Investigation on Core Downward Flow by a Passive Residual Heat Removal System of Research Reactor

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Introduction

Background

- ✓ When a PCP failure occurs, the residual heat of reactor core must be removed to prevent more serious accidents.
- ✓ Active residual heat removal system takes much cost and is hard to design pump system.
- ✓ A new concept of Passive Residual Heat Removal System(PRHRS) in research reactor proposed recently is much cheaper and easier to design the system.

System Description

- ✓ Main components of the PRHRS for removing residual heat are a flywheel, a flap-valve, and a Gravity Core Cooing Tank(GCCT), which this study focused on.
- ✓ When PCP is running, differential head between reactor pool and GCCT will be made due to pressure drop in reactor core.
- ✓ When PCP is turned off, water in the reactor pool will move to the GCCT, which keep downward flow in reactor core.

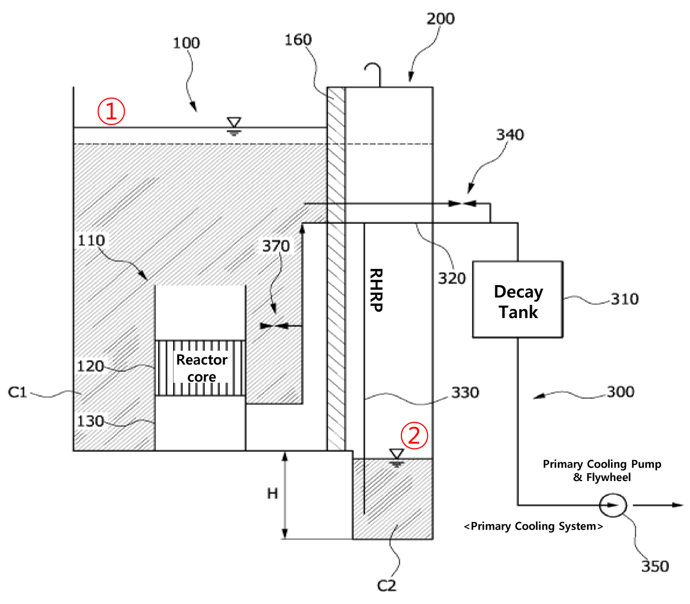


FIG. 1. Conceptual drawings of PRHRS

Research objective

- ✓ Manufacturing downscaled experimental facility of the PRHRS
- ✓ Analyzing performance of core downward flow by experiment
- ✓ Developing theoretical and computational fluid dynamics (CFD) model which can predict the core downward flow based on the experiment results

Experiment

Detail design of experimental facility

- ✓ **Reactor pool** : Simplified T-shape (D=700 mm)
- ✓ **GCCT** : 1.7 m water level change (D=150 mm)
- ✓ **Differential Pressure Pipe(DPP)** : experimental variable – size : ¾ inch, 1 inch
- ✓ **Pump** : 27 m maximum head(suction : 5 m), maximum flow rate 14 m^3/hr with inverter
- ✓ **Pressure sensor** : measuring the water level and mass flow rate in the GCCT– model : PNS (0~0.6 bar)
- ✓ **Differential pressure sensor** : measuring pressure drop at the DPP – model : PX2300-10DI (0~10psi)
- ✓ **Turbine flowmeter** : Checking Inertia flow of the pump

Procedure and condition of experiment

- ✓ Filling the facility with water up to about 1.95 m high
- ✓ Making 1.8 m differential head between the reactor core and the GCCT by adjusting frequency of pump and globe valve
- ✓ After turning off the pump, measuring data from several instruments

