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Preliminary Analysis of a Steam -Water Natural Circulation Flow under ERVC

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1. Introduction

Under an ERVC(External Reactor Vessel Cooling) condition of APR1400 Reactor Vessel, a natural circulation two-phase flow between the reactor vessel and insulation should be formed sufficiently enough to maintain the integrity of reactor vessel. For this reason, T-HERMES(Thermo-Hydraulic Evaluations of Reactor vessel cooling Mechanisms by External Self-induced flow) program has been performed at KAERI[1] to observe and evaluate the two-phase natural circulation phenomena.

T-HERMES-1D study was launched to evaluate the property and geometry scaling of a HERMES-HALF experiment [1]. The 1-dimensional facility was set up by scaling down the channel width of HERMES-HALF as 0.1m. The facility is designed to perform both air-water and steam-water experiments for a property scaling between the air and steam. From the air-water experimental results, thermo-hydraulic phenomena were found in that a churn turbulent two-phase flow and a local recirculation flow were observed. Also, given a experimental inlet/outlet area condition that is scaled down by the gap area ratio of T-HERMES-1D to the HERMES-HALF facility, the natural circulation mass flow rates showed at about 0.5~3.2kg/sec. Using these results and the ongoing steam-water experiment of T-HERMES-1D, a natural circulation flow rate in the annular gap of APR1400 reactor can be presented by a property and geometry scaling.

In this study, the T-HERMES-1D facility for the steam-water experiments was introduced and the preliminary simple loop analysis was carried out.

2. Methods and Results

2.1 T-HERMES-1D Experiments

Figure 1 shows the schematics of the T-HERMES 1D facility and the ranges of the experimental variables.

The one-dimensional facility on the basis of a scaling analysis proposed by Cheung[2] has a half height and 1/238 channel area of the APR1400 reactor vessel. The flow channel for simulating the annular gap between the external reactor vessel and insulation is a rectangular shape which has an aspect ratio of 0.153×0.1m. Here the gap size of 0.153m is the root square value of the real gap

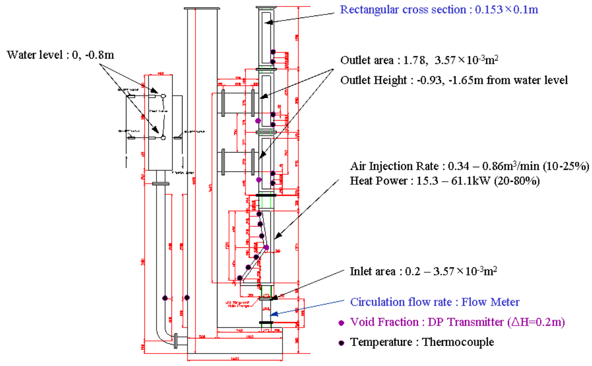

Figure 1. Schematics of T-HERMES-1D Facility.

size of the APR1400 reactor and a width of 0.1m was determined for a scaling down as a 1-dimesional flow channel. The facility was designed to perform both air-water and steam-water experiments by changing the gas generation system (wall heating system and air injection system). Turbine flow meter to measure the liquid flow rate was installed at the bottom of the coolant inlet port. Also, in order to investigate the volume-average void fraction, 3 differential pressure transmitters were installed respectively at the minimum gap, air injector exit, and coolant outlet area region. Also to measure the coolant temperature with the height of the test section, 7 thermocouples were installed. There were 2 reservoirs to supply a constant hydrostatic pressure head which could be controlled by changing the water level in the reservoir. One of the reservoirs, the main thank, was connected to the coolant outlet port for a natural circulation of the coolants.

