Experiments of Aerosol Behavior in Containment with Containment Spray

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1. Introduction

Containment spray system is an engineering safety feature of nuclear power plants, to decrease the temperature and pressure also to remove fission products during accidents. The fission products released by an accident are either deposited on the structure or wall surface by different deposition mechanisms, such as gravitational settling, thermophoresis, and diffusion. While the fission products are mobile in the containment, the containment spray effectively remove them because the small droplets directly captures the aerosol before they sits on adjacent surfaces.

In this article, the aerosol behavior in containment were examined experimentally by using a vessel and a spray system. The aerosol concentration in the vessel were measured by particle size along time, with and without the spray.

2. Aerosol-Spray Experiment

Figure 1 shows the schematic aerosol-spray experiment. The vessel resembles the containment building, and aerosol is injected into the vessel. When the vessel is filled with aerosol, it is isolated by shutting the inlet and outlet. There are two sampling nozzle for ELPI (electrical low pressure impactor, DEKATI) installed at the top and bottom of the vessel, and the distance between the nozzles is 700mm. The vessel height is 2080 mm and the inner diameter is 1580 mm. Initially, SiO_2 aerosol was generated and injected into the vessel for 20 min, and then the vessel was kept isolated for another 20 min. Then, water sprayed from the vessel top to remove the aerosol.

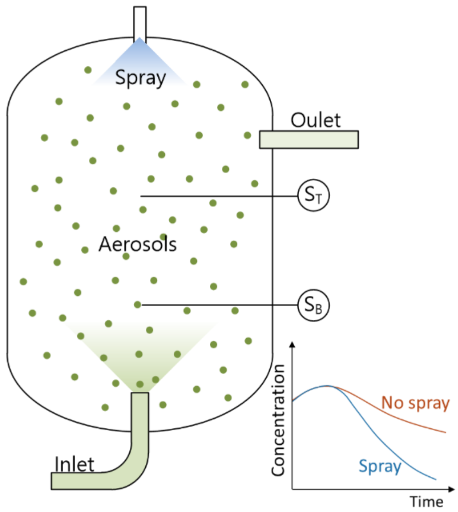

Fig. 1 Schematic of Spray-Aerosol Experiment

Table 1 Specification of Spray Nozzle

Variable		OPR1000	Experiment
Spray	$D_{droplet}$ (μm)	295	300
	Flow rate (slpm)	57.6	17.2
Area per nozzle (m^2)		6.58	1.96
Flow rate per area (slpm/m^2)		8.8	8.8

Table 2 Experimental Condition

Condition	Value
Gas in vessel	Air
Temperature (ºC)	60
Pressure (bar abs)	1
Aerosol particle	SiO_2
Aerosol particle diameter (μm)	0.7

Table 1 shows the specification of the aerosol nozzles installed in existing OPR1000 nuclear power plant and the nozzle used in the experiment, which is designed such that the flow rate per area and the droplet diameter are the same as those of OPR1000 [1]. Table 2 shows the experimental conditions. The vessel is in atmospheric condition with 60ºC, and SiO_2 particles with 0.7 μm diameter were used for the experiment.

ELPI measured the aerosol concentration by particle size. Aerosol concentrations for 14 size bin were measured in real-time during the experiment, from the aerosol injection to the containment spray. Among the 14 size bin, dominant size bins in terms of the mass and number density, 0.75 μm, 1.2 μm, 2 μm, and 3 μm were presented here.

3. Experimental Results

Figure 2 shows the aerosol mass concentration at the vessel top, and Figure 3 shows that at the vessel bottom. The aerosol concentration increases during the injection period, and then decreases slowly after the vessel is isolated. Here, the most dominant aerosol diameters are 2 μm and 3 μm, whereas the injected SiO_2 particle is 0.7 μm in diameter. The large diameter detected by ELPI means the aerosol particles agglomerates, and becomes bigger. As the evidence of the agglomeration, the concentration of 3 μm particles at the vessel top increases a little after the vessel isolation, which means that the injected aerosol agglomerates and falls down to the vessel bottom. The figures also shows the abrupt decrease of aerosol concentration by the spray. The spray removes aerosols efficiently within very short time.

