Heat Transfer Coefficient Measurement for Downward Facing Flow Boiling Heat Transfer to Simulate IVR-ERVC Condition of LLOCA Case

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1. Introduction

At severe accident, minimizing radioactive material release and removing decay heat are major issues to mitigate damage. In-vessel retention by external reactor vessel cooling (IVR-ERVC) is one of severe accident management strategy. The ERVC is decay heat removing method by cooling outer wall of reactor vessel lower head after corium relocation. To evaluate heat transfer capability of the ERVC, estimating heat transfer coefficient (HTC) is important. In this study, the HTCs were experimentally measured, and large break loss of coolant accident (LLOCA) was used as basic accident. At the lower head outer wall, heat transfer phenomenon was downward facing flow boiling heat transfer. Because, natural circulation occurred. Hence, to simulate the flow boiling, water loop was designed. The reactor vessel lower head was simulated as 2-D slice main heater. To simulate the heat transfer characteristics of material and geometry, the main heater was made of SA508 consisting the reactor vessel, and its radius curvature was 2.5 m. The main heater outer surface (facing to air) temperature was measured by infrared (IR) camera, and the inner surface (facing to working fluid) temperature was calculated by solving conduction equation of main heater. DI water was used as working fluid. Experiment ranges of working fluid mass flux and angular location were 300 ~ 500 kg/m2s and 45 ~ 90 ° respectively. The main heater heat flux was under CHF value of previous research. Finally, object of this research is producing the HTC database to utilize it as heat transfer model and system code development.

2. Methods and Results

In this study, experiment water loop was design to simulate the ERVC natural circulation. The outer wall of reactor vessel lower head was simulated as the 2-D slice main heater. The HTC results were plotted with angular location and working fluid mass flux.

2.1 Experiment apparatus

Figure 1 shows concept of the ERVC. Reactor cavity was filled with cooling water, and the cooling water was came from IRWST. At the cavity, space was roughly divided by thermal insulator, and water channel was built between the vessel lower head and the thermal insulator. At inner part of the insulator, boiling occurred, but there was no boiling at outer part of the insulator. Because of it, natural circulation occurred by density difference. The water channel was experiment area of this research.

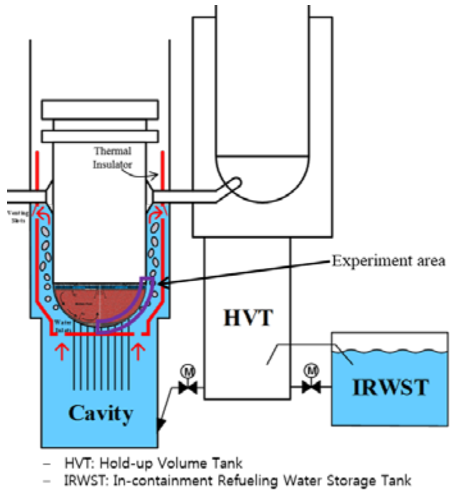

Figure 1. Concept of IVR-ERVC [1]

Figure 2 shows the reactor vessel lower head modification process. The lower head was downward facing hemisphere, and it was simplified as 2-D slice main heater for experiment like Figure 2. The main heater's length, width and thickness were 1 m, 0.07 m and 1.2 mm respectively. The main heater was placed at test section like Figure 3, and was directly heated by DC rectifier.

