs, and blockage of hot leg.

From the experiments, the mechanism of sweepout can be explained with the hydraulic phenomena near the inlet of gas, rather than the outlet. The injected gas hits the surface of the water body and generates waves and droplets from the bulk water, which are transported to the break by the lateral gas flow. That is, the amount of sweepout is composed of water-slug flow and droplet flow. Therefore, correcting off-take model[3] as shown in Eq. (1), the critical void height was expressed with the inlet Froude number.

$$Fr_{g,in}\sqrt{\frac{\rho_g}{\Delta\rho}} = A\left(\frac{h_c}{D}\right)^{2.5} + B \qquad (1)$$

, where the coefficient, B , means a critical Froude number correspondent to a threshold gas velocity exists to initiate the sweepout due to the gravity and the surface tension of the liquid.

3. Development of Sweepout Model

Sweepout model was developed for critical void height and break quality according to the each flow regime.

3.1 Water-slug Flow

As shown in Figure 1, the critical void height for water-slug flow is reached when the wave height (δ) is equivalent to $h - D/2$.

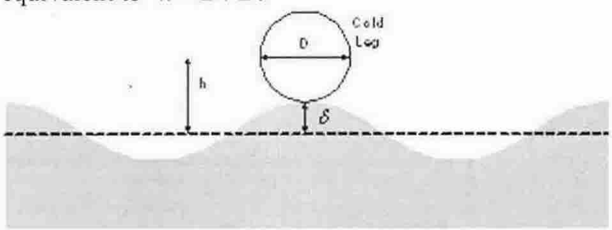

Figure 1. Modeling Diagram for Wave near Inlet

The wave height can be determined from the hydrostatic head, which is induced by the difference of gas velocity on the free surface as represented in Eq. (2).

$$\Delta p = \frac{1}{2}\rho_g v_{max}^2 = \Delta\rho g\delta \qquad (2)$$

Applying the potential theory, Eq. (3) determines the maximum velocity so that the critical void height for water-slug flow(h_s) is represented in the form of Eq. (4)

$$v_{max} = \frac{1}{2\pi}\cdot\frac{Q}{bh} \qquad (3)$$

$$Fr_g\sqrt{\frac{\rho_g}{\Delta\rho}} = K\cdot\frac{h_s}{D}\sqrt{\frac{h_s}{D} - 0.5} \qquad (4)$$

Eq. (4) was converted to more explicit form and the coefficient K was determined from experimental results with considering the non-dimensional distance between inlet and outlet(L/D), as in Eq. (5).

$$\frac{h_s}{D} = \left(1.510 - 6.240\times10^{-2}\frac{L}{D}\right)Fr_{in}\sqrt{\frac{\rho_g}{\Delta\rho}} + 0.5 \qquad (5)$$

The discharge flow rate by water-slug flow was correlated with the critical void height of Eq. (5).

$$\left(\frac{W_f}{W_{g,in}}\right)_{slug} = 14.31\left(1 - \frac{h}{h_s}\right)^{3.35} \qquad (6)$$

3.2 Droplet Flow

The critical void height for droplet flow in single injection(h_{c1}) was determined from the form of Eq. (1)

$$\frac{h_{c1}}{D} = 2.368\left(Fr_{in}\sqrt{\frac{\rho_g}{\Delta\rho}} - 6.110\times10^{-2}\left(\frac{L}{D}\right)^{0.6134}\right)^{0.4} \quad (7)$$

From non-dimensional analysis, the water flow rate discharged by droplet flow was identified to be dependent on the inlet Froude number of gas, distance between inlet and outlet, and void height. Thus, the droplet flow rate is,

$$\left(\frac{W_f}{W_{g,in}}\right)_{drop} = 29.34\cdot\left(Fr_{in}\sqrt{\frac{\rho_g}{\Delta\rho}}\right)^{2.4}\left(\frac{L}{D}\right)^{-1.3}\left(1-\frac{h}{h_{c1}}\right)^{1.7} \quad (8)$$

3.3 Superposition effect

In the case of double injection of gas, the effect of acceleration of gas near the outlet increases the critical void height (h_{c2}) and water discharge flow as represented in following equations.

$$\frac{h_{c2}}{D} = 2.771\cdot\left(Fr_{in}\sqrt{\frac{\rho_g}{\Delta\rho}} - 0.1600\right)^{0.4} \quad (9)$$

$$\left(\frac{W_f}{W_{g,in}}\right)_{acc} = 2.190\cdot\left(1-\frac{h}{h_{c2}}\right)^{3.35} \quad (10)$$

4. Validation of the Developed Model

The developed model was generally evaluated for the scale-up capability according to the validation procedure suggested by Zuber et al.[4] In order to scale up the experiment results to the prototype, the counter-part tests are required essentially.

In this study, there are the counter-part tests with 1/5, 1/7 and 1/10 scale of APR1400 for the critical void height [2]. The correlation of critical void height complied well with not only the results of this study but also those of counter-part tests which have been performed in the annular type downcomer, within $\pm2\sigma$ without significant distortion as shown in Figure 2.

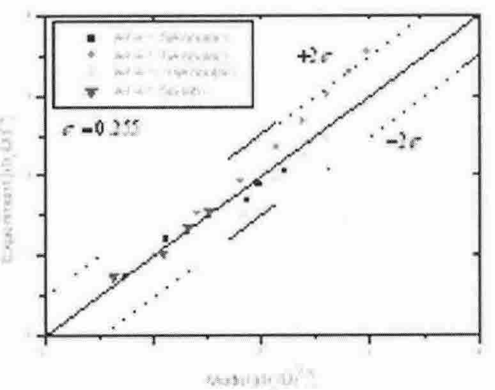

Figure 2. Validation of Critical Void Height

The flow quality at the break is computed with combining discharge flow rate for each flow regime. In the comparison with the counter-part test, which is 1/10-scale annular type downcomer of APR1400[5], they showed good agreement within the uncertainty band of 15 % in betweens as shown in Figure 3.

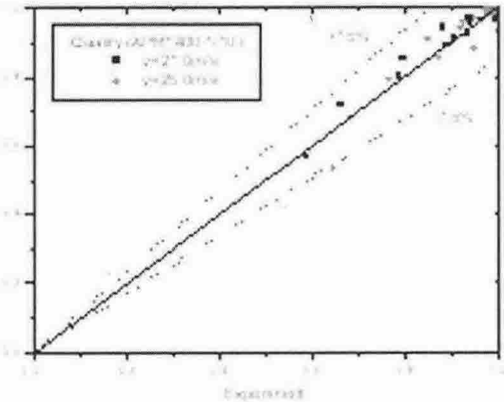

Figure 3. Validation of Flow Quality at Break

5. Conclusion

This study intended to develop the model for predicting critical void height and the discharge flow by sweepout in downcomer. For this purpose, sweepout was investigated experimentally and analytically. The correlations for critical void height and break quality were developed according to water-slug flow, droplet flow, and superposition effect. Each one reflects the individual effect of the parameter affecting sweepout phenomena. In the validation of the developed model, the results of this study were compared with the counter-part tests and the developed model showed reasonable agreements with the results of them. Therefore, it can be concluded that the sweepout model developed in this study has the applicability to an actual downcomer without inducing a significant distortion.

REFERENCES

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