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Effect of pool height and injection gas flow rate on aerosol particle removal in pool scrubbing

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1. Introduction

In a nuclear power plant, radioactive material can be released in a severe accident that melts the core. These substances mix with steam and non-condensable gases and behave in the form of aerosols. In the case of radioactive materials in the form of aerosols that may leak into the environment, they can be physically decontaminated by passing them through a water pool, which is called 'pool scrubbing. Aerosol removal by pool scrubbing acts as a factor that greatly affects the reduction of the source term in a severe accident. Removal of radioactive material through pool scrubbing in nuclear power plants can occur in a number of situations. For example, radioactive material can be removed by passing through a water pool in the containment building (Pressurizer relief tank, steam generator secondary side) [1]. It is also used in containment filtered venting system (CFVS) for decompression and removal of radioactive materials. Evaluating the removal effect of radioactive materials through pool scrubbing is crucial in evaluating the source term. A number of experimental studies have been conducted to evaluate the factors affecting pool scrubbing. However, these experimental results show a large difference due to different experimental environments, experimental systems, and experimental conditions. Therefore, a pool scrubbing facility was prepared to perform various experiments while maintaining the consistency of the experimental environment and experimental system. In this study, experiments were performed to evaluate the effect of pool height and injection gas flow rate on pool scrubbing efficiency. In addition, performance verification of POSCAR, a pool scrubbing code, was performed using these experimental data.

2. Methods and Results

2.1 Pool scrubbing facility

An experimental facility was built to evaluate the decontamination factor of the water pool under various conditions, and the schematic diagram of the pool scrubbing facility was shown in Fig. 1. The main system of the test facility is largely composed of an aerosol generator, a test water pool, and an aerosol measurement system. The test pool has a width/ length/ height of 1000 mm/ 1000 mm/ 1600 mm, respectively, and polycarbonate visualization windows are attached to the front and rear surfaces of the test pool to observe bubble behavior. The gas supply system includes a line supplying the test fluid air, a mass flow controller for flow control, a flow meter and pressure gauge, and a thermometer for measurement. As a method of generating an aerosol, air is passed through an aerosol generator (Solid particle generator, TSI9309) to make air containing aerosols. The aerosol measuring device mainly performs measurement with a filter and an optical device (optical particle sizer, TSI OPS3330). The aerosol measuring device mainly performs measurement with a filter and optical device (Optical particle sizer, TSI OPS 3330). The filter measures the aerosol mass and concentration. The optical particle sizer measures the size distribution of aerosol particle and the number concentration of the injected aerosol particles near the entrance to the pool.

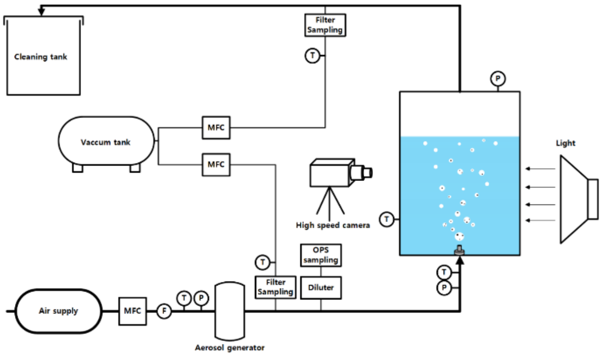

Fig. 1. Schematic diagram of pool scrubbing experimental facility.

2.2 Experimental test matrix

The experimental conditions for evaluating the aerosol removal effect according to the pool height and the injection flow rate are shown in Table I. The aerosol particle used in the experiments was 0.7μm spherical Silicon dioxide, and experiments were performed in a water pool under room temperature and atmospheric pressure conditions. The inner diameter of the injection nozzle used in the experiment was 5mm, and the injection gas was air. Decontamination factors were calculated by comparing the weight of the aerosol using filters installed at the front and rear parts of the pool.

Table I: Experimental test matrix

Test No.	Air flow rate (kg/h)	Pool depth (m)
LP-JF-5mm	21	0.3
MP-JF-5mm	21	0.5
DP-JF-5mm	21	1.0
MP-JF2-5mm	11	0.5
MP-JF3-5mm	34	0.5

2.3 Pool scrubbing code calculation algorithm

Pool scrubbing calculations were performed using the POol SCrubbing Aerosol Removal code (POSCAR) [2]. The code calculation algorithm initially discretized the bubble size distribution and the aerosol size distribution. Then, depending on the injection conditions, it is checked whether it forms globule or starts with broken bubbles. When forming a globule, the code calculates the thermos-hydrodynamic properties of the globule and uses the information about the aerosol to calculate the DF due to jet impaction and condensation occurring in the injection area. After that, the DF is calculated from the rising globule, and when the globule breaking condition is reached, the thermodynamic properties of the broken bubble group are calculated. Then, the DF is calculated from the rising broken bubble group, and the total DF is calculated using all these DFs. The code calculation algorithm is shown in Fig. 2, and the total DF can be obtained as Equation 1.

