Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Development of Ex-Vessel Corium Debris Bed under Two-Phase Natural Convection Flows in Flooded Cavity Pool during Severe Accident

Eunho Kim [a], Mooneon Lee [a], Hyun Sun Park [a*]
[a] *Division of Advanced Nuclear Engineering, Pohang university of science and technology (POSTECH)*
77 Chuongam-Ro, Nam-gu, Pohang, Gyungbuk, Republic of KOREA, 790-784
[*] *Corresponding author: hejsunny@postech.ac.kr*

1. Introduction

Cooling of ex-vessel corium mixture is one of the most important issues of the severe accident for preventing the accident progress and mitigating the accident result. To avoid MCCI and secure the safety from the threat of radioactive material release to environment, the coolability of ex-vessel corium should be sufficiently secured.

In the flooded cavity with coolant water, there must be FCI, and following fragmentation of the discharged melt jet. For massive discharge of melt during very short time, there must be corium melt pool which is harder to be cooled. However, for the condition of deep enough cavity flooding and long enough melt release time, the development of corium fragments debris bed can be expected[1], which is more advantageous for cooling due to its porous characteristics. Though the 'Dripping mode' of melt release in deep cavity pool for long term cooling could not be the most conservative condition, but it might be one of the most probable ones and worthy of consideration.

On the assessment of the porous corium debris bed coolability, most studies have used various arbitrary assumptions on the debris bed like flat[2], cylinder and mound shape[3]. However it is also known that the coolability largely depends on the debris bed shape, especially the bed height and overall distribution state[4]. The process of debris bed development includes a series of complex physical phenomena (Fig. 1), and still there is little study which covers all of those. Recently, Yakush at IPMech RAS reported the effect of the natural convection in cavity pool on the debris bed formation by simulation, where it was shown that the natural convection tends to abate the debris bed height growth by spreading the particle sedimentation[1].

The objective of this study is experimental verification of the two-phase flow effect on the ex-vessel corium debris bed formation. Especially, dynamic growth trend of debris bed was observed by utilizing 'Gap-Tooth' approach[5] for reflecting the heat generation change of developing debris bed.

From the time sequential comparative studies with quiescent pool condition test and air bubble driven natural convection condition test, it was observed that the two-phase natural convection induces the slower bed mound top growth rate and the flatter configuration of debris bed, which are known as to guarantee the higher coolability and the delay of dryout occurrence.

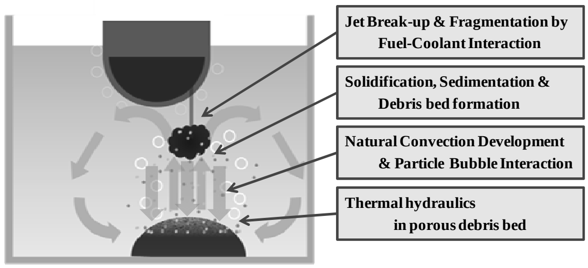

Fig. 1. A conceptual figure of the corium debris bed development process in the flooded cavity pool

2. Methods and Results

2.1 Test facility & Simulant particle

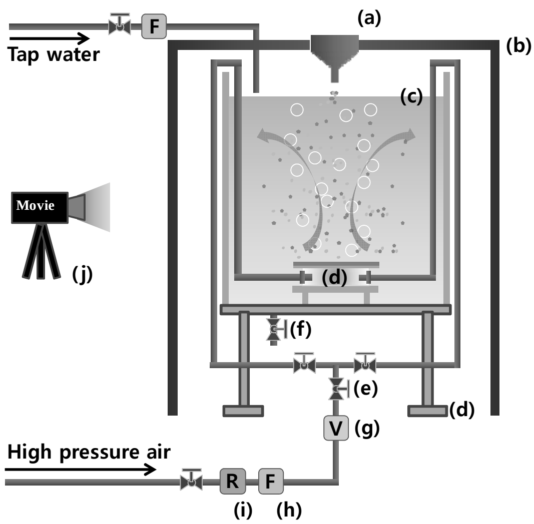

Fig. 2. A schematic diagram of DAVINCI test facility: (a) funnel, (b) funnel rack, (c) test pool, (d) bubble generator & catcher plate, (e) flowrate controller, (f) drain valve, (g) flow sensor, (h) mist separator, (i) filter-regulator, (j) camera

