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Preliminary Calculation of Aerosol Removal Rate inside Experimental Facility pipes

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1. Introduction

Steam generator tube rupture (SGTR) accident is one of the most important accident scenarios should be considered to ensure regulations on the severe accident in Korea. There are a lot of studies on the SGTR accident probability to increase a safety of nuclear power plant [1,2]. In case of ARTIST project, experiments had been conducted to evaluate the aerosol removal rate inside steam generator with or without water, and decontamination factors were found with conducting separate and integrate test [3]. In order to evaluate risk of fission product during SGTR accident with domestic steam generator, steam generator experimental facilities were installed in KAERI, and aerosol experiments have been conducted to understand the amount of removed aerosol inside steam generator [4]. In order to evaluate the aerosol decontamination factor inside steam generator accurately, it is necessary to understand the aerosol removal rate in the experimental facilities, such as pipes. In the study, preliminary calculations were performed to understand the aerosol removal rate inside the experimental facilities using calculation tools.

2. SGTR Experiment

2.1 General description

SGTR experimental facilities in KAERI were installed, and a lot of aerosol experiments have been performed. General system is shown in Fig. 1. It consists of gas supply system, aerosol generation/sampling system, SGTR vessel, and cooling system. The gas supply system includes steam boiler, air compressor, liquid nitrogen tank and steam heater. In the aerosol experiment, aerosol was added to the gas in the mixing chamber that is connected to aerosol generation system. Properties of aerosol, such as aerosol size distribution, mass concentration were measured using aerosol sampling system (Fig. 2) right after adding the aerosol. The gas including aerosol goes to the SGTR vessel and some portion of aerosol removed inside the vessel. The gas was released to environment after passing cooling and filtering system.

2.2 Aerosol loss in pipes

Although the properties of aerosol are measured with aerosol sampling system, it could have uncertainty. This is because that the aerosol measuring point is not the same position of the decontamination calculation point. The measuring point of aerosol mass concentration is right after the mixing chamber, but the aerosol mass concentration right before the entrance of SGTR vessel is necessary to calculate decontamination factor exactly. Thus aerosol loss calculation should be preceded in the pipe between the aerosol measuring point and the SGTR vessel entrance. In addition, aerosol sampling system also contains aerosol loss uncertainty. As indicated in the Fig 2, the aerosol sampling system also have pipe lines and it means that aerosol loss also could occurred in the pipes. In this reason, the aerosol loss calculation is essential to increase the reliability of the experiment results.

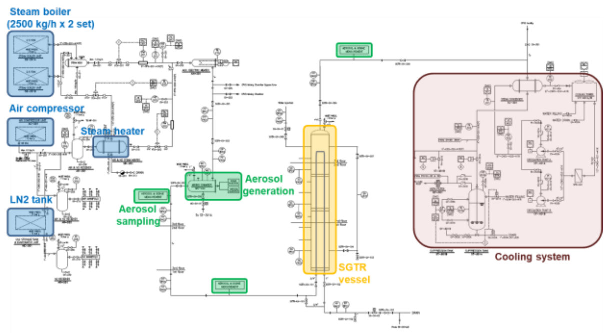


Fig. 1. Aerosol experimental facility in KAERI

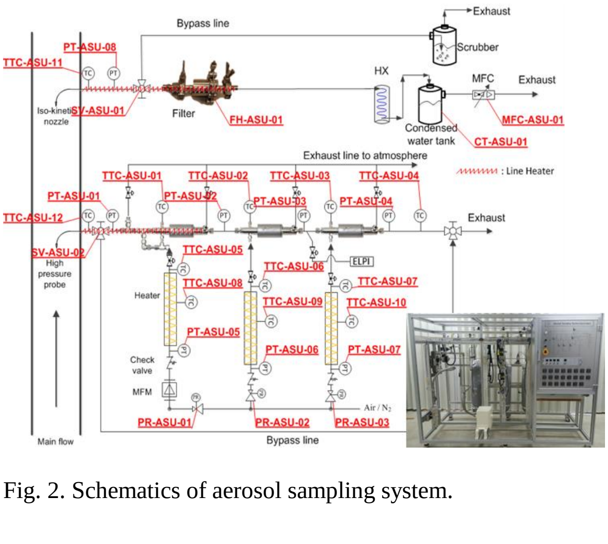


Fig. 2. Schematics of aerosol sampling system.

