Preliminary analysis of the KAERI RCCS Experiment Using GAMMA+

Samukelisiwe Khoza, Nam-il Tak*, Hong-Sik Lim, Sung-Nam Lee, Bong-Hyun Cho, Jong-Hwan Kim
Korea Atomic Energy Research Institute, Daedeok-daero 989 Beon-gil 111, Yuseong, Daejeon, Korea 305-353
**Corresponding author: takni@kaeri.re.kr*

1. Introduction

This paper describes the analysis of the KAERI RCCS experiment. GAMMA+ code was used for analysis of the RCCS 1/4-scale natural cooling experimental facility designed and built at KAERI to verify the performance of the natural circulation phenomenon.

The results obtained from the GAMMA+ analysis showing the temperature profiles and flow rates at steady state were compared with the results from the preliminary experiments conducted in this facility.

2. Experiment description and system model

In the RCCS experiment setup, the height is a 1/4 of the original PMR200 reactor height and the distance from the reactor vessel to the RCCS risers remains the same as the prototype [1].

The test section shown in Figure 1 below is 4m high and is located above the inlet chamber and consists of the heating panel and six rectangular riser tubes inside the test section cavity walls.

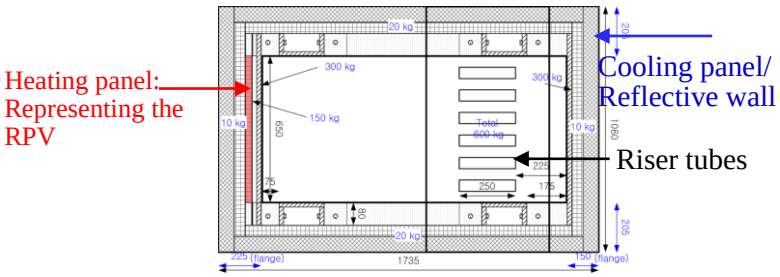

Figure 1: Top view of the test section

GAMMA+ system model for the KAERI RCCS experiment is shown in Figure 2 below. The fluid model consists of the flow from the inlet boundary, two inlet pipes, inlet chamber, riser tubes, outlet chamber, left and right outlet pipes 1 and outlet pipes 2 and left and right chimneys through to the outlet boundary. These fluid blocks were one-dimensionally modeled. The inlet pipes, inlet and outlet chambers were modeled as single cell fluid blocks.

The solid model consists of the heating panel (representing the reactor pressure vessel), the six riser tubes and the test section cavity walls. The heating panel was modeled as a 2-D plate with a heat flux of 4.34 kW/m^2, as obtained from the experiments. The RCCS riser tubes were modeled as 3-D closed cylinder so as to consider radiative and convective heat transfer of the surfaces. The test section is encased by the heaters/heating panel, two side walls on each side and the reflective wall/cooling panel. The walls surrounding the cavity were modeled as 2-D plates. A thickness of 3cm was assumed for the walls. The RCCS two outer-lying and the four inner-lying RCCS riser tubes were grouped as W3_Riser_Tubeo and W3_Riser_Tubei, respectively.

A radiation model was generated to simulate the heat transfer in the test section between the heating panel, side walls, reflective wall and RCCS riser tubes surfaces. The emissivity for the heating panel was taken as 0.75, 0.1 for the surrounding walls and 0.8 for the riser tube surfaces.