For this study, DAVINCI test facility (Fig. 2) in POSTECH was used[6]. The cylindrical test pool has 600 mm diameter, and 14.5 mm diameter nozzle was used for the funnel. The falling distance of particles from the nozzle tip to free surface of the test pool is 90 mm, and from the free surface to the particle catcher plate is around 830 mm. The bubble generator simulates the steam vapor generation from corium debris bed with air bubble, and the air bubbles were supplied through 256 holes in 1.5 mm diameter on the sixteen 40 x 40 mm cells at the center of the catcher plate. For the two phase flow condition test, air flowrate was controlled separately for each cell, depending on the volume of particles included in each cell area. To determine the air flowrate, 4 MW/m^3 of heat generation rate for particle bed volume and saturation temperature condition for direct coolant evaporation were assumed in calculation. Cylindrical stainless steel 304 particles (2 mm diameter, 2 mm height) were used for simulant particle. In the all test, same amount of quantity (1kg) was used.

2.2 Experiments

Because the corium particle is heat source itself, the debris bed becomes to make more steam vapors with larger heat generation with successively added corium fragments. However, in the experiment with simulant particle, it is not easy to reflect the heat increase of debris bed instantaneously along its volume growth. In order to overcome this problem and observe the time sequential debris bed development characteristic, 'Gap-Tooth' approach, which is usually used for multi-timescale simulation[1, 5], was adapted for this study. For updating the changed two-phase natural convection flow due to debris bed growth in the cavity pool, the resultant particle bed of the previous time sequence was scanned in 3D, and the volume data for each cell was calculated. Figure 3 describes the modified concept of this approach, and total three time sequence was tried in this study. For comparative study, test cases were classified into two groups, one with two-phase natural convection flow condition and the other with quiescent pool condition as a reference case.

Table 1. Total air flowrate for each test case [lpm]

Case	**Time Sequence**		
	t^1	**t^2**	**t^3**
Quiescent Pool Condition	0	0	0
Two-Phase Condition		22.7	45.6

2.3 Results

The highest point of debris bed has importance in the aspect of heat flux. Because of the largest amount of corium particles per unit area, the top point of debris bed is more prone to dryout. The top debris bed height (h_{top}) change by time sequence can be observed in the cross-section view from Figure 4, and Figure 5 shows that the two-phase condition case has slower increase trend of the top debris bed height and lower possibility of occurrence of dryout than the conventional quiescent pool assumption case has.

