Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

Evaluation of a spray technology to capture aerosols for severe accident mitigation outside a nuclear power plant

J. W. Go[a], M.S. Yim [a*]
[a]*Korea Advanced Institute of Science and Technology (KAIST), Nuclear & Quantum Engineering dept,*
[*]*Corresponding author: msyim@kaist.ac.kr*

1. Introduction

When a severe accident occurs at a nuclear power plant (NPP), it is possible that nuclear fuels and reactor wall will melt. In this situation, radioactive aerosols can be generated in the reactor. Cesium iodide (CsI) is the dominant component of the aerosols [1, 2]. Also, the aerosols generated in the reactor can be released from the containment to the atmosphere through a leak or a rupture. If the release is ignored, workers near or in the NPP can be exposed to a large amount of radioactivity. This is especially true when workers inhale the radioactive aerosols which can lead to serious consequences. Therefore, this study explores the capture of airborne aerosols to mitigate the consequence of a severe accident. The experimental setup used in this study, included an experimental chamber, a scaled-down NPP model, an aerosol release line, and a liquid spray line. The aerosols were released at a breach hole on the containment surface and were captured using droplets released from a spray nozzle.

2. Experiment setup

In this section, the experimental setup is explained. The experimental setup included a NPP model, aerosol release line, liquid spray line, and aerosol release system.

2.1 NPP model

Figure 1 represents an NPP model based on an APR-1400. Holes were drilled into the containment surface, and the aerosol was discharged from the holes. The size of the hole was based on the literature's definition of a standard rupture [3].

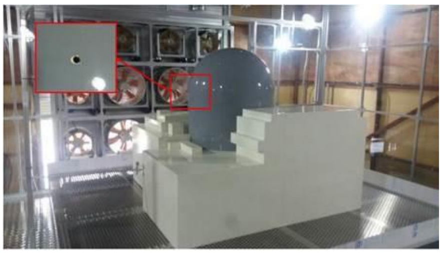


Fig. 1. Scaled-down nuclear power plant model

2.2 Experimental chamber

The experimental chamber was constructed to isolate experimental condition from the external environment. The chamber was enclosed by acrylic boards, allowing the experiments to be observed and contained. The relatively small size of the chamber prevents the released aerosol from escaping since the natural dispersion of the sprayed droplets is ultimately contained when they reach the acrylic walls. Thus, the chamber size was set big enough to allow the dispersion of aerosols and sprayed droplets. On the backside of the chamber, HEPA filters were installed with ventilators, to discharge the filtered/cleaned air.

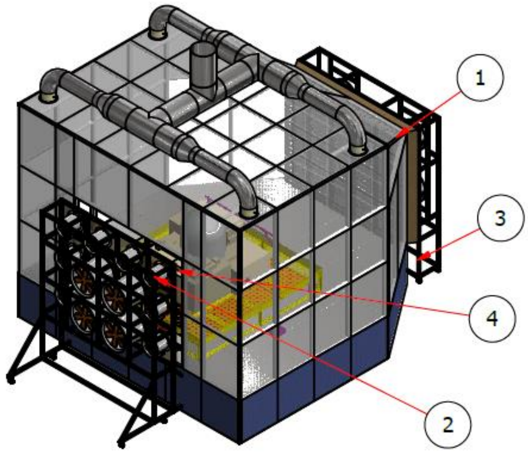


Fig. 2. 3D modelling of a large chamber for aerosol capture experiments

2.4 Experimental schematic

Figure 3 is a schematic of the experimental setup. Blue line represents the liquid spray line, and the orange line depicts the aerosol release line. The air flow rate was controlled using a flow meter valve, with four air flow rates (20, 30, 40, and 50 L/min) per experiment. The liquid flow rate was adjusted by the bypass value, with three the liquid flow rates (2, 3, and 4 L/min) per experiment.

The name of this spray nozzle is the 1/8 G5 spray nozzle model, which sprays liquid in a full cone shape. The spray angle range was between 55~65°.

