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Effect of Steam Spike on Dispersion of Particle Jet Entering the Water Pool

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1. Introduction

When a severe accident occurs in light water nuclear power plants, molten corium could be released from the reactor vessel to the pre-flooded cavity. By interaction with cooling water, the molten corium is fragmentized into small solid particles and a debris bed is formed. The debris bed coolability is important to secure the containment integrity.

A debris bed is cooled by water ingression into the bed. Thus, the bed coolability is related to the debris bed shape [1]. Several researches were done to find parameters affecting debris bed shape experimentally and numerically [2-5]. However, because debris bed shape is determined by various parameters, studies about the effect of individual parameters, especially thermal characteristics, are insufficient. Thus, in this study, as one of the thermal characteristics of debris bed shape, the initial particle jet dispersion by steam spike during the entrance into the water pool affecting the early debris bed shape, was experimentally investigated with varying thermal conditions.

2. Experimental Method

2.1 Experimental Setup

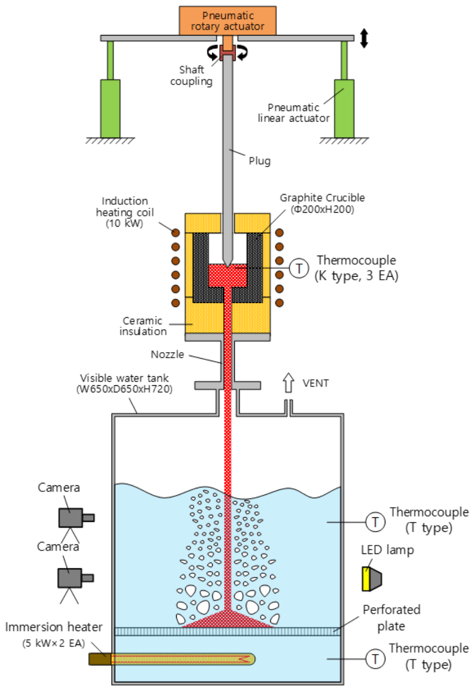

Fig. 1. Experimental schematic of DEFCON-S

Figure 1 shows a schematic of the experimental facility called DEFCON-S, which is small sized version of DEFCON (DEbris bed Formation and COolability experimeNt) facility [6]. DEFCON-S facility consists of particle heating system, particle delivery system, and water tank. Particle heating system includes the graphite crucible in which particles are filled and an induction heating device for heating the crucible and particles. Particle delivery system has a plug blocking the bottom hole of the crucible, a linear actuator to pull up the plug to transport particles, and a rotary actuator that periodically rotate the plug to prevent particle sintering during heating. Front and back sides of water tank are made of transparent acrylic windows for visualization, and two immersion heaters are installed inside the water tank to heat cooling water to target temperature. A more detailed explanation about experimental facility can be found in the previous work [7].

2.2 Experimental Methods

5 kg stainless steel particles were used as simulants of the corium particle and delivered through a nozzle with 20 mm in diameter. Water level and free fall height of particles were fixed at 300 mm and 660 mm, respectively. Differences between tests were the particle shape and temperature. Detailed experimental condition is shown in Table I. At this time, SMD (Sauter mean diameter) was used for equivalent diameter of a cylindrical particle.

Table I: Experimental condition

Test #	Particle			Water
	Shape	Diameter (mm)	Temp. (˚C)	Temp. (˚C)
#1	Cylinder	3	20	20
#2	Cylinder	3	500	100
#3	Cylinder	3	800	100
#4	Sphere	3	800	100

Experiments were carried out in the following sequence. First, particles were filled in the crucible and heated to the target temperature. Also, cooling water in the water tank was heated to the target temperature. Then, by raising the plug up, heated particles were delivered to cooling water. Using camcorders and LED lamp, backlight images of falling particles were taken with 60 frame per seconds.

Figure 2 (a) shows one of the backlight images of heated case. Particles were distinguished with black pixels. Therefore, with appropriate binarization technique, only particles could be extracted from original image, as shown in Fig. 2 (b). By summating these particle images with respect to time, dispersion of particles was obtained as shown in Fig. 2 (c). The legend of Fig. 2 (c), which is the value of a particular pixel location, represents the number of times that a particle has passed that pixel location from 120 images taken over 2 seconds.

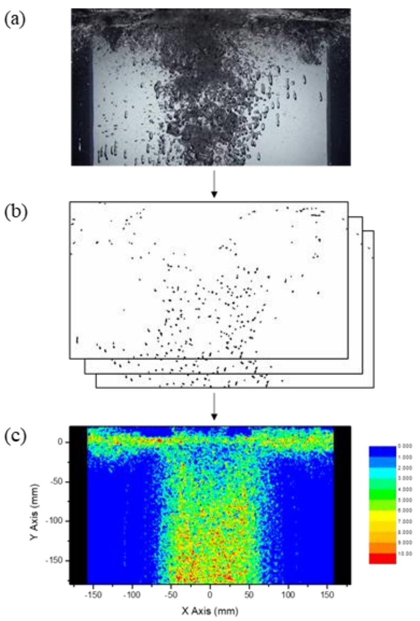

Fig. 2. Method to obtain dispersion of particle jet

3. Results and Discussions

Figure 3 shows images without and with heating. Without heating, particles dispersed by collision of each particles as shown in Fig. 3 (a). On the other hand, particles went down vertically when heated particles enter to the saturated water pool as shown in Fig. 3 (b).

