The effect of the time constant of pump coastdown curve on LOFA in a research reactor

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1. Introduction

The research reactor recently developed in Korea applied plate-type fuel with the downward flow in the core under nominal operating conditions. Fig. 1 is the schematic configuration of the primary cooling system (PCS) of the research reactor. One of the design basis accidents of the research reactor is a loss of flow accident (LOFA), where the pump at the PCS loses electric power. Immediately after the LOFA, the reactor is scramed. Since the flywheel of the pump has rotational inertia, the flowrate in the core gradually decreases after losing the electric power of the pump (pump coastdown). The surface temperature of the fuel sharply rises when the flowrate in the core is small due to the end of pump coastdown. At the same time, upward natural convective flow is established in the core because of the heat transferred from the fuel to the coolant in the sub-channel. The flap valve at the PCS inlet pipe opens during the transient process to form a natural circulation loop and flow. The natural circulation removes the decay heat of the core.

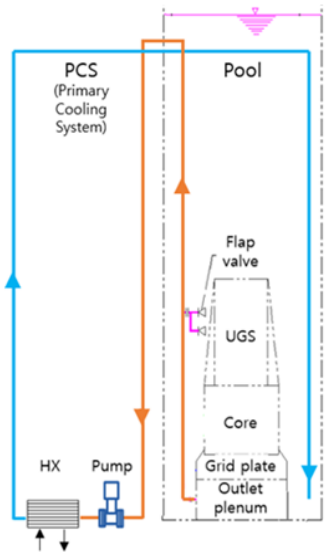

Figure 1. Schematic of PCS of the research reactor

Few experiments have simulated LOFA in the research reactor with such design characteristics [1, 2, 3]. Moreover, the experimental measurements are limited to few variables or long-time intervals between the measurements for the transient analysis of thermal-hydraulic phenomena. Therefore, in the present study, The experiments simulating LOFA were conducted. Therefore, this study aims to investigate the thermal-hydraulic phenomena during LOFA in the research reactor with short time interval measurement.

2. Experiment

Fig. 2 shows the schematic of the experimental apparatus. The design of the experimental apparatus is a scaling down of Jordan research and training reactor (JRTR) in accordance with the scaling law presented by Ishii et al. [4]. The scaling ratios of the flow area and the height of the apparatus are 1/42 and 1/3, respectively. The core of the apparatus consists of 9 narrow rectangular sub-channels with dimensions of 2.35 mm × 65 mm (Gap × Width). The dimensions are the same as the prototype. In-house instruments such as RTD and BiFlow flowmeter [5] are applied to the apparatus to measure heater surface temperature and natural circulation flowrate, respectively. The heater surface temperature is measured at 4 locations (L/D_h =2, 16, 30, and 44, L=the hight of heated surface, D_h=4.563 mm) along the sub-channel at each sub-channel.

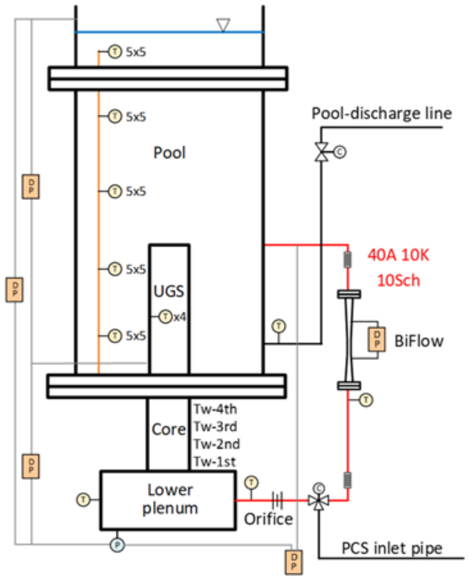

Figure 2. Schematic of the experimental apparatus

The pump coastdown curve in the experiment is represented by an exponential function. As shown in Fig. 3, a total of 3 test cases was conducted with time constants 5, 6.9, and 10 s for the curves. The time constant of 6.9 s is the reference condition corresponding to the that of the JRTR. As shown in Fig. 3, the transient heat generation of the core and steady-state flowrate are equivalent to the prototypical conditions by applying the scaling law and equally applied to all test cases. The coolant temperature at the inlet of the core is 39°C in the steady-state condition. The flap valve was opened when each transient flowrate reaches 30% of that in steady-state. After the end of the coastdown, the pool was isolated from the PCS by control valves.

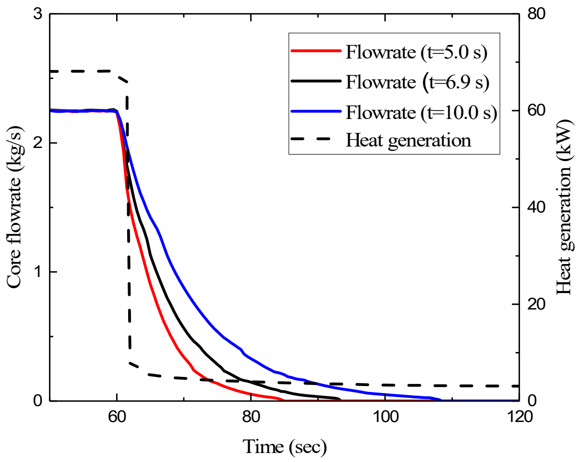

Figure 3. Conditions of flowrate and heater power

3. Results

Fig. 4 shows the heater surface temperature at each measurement location of the edge sub-channel. The vertical solid and dotted lines in the figure represent the opening time of the flap valve and pool isolation time, respectively. The heater surface temperatures shows a peak after the flow reversal in the core. It decreases again since the coolant of low temperature in the pool flows into the sub-channel as the natural circulation starts and heater power decreases.

