Preliminary Calculation of Natural Circulation Core Cooling Experiment Simulating a Loss of Normal Electric Power in Research Reactors

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1. Introduction

In typical open-pool-type research reactors such as JRTR and KJRR, the heat generated from the core is cooled by downward forced flow in normal operation. The core is located on the bottom of the pool and submerged in the pool water to utilize the water as the ultimate heat sink as well as radiation shielding.

When a loss of forced downward flow occurs in an accident, the core is cooled by natural circulation of the pool water. If the Primary Cooling System (PCS) pumps stop, the flowrate through the core decreases. Due to the reduced core flow, the reactor is shut down to protect the reactor, resulting in a sharp drop in core power. When the flowrate in the PCS decreases further, flap valves open, which provide a flow path from the pool to the PCS pipe. At the beginning of the opening of the flap valve, the flow through the flap valve is forced through the pump because of the relatively high coastdown flowrate. As the forced flow decreases, the buoyancy of the heated fluid by the core residual heat becomes larger than the inertia of the forced flow, and a flow reversal occurs in the core. After the flow reversal, the core is cooled by natural circulation through the flap valve.

The phenomena in the accident are of importance in the safety analysis since the flow in the core is stagnant at the flow reversal. But there are very few experimental data to validate safety analysis codes regarding the phenomena.

A project has been on-going to acquire more experimental data through integrated effect tests. Pusan National University (PNU) is in charge of constructing the test facility and conducting experiments. Using the experiments data, KAERI will validate the system thermal hydraulic codes. In this paper, the preliminary simulation of natural circulation core cooling experiment is presented based on the design of the test facility.

2. Experiment facility

The design of the experimental facility is based on the JRTR applying the scaling law of the natural circulation [1]. The schematic diagram of the experiment facility is shown in figure 1.

In the experiment facility, a 3way valve takes the role of the flap valve. In forced circulation, the 3way valve provides the flow path from the low plenum to the pump, while it does from the pool to the low plenum in natural circulation.

The power of a heater can be adjusted by the power controller to simulate the decay power, and the pump flowrate is controlled to simulate the coastdown.

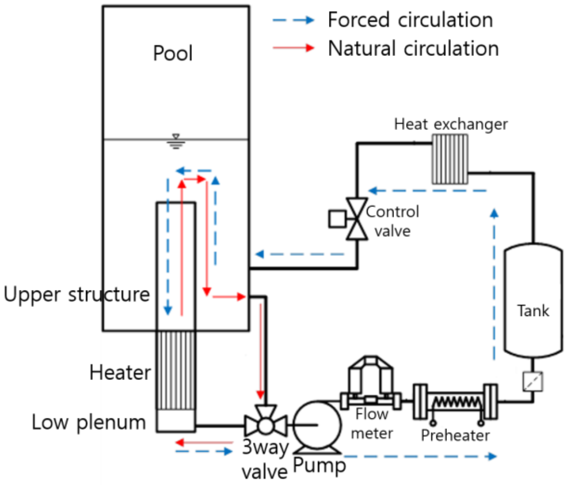

Fig. 1. Schematic diagram of the natural circulation core cooling experimental facility

3. Numerical calculation method

A calculation of natural circulation core cooling experiment simulating a loss of normal electric power in an open-pool-type research reactor was performed using RELAP5 code [2]. The initial conditions for simulation are shown in the table I.

Table I. Initial conditions on the calculation

Initial condition	value
Power	70 kW
Temperature	312 K
Flowrate	2.7 kg/s

3.1. Nodalization

The node diagram for the experiment facility is shown in Figure 2. The part from the 3way valve to the pool for forced circulation is simply modeled using time-dependent junctions and volumes.

