Aerosol Retention Test in Dry Steam Generator during Steam Generator Tube Rupture Accident Condition

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1. Introduction

Nuclear safety act was amended in 2015, now specifically providing a regulatory framework for accident management plans to include severe accidents [1]. Accident management plans for all operating nuclear power plants in Republic of Korea were submitted by 2019. Under the circumstance, containment bypass accident has become one of the important accident should be considered because a consequence of the accident is serious. Steam generator tube rupture (SGTR) accident is a representative containment bypass accident, and it is necessary to study on the radionuclides behavior inside the steam generator in order to evaluate the amount of fission product in environment during SGTR accident accurately. Comprehensive experimental and analytical studies on aerosol behavior inside steam generator during SGTR accident had been conducted in European Union 5th Framework Program and ARTIST international collaborative project [2, 3]. In the study, experimental facility reflecting the geometrical properties of the steam generator in the domestic nuclear power plants was designed and established. Experimental results with short tube bundle in dry condition are presented in this study.

2. Experimental Facility

Experimental facility consists of several parts, gas supply system, aerosol generation/sampling systems, steam generator mockup, and cooling system, as shown in Figure 1. Air compressor supply main stream gas to simulate the flow through steam generator break path, and the flow rate is controlled with using control valve and flow meter. Steam boiler was also employed to increase the air temperature, and heat transfer from steam to air occurred at steam heater. The steam heater could not be sufficient in some cases, so auxiliary air heater was also used. All pipes in the facility were equipped heating system with insulation. The gas supply system also had been used in FCVS experiment performed in KAERI previously [2]. In order to simulate aerosol type radionuclides, non-toxic SiO_2 particle was used in the experiment. Aerosol generation and sampling system were designed to produce a required aerosol mass concentration during experiment and to measure the concentration accurately. In case of the aerosol sampling system, filter measurement method was mainly used with glass fiber filter and mass flow controller to regulate an inhaled gas flow rate through a sampling nozzle [5]. Additionally, aerosol size distribution was also measured with Electrical Low Pressure Impactor (ELPI) and diluters. Steam generator vessel was installed to consider steam generator geometrical design of domestic operating nuclear power plant (Optimized Power Reactor: OPR1000). Scaling analysis had been conducted taking account of major aerosol removal mechanism during SGTR accident condition and conservative point of view, the diameter and height of vessel were determined to 0.6 m and 8.2 m, respectively. The geometry and layout of the steam generator tubes followed the real diameter and pitch in order to reflect the major aerosol removal mechanism such as impaction and turbulent deposition in reality.

3. Experiment Results

Schematic of short tube bundle test in dry condition for aerosol retention on tubes is shown in Figure 2. The test results in dry condition with thermal hydraulic conditions are summarized in Table 1. Total five tests were conducted and the tests were performed in two different days with different test name, ADB01 and ADB02. Gas flow rates were varied from 0.169 kg/s to 0.173 kg/s. Aerosol sampling duration was 1,800 s in