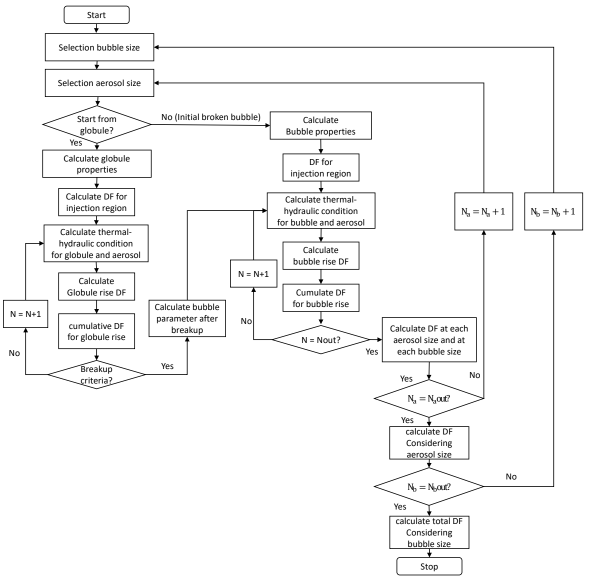

Fig. 2. Pool scrubbing code (POSCAR) calculation algorithm.

$$DF_{tot} = DF_{jet} \times DF_{con} \times (DF_{GR}) \times DF_{SR} \qquad (1)$$

2.4 Pool scrubbing experimental results

The experiments with respect to pool height were performed as shown in Fig. 3, and the DF for this is shown in Fig. 5. According to the experimental results, it was shown that the higher the pool height, the better the aerosol removal occurred. This is because the residence time of the bubbles increases with pool height. Experiments with the gas injection flow rate were conducted as shown in Fig. 4, and the DF results were shown in Fig. 6. From the experimental results, the removal of aerosol particles occurred more as the injection flow rate increased. In particular, in the case of injection flow rate of 34 kg/h, it was confirmed that DF increased very rapidly compared to other conditions, which can be predicted due to the effect of jet impaction. In the case of the 34 kg/h experiment, the DF was about 77~ 260, which was a bigger difference than expected, which is thought to be because the downstream sampling mass is very sensitive in determining the DF.

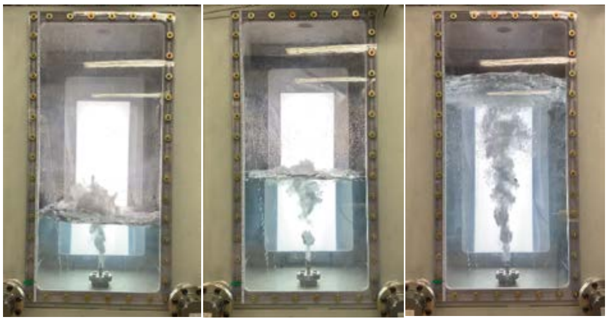

Fig. 3. Pool scrubbing experiments with pool height.

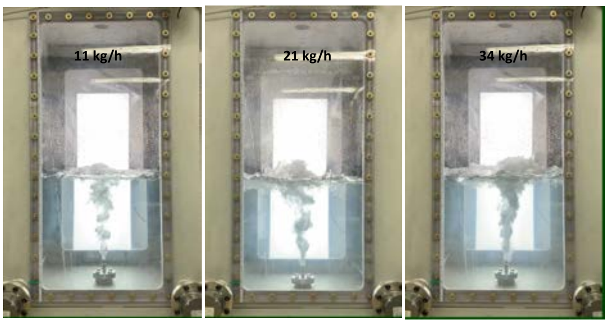

Fig. 4. Pool scrubbing experiments with injection gas flow rate.

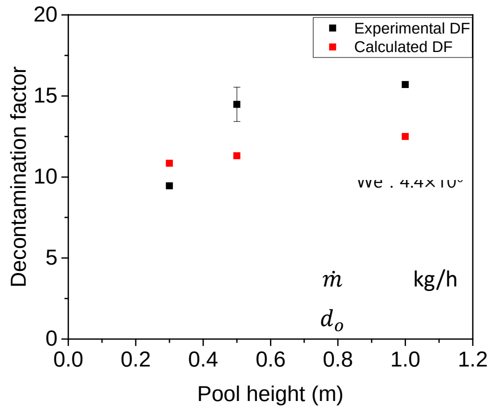

Fig. 5. DF results with pool height.

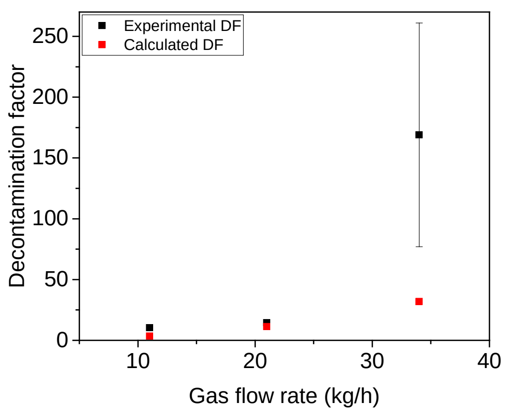

Fig. 6. DF results with injection gas flow rate.