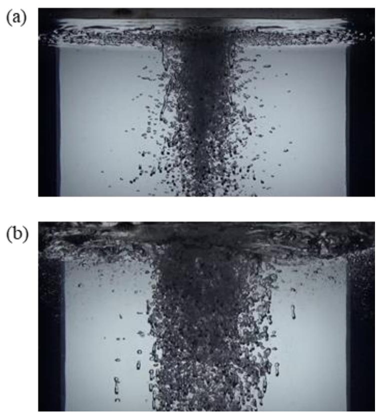

Fig. 3. Particle falling images (a) without and (b) with heating

Figure 4 shows dispersion of particles within initial 2 seconds with different thermal conditions. Black arrows, D_{j0} and D_{j150}, in Fig. 4 indicate particle jet diameters at the water surface and at a depth of 150 mm, respectively. Without heating, particle jet diameter gradually increased with a certain angle while particle fell through water pool as shown in Fig. 4 (a). On the other hands, for heated cases, particle jet diameter increased rapidly and then remained almost same as shown in Fig. 4 (b) - (d).

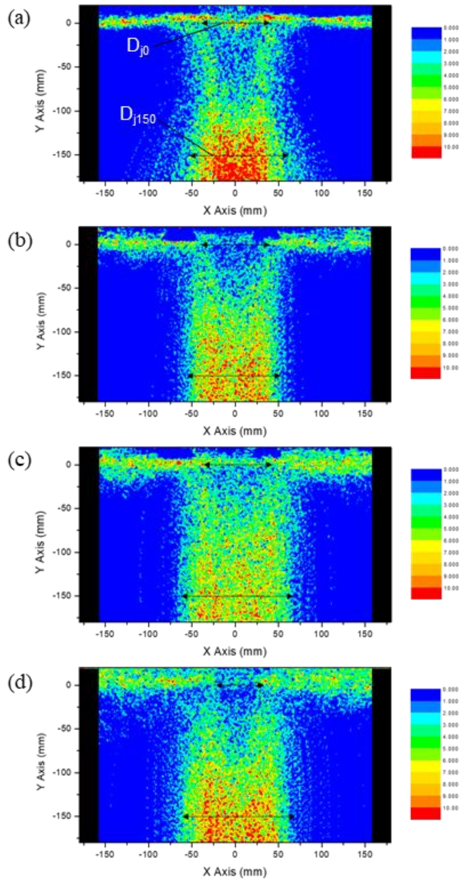

Fig. 4. Dispersion of particles within initial 2 s with (a) non-heated cylinder, (b) 500˚C heated cylinder, (c) 800˚C heated cylinder, and (d) 800˚C heated sphere particles

Table II shows values of particle jet diameters with test conditions. By eliminating bubble in Fig. 3, it was shown that D_{j0} are same with and without heating when particle shapes are same. From results of test #2 and test #3, particle jet dispersed wider as the particle temperature increases. From results of test #3 and test #4, particle jet dispersed wider with sphere particles than cylindrical particles. At this time, D_{j150} were similar, but cylindrical particles had larger jet diameters at the water surface. For spherical particles, the surface area is always constant when falling. Therefore, collisions due to the velocity difference caused by drag were small. On the other hand, cylindrical particles have different surface areas depending on the direction of falling, which could make velocity difference due to drag easily. Therefore, cylindrical particles collide more frequently with each other and have larger jet diameter at the water surface than spherical particles.

It is known that particles spread widely with higher gas flow rate and lower particle mass [3]. Total amount of steam generated by steam spike increased at high heating temperature and high flow rate could be made. Also, particles might be affected by steam flow strongly with sphere particles because mass of spherical particle is smaller than that of cylindrical particle with same SMD. Consequently, particle jet dispersed wider by increasing total heat of particles and decreasing particle mass.

Table II: Particle jet diameters with test conditions

Test #	D_{j0} (mm)	D_{j150} (mm)	D_{j150}/D_{j0}
#1	79.77	114.86	1.44
#2	79.77	109.12	1.37
#3	79.77	129.73	1.63
#4	55.90	130.74	2.34

4. Conclusions

The effect of steam spike on dispersion of particle jet entering the water pool was experimentally investigated in this study. Consequently, it was found that heating temperature and mass of particles are key parameters of particle dispersion by steam spike. As a future works, by applying the results of this study to the DEFCON integral test, the effect of the initial steam spike on the debris bed shape will be investigated and applied to the debris bed formation model.

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