An Experimental Study on the Two-Phase Natural Circulation Flow under ERVC

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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 the external vessel cooling, the T-HERMES (Thermo-Hydraulic Evaluations of Reactor vessel cooling Mechanisms by External Self-induced flow) program has been performed in KAERI [1]. The HERMES-HALF study, which is one of the T-HERMES programs, is a non-heating experimental study on the two-phase natural circulation through the annular gap between the reactor vessel and the insulation. In this paper, the HERMES-HALF experimental results were presented.

2. Methods and Results

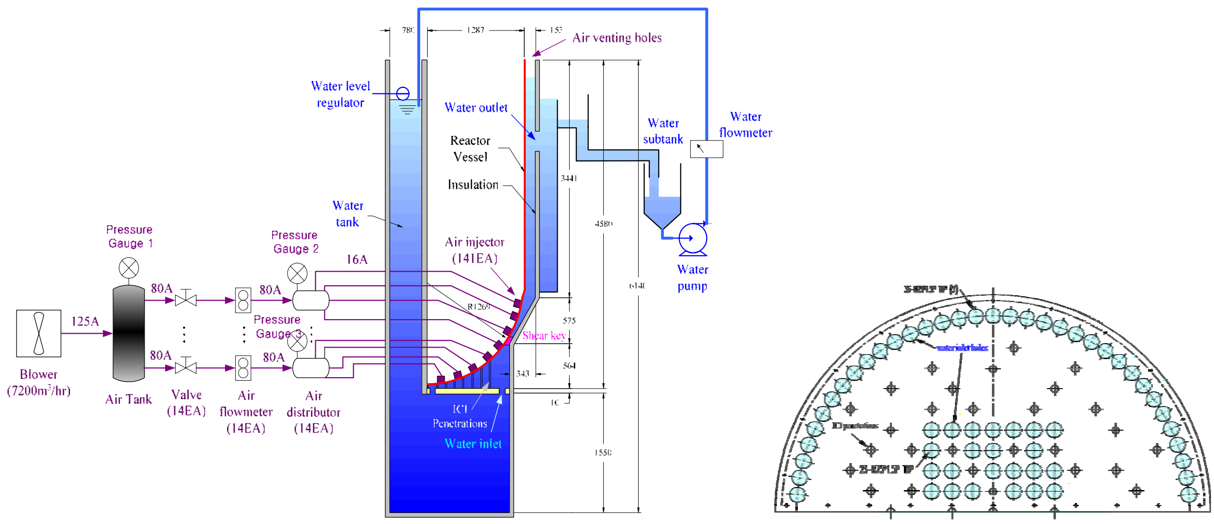
2.1 HERMES-HALF Experimental Setup [1]

The schematics diagram of the HERMES-HALF experimental facility is shown in figure 1. The facility consists of 3 parts, that is, a main experimental facility, an air supply system and a water recirculation system. The main facility is a half scaled-down reactor vessel and an insulation part which is prepared utilizing the results of a scaling analysis proposed by Cheung [2] to simulate the APR1400 reactor and insulation system. 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 is discharged to two outlets in the insulation. Two outlets have rectangular shapes, which are located at a 45, and 135 degrees of longitude on the annular section of the reactor vessel wall. The horizontal size of each outlet is 0.1m (or 0.2) and the vertical is 0.375m. The height from the bottom of the reactor vessel to the center of the outlet port is 3.384m.

In the HERMES-HALF experiment, the two phase flow is generated by not a direct heating method but a non-heating method. For the non-heating experiment, an equivalent air is injected through 141 air injectors by the air supply system. The experimental heat distribution for determining the air injection rate is obtained by the IVR evaluation. The 100% air injection condition is equivalent to 8380m^3/hr of total air injection rate.