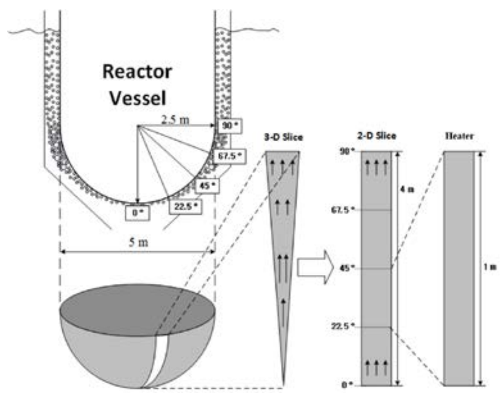

Figure 2. Lower head modification process

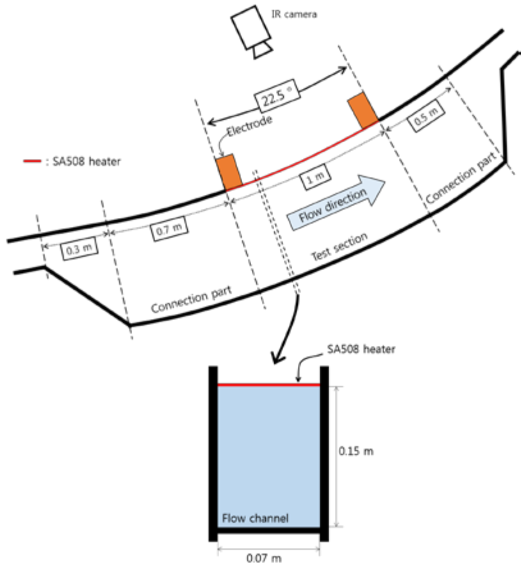

Figure 3. Schematic diagram of test section

Figure 3 shows schematic diagram of test section side view and cross section. The test section was curved rectangular channel, and the main heater was placed at inner side of the test section to simulate the lower head outer wall. The main heater was heated by DC rectifier and, its surface temperature was measured by IR camera (measurement error; ±0.6 °C). At inlet and outlet of test section, connection parts were connected to maintain working fluid flow regime.

Figure 4 shows schematic diagram of experiment water loop. Working fluid mass flux was controlled by controlling pump RPM, and measured by flow meter. Preheater controlled working fluid inlet condition. The test section could be inclined to simulate upper part of the lower head (45 ~ 90 °). The working fluid temperatures were measured by K-type thermocouple at two point. Experiment was conducted at 300, 400 and 500 kg/m^{2}s of working fluid mass flux.

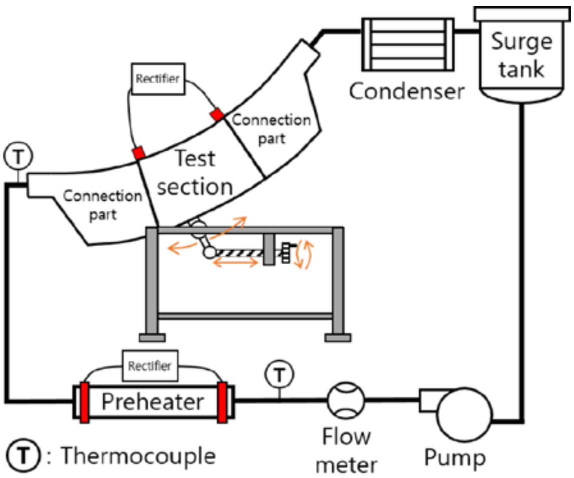

Figure 4. Schematic diagram of experiment water loop

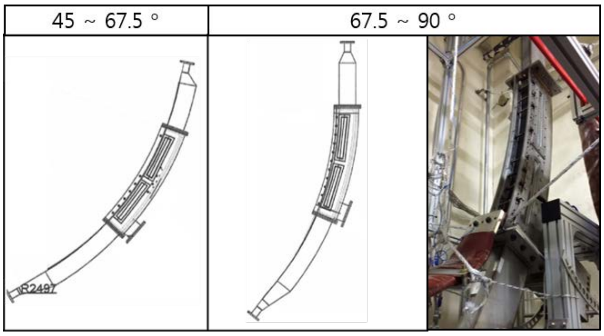

Figure 5. Schematic diagram and picture of Experiment angular range

In this study, the experiment was conducted at 2 angular ranges; 45 ~ 67.5 ° and 67.5 ~ 90 °. Figure 5 shows experiment angular range schematic diagram and picture. At each range, 60 and 90 ° results were conducted as representative location.

Figure 6 shows heat flux loading the lower head for LLOCA (Large break Loss of Coolant Accident) and MLOCA (Medium break Loss Of Coolant Accident), and CHF value of previous research. In this study, the LLOCA was used as accident condition. To simulate thermal condition of the LLOCA, LLOCA heat flux distribution of Figure 6 was used. For example, if 45 ~ 67.5 ° angular range experiment was conducted, energy of 0 ~ 45 ° LLOCA heat flux distribution was supplied by preheater. For calculating the energy, the lower head surface area was also considered. Based on Figure 6, experiment was conducted under CHF value.