2.5 Pool scrubbing code calculation results

In the code calculation results, the removal of aerosol increased, as the pool height increased as shown in Fig. 5. This is because the bubble residence time increases as the pool height increases, as shown in Fig 7. On the other hand, since all conditions other than the pool height are the same, the aerosol removal due to jet impaction was similar ,as shown in Fig. 8. The calculation results that the removal efficiency increases as the pool height increases are the same as the trend of the experimental results. The code calculation results with gas injection flow rate is shown in Fig. 6. The calculation results showed that the DF increased as the gas injection flow increased. When the injection flow rate increases, the residence time decreases, as shown in Fig. 9. However, the influence of this residence time was insignificant compared to the jet impaction as shown in Fig. 10. The peculiarity of the experimental results and calculation results was what when the injection flow rate was 34 kg/h, the code calculation DF had a much smaller value than the experimental results. The possible reason for showing this result is that the highest DF in the code by jet impaction is assumed to be 50. Therefore, it can be judged that the actual removal of aerosol particles due to jet impaction may be underestimated in the code.

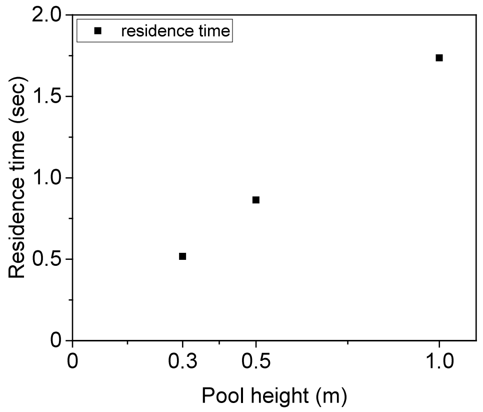

Fig. 7. Residence time calculation results with pool height.

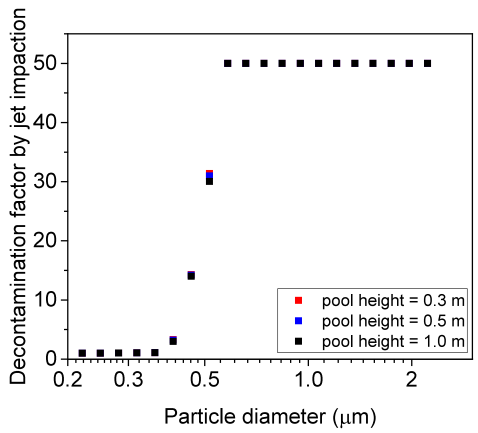

Fig. 8. DF by jet impaction with pool height.

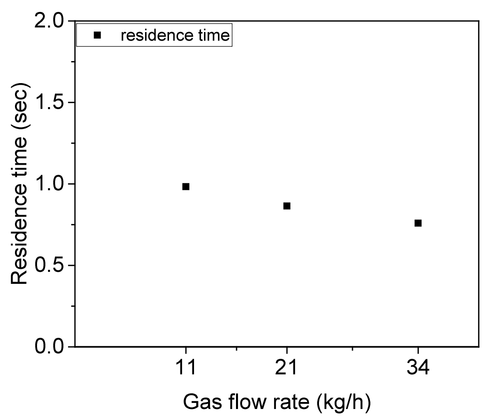

Fig. 9. Residence time calculation results injection gas flow rate.

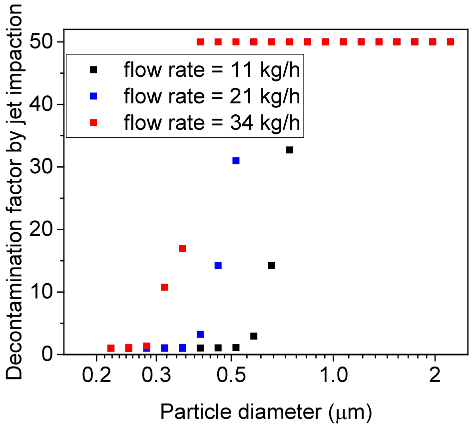

Fig. 10. DF by jet impaction with injection gas flow rate

3. Conclusions

Pool scrubbing experiments were performed for pool height and injection gas flow rate. As a result of the experiments, the DF increased as the height of the pool increased. This is judged to be influenced by the residence time. Regarding the pool height, the code results showed a similar trend to the experimental results. Second, as a result of the experiments on the gas flow rate, the DF increased as the injection flow rate increased. This is predicted by the effect of jet impaction. Regarding the injection flow rate, it showed a similar trend to the code results, but under the condition of 34 kg/h, the code results predicted the experimental results very low.

4. Acknowledgments

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