2.2 Preliminary simple Analysis

The 1-D simple analysis was carried out to evaluate the two-phase natural circulation phenomena. For a steady state and thermodynamic equilibrium condition, the mass conservation equation along the loop is given as

$$\dot{m} = \dot{m}_g + \dot{m}_f \cong \dot{m}_f = \text{constant}, \qquad (1)$$

where a $\dot{m}$ is a total natural circulation mass flow rate, and subscripts g and f stand for gas and liquid respectively. Because of small density of the steam, total mass flow rate is equal to liquid flow rate. Momentum and energy equations in the1-D drift model[3] is used to calculate the mass flow rate. Considering the inertia, gravity, friction, drift velocity, and form loss pressure drop, the loop-wise integrated expression of the momentum equation can be written as

$$\oint \partial p = -\oint \langle \rho_m \rangle \bar{u}_m \partial \bar{u}_m - \oint \langle \rho_m \rangle g \partial z - \oint \frac{f_m}{2D} \langle \rho_m \rangle \bar{u}_m{}^2 \partial z - \oint \partial \left[\frac{\langle \alpha_g \rangle \rho_g \rho_f}{\left(1-\langle \alpha_g \rangle\right)\langle \rho_m \rangle} \bar{u}_{gj}{}^2 \right] - \frac{K}{2} \langle \rho_m \rangle \bar{u}_m{}^2, \quad (2)$$

where the p, $\langle \rho_m \rangle$ and $\bar{u}_m$ is the local pressure, mixture density and mixture velocity of coolant. And D, f_w, $\langle \alpha_g \rangle$, $\bar{u}_{gj}$, and K are the hydraulic diameter, wall friction factor, void fraction, drift velocity, and shape factor. The mixture density of the coolant can be calculated from the void fraction and fluid quality integrated by the energy balance equation. To calculated the circulation mass flow rate, the correlations of f_w, $\bar{u}_{gj}$, K in the momentum equation should be given properly. In the eq.(2) the friction factor, f_w, was found using the Darcy friction factor and Blasius equation for a smooth pipe. The correlation of the drift velocity and distribution parameter, $\bar{u}_{gj}$, C_0 for churn-turbulent flow was used from the Ishii's correlation[3]. The shape factor correlation of the coolant inlet/outlet and minimum gap was obtained by considering the orifice and conversing-diverging transition pieces respectively[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 increased with the inlet area. And the increments of the circulation mass flow rate were small in case of large inlet areas. This is the same trend as the air-water experimental results that have the range of a 0.5 ~ 3.2kg/sec circulation mass flow rate. Figure 3 shows the calculated quality and void fraction in the heater region. This calculation result was reflected satisfactorily in the supplied heat flux distribution[1] that is very high in the

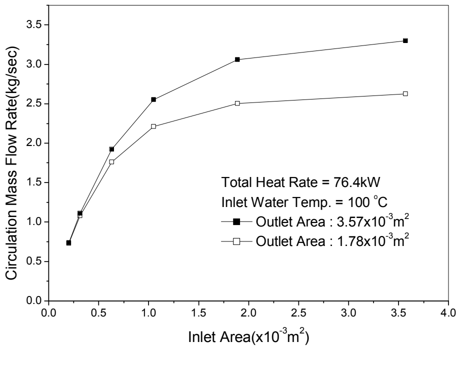

Figure 2. Simple analysis results.

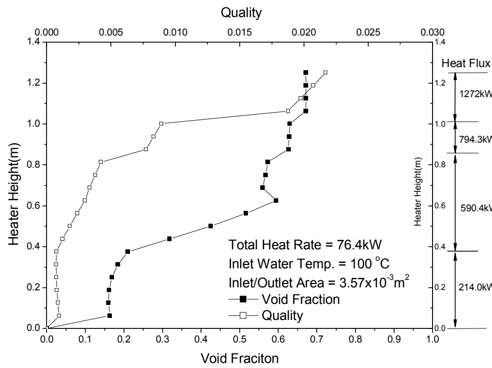

Figure 3. Calculated void fraction and quality.

upper heater region when compared with the bottom heater region.

3. Conclusion

To evaluate the property and geometry scaling of HERMES-HALF experimental results, the T-HERMES-1D experimental facility was set up and a preliminary simple loop analysis by using a drift flux model under steady state and thermodynamic equilibrium conditions was performed. Calculated circulation mass flow rate depended highly on the inlet/outlet area, and showed the same trends as the air-water experimental results.

Acknowledgments

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