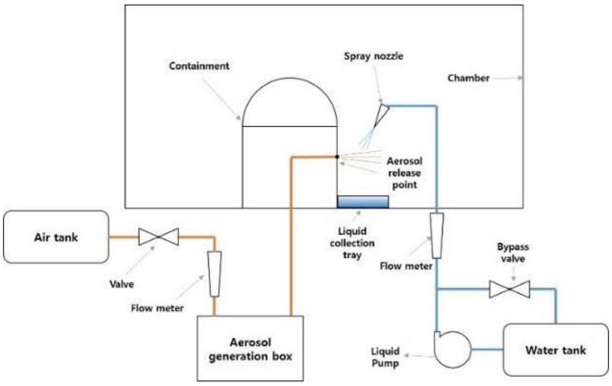


Fig. 3. Schematic diagram of experimental setup [4]

2.4 Material properties

Table 1 contains the information on the material properties of titanium dioxide (TiO_2), tap water, and foam solution that has 0.75% sodium lauryl sulphate ($NaC_{12}H_{25}SO_4$) in water. The reason TiO_2 was selected as a release aerosol instead of radioactive substances is that the density of TiO_2 is similar to CsI, which is the dominant component of radioactive aerosols generated during a severe accident [1, 2]. The properties of the foam solution are similar to tap water except for surface tension. The foam solution has half of the surface tension value compared with tap water because the foam solution was a mixture of sodium lauryl sulphate ($NaC_{12}H_{25}SO_4$) and tap water [5].

Table I: Properties of each material including atomization characteristics

	Titanium dioxide (TiO_2)	Tap water	Foam solution (0.75% of SLS)
Phase	Solid	Liquid	Liquid
Density (g/cm^3)	3.79	0.997	0.997
Average size (µm)	0.02	300 ~ 415	150 ~ 210
Viscosity (cpoise)	-	1.002	1.1
Surface tension (mN/m)	-	72	31

3. Result & Discussion

3.1 Air flow rate

Figure 4 represents the capture efficiency as a product of air flow rate. The liquid spry flow rate was fixed at 4.0 L/min. These experiments were performed using only tap water. At a 20 L/min air flow rate, the capture efficiency reached the maximum value of approximately 63%, in the 20 ~ 50 L/min air flow rate range. The capture efficiency decreased as the air flow rate increased to 40 L/min. At 40 L/min air flow rate, the capture efficiency reached approximately 44%, which is the local minimum value in this case. At 50 L/min air flow rate, the capture efficiency was a little higher than 40 L/min, but the value is not significantly different from the 40 L/min value.

Figure 5 (a) ~ (d) shows the experimental pictures at each air flow rate. According to these pictures, the penetration length increased following an increase in the air flow rate. At a 40 L/min air flow rate, the penetration length is little longer than the 30 L/min rate. However, there was quite a large difference between the 40 and 50 L/min air flow rates. In this region the longer penetration length of the 40 L/min air flow rate may create a larger area that has a stronger relative velocity. And this fact may lead to an increase in the capture efficiency.