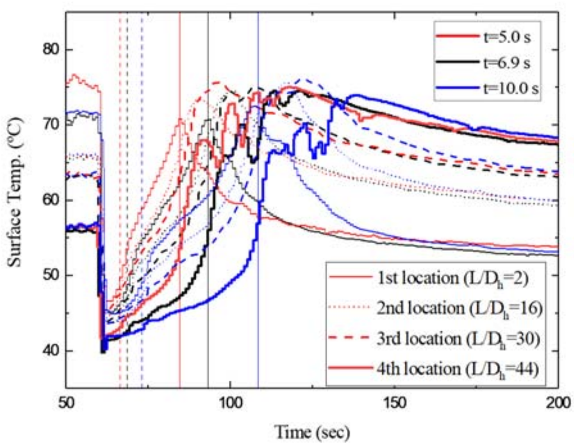

Figure 4. Heater surface temperatures in the edge sub-channel

The high-temperature coolant is observed at the bottom of a sub-channel when flow reversal occurs. This hot coolant rises and flows to the upper guide structure (UGS) because of the buoyancy right after the flow reversal. According to the rising of the hot coolant, the peak location of the heater surface temperature in each sub-channel also changes to the top of the sub-channel as time goes by. Subsequently, a backflow that the low-temperature coolant located in the UGS flows into the sub-channels during the rising of the hot coolant affects heater surface temperature. Thereby, the heater surface temperature at the highest measurement location was not repetible due to the complicated flow as shown in Fig. 5.

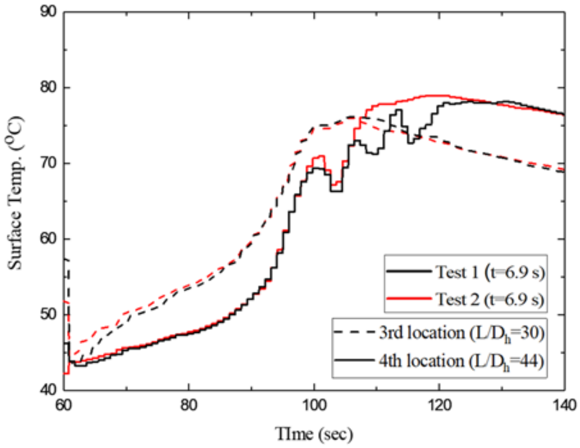

Figure 5. Comparison of heater surface temperature between repeatable tests

The rising velocity of the hot coolant is calculated based on the time difference of the peak values of heater surface temperature between measurement locations 1 and 2. The rising velocity is higher as the sub-channel locates near the center of the core or the time constant of the pump coastdown curve is smaller. A smaller time constant results in more thermal energy storage in the heater. This energy is then transferred to the coolant in sub-channel and contributes to increasing the buoyancy. The effect of the backflow from the UGS is significant at the edge sub-channels where the hot coolant has a small rising velocity. Thus, as shown in Table 1, the maximum peak value of the heater surface temperature was observed at the 3rd measurement location in the edge sub-channel. On the other hand, in the center sub-channel, it appeared at the 4th measurement location.

The peak value of the heater surface temperature at the 2nd measurement location where the backflow does not affect was lowest under the time constant of 6.9 s. In the case of 5 s, the peak value of heater surface temperature is higher than that of 6.9 s due to the shorter time for convective heat transfer. Moreover, the test for the time constant of 10 s showed a higher temperture coolant in the lower plenum because of longer exposure to the downward flow. It is caused by the fact that the high-temperature coolant in the lower plenum flows into the sub-channels at the beginning of natural circulation. Therefore, a higher peak value of heater surface temperature was obseved.

Table I. Peak value of heater surface temperature (°C)

Time constant (sec)		5.0	6.9	10.0
Edge sub-channel	3rd Measurement location	75.04	75.65	76.16
	4th Measurement location	74.53	75.03	73.91
2nd Measurement location	Center sub-channel	74.82	73.82	75.76
	Edge sub-channel	74.43	73.36	75.61

4. Conclusion

The time constant of the pump coastdown curve significantly affects thermal-hydraulic parameters during the transient process of LOFA. The peak value of heater surface temperature at the lower region of the core was high when the time constant was smaller or larger than 6.9 s, which is the reference condition corresponding to the condition of the JRTR. However, the effect is insignificant after reaching the quasi-steady-state natural circulation. The results showed irregular local multi-dimensional flow after flow reversal under LOFA, and the behavior of the hot coolant in the sub-channel has a significant effect on the cooling of the fuel in the research reactor.

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