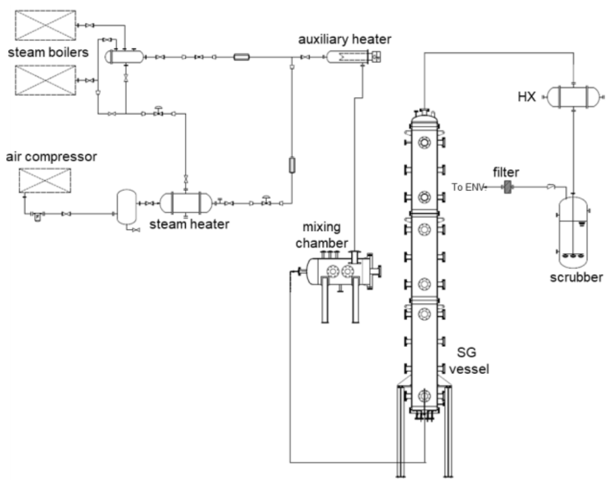

Figure 1 Schematic of experimental facility for aerosol retention test

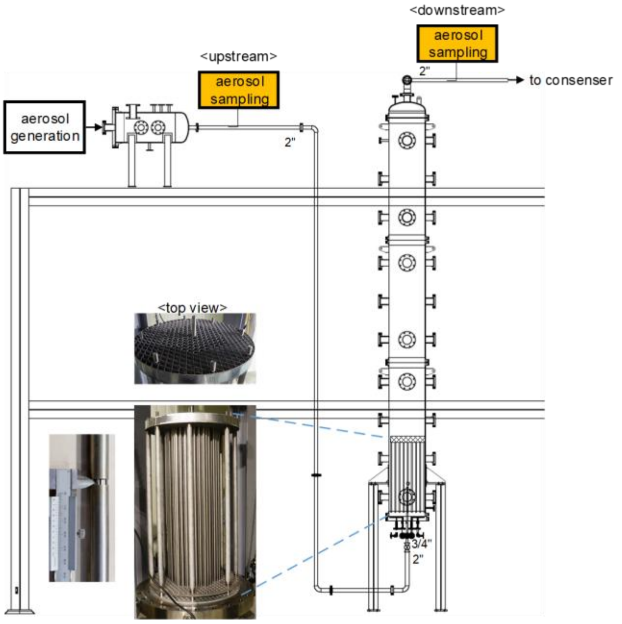

Figure 2 Schematic of short tube bundle test with aerosol sampling position

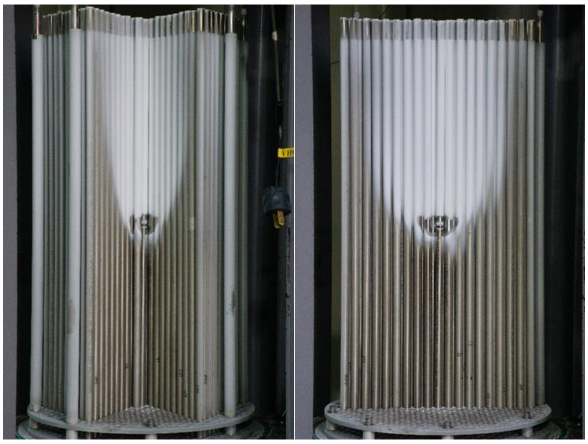

Figure 3 Pictures of tube bundle after finishing ADB01 test

both sampling positions.

As the experimental results shown in the Table 1, decontamination factors of all cases were located between 3.6 and 8.2. Pictures of short tube bundle after conducting ADB01 experiment were presented in Figure 3. It was found that upper part of the tube above steam generator break path mostly contributes to aerosol deposition. Main flow was developed to upper direction because there was an open path on top of steam generator shell, that could be occurred in a real operating plant with main steam safety valve (MSSV) stuck open or atmospheric dump valve (ADV) open conditions. Moreover, aerosol deposition was not observed in some portion of tubes near the broken tube where the aerosol was directly impacted, due to aerosol resuspension with high gas flow rate. Flaws and scars were observed in the closest tubes from the broken tube,

