Multi-dimensional Natural Circulation Analysis for a Research Reactor Including a Flap Valve

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1. Introduction

Typical research reactors (RRs) such as JRTR have equipped a natural circulation loop as the main decay heat removal system. The validation for the natural circulation loop is necessary. So far, the numerical analysis for the nuclear systems has been investigated using the one-dimensional thermal hydraulics safety analysis codes, such as, REALP5 and MARS. Natural circulation phenomenon, however, has multi-dimensional features since the driving force is small than the forced convective flows. Moreover, as the flow goes in turbulent condition and diffusion becomes stronger, multi-dimensional movements of the fluid would be increased.

In this research, the multidimensional thermal hydraulics for the natural circulation loop of the simplified research reactor model is analyzed using the CUPID code [1].

2. Problem Definition and Analysis Result

2.1 Natural Circulation Loop Configuration

Figure 1 shows the natural circulation loop and the flap valves (Fig. 1 right: A~D). The flap valve installed in the natural circulation loop provides natural circulation flow path from the pool to the core. In normal operation, the flap valve is closed and the flow goes downward to the heat exchanger. In accident condition, the flow direction is changed into upward direction by opening the flap valve. In this research, the natural circulation phenomenon is tested for the case of flap valve A opened.

2.2 Test Conditions and Physical Models

Table I shows the test conditions. In this research, the power is constant 70 kW.

Table I: Test Condition

	Properties	Value
Initial Condition	Temperature	320.15 K
	Pressure	1 bar
Boundary Condition	Temperature	300 K
	Pressure	1 bar
Constraint	Power	70 kW

The pool is in turbulent condition, since Rayleigh number is 3.8e+13 when the temperature difference is assumed to be 100 K.

The heater, the red part of Fig. 1(right), is modeled with porosity (porosity is 0.5) and the Darcy's friction model is applied. The heat partitioning model is used to describe the subcooled boiling on the heater surface [2].

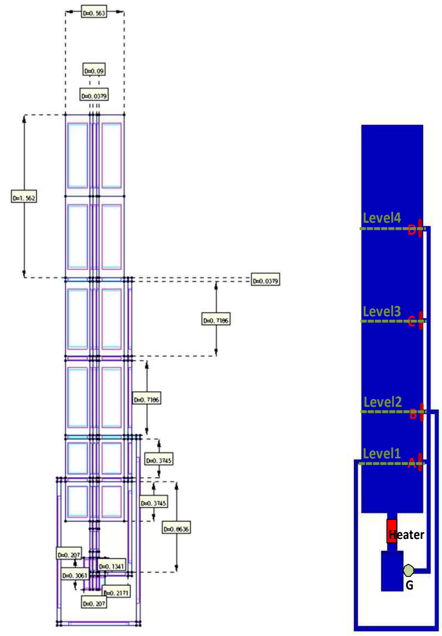


Fig. 1. Natural circulation loop configuration (left) and flap valve location (right).

2.3 Analysis Results

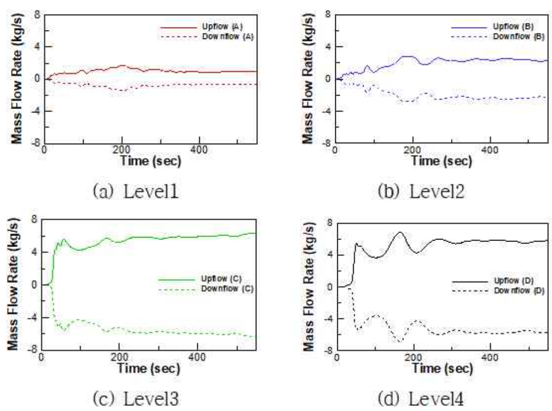


Fig. 2. Up- and down-flow rate at level 1~4.

Figure 2 shows the up- and down-flow rate at level 1~4. As the result presents, low height cases (level 1 and 2) show low flow rate around 2 kg/s, while higher heights show strong mixing around 5 kg/s.

Figure 3 shows flow rate at the lower plenum (0.4 kg/s) and the temperature transients. The temperature increase through the heater is estimated to be 25 K during 550 seconds.

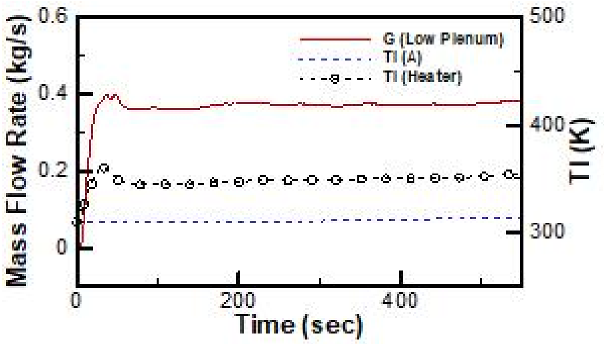
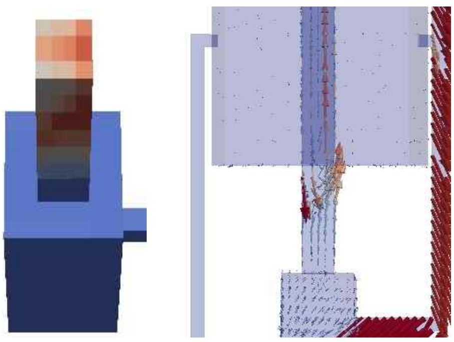
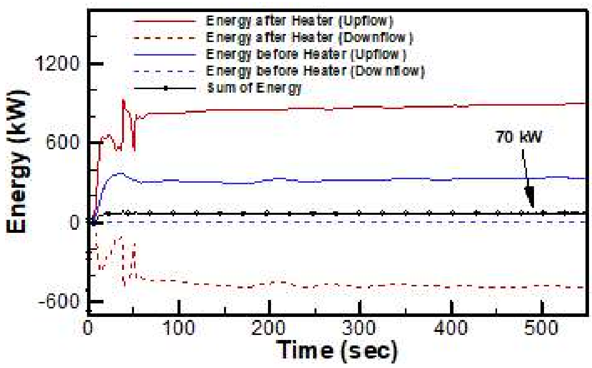


Fig. 3. Natural circulation flow rate and temperature transient



(a) Mass flowrate (left) and velocity (right)



(b) Power transferred to fluid

Fig. 4. Total Power transient and the multi-dimensional flows in the stand pipe.

Figure 4 shows the multi-dimensional flows at right after the heater part. As Fig. 4(a) shows, there is inflow with low temperature, so that the energy balance should consider the inflow (Fig. 4(b)). Without the inflow from the above part, it can overpredict the temperature transient, even though the loop flow rate is in design condition.

3. Conclusions

Simulations for the natural circulation loop is performed using the CUPID code. Throughout the test, the multi-dimensional pool mixing effect is observed and the mixing flow rate 5 kg/s, that is almost 10 times bigger than the loop flow rate. For the decay heat removal analysis, multi-dimensional inflow feature right after the heater part is observed. Even though the loop flow rate is estimated within the design condition, it is found that the heat removal performance can be deviated without considering the multi-dimensional effect.

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