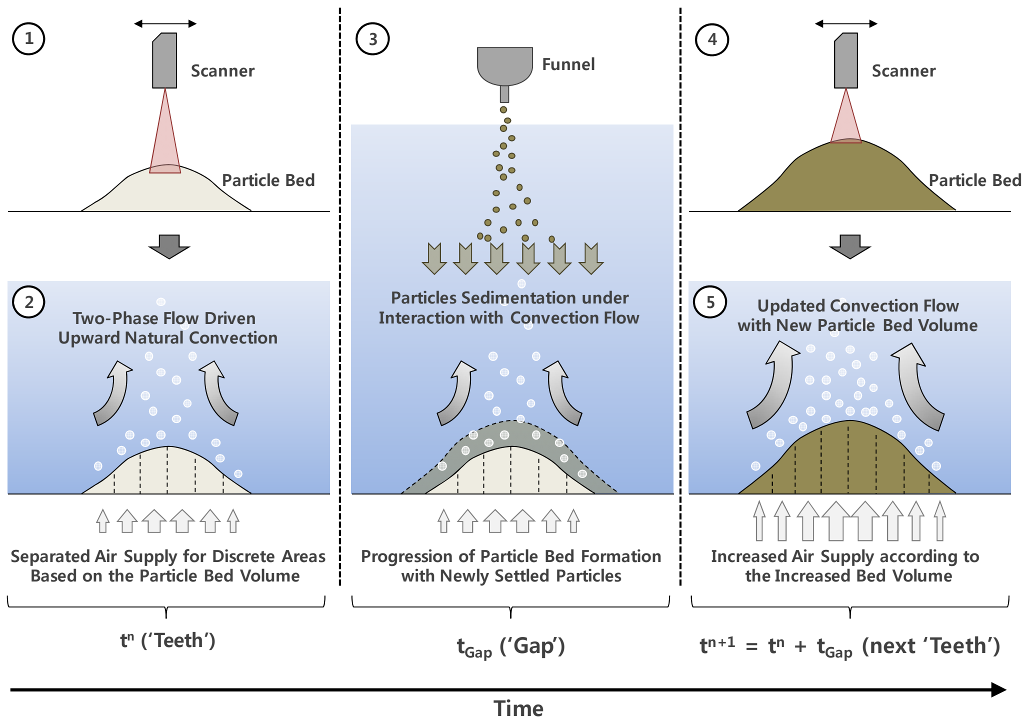

Fig. 3. A conceptual description of 'Gap-Tooth' approach for 'Two-Phase Condition' test case of this experimental study

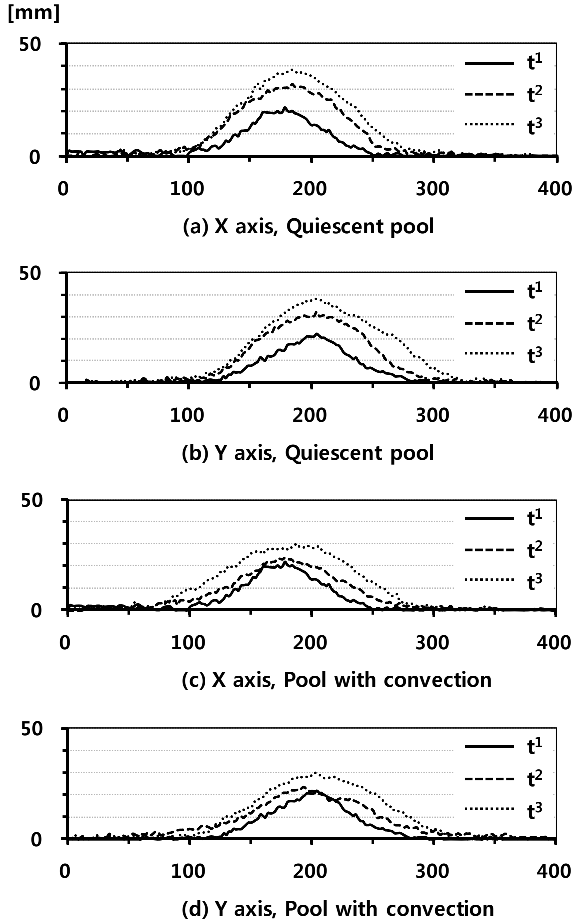

Fig. 4. Time sequential change of the resultant particle bed along the X & Y axis cross-sections

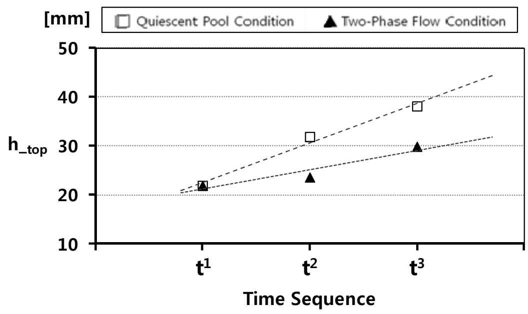

Fig. 5. 'Top debris bed height ($h_{\_top}$)' change according to the time sequence

On the other hand, though the top debris bed height is the most vulnerable site to dryout, it has limitation as a local situation not enough for representing the coolability of whole debris bed area. To cover the overall distribution state of simulant particles, two characteristic length values were used for a nondimensional parameter '$h_{\_top}/A_{75\%}^{0.5}$', where $A_{75\%}$ means the area where the 75% of total particle bed volume is located. The increase of '$h_{\_top}/A_{75\%}^{0.5}$' means higher particle concentration per unit area which is connected to the overall debris bed coolability decrease. Figure 6 shows the consistent increase of the quiescent pool condition case and the up and down movement of the two-phase condition case. Though the difference between two conditions was clear, but still more tests and scaling are required to assure the tendency and induce the useful model for reactor application.

