1-D Air / Water Experiments of a Two-Phase Natural Circulation Flow under ERVC

Kwang-Soon Ha[a], Jae-Cheol Kim[a], Rae-Joon Park[a], Young-Rho Cho[a] , and Sang-Baik Kim[a]
a Thermal-Hydraulic Safety Research Division, Korea Atomic Energy Research Institute
150 Deokjin-dong, Yuseong-gu, Daejeon, 305-353, tomo@kaeri.re.kr

1. Introduction

To observe and evaluate the two-phase natural circulation phenomena through the gap between the reactor vessel and the insulation in the APR1400 under an external vessel cooling, the T-HERMES (Thermo-Hydraulic Evaluations of Reactor vessel cooling Mechanisms by External Self-induced flow) program has been performed at KAERI [1].

The HERMES-HALF study [1], which is one of the T-HERMES programs, has been performed to observe and evaluate the two-phase natural circulation phenomena through the gap between the reactor vessel and the insulation in the APR1400. The HERMES-HALF is a non-heating and a half-scaled three-dimensional experimental study on the two-phase natural circulation through the annular gap between the reactor vessel and the insulation. The behaviors of the two-phase natural circulation flow in the insulation gap are observed, and the liquid mass flow rates driven by the natural circulation loop are measured.

From the HERMES-HALF experimental results, the natural circulation flow rate can be generated up to 200kg/s by adjusting the inlet and outlet area of the insulation. This flow rate value is the same as the 323kg/m^{2}s mass flux value normalized with the annular section area. Compared to the KAIST and SULTAN experimental results, the CHF values reach about 1.3 – 1.5MW/m^2 at the top of the lower head vessel (90 degrees) based on the 323kg/m^{2}s mass flux which is measured from the HERMES-HALF experiments. Though the scaling law is adapted to the HERMES-HALF experimental facility, the similarity of the non-heating experiment to the heating experiment should be certified. This property scaling and geometry scaling should be studied to apply the experimental data to a real APR1400.

A T-HERMES-1D study has been launched to evaluate the property and geometry scaling of the HERMES-HALF experimental results. The T-HERMES-1D is a one-dimensional non-heating / heating experimental study on a two-phase natural circulation through the annular gap between the reactor vessel and the insulation. For the property scaling, the non-heating results should be compared with the heating experimental ones. That is, a coolant sub-cooling effect, such as a steam bubble behavior and a flashing effect, and a natural circulation flow instability should be evaluated. For the geometry scaling, the 1-D phenomena should be compared with the 3-D ones of HERMES-HALF.

In this paper, the T-HERMES-1D non-heating experimental results are presented.

2. Methods and Results

2.1 T-HERMES-1D Experiments

A schematic diagram of the T-HERMES-1D experimental facility is shown in figure 1. The facility is a one-dimensional one when compared with the HERMES-HALF facility [1] which simulates a three-dimensional half height and half section of the APR1400 reactor vessel and insulation system. The height of the main test section is a half scaled-down reactor vessel and an insulation part which is prepared by utilizing the results of a scaling analysis proposed by Cheung [2] to simulate the APR1400 reactor and insulation system. The width of the main test section is 100mm, therefore the T-HERMES-1D has a rectangular cross section. The facility is design to perform both direct heating and non-heating experiments by changing the bottom region of the reactor vessel wall. To measure the flow void fraction, three differential pressure transmitters are installed on the test section wall.

The water inlet pressure condition is controlled by changing the water head level in the reservoir. For maximizing the natural circulation flow, water inlets and outlet ports exist in the insulation. The natural circulation flow rate is measured by the turbine flow meter which is installed on the bottom of the inlet hole.