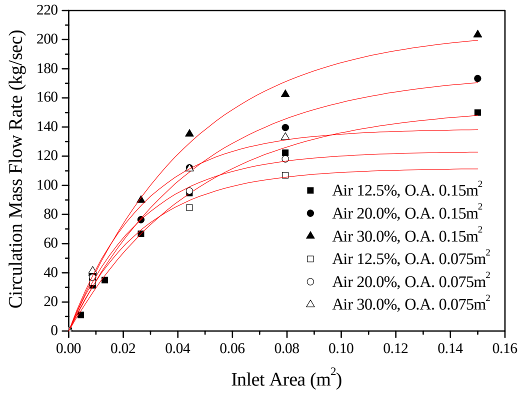
2.2 Experimental Results

The parameters of the HERMES-HALF experiments are the air flow rates, the water inlet area / configurations and outlet area. The external water reservoir is filled with stagnant water up to 3.571m from the bottom of the reactor vessel.

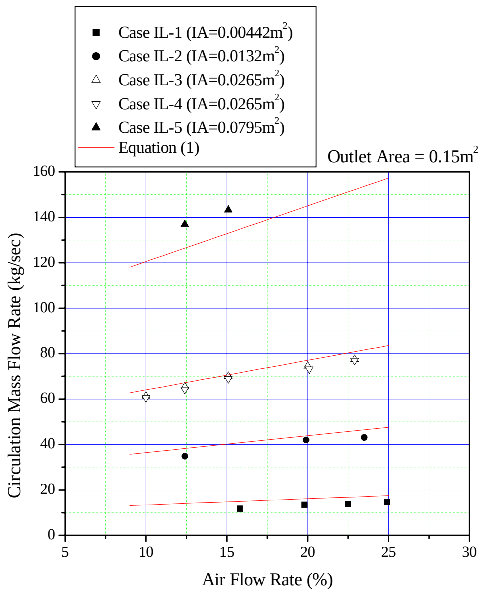


(a) Schematic diagram of HERMES-HALF experimental facility (b) Coolant inlet plate

Figure 1. HERMES-HALF experimental facility



(a)



(b)

Figure 2. Experimental Results (I.A. : inlet area)

Figure 2 shows the HERMES-HALF experimental results according to the injected air flow rate, inlet area, and water head. As shown in figure 2, as the injected air flow rate and inlet area increase, the circulation water flow rates also increase. That is, the natural circulation flow rates linearly increase as the air flow rates increase.

Figure 2(a) shows the experimental results of circumferential inlet condition. That is, to adjust the water inlet area, some holes of the 35 holes at the circumferential part of the water inlet plate [Figure 1(b)] are plugged. The angular position of the inlet is the same as that of the outlet, that is, 45 and 135 degrees of longitude on the annular section. As shown in figure 2(a), the natural circulation mass flow rates asymptotically increase, that is, they converge at a specific value as the inlet area increased. So a minimal water inlet area should be selected to optimize the natural circulation flow. From the experimental results, simple empirical correlations are obtained within a ±10% error bound as shown in equations 1 and 2.

$$CF = (117 + AF/27.9)[1 - \exp(-IA/0.0463)] \quad \text{at outlet area } 0.15\text{m}^2 \qquad (1)$$

$$CF = (92.5 + AF/54.4)[1 - \exp(-IA/0.0273)] \quad \text{at outlet area } 0.075\text{m}^2 \qquad (2)$$

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

Figure 2 shows the experimental results of other inlet configured conditions. That is, the circumferential center (90 degrees of longitude) inlet holes of the inlet plate are opened [Case IL-1, 2], or some center holes are opened [Case IL-3, 4, 5] in figure 1 (b). As shown in figure 2 (b), the circulation mass flow rates are somewhat smaller than the predicted values of equation (1). The flow characteristics also vary with the inlet configurations.

3. Conclusion

The two-phase natural circulation mass flow rates through the gap between the reactor vessel and the insulation in the APR1400 under the external vessel cooling have been measured experimentally as variations of the injected air flow rate, water inlet area / configurations and outlet area. And simple empirical correlations to predict the circulation mass flow rates are obtained from the experimental results.

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.