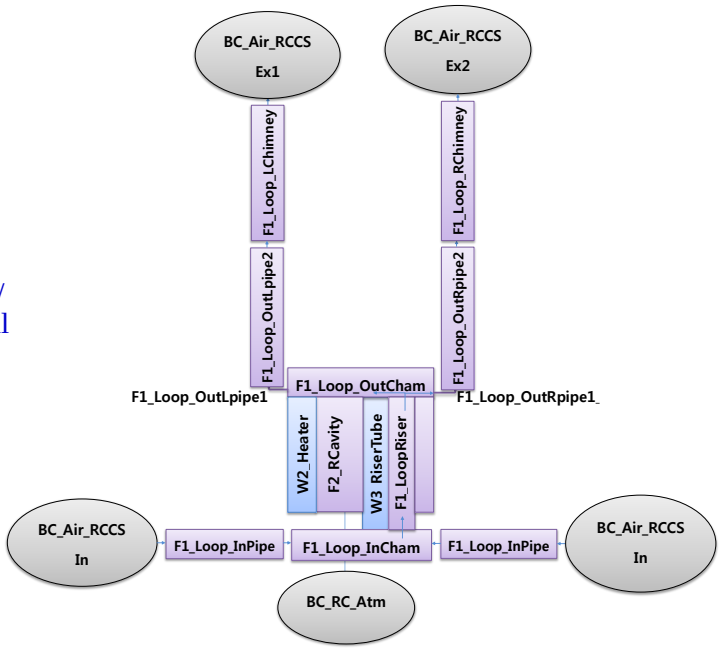

Figure 2: RCCS experiment GAMMA+ code analysis model

3. Preliminary Steady State Results

Figure 3 below shows the heating panel temperature calculated with GAMMA+. In the analysis results, the temperature was observed to rise from just below 365 to 385℃ in the lower part of the test section (below 1m) and then reaching a maximum of 399℃ at the top of the test section.
The experimental results on the other hand indicate a

lower temperature (~192℃) at the bottom of the test section and a dip in the middle of the test section owing to the heat loss in the flanges connecting the lower and upper heating panel. The temperature was observed to be very low below 1m height of the test section. The reason for the larger heat loss in the bottom and mid-section flanges compared to the top flange was due to the fact that the weight of the lower and upper panels rests on the bottom and mid-section flanges respectively and not on the top flange thereby transferring heat to these flanges [1].

When comparing the experimental and GAMMA+ heating panel temperature results, the highest temperature for the heating panel was found to be around 410℃ from the experiments and steady state value of 399℃ with GAMMA+. Both these values indicate the heating panel's capability to reach the reactor accident condition of 420℃ on the heating panel surface representing the RPV wall. The heat loss in the flanges was not modeled with GAMMA+ so the GAMMA+ results do not show a temperature drop at the position of the bottom and mid-section flanges, 0 and 2 m respectively.

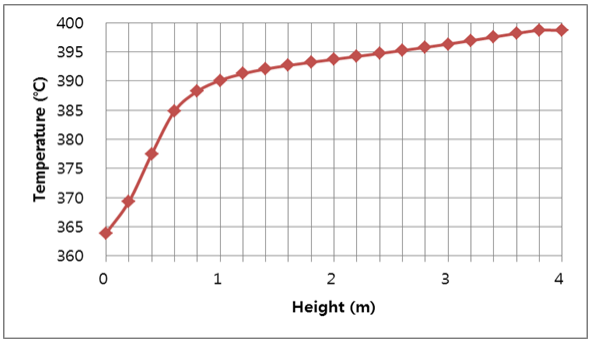

Figure 3 : Heating panel temperature

Figure 4 below shows the maximum riser tube temperatures obtained from GAMMA+ calculations. The temperature for the surface of the riser tube positioned on the side of the heating panel is denoted by legend T_riser_hot_max and that of the surfce closest to the reflective wall is denoted by T_riser_cold_max. This was plotted for both the outer- and inner-lying riser tube groups.

The curve trend is similar for both the inner and outer-lying tubes, with the initial ambient temperature of 25℃ and then a very steep rise of the temperature is observed in the first 0.3m of the test section height.

T_riser_hot_max for the outer-lying riser tubes was found to be 233℃ and T_riser_cold_max on the side of the reflective wall reached 170℃. The maximum delta between T_riser_hot_max and T_riser_cold_max for the outer-lying tubes was found to be 63℃. For the inner-lying riser tubes, it can be observed that T_riser_hot_max is 229℃ which is close to that of the outer-lying riser tubes. T_riser_cold_max reached 163℃. Here, the maximum delta between T_riser_hot_max and T_riser_cold_max for the outer-lying tubes was found to be 66℃.

T_riser_cold_max for the inner-lying tubes was found to be 7℃ lower than that of the outer-lying riser tubes. T_riser_hot_max for the inner-lying riser tubes was only 4℃ lower than that of the outer-lying riser tubes.

