Experimental investigation for loss of flow accident on research reactor

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1. Introduction

Newly developed korean research reactor adopts plate-type fuel in the core and operates with downward flow under nominal operating condition. Fig. 1 is a conceptional diagram of primary cooling system (PCS) of the research reactor. If power of the pump in the PCS is lost, loss of flow accident (LOFA) in which the flow rate of the coolant decrease occurs. When the reactor is tripped due to the low core flow rate, nuclear reaction in the core is rapidly reduced, and then decay heat is continuously generated. As downward flow rate in the core gradually decreases according to the coastdown of the pump, surface temperature of the fuel increases rapidly as heat transfer from the fuel to the coolant decreases. Meanwhile, flow reversal occurs in the core because the coolant rises due to buoyancy. Thereafter, the flap valve located at the intake pipe of the PCS is opened, so that the pool and the PCS are connected to each other to form natural circulation loop. Some experiments simulating LOFA in the research reactors have been conducted [1-2]. However, it is difficult to find experimental data which shows all the local thermal hydraulic parameters together. Accordingly, this study aims to produce local experimental data through the experiment simulating LOFA in the research reactor.

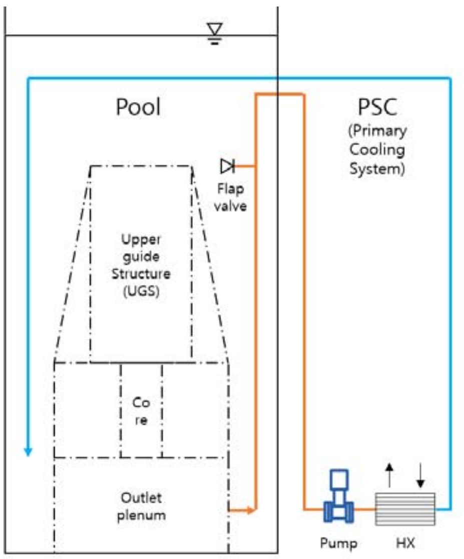

Fig. 1. Conceptional diagram of PCS of the research reactor.

2. Experimental Facility

2.1 Scaling analysis

The experimental facility was designed as a reduced-scaled model of the Jordan research and training reactor (JRTR) according to the scaling law proposed by Ishii et al.[3] for the preservation of the natural circulation flow. The scaling ratio for area and height of the experimental facility are 1/42 and 1/3, respectively. Table 1 shows the major scaling ratio applied to the design of the experimental facility.

Table I: Major Scaling Ratio of The Experimental Facility

System Parameter	Symbol	Scaling ratio
Pressure	p_R	1
Height	l_{oR}	l_{oR}
Area	a_{oR}	a_{oR}
Temperature rise in core	ΔT_{oR}	1
Velocity	u_{oR}	$l_{oR}^{1/2}$
Time	τ_R	$l_{oR}^{1/2}$
Gravity acceleration	g_R	1
Heat flux	q''_R	$l_{oR}^{-1/2}$

2.2 Plate-type Fuel Simulator

The plate-type fuel simulator which consists of 9 sub-channels as shown in Fig. 2 is installed in the core of the experimental facility. The size of gap and width of the sub-channels are 2.35 and 65 mm, respectively, which are same with those of the prototype. However, the height is reduced to 234 mm (heated length : 215 mm) in accordance with the scaling ratio. The heaters on the surface of the sub-channels are indirectly heated with uniform heat flux. Inhouse-developed RTD sensors are installed at 4 axial elevations (L/D=2, 16, 30, 44 from the bottom) on each heater surface in order to measure area averaged surface temperature.

2.3 Piping

Fig 3. is piping and instrumentation diagram (P&ID) of the experimental facility. The experimental facility is an open loop as the prototype. When natural circulation is formed, coolant flows from the heater to the pool via upper guide structure (UGS) where 4 thermocouples are installed at the center of the flow path along the axial direction. The inlet of natural circulation pipe locates at the same elevation corresponding to the top of the UGS. The walls of the UGS and pool are made of transparent polycarbonate, so that the flow can be visually observed. Natural circulation flow rate is measured using the BiFlow flowmeter which is a differential pressure flowmeter developed by Yun [4]. The BiFlow flowmeter is installed in the throat of the venturi tube at the natural circulation pipe in order to enhance the measurement accuracy with increased velocity.

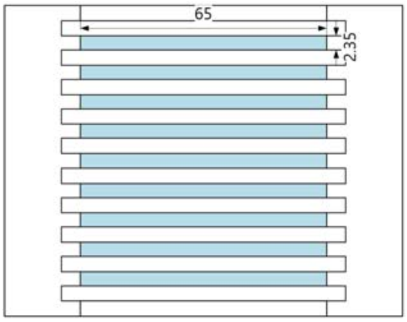

Fig. 2. Top view of the plate-type fuel simulator.