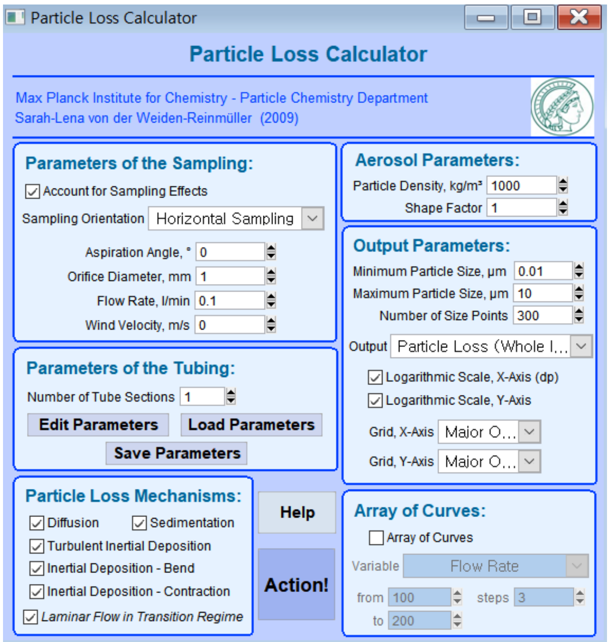
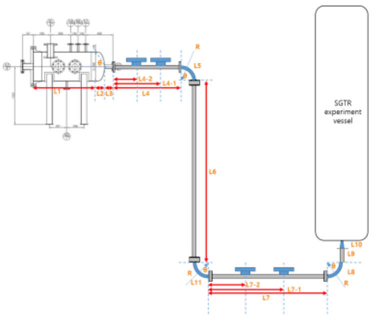


Fig. 3. Main parameters of particle loss calculator.



region	Length(mm)	Dia. (mm)	Angle(°)	Curvature
L1	1000	496	58	-
L2	229	-	-	-
L3	140	52.5	-	-
L4	L4-2 : 564	52.5	-	-
	L4-1 : 964		-	-
	L4 : 1325		-	-
L5	108	52.5	90	69
	157			100
	206			131
L6	7050	52.5	-	-
L7	L7-2 : 570	52.5	-	-
	L7-1 : 1170		-	-
	L7 : 1870		-	-
L8	108	52.5	90	69
	157			100
	206			131
L11	108	52.5	90	69
	157			100
	206			131

Fig. 4. Geometrical information of SGTR facility.

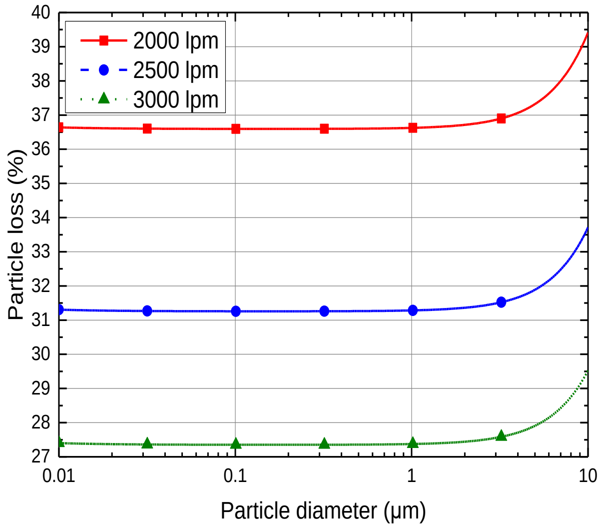


Fig. 5 Particle loss with changing flow rate.