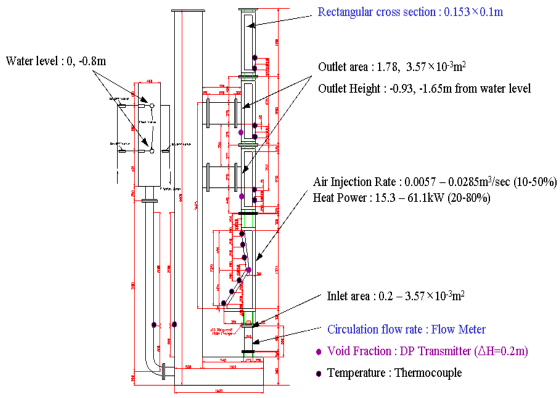
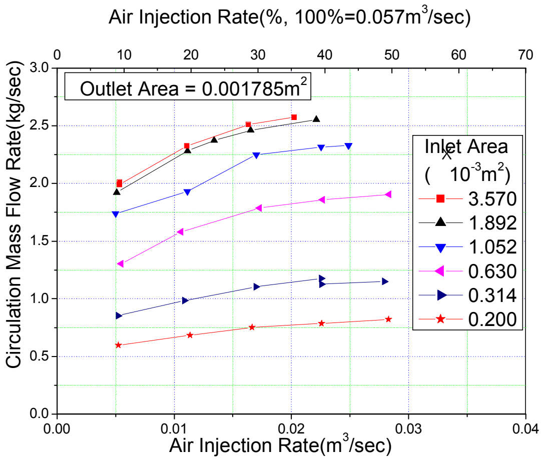
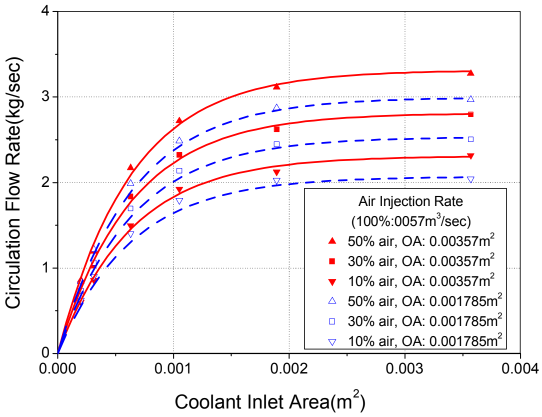


Figure 1. Schematics of T-HERMES-1D Facility

2.2 Experimental Results



(a)



(b)

Figure 2. Experimental Results (O.A. : outlet area)

The parameters of the T-HERMES-1D non-heating experiments were the air flow rates (10 ~ 50%, 100%=0.057m^3/sec), the water inlet area (0.2 ~ 3.57× 10^{-3} m^2), and outlet area (1.785, 3.57× 10^{-3} m^2). The external water reservoir was filled with stagnant water up to 3.925m from the water inlet.

Figure 2 shows the T-HERMES-1D non-heating experimental results according to the injected air flow rate, inlet area, and outlet area. As shown in Figure 2, as the injected air flow rate and inlet area increase, the circulation water flow rates also increase. As shown in Figure 2(b), the natural circulation mass flow rates asymptotically increase, that is, they converge at a specific value as the inlet area increases. So a minimal water inlet area should be selected to optimize the natural circulation flow. This is the same feature as the HERMES-HALF experimental results [1]. From the experimental results, simple empirical correlations were obtained within a ± 15% error bound as shown in equations 1 and 2.

$$CF = (2.06 + AF/82.4)[1 - \exp(-IA/0.635)] \quad \text{at outlet area } 3.57\times 10^{-3}\ \text{m}^2 \qquad (1)$$

$$CF = (1.84 + AF/89.4)[1 - \exp(-IA/0.589)] \quad \text{at outlet area } 1.785\times 10^{-3}\ \text{m}^2 \qquad (2)$$

where CF : circulation mass flow rate (kg/s),
AF : air flow rate (m^3/hr),
IR : inlet area (× 10^{-3} m^2).

3. Conclusion

To evaluate the property and geometry scaling of the HERMES-HALF experimental results, the T-HERMES-1D experimental facility was set up and non-heating experiments were performed. That is, the two-phase natural circulation mass flow rates through the gap between the reactor vessel and the insulation in the APR1400 under an external vessel cooling have been measured experimentally with variations of the injected air flow rate, water inlet area, and outlet area. And simple empirical correlations to predict the circulation mass flow rates were obtained from the experimental results. The T-HERMES-1D non-heating experimental results showed the same trends as the HERMES-HALF experimental ones.

Acknowledgments

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References

[1] K. S. Ha, R. J. Park, H. Y. Kim, S. B. Kim, and H. D. Kim, An Experimental Study on the Two-Phase Natural Circulation Flow through the Gap between Reactor Vessel and Insulation under ERVC, KAERI Technical Report, KAERI/TR-2958/2005, 2005.

[2] F. B. Cheung and Y. C. Liu, "CHF Experiments to Support In-Vessel Retention Feasibility Study for an Evolutionary ALWR Design", EPRI WO# 5491-01, PSU/MNE-99-2633, 1999.