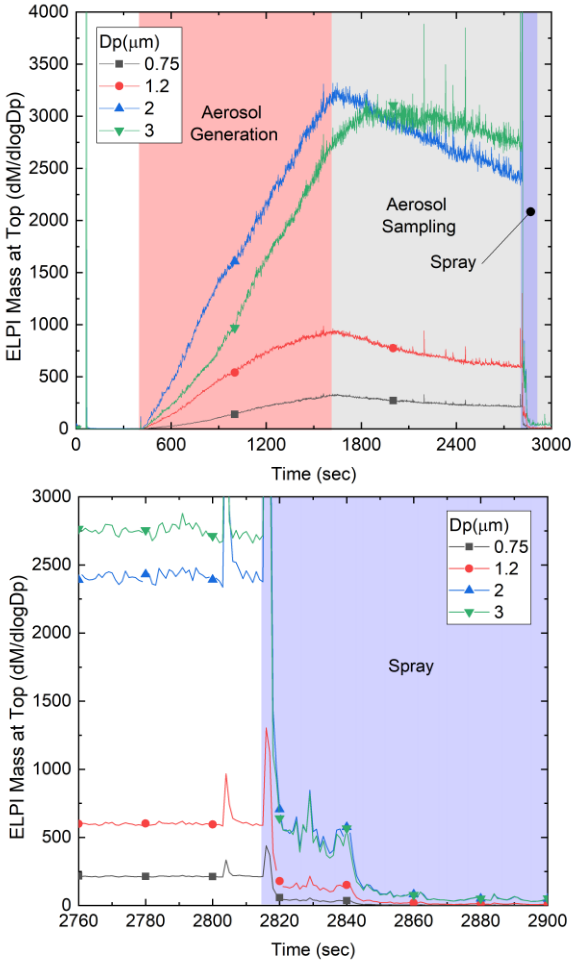

Fig. 2 Aerosol Mass Concentration at Vessel Top

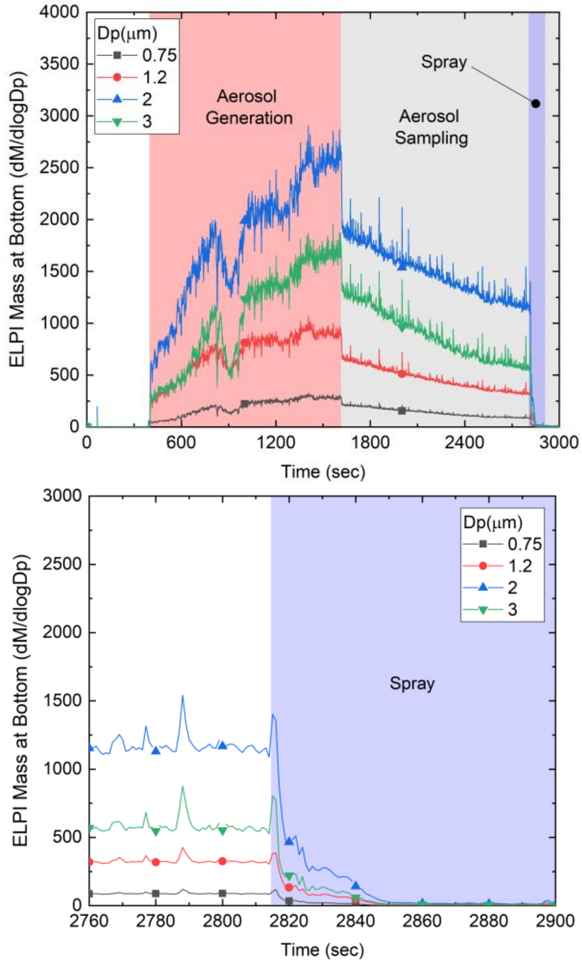

Fig. 3 Aerosol Mass Concentration at Vessel Bottom

Table 3 shows the aerosol concentration decrease with and without spray. After the aerosol injection was finished and the vessel was isolated, the aerosol concentration decreases slowly for 20 min without spray, and then 98% to 99% of aerosol were removed abruptly by the spray within 1 min. It is note that the aerosol concentration is higher at the vessel top compared to the vessel bottom, and also decreases slowly at the vessel top than that of vessel bottom. One possible explanation of higher aerosol concentration at the vessel top is that the injection air not only deliver the aerosol into vessel, but also pushing the existing aerosols to the vessel top.