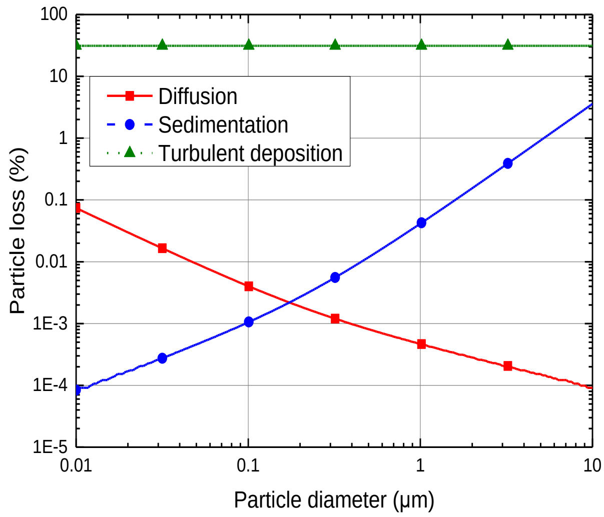


Fig. 6 Particle loss mechanisms.

Table 1 Thermal hydraulic conditions of SGTR experiment

Variables	Value
Flow rate	0.2 kg/s
Gas species	Nitrogen
Pressure	6 bar(a)
Temperature	423 K
Gas density	4.7698 kg/m^3

3. Aerosol Loss Calculation

To calculate aerosol loss inside pipes, commercial particle loss calculate was used, Igor Pro 6.37 [5]. The tool usually used to quickly determine aerosol sampling efficiency and particle transport losses due to passage through arbitrary tubing systems. The software employs relevant empirical and theoretical relationships found in established literature and accounts for the most important sampling and transport effects The software treats non-isoaxial and nonisokinetic aerosol sampling, aerosol diffusion and sedimentation as well as turbulent inertial deposition and inertial deposition in bends and contractions of tubing. The main properties need to insert to calculate aerosol loss are indicated in Fig. 3, which is window of Igor Pro software.

To use the software, geometrical information of the experimental facilities should be inserted including pipe inner diameter, length, bend. In addition, thermo-hydraulic conditions are also necessary, such as gas temperature, velocity, species. Aerosol information also should be considered, aerosol species, size, density. All data required to conduct calculation has been collected and it would be reflected in the aerosol loss calculation.

4. Preliminary Results

4.1 Boundary conditions

In order to calculate the aerosol loss inside SGTR facility, it is necessary to reflect the geometry of the facilities, and it is indicated in Fig. 4. In addition, major thermal-hydraulic conditions that was used as experiment conditions were also considered, and it is summarized in Table 1.

4.2 Results

It is expected that the software is optimized for measuring the amount of aerosol remained in the SGTR experimental facilities, pipes. Preliminary calculations have been conducted by changing one of the main parameters, flow rate inside pipe. In the sensitivity calculation, flow rates were set from 2000 lpm to 3000 lpm, and the calculation result was shown in Fig. 5. It was found that particle loss increased in the case of small flow rate. In case of particle size of 0.7 μm, about 36.5% of aerosol would be removed in flow rate of 2000 lpm inside the SGTR experiment pipes. On the other hand, about 27.5% of aerosol would be eliminated in flow rate of 3000 lpm. The contribution of each aerosol removal mechanism was found, and it is indicated in Fig. 6. As indicated in the Fig. 6, major factor to affect the aerosol loss in the flow regime is turbulent deposition loss. The turbulent inertial deposition is the inertial deposition loss of large particles due to the curved streamlines (eddies) in a turbulent flow. Large particles cannot follow the streamlines due to their high inertia and are deposited on the walls of the tube [5]. Transport efficiency equation considering turbulent inertial deposