Fundamental Experiment to Investigate the Effect of Steam Spike on Ex-vessel Debris Bed Shape

Ki Han Park [a], Seokgyu Jeong [a], Sang Mo An [a*]
[a]*Korea Atomic Energy Research Institute (KAERI), 989-111 Daedeok-daero, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: sangmoan@kaeri.re.kr*

1. Introduction

The SAMG (Severe Accident Management Guidance) for Korea standard nuclear power plant has seven major strategies to mitigate severe accident. Among them, the fourth strategy (SAG-04; Injection into the containment) leads to fill a reactor cavity with water and ex-vessel corium falls into the pre-flooded cavity. By the interaction with water, the falling corium would become a lot of solidified particles and then form a debris bed on the bottom of the cavity [1, 2].

In order to prevent the debris bed from being remelted and resulting in MCCI (Molten Corium Concrete Interaction), coolability of the debris bed should be ensured sufficiently. The geometric shape of the bed has an effect on the coolability [3]. At this time, early phase of the debris bed formation affected by steam spike which spread falling debris far away [4].

In this paper, the experimental facility constructed in KAERI to investigate the effect of steam spike on debris bed shape and the fundamental experiment results are introduced.

2. Experimental Facility

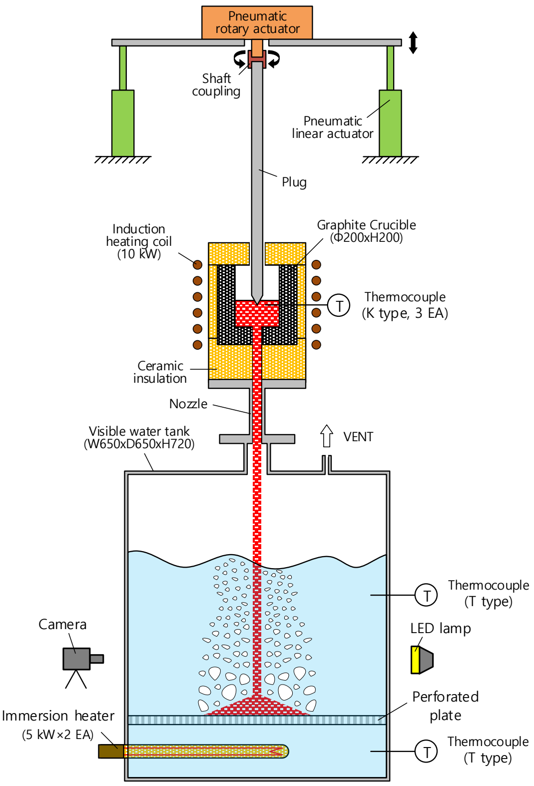

Fig. 1. A schematic design of DEFCON-S

Fig. 1 shows a schematic design of the experimental facility, so called 'DEFCON-S', which is a small version of DEFCON facility. It was constructed for experiments using about 5 kg stainless-steel simulant particles. The graphite crucible which is filled with the particles is heated by induction heating, and heat is transferred from the crucible to the particles by thermal conduction. In order to confirm the uniformity of temperature in the radial direction, K-type thermocouples are installed in the middle of particle filling such as Fig. 2. At each tip of the thermocouples, the particle is welded.

Fig. 2. Installation of thermocouples for measuring the temperature of the particles

The pneumatic rotary actuator rotates repeatedly the stainless-steel plug with cogwheel cross section clockwise and counterclockwise. It allows to prevent the particles from sintering. Operating pneumatic linear actuators upwards, the particles heated up to a certain temperature fall free into the visible water tank through the nozzle which has ϕ20 mm hole. The cuboid tank with face-to-face polycarbonate windows has the size of 650 mm × 650 mm × 720 mm. Stainless-steel perforated plate with a lot of ϕ0.8 mm holes is installed inside the tank and the falling particles are piled up on the plate. Under the plate, there are two immersion heaters to heat water. Experiment process is recorded by using camera and LED lamp.

3. Experiment Result

3.1 Experiment Conditions

Table 1: Experiment Conditions

Exp. #	Particle				Water	
	Shape	Size (*mm*)	Mass (kg)	Temp. (℃)	Level (*mm*)	Temp. (℃)
#1	Sphere	3	5	12	300	10
#2	Sphere	3	5	700	300	100

Table 1 shows the experiments conditions in this paper. For the base case, Exp. #1 was performed at the unheated condition. Water level was based on the perforated plate.

3.2 Heating Process

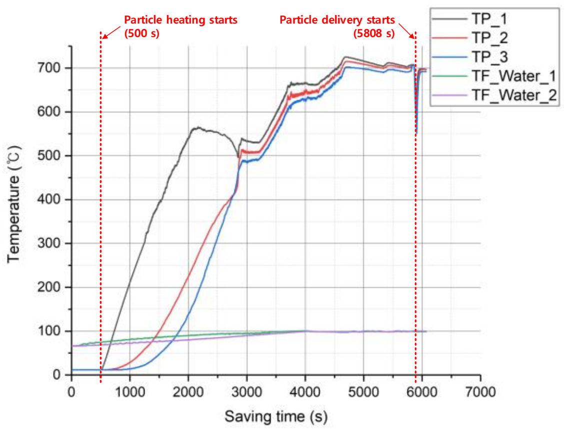

Fig. 3. Water and particles temperature graph of Exp. #2

Fig. 3 shows temperature change of water and particles in heating process of Exp. #2. Since heat was transferred from the crucible to the particles by thermal conduction, TP_1 was heated first. Induction heating power was controlled to heat particles uniformly. Since the thermocouples remained in the crucible after particles' delivery, the temperature change of the particles by the interaction with water was not measured.

3.3 Delivery Process of Particles

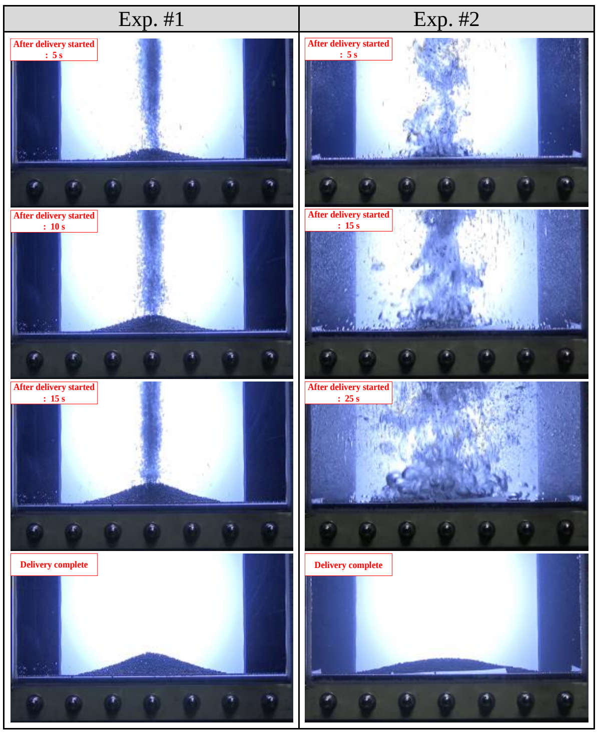

Fig. 4. Delivery process of each experiment

Fig. 4 shows the delivery process of particles. First, at Exp. #1, the time taken for 5 kg of the particles to be delivered completely was 20 seconds. The particles fell into water with air and a few of bubbles were generated.

At Exp. #2, it was hard to determine the delivery time exactly because a lot of steam bubbles screened the falling particles. It took more than about 10 seconds for all the particles to fall on the plate as compared with Exp. #1. It was thought the time taken for the particles to escape from the nozzle was similar with that of Exp. #1. If so, some particles would stay in the water for a while because of a lot of steam bubbles. In the camera footage, it was also seen that the particles which were pushed away due to the bubbles and fell on the side of perforated plate rolled towards the center due to convection flow of water.

3.4 The Shape of Particle Bed

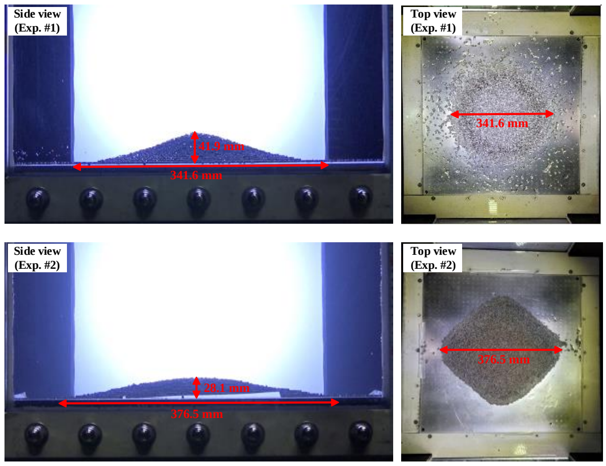

Fig. 5. Particle bed of each experiment

Fig. 5 shows the particle bed of each experiment. Both beds looked like a hill, however, that of Exp. #2 had a lower height and a gentle slope. That was because steam bubbles pushed falling particles far away. Comparing top views, Exp. #1 had a circular shape, while Exp. #2 had a diamond shape. It seemed that the regions close to the tank wall had more strong convection flow and thus particles accumulated much more than other regions. Also, since the particles rolled towards the center due to the convection flow, there were few particles around the bed of Exp. #2.

4. Conclusions

DEFCON-S facility was constructed to investigate the effect of a sudden steam generation on the shape of fragmented debris bed and the fundamental experiments using 5 kg of 3 mm stainless-steel ball were conducted. An explosive steam generation by the interaction between heated particles and saturated water pushed falling particles far away. As a result, the particle bed spread more widely.

The coolability of debris bed is related to its shape and early phase of it primarily affected by a sudden steam generation. It is expected that performing experiments under various conditions by using DEFCON-S facility will contribute to COLAS (COrium cooLability of Analysis Simulator) code development.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science and ICT; Grant No. 2017M2A8A4015274).

REFERENCES

[1] S.W. Jang, S.W. Lee, H.C. Oh, Improvement of Diagnostic Flow Chart in Severe Accident Management Guidance for Nuclear Power Plants in Korea, Proceedings of Korean Nuclear Society Autumn Meeting, October 27-28, 2016, Korea.
[2] S.M. An, K.S. Choi, K.H. Park, C.W. Kang, Ex-vessel Debris Bed Formation in the Pre-flooded Reactor Cavity Using 3 mm Stainless Steel Particles, Proceedings of Korean Nuclear Society Virtual Spring Meeting, July 9-10, 2020, Korea.
[3] E. Takasuo, An experimental study of the coolability of debris beds with geometry variations, Annals of Nuclear Energy, Vol.92, p.251, 2016.
[4] A. Konovalenko, S. Basso, P. Kudinov, S.E. Yakush, Experimental Investigation of Particulate Debris Spreading in a Pool, Nuclear Engineering and Design, Vol.297, p.208, 2016.