Experimental results, however, showed an increase up to 254℃ in the riser tube temperature [2]. T_riser_cold_max value was seen to increase until about 214℃ and the delta between T_riser_hot_max and T_riser_cold_max to be around 40℃. When compared with GAMMA+ results, the T_riser_hot_max and T_riser_cold_max values from experiments were slightly higher than the values obtained with GAMMA+ calculations, with a delta of ~20℃ and ~40℃ respectively.

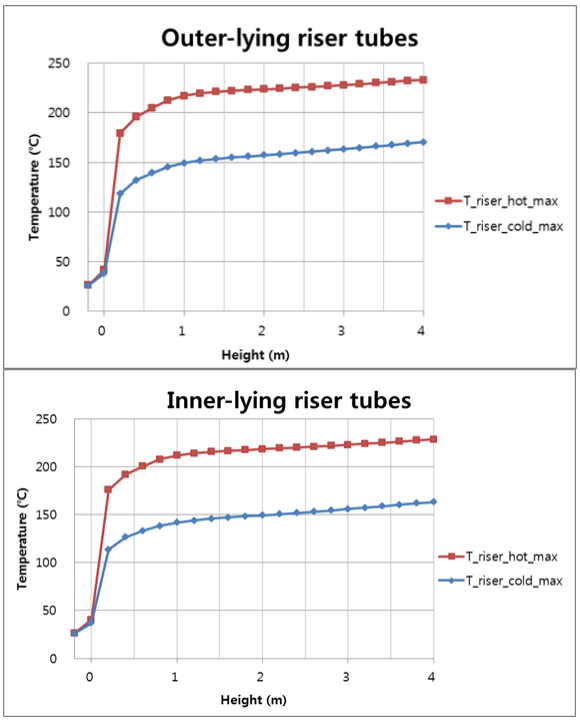

Figure 4 : RCCS riser tubes temperature

The result for the reflective wall temperature is shown in Figure 5 below. GAMMA+ steady state results show that the reflective wall temperature reached a maximum of 258℃ at the top of the test section and was just below 190℃ at the bottom of the test section.

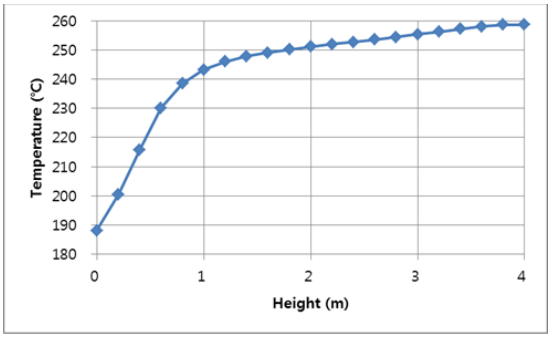

Figure 5 : Reflective wall temperature

The experimental results given in [2] for the reflective wall temperature showed an increase to 50℃ at the bottom of the test section and reaching around 200℃ at the top. GAMMA+ reflective wall temperature values were found to be much higher than those obtained through experiments.

The steady state GAMMA+ value for the flow rate at one chimney exit was found to be 579 m^3/hr and was measured at ~600 m^3/hr during experiments.

4. Conclusions

GAMMA+ analysis for the KAERI RCCS experimental setup was carried out to understand its natural circulation behavior.

- The maximum temperature for the heating panel obtained from the experiments was ~10℃ higher that obtained by GAMMA+ calculation . The maximum delta between the hot riser tube surface, T_riser_hot_max, and the heating panel was found to be ~170℃ for both the GAMMA+ and experimental results.
- Comparison of T_riser_hot_max and T_riser_cold_max showed that for GAMMA+ results, the difference was 63-65℃ whereas the experimental results delta was only 40℃.
- Experiments showed that the reflective wall temperature is 14℃ lower than T_riser_cold_max since steady state was not achieved but 88-95℃ higher for GAMMA+.
- The air flow rate at the chimney exit achieved by experiments was found to be almost same as that of GAMMA+.

ACKNOWLEDGEMENTS

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[2] J.H. Kim, "Experiments of Reactor Cavity Cooling System presentation slides," *5th KAERI-NWU Joint Research Collaboration Meeting*, Gyeongju, Korea, 04 November, 2014.