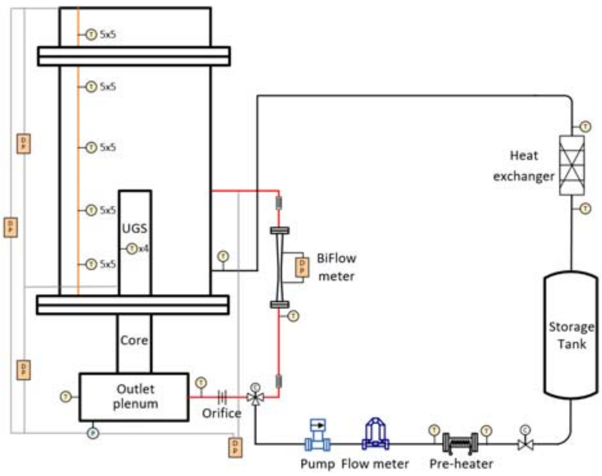

Fig. 3. P&ID of the experimental facility.

3. Experimental Results

3.1 Experimental procedure

Pool temperature of the prototype is maintained in the initial state of experiment under atmospheric pressure. The applied initial flow rate and heater power are 2.2 kg/s and 30 kW, respectively, according to the scaling analysis. With the simulation of LOFA, the two parameters are changed according to the preset curves as shown in Fig. 4. The flap valve, which is opened under the natural circulation mode of the prototype, is simulated by the 3-way valve located at the bottom of the natural circulation pipe. The 3-way valve is opened when the flow rate reaches 30% of the initial flow rate. However, 50% of 3-way valve is opened for a connection of the core flow path to both the natural circulation pipe and the PCS unlike the 100% opening of the flap valve. When the pump is stopped, the pool was completely isolated from the PCS. The experiment lasted until the development of steady flow rate of the natural circulation.

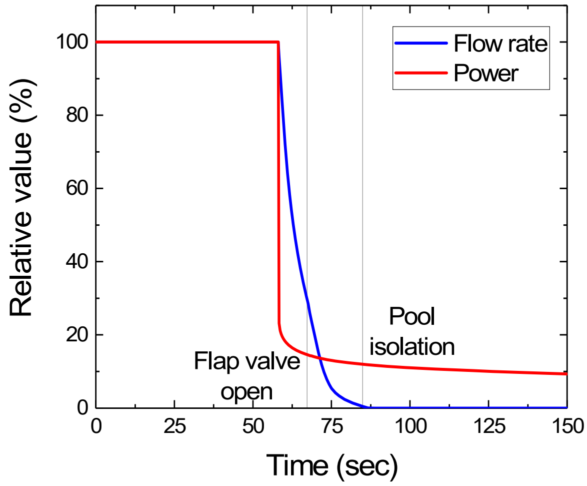

Fig. 4. Preset curves of the flow rate and heater power.

3.2 Flow rate

The flow rates during initial and transient state of experiment are shown in Fig. 5. The flow rate of the core is calculated as a difference between the flow rate of the PCS and the natural circulation pipe, and flow reversal at the core occurred at 81.8 s. Fig. 6 shows the flow rate in the natural circulation pipe and the core. When the 3-way valve is opened, the water in the pool rapidly flows into the natural circulation pipe by suction of the pump. Thereafter, the flow rate in the natural circulation pipe decreases as the pump coastdown is terminated. After the PCS is isolated from the pool, the flow rate in the natural circulation pipe increases and reaches constant value with the development of the natural circulation.

3.3 Fluid Temperature

Fig. 7 shows the change of fluid temperature in the UGS and the outlet plenum. After 60 seconds of the initiation of the experiment, the fluid temperature in the outlet plenum decreases because of the faster decrease in the heater power than that in the pump flow rate. Subsequently, since the decrease of the pump flow rate is faster than that of the decay heat, the temperature increases again (60 s). After the pool is isolated from the PCS (84 s), the temperature is maintained. The coolant in the plenum is cooled after 300 s, and the temperature reaches gradually to that of the pool.

For the fluid temperature in the UGS, the high temperature coolant, which was stagnant at the bottom of the heater at the initial state, flows to the pool via UGS after the flow reversal. After the high temperature coolant flows out from the UGS, the coolant temperature in the UGS gradually decreases due to the decreasing decay heat. The figure shows the local temperature in the UGS fluctuates significantly. It is caused by mixing phenomena of reverse flow from the cold pool and upward flow from the heater during natural circulation condition.

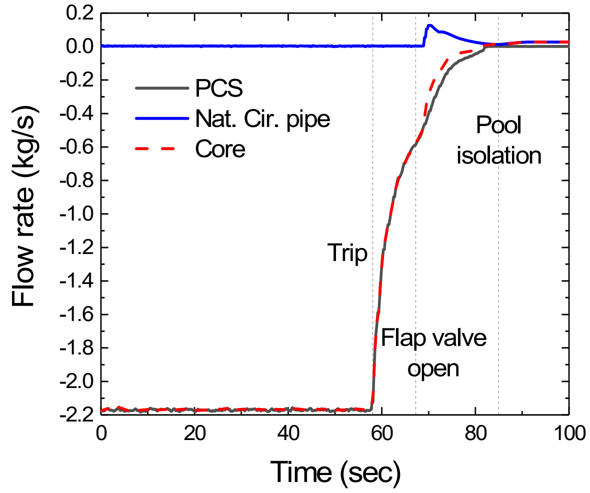

Fig. 5. Flow rate in initial and transient state.