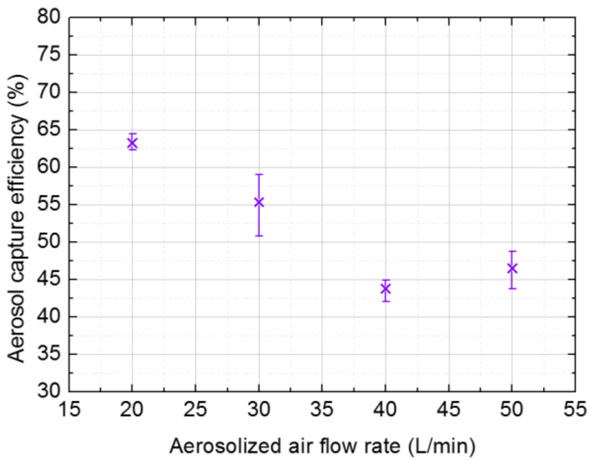
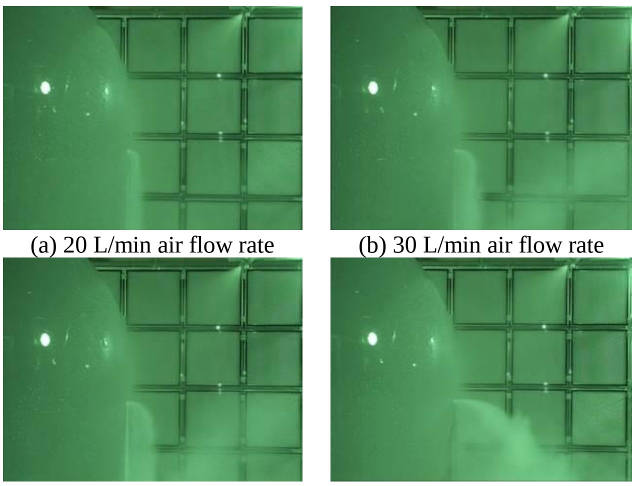


Fig. 4. Graph for aerosol capture efficiencies as a product of air flow rate



(a) 20 L/min air flow rate (b) 30 L/min air flow rate

(c) 40 L/min air flow rate (d) 50 L/min air flow rate

Fig. 5. Experimental pictures for air flow rate

3.2 Spray flow rate

Figure 6 explains the relationship between the capture efficiency and spray flow rate. The air flow rate was fixed at 40 L/min in these experiments. In these experiments, the foam solution and tap water were sprayed separately to evaluate their capture efficiency. At a 2.0 L/min spray flow rate, the foam solution and tap water have minimum capture efficiencies. The capture efficiency of tap water has the local maximum value at 3.0 L/min. This may occur because the situation, is similar to that in section 3.1, which occurred due to the longer penetration length.

Figure 7 (a) ~ (f) depicts the penetration length decreased following an increase in spray flow rate. In tap water cases, the penetration length decreased quite sharply compared with the foam solution cases. However, there was little difference between the 3 and 4 L/min spray flow rates for the foam solution cases. This occurred as the foam solution was more atomized than tap water and the tinier droplets may affect the fluid flow field less than the bigger droplets.

All capture efficiencies for the foam solution were higher values than for tap water at same spray flow rate. The foam solution had better capture efficiencies since it has half the surface tension of tap water, and the lower surface tension leads to more atomize droplets. The smaller droplets had less of an effect in transferring momentum to fluid flow field, and covering a larger area for spray capture than bigger droplets. Finally, the smaller droplets have a larger projection area. These factors may lead to the improved capture efficiency.