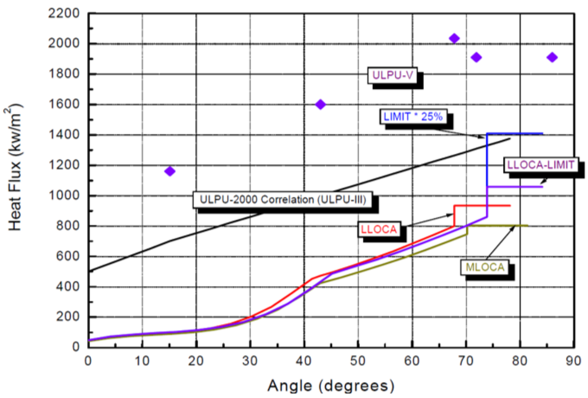

Figure 6. Heat flux loading for lower head at LOCA and CHF limit of previous research [2]

2.2 HTC calculation

The IR camera measured the main heater outer side (facing to air) surface temperature. Therefore, the main heater inner side (facing to working fluid) surface temperature was calculated by soling conduction equation to measuring the HTC. The main heater's thickness was 1.2 mm, and it was thin enough to assume 1-D conduction condition of the main heater. Equation 1 shows 1-D conduction equation, and boundary conditions were as follows; measured surface temperature of the main heater outer side, the outer side surface temperature was almost adiabatic condition. By solving the Equation 1, the main heat inner side surface temperature was calculated. Finally, the HTC was calculated like Equation 2. At Equation 2, q'' was applied surface heat flux.

$$\frac{d^2T}{d^2x} + \frac{\dot{q}}{k} = 0 \qquad \text{Equation 1}$$

$$HTC = \frac{q''}{(T_{wall,in} - T_{water})} \qquad \text{Equation 2}$$

2.3 Result

All HTC data was plotted with wall superheat (ΔT). Horizontal error bar means temperature measurement error (±0.6 °C), and vertical error bar means the HTC error which was affect by temperature error.

Figure 7 shows 60 ° HTC result with wall superheat. Overall, as heat flux increased, wall superheat and the HTC increased. The HTC increasing ratio increased at 200 kW/m^2, and it meant that heat transfer occurred actively. At 300 and 400 kg/m^{2}s, results were similar. At 500 kg/m^{2}s, the HTC decreased than one of the other mass flux.

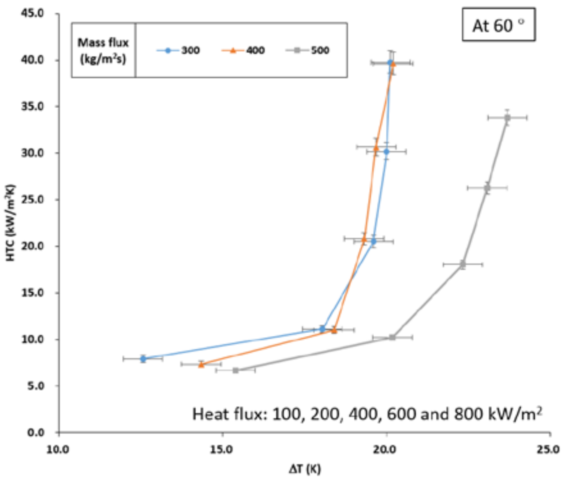

Figure 7. The HTC result for 60 ° angular location

Figure 8 shows 90 ° HTC result with wall superheat. Overall, as heat flux increased, wall superheat and the HTC increased. However, the HTC increasing ratio was not that changed. At 300 and 400 kg/m^{2}s, results shown parallel trend, but result of 500 kg/m^{2}s shown different trend.

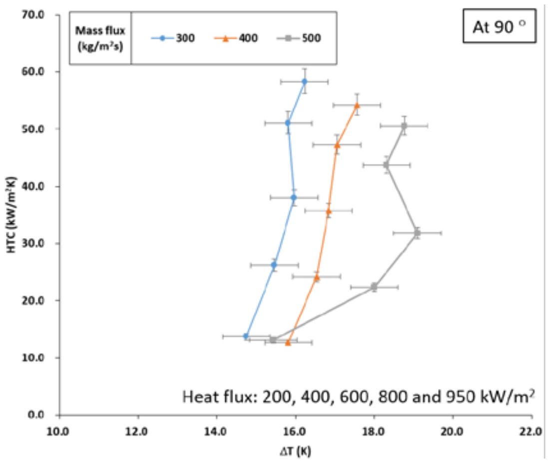

Figure 8. The HTC result for 90 ° angular location

3. Conclusions

In this research, the HTCs of the lower head outer wall were experimentally measured for upper part of lower head (45 ~ 67.5 ° and 67.5 ~ 90 °). The results of 60 ° and 90 ° were used as representative angular location data. LLOCA was used as basic accident. Through this experiment, the HTC data was produced for SA508 heat transfer surface material and 2.5 m of radius curvature.

The HTCs result shown different trend at each angular location. The HTCs commonly increased with heat flux increment, but the trends were different for angular location. However, in this experiment, the HTC was affect by angular location and inlet condition. Therefore, further experiments are needed to distinguish the each parameter effect.

4. Acknowledgments

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