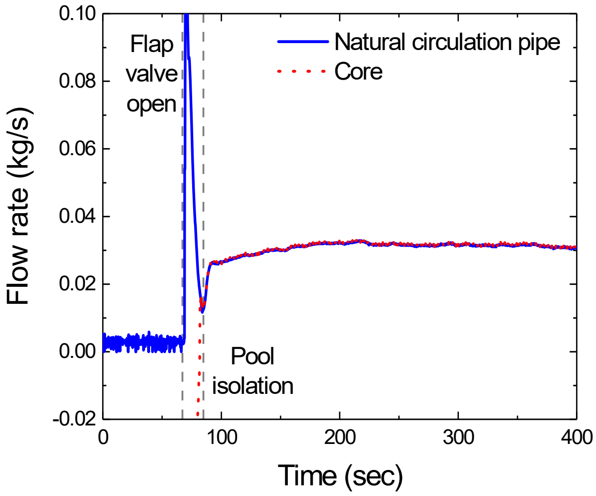

Fig. 6. Flow rate in the natural circulation pipe and core.

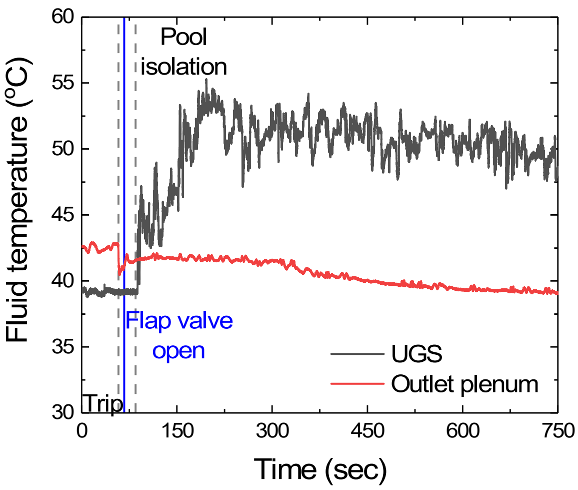

Fig. 7. Fluid temperature in the UGS and outlet plenum.

3.4 Heated Surface Temperature

Fig. 8 shows the surface temperature of the central sub-channel along the axial elevation. The temperatures decrease suddenly due to the decrease of heater power with the simulation of the LOFA, and then increases as time goes by due to decrease of the heat transfer coefficient in the heater because of the subsequent flow decrease. Peak surface temperatures were observed at the time of flow reversal, and the surface temperatures gradually decrease due to the development of natural circulation flow and the decreasing decay heat. During this process, the high temperature coolant in the heater rises from the bottom to the top of the heater and flows out. As the high temperature coolant moves, the peak surface temperature of the heater also sequentially moves accordingly. It is also observed that the surface temperature of the fourth elevation decreases suddenly and then increases again in 90-100 s. It is due to the cooling of heater by the cold water flowing down from the UGS after the high temperature coolant rises and flows out from the heater. Therefore, surface around the top of the heater can be cooled by the reverse flow of cold water from the UGS at this period.

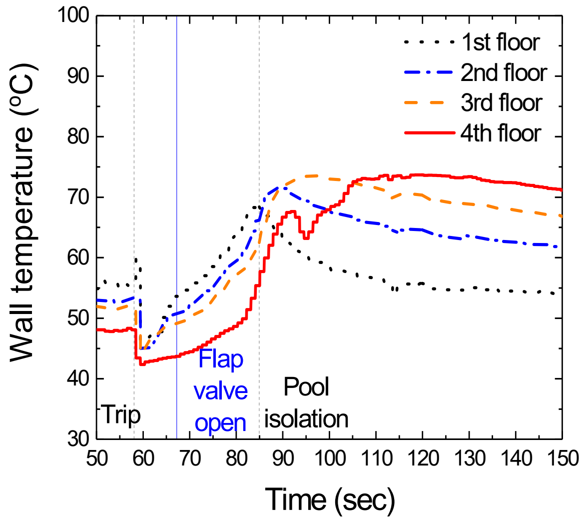

Fig. 8. Surface temperature of the heater.

4. Conclusions

The experimental study simulating LOFA in the research reactor was conducted to figure out the thermal-hydraulic phenomena and transient behavior of the local parameters. The experimental facility was constructed according to the scale analysis for preservation of the natural circulation. While the macroscopic variables measured in the experiment show typical transient behavior of LOFA, three-dimensional flows occur locally. The local experimental data obtained in this study will be used for the validation and improvement of the safety analysis codes for research reactor.

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