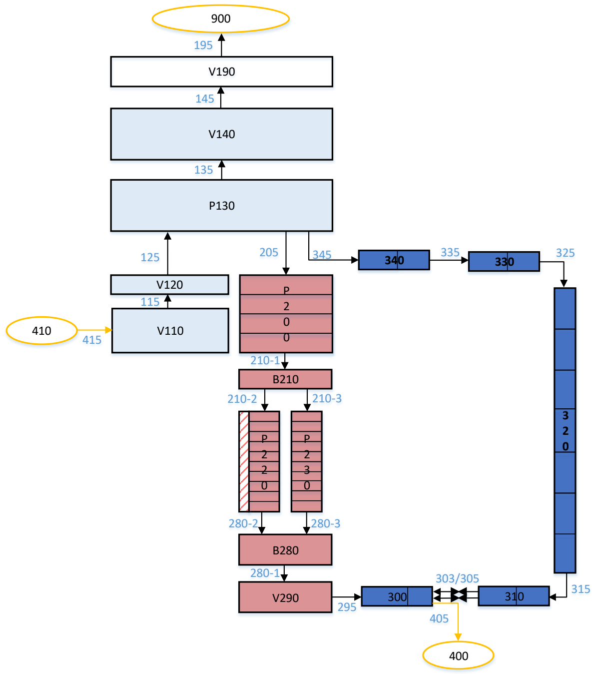

Fig. 2. Node diagram of the experiment facility

3.2. Description of transient model

Figure 3 shows the time-dependent heater power and coastdown flow assumed in the simulation. These transients occur simultaneously at 0 seconds.

When the coastdown flow decreases to 30% of the initial flowrate, the 3way valve is assumed to be actuated partially (opened and closed partially). At this point, the half of the flow area in pipelines to both forced circulation and natural circulation is opened to maintain the forced flow using the 3way valve. The 3way valve is opened and closed fully at the coastdown flow of zero.

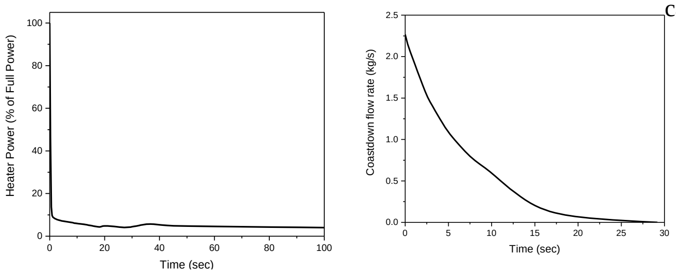

Fig. 3. Time-dependent heater power and coastdown flow as transient input

4. Result

Figure 4 shows the flowrate at some locations of interest from the calculation result. The legend of 3way valve indicates the flowrate through the natural circulation pipe. The forced flowrate reaches 30% of the initial flowrate at 7.5 seconds after the transient initiation and the 3way valve is actuated partially. Because of the coastdown flow, the water in the natural circulation pipeline flows through the 3way valve to pump, and flowrates in the heater (node # 220) and bypass (node # 230) decrease.

The sub-figure in figure 4 shows the magnified view of flow reversal. The flow reversal occurs at around 26 seconds and the flow direction in the heater is switched to the upward. And the coolant in the flows downward still at the moment since the pump flow is not zero yet. As the upward flow in the heater by the buoyancy develops, natural circulation flow through the heater, pool, 3way valve and low plenum is established.

Figure 5 shows temperatures of the upper structure (node # 210) and low plenum (node # 280) in the result of the calculation. As the heat power decreases sharply at the beginning, the temperature at the low plenum below the heater decreases. When the heater is cooled by the upward flow after the flow reversal, the temperature in the upper structure above the heater increases.