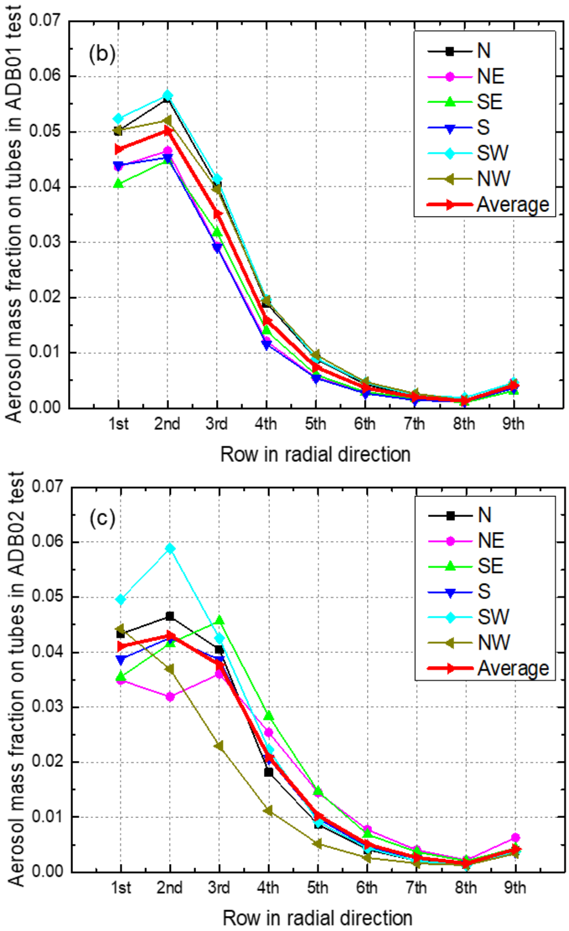

Figure 4 Aerosol mass fraction deposited on tubes (a) ADB01 test (b) ADB02 test

Table 1: Experiment results with thermal hydraulic conditions

Test name.	Case	Gas flow rate (kg/s)	Pressure at Mixing chamber (bar(a))	Gas temperature (oC)	Sampling time (s)	Aerosol concentration at upstream (mg/m3)	Aerosol concentration at nozzle (mg/m3)	DF
ADB01	1	0.173	6.85	175	1800	322.3	75.2	4.3
	2	0.173	6.85	175	1800	391.3	93.1	4.2
	3	0.173	6.85	175	1800	171.2	47.4	3.6
ADB02	1	0.169	6.9	175	1800	132.1	16.2	8.2
	2	0.169	6.9	175	1800	374.2	83.7	4.5

and it was confirmed that there was an impaction of aerosol to peripheral tubes.

Aerosol mass deposited on the tubes were measured after finishing the ADB01 and ADB02 tests, and the results are indicated in Figures 4. Representative six

axes were selected in north, north east, south east, south, south west, and north west directions. Aerosol mass fraction on tubes in each direction were obtained by dividing with total deposited mass. Figure 4 (a) and

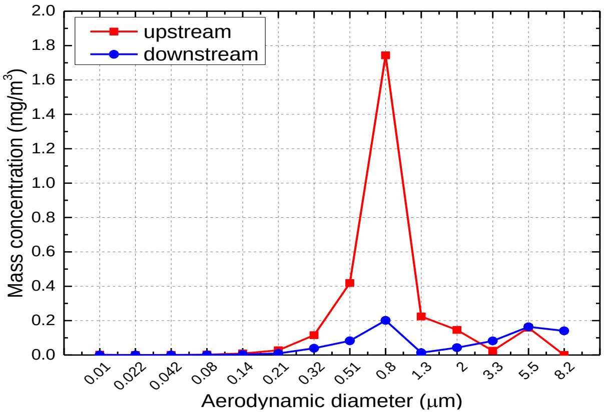

Figure 5 ELPI measurement result for case 2 in ADB02 test

(b) indicate the aerosol mass fraction on tubes in the ADB01 and ADB02 test with average value, respectively. Total mass deposited on the tube bundle was calculated with using the average value and the number of tubes, and it was found in both tests that about 80% of deposited aerosol would be stored within fifth row tubes from the broken tube. As shown in the

Figures 4 (a) and (b), the aerosol deposition mass on first row tube closest to broken tube were smaller than second tube because of resuspension of aerosol and the results correspond with the Figure 3.

In the case 2 of ADB02 test, Electrical Low Pressure Impactor (ELPI) was applied to confirm the aerosol concentration with size at the aerosol sampling points, and mass concentration measured at the upstream and downstream are shown in Figure 5. The graph in the Figure 5 used aerodynamic diameter of aerosol, and the aerodynamic diameter of particle used in the experiment was calculated to about 0.95 μm considering density of SiO_2. Peak of mass concentration at the upstream was observed nearby the corresponding diameter of used particle. The mass concentration at the downstream was decreased and small peak was observed at the same particle size. The decontamination factor was evaluated to 3.69 with using mass concentration in all sections of the ELPI data.

4. Conclusion

Experimental facility for evaluating aerosol retention inside steam generator of domestic nuclear power plant was installed. Geometrical properties of real plant were reflected to the facility in order to consider major aerosol removal mechanism during SGTR accident condition. Decontamination factors were presented in dry and flooded conditions, as an initial result. In addition, aerosol behavior inside steam generator was evaluated with analyzing the deposited mass on the tubes and ELPI result. More experiments will be followed with a long tube, separator and dryer.

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