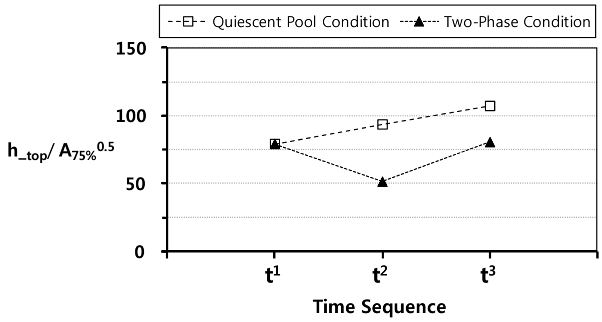

Fig. 6. Variation trend of '$h_{\_top}/A_{75\%}^{0.5}$' parameter according to the time sequence

3. Conclusions

Development of ex-vessel corium debris bed in the flooded cavity pool during severe accident was experimentally studied. Dripping mode of corium discharge with deep cavity pool depth and long melt release time was assumed for full fragmentation of melt jet. The two-phase natural convection flows was simulated by air bubble generation which is controlled by each location, and its effect on the particle bed development was traced time sequentially.

From the comparative studies with the quiescent pool condition test and the two-phase, air bubble driven, natural convection condition test, it was observed that the two-phase natural convection flows induce the slower bed mound top growth rate and the flatter configuration of debris bed, which is known as to guarantee the higher overall coolability and the delay of dryout occurrence. More test case based on scaling analysis are necessary and modeling will be conducted for reactor scale extension.

ACKNOWLEDGEMENTS

This research was supported by National Research Foundation of Korea (NRF) grants funded by Korean government (MSIP) (NRF-2013M2A8A1040987) and the Nuclear Safety Research Program of the Korea Radiation Safety Foundation grants funded by Korean government (NSSC) (Grant Code: 1305008-0113-HD140).

REFERENCES

[1] Yakush, S., Kudinov, P., and Dinh, T.-N., 2009, "Multiscale simulations of self-organization phenomena in the formation and coolability of corium debris bed," The 13rd International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-13), Kanazawa City, Ishikawa Prefecture, Japan.

[2] Ma, W. M., and Dinh, T. N., 2010, "The effects of debris bed's prototypical characteristics on corium coolability in a LWR severe accident," Nucl Eng Des, 240(3), pp. 598-608.

[3] Yakush, S., Kudinov, P., and Dinh, T.-N., "Modeling of Two-Phase Natural Convection Flows in a Water Pool with a Decay-Heated Debris Bed," Proc. Proceedings of International Congress on Advances in Nuclear Power Plants (ICAPP 2008).

[4] Yakush, S. L., Nazar T.; Kudinov, Pavel, "Risk-Informed Approach to Debris Bed Coolability Issue," Proc. 20th International Conference on Nuclear Engineering collocated with the ASME 2012 Power Conference, pp. 531-543.

[5] Gear, C. W., Li, J., and Kevrekidis, I. G., 2003, "The gap-tooth method in particle simulations," Physics Letters A, 316(3), pp. 190-195.

[6] Kim, E., Park, J.H., Kim, M.H., Park, H.S., 2014, "The Influence of Two-Phase Flow on Pore Clogging by Fine Particle Settlement during Ex-Vessel Debris Bed Formation in Severe Accident," The 22nd International Conference on Nuclear Engineering (ICONE22), Prague, Czech Republic.