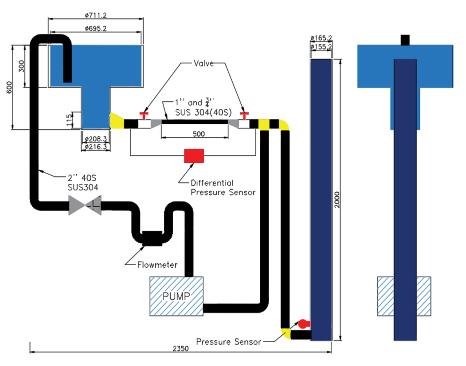


FIG. 2. Detail drawing of experimental facility

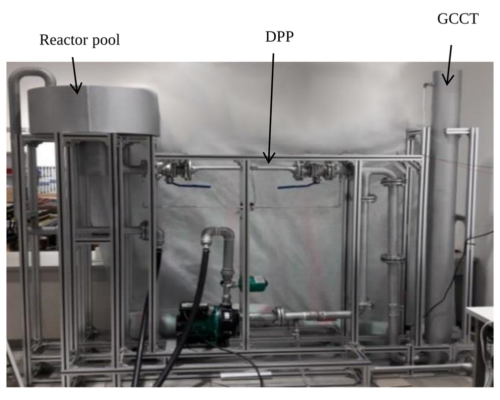


FIG. 3. Experimental facility

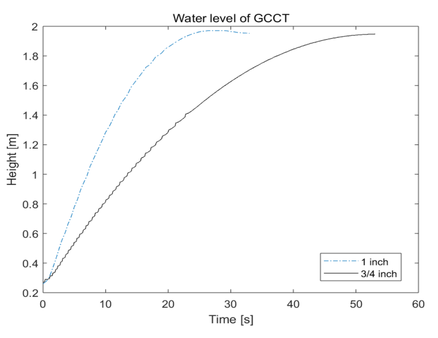


FIG. 4. Hydraulic head of the GCCT (1.8 m)

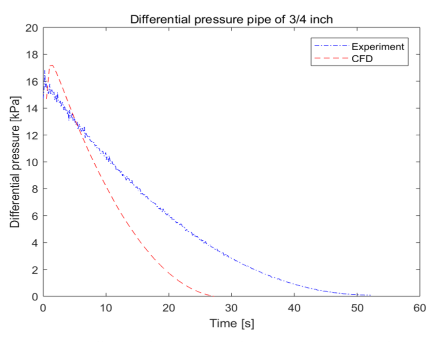


FIG. 5. Differential pressure at the DPP(1.8 m, 3/4 inch DPP)

Theoretical analysis

Based on Bernoulli equation previous researchers calculated velocity at RHRP (330) as

$$V_p = \sqrt{\frac{2g(H_1 - H_2)}{1 + K_{12}}} \qquad (1)$$

, when the PCP is turned off with some assumptions; atmospheric pressure of both the point 1 and 2 is same as 1atm, and water velocity at the point 1 is negligible compared to that at the point 2.

But it was modified a bit in this study as

$$V_p = \sqrt{\frac{2g(H_1 - H_2)}{(\frac{A_p}{A_2})^2 + K_{12}}} \qquad (2)$$

, taking into account area ratio of the RHRP and the GCCT. This change makes prediction of mass flow rate bit higher as seen in *FIG.6*.

With following equation, a differential equation was solved.

$$\dot{m} = \rho A_{RHRP} V_p \qquad (3)$$

$$H_1 = H_{RX} - \int \frac{\dot{m}(t)}{\rho A_{RX}} dt \qquad (4)$$

$$H_2 = H_{GCCT} + \int \frac{\dot{m}(t)}{\rho A_{GCCT}} dt \qquad (5)$$

The mass flow rate at RHRP was calculated as seen in equation (6).

$$\dot{m} = -\frac{(\frac{1}{\rho A_{RX}} + \frac{1}{\rho A_{GCCT}}) \times (\rho A_p)^2 g}{(\frac{A_p}{A_{GCCT}})^2 + K_{12}} t + \dot{m}_{ini} \qquad (6)$$

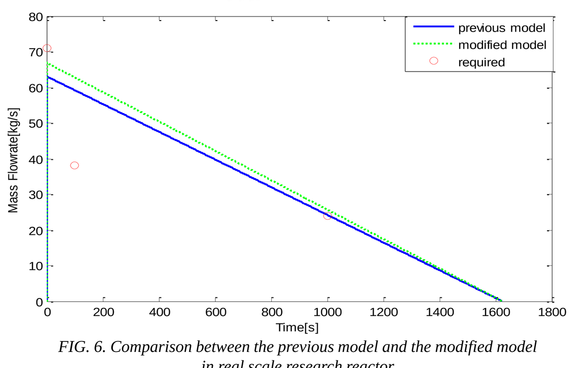


FIG. 6. Comparison between the previous model and the modified model in real scale research reactor

CFD analysis

Flow Simulation with Fluent

- ✓ Make the upper side of water tank mesh into coarse hexahedral to check only the water level through simulation.
- ✓ Make mesh of Lower tank into fine tetrahedral and mesh of central pipes into fine hexahedral
- ✓ To calculate accurately, assign smooth inflation (3 layers, ratio:0.35, growth :1.3)
- ✓ Using VOF and K-ε realizable model.
- ✓ Set ambient(pressure-outlet) condition at top of the pipe and PISO Method.
- ✓ Water region patch on the model
- ✓ Make animation of the CFD calculation
- ✓ Total mesh elements: **120316**, avg. skewness: **0.19421**, avg. ortho quality: **0.95157**