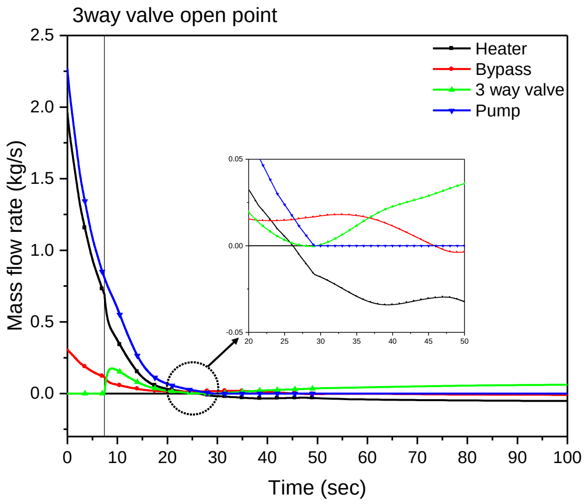

Fig. 4. Flowrate behavior with time in the result of the calculation

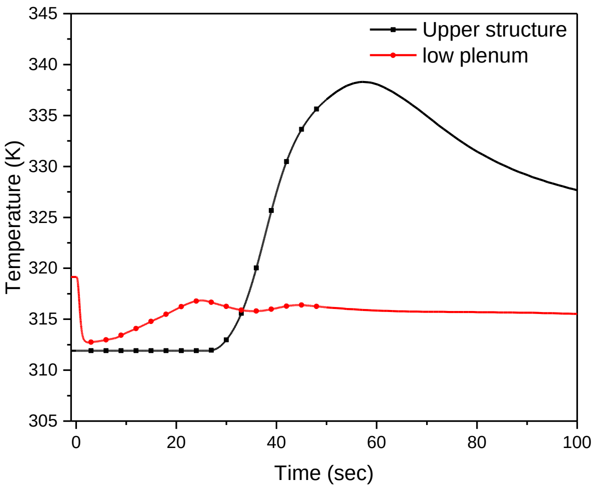

Fig. 5. Temperature behavior with time in the result of the calculation

Figure 6 shows the surface temperatures of the heater in axial direction. The legend of 1 indicates the surface temperature on the top of the heater while that of 10 does on the bottom. The surface temperatures also decrease sharply due to the power drop. As the coastdown flow decreases, the surface temperatures rise. After the flow reversal, the surface temperature at the bottom of the heater begins to decrease due to the flow direction change to the upward flow. As the upward flow in the heater is being developed, the axial temperature distribution is switching. When the natural circulation is established, the surface temperatures at all axial locations decrease.

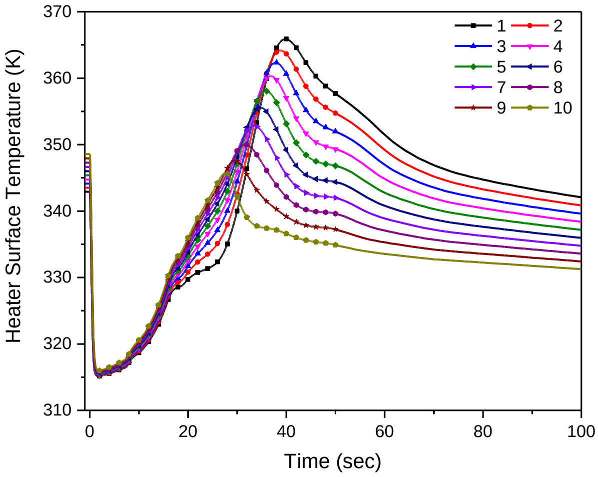

Fig. 6. Surface temperature behavior with time in the result of the calculation

5. Conclusion

The preliminary numerical calculation of the natural circulation core cooling experiment simulating a loss of normal electric power in an open-pool-type research reactor has been performed using RELAP5 code. From the calculation, it is concluded that the experimental facility is properly designed to simulate the integrated effects of the natural circulation in an open-pool-type research reactor with flat plate fuels and a downward flow in the reactor core during power operation. In the future, we will validate thermal hydraulic system codes such as RELAP5, MARS and SPACE [3] by comparing the experimental data obtained in the facility and the numerical simulations.

ACKNOWELGEMENTS

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