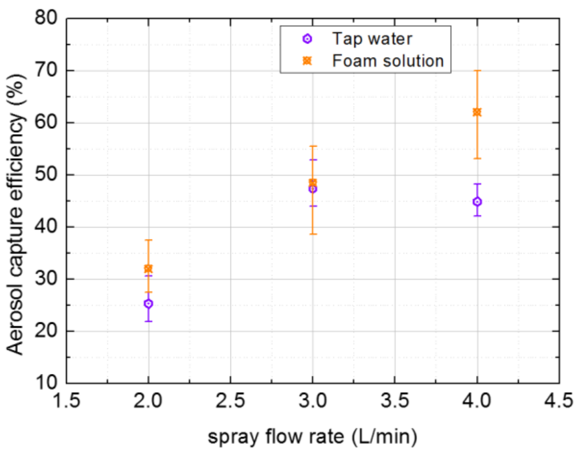
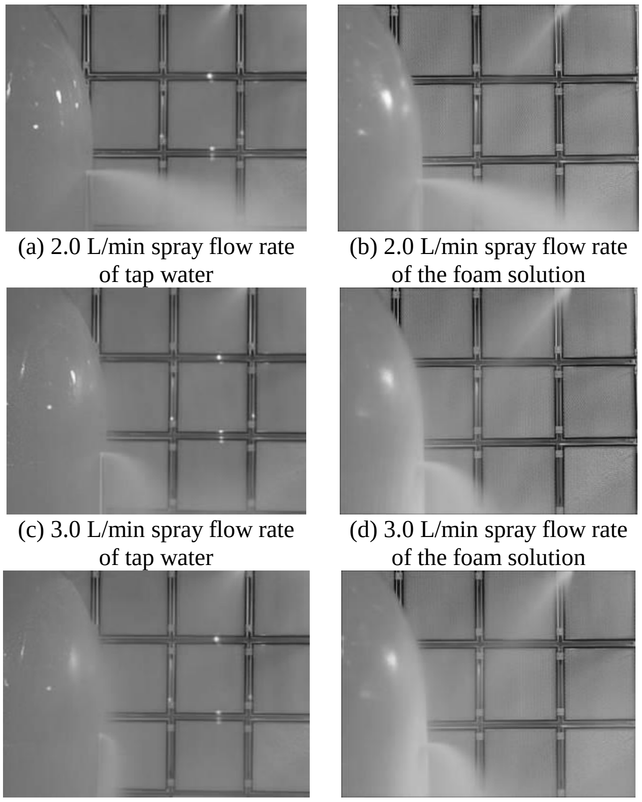


Fig. 6. Graph for aerosol capture efficiencies as a product of spray flow rate of tap water and foam solution



(a) 2.0 L/min spray flow rate of tap water
(b) 2.0 L/min spray flow rate of the foam solution
(c) 3.0 L/min spray flow rate of tap water
(d) 3.0 L/min spray flow rate of the foam solution
(e) 4.0 L/min spray flow rate of tap water
(f) 4.0 L/min spray flow rate of the foam solution

Fig. 7. Experimental pictures for spray flow rate of tap water and the foam solution

4. Conclusions

In this study, the capture of airborne aerosols was explored external to the reactor (reactor release). The experimental setup was built and experiments was performed to evaluate the capture of airborne aerosols changing air and spray flow rate with tap water and a foam solution. The conclusions are as follow:

1. An increase in liquid-to-gas ratio leads to an improvement in the capture efficiency in most cases. There were two exceptions. In these cases, the relative velocity between droplets and aerosols appeared to have a greater but temporary effect on the capture efficiency when compared to the effect of the liquid-to-gas ratio.
2. The foam solution has a more effective capture efficiency. This occurred since the foam solution is more atomized due to lower surface tension than tap water.
3. The reason more atomized droplets were more effective capture efficiency is that smaller droplets less transfer of momentum to fluid flow and greater the relative velocity.

Based on this study, future work will consider variables such as freestream flow (like sea breeze) and scaling methodology to further define the design of a full scale spray system.

REFERENCES

[1] L. Baker, J.K. Fink, R. Simms, B.J. Schlenger, J.E. Herceg, Source Term Experiments Project (STEP): A summary: Final report, Argonne National Lab., IL (USA), Mar 1, 1988.
[2] Source Term Uncertainties: Recent Developments in Understanding Fission Product Behavior. OECE Nuclear Energy Agency. NEA/CSNI/R(92)2. 1992.
[3] M.F. Hessheimer, R.A. Dameron, Containment Integrity Research at Sandia National Laboratories, Division of Fuel, Engineering & Radiological Research, Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission, 2006.
[4] I. Younus, M.S. Yim, Aerial spraying to capture released radioactivity from NPP in a severe accident, Korean Nuclear Society Spring Conference Meeting, May 11-13, 2016.
[5] M.W. Sulek, T. Wasilewski, K.J. Kurzydłowski, The effect of concentration on lubricating properties of aqueous solutions of sodium lauryl sulfate and ethoxylated sodium lauryl sulfate, Tribology letters, Dec 1, 2010;40(3) 337-45.