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1-D 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 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 experi-mental 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 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 experimental facility and preliminary loop analytical results were 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.

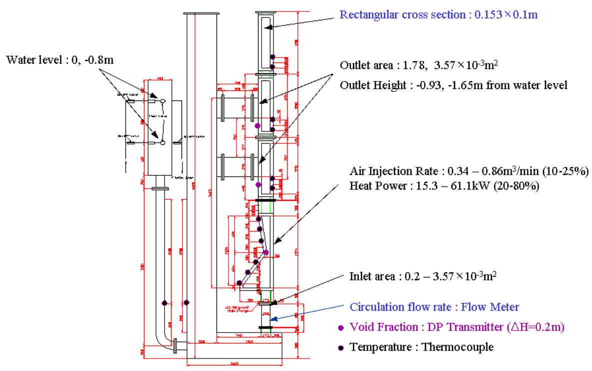

Figure 1. Schematics of T-HERMES-1D Facility

2.2 Preliminary Loop Analysis

Preliminary steady state simulations of the heating experiments have been performed to determine the coolant behavior between the reactor vessel wall and the insulation material by using a simple loop analysis. For the steady-state and one-dimensional homogeneous flow, the mass conservation equation at every flow cross section along the loop is written as eq (1).

$$\dot{m} = \rho_m u_m A_c = const. \qquad (1)$$

where $\dot{m}$ is a natural circulation mass flow rate, and ρ_m, u_m, and A_c are the mixture fluid density, mixture fluid velocity, and the flow cross-sectional area, respectively. The steady state momentum equation is integrated over the flow loop to obtain a general force balance relating to the frictional and buoyancy forces.

$$\oint \rho_m u_m \frac{\partial u_m}{\partial z} dz = -\oint \rho_m \, g \, dz - (\oint \frac{f}{2D_h} \rho_m u_m^2 \, dL + \frac{K_{inlet}}{2} \rho_{m,inlet} u_{m,inlet}^2 + \frac{K_{outlet}}{2} \rho_{m,outlet} u_{m,outlet}^2) \qquad (2)$$

where L is the flow path and f, K, and D_h are the friction factor, resistance coefficient, and hydraulic diameter, respectively. The mixture fluid density, ρ_m, is given for a two-phase fluid quality (χ_z) under homogeneous equilibrium conditions. And an equilibrium vapor quality at the elevation z can be obtained by integrating the energy balance equation. That is:

$$\chi_z = \frac{h_{inlet} - h_f + \int_{inlet}^{z} \frac{q'' \xi \, dz}{\rho_m \, u_m \, A_c} dz}{h_{fg}} \qquad (3)$$

where h_{inlet}, h_f, and h_{fg} are the enthalpy of the inlet fluid, saturated liquid enthalpy, and the latent heat of a vaporization, and q'' and ξ are the wall heat flux and heating perimeter of the heating vessel, respectively. Finally, the natural circulation mass flow rate can be obtained by solving the loop-integrated momentum equation, eq(2). In eq(2), the friction factor, f was found by using the Moody chart for smooth pipe which was expressed in terms of the mixture viscosity defined by Cicchitti [3], and the resistance coefficients at the inlet(K_{inlet}) and outlet(K_{outlet}) were chosen by considering the thick-edged orifices in a straight channel [4].

Figure 2 shows the preliminary calculated natural circulation flow rates by varying the water inlet and outlet area. As shown in Figure 2, the natural circulation mass flow rates asymptotically increased, that is, they converged at a specific value as the inlet area increased. This is the same trend as the HERMES-HALF results.

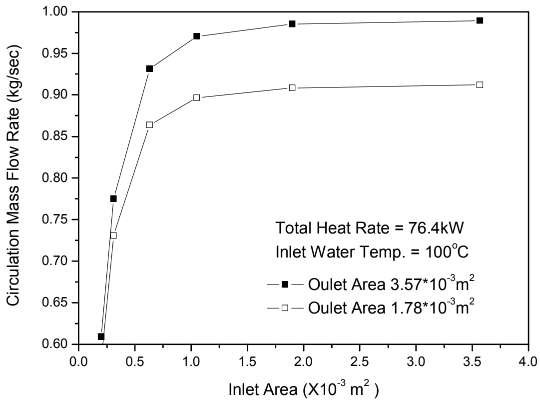

Figure 2. Preliminary results of T-HERMES-1D

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 a preliminary steady-state, homogeneous loop analysis was performed. The preliminary T-HERMES-1D analytical results showed the same trends as the HERMES-HALF experimental ones.

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Acknowledgments

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