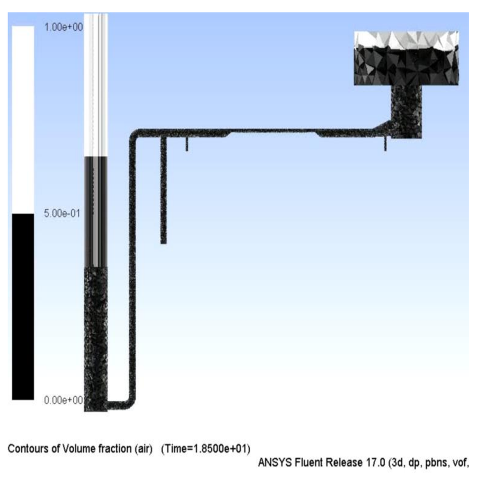


FIG.8. An animation of the CFD calculation

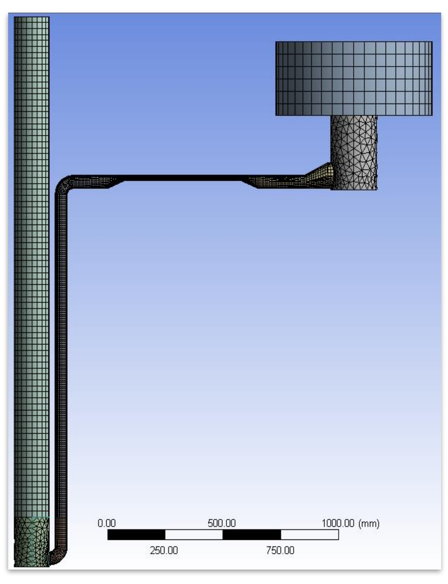


FIG.7. A mesh model of the PRHRS

Results and Discussion

Comparison of core downward flow to the GCCT

- ✓ For both 3/4 inch and 1 inch DPP cases, CFD and theoretical results of core downward flow have similar tendencies. On the contrary, compared to CFD and theory, mass flow rate of the experiment has 70.4% and 61.8% lower value in 3/4 inch DPP, and 41% and 38.2% lower in 1 inch DPP respectively.
- ✓ The main reason of difference is an effect of pump inertia in experimental facility. In CFD and theoretical model, all of water in the reactor pool flows into the GCCT, i.e. there is no flow loss. However, in the experiment, some amount of water is divided into pump lines, therefore, the initial mass flow rate measured at the GCCT was relatively low.
- ✓ The area under the graph represents the total amount of water moved to the GCCT. In both cases, it was checked that the area under the each graph, total amount of water, is same. It means the seperated water stream comes back to the reactor pool and eventually flows into the GCCT, thereby prolonging duration time of core downward flow.