Table 3 Decrease of Aerossol Concentration

Position	Aerosol Concentration decrease (%) by	Particle size (μm)			
		0.75	1.2	2	3
Top	20 min without spray	33.8	35.4	24.2	-0.6
	1 min with spray	98.5	97.9	97.9	98.2
Bottom	20 min without spray	57.3	50.0	37.4	54.3
	1 min with spray	98.8	98.5	98.6	98.5

Table 4 shows two important aerosol deposition mechanism in the isolated vessel without spray, the gravitational settling and the diffusion [1]. The deposition velocity by gravitational settling is

$$v_{grav} = \frac{d_p^2 \rho_p g C_m}{18\mu}$$

where d_p is particle diameter, ρ_p is particle density and μ is dynamic viscosity of air. And the deposition velocity by diffusion is

$$v_{diff} = \frac{kTC_m}{3\pi\mu d_p \delta}$$

where k is Boltzmann constant, T is temperature, and δ is diffusion boundary layer thickness assumed to be 10 μm. The Cunningham slip correction is given by

$$C_m = 1 + \frac{2\lambda}{d_p}\left[1.257 + 0.4\exp\left(-\frac{1.1d_p}{2\lambda}\right)\right]$$

where λ is the mean free path which can be calculated by

$$\lambda = \frac{\mu}{\rho_g}\sqrt{\frac{\pi M}{2RT}}$$

where M is molecular weight and R is gas constant. The thermophoresis is not important in this experiment due to the isothermal condition in the vessel.

Table 4 Deposition Velocity of Aerosol

		Particle size (μm)			
		0.75	1.2	2	3
Deposition velocity (m/s)	Grav. settling	5.0E-5	1.2E-4	3.1E-4	6.8E-4
	Diffusion	4.1E-6	2.4E-6	1.3E-6	8.7E-7
Time to travel 1 m by Grav. settling (hr)		5.5	2.3	0.9	0.4

For the particle size from 0.75 to 3 μm, deposition velocity of gravitational settling is more than 10 times larger than that of diffusion. Therefore, the aerosol behavior is dominated by gravitation. Even for the largest 3 μm particle, the deposition velocity, which means the falling velocity of aerosol is only 0.68 mm/s, therefore the aerosol concentration decreases very slowly. This explains the slow decrease of aerosol concentration in the experiment before the spray.

5. Summary

Experiment to examine the aerosol behavior in the containment were performed using a vessel and a spray system. The vessel simulated the containment and the spray system were designed such that the flow rate per area is the same as the existing OPR1000. The aerosol were injected into the vessel with air, and then the vessel isolated. After a while, water sprayed from the vessel top. During the experiment, the aerosol concentration were measured by the particle size using ELPI.

The most dominant particle size were 2 μm and 3 μm, which were larger than the injected particle size of 0.7 μm due to the agglomeration. The particle concentration decreases slowly by time when the spray were not activated. When the water sprayed, more than 98% of aerosols were removed within 1 min. The overall aerosol concentration is higher at the vessel top than at the bottom, and the concentration decreases slower at the top than at the bottom. The dominant deposition mechanism of aerosol without spray were gravitational settling, and the falling speed of aerosol were less than 1 mm/s even for the largest particle.

Series of experiments with different nozzles are planned considering the effect of droplet size and flow rate of spray, which seems influential for the aerosol behavior in the vessel.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (Ministry of Science and ICT) (RS-2022-00144202).

REFERENCES

[1] Korea Hydro-Nuclear Power Cooperation (KHNP), Final Safety Analysis Report (FSAR) of Shin-Kori Unit 1 & 2, Chapter 6 Engineering Safety Feature, 2018.
[2] Comparing the MELCOR Aerosol Deposition Model with Exact Analytical Solution, SAND2024-03561R, Sandia National Laboratory, 2024