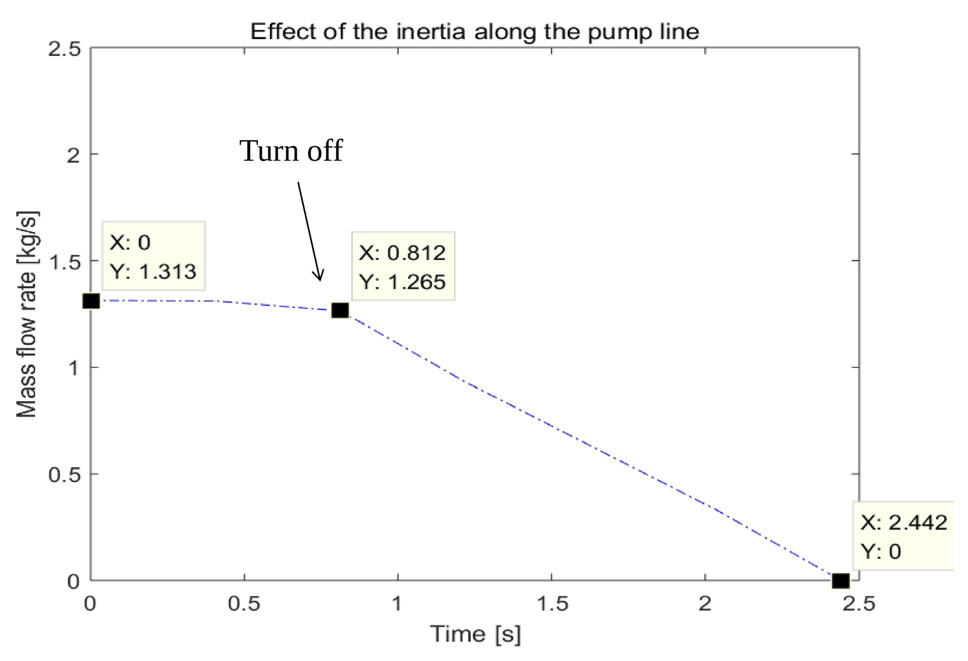
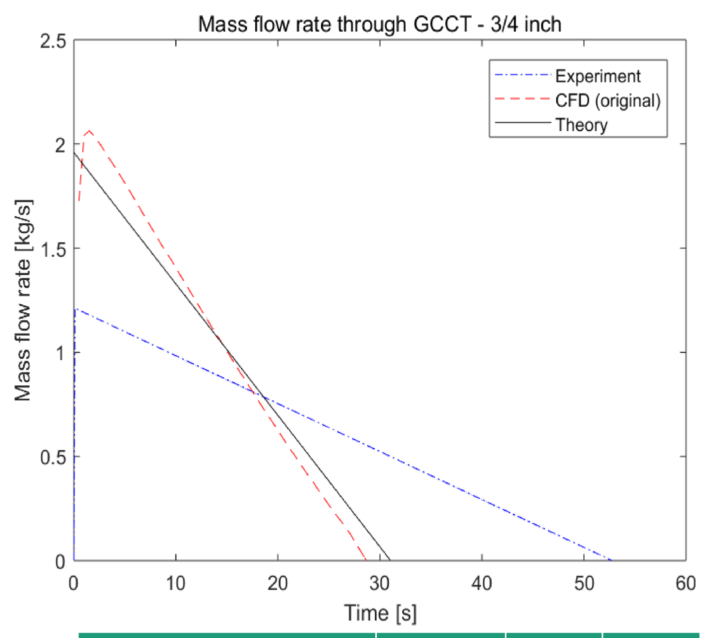
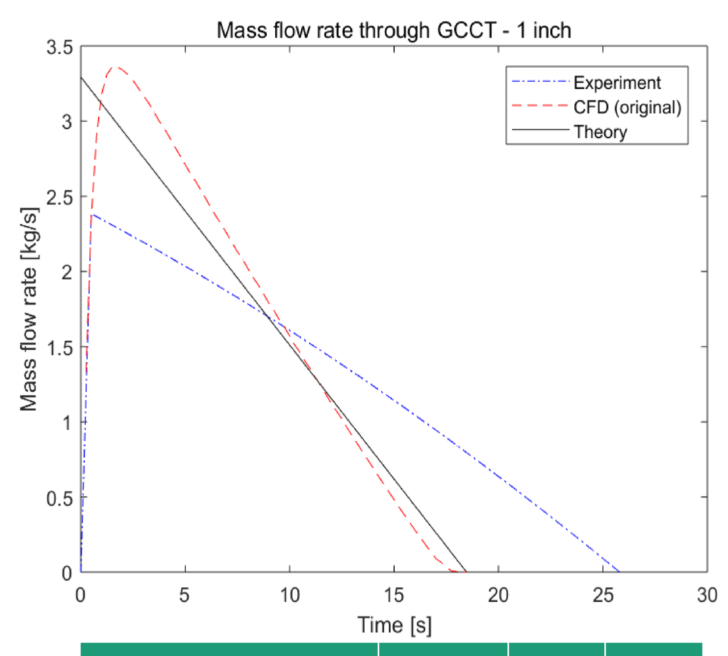


FIG. 5. Mass flow rate of the Pump (1.8 m, ¾ inch)



		Experiment	CFD	Theory
Maximum mass flow rate	Value (kg/s)	1.211	2.064	1.959
	% difference	0	70.4	61.8
Duration time	Value (s)	52.7	28.5	31
	% difference	0	-45.9	-41.2

FIG. 8. Comparison of core downward flow (3/4 inch DPP)



		Experiment	CFD	Theory
Maximum mass flow rate	Value (kg/s)	2.383	3.361	3.293
	% difference	0	41	38.2
Duration time	Value (s)	25.5	18.5	18.4
	% difference	0	-27.5	-27.8

FIG. 9. Comparison of core downward flow (1 inch DPP)

- ✓ Therefore, the inertia flow of pump should be taken into account to analyze the experiment results.
- ✓ If mass flow rate of core downward flow is measured at position of the reactor core, a slope of graph of the experiment results will be stiffer, which means difference with the models is smaller.
- ✓ Furthermore, it implies that if the inertia effect of the pump is increased by using a flywheel, the core downward flow can be further continued.

Conclusion

- ✓ An investigation of PRHRS which had been proposed recently as an alternative safety system for research reactor was conducted by experimental and analytical methods. In current study, the investigation was focused on the GCCT of the PRHRS which keeps core downward flow when the pump is malfunctioned.
- ✓ Theoretical and CFD model that predict core downward flow of the GCCT was developed based on the experimental facility. In terms of maximum mass flow rate, the experiment results was 38% to 70% lower than theoretical and CFD model respectively.
- ✓ The main reason of difference is inertia flow of the pump which maintains flow though the pump line during about 1.6s after the pump is turned off. It has 1.265 kg/s for maximum and gradually decrease.
- ✓ In fact, core downward flow of the PRHRS should be considered at not the GCCT but the core. Therefore, the inertia flow of pump have to be taken into account to experiment results.
- ✓ With the experimental values reflecting this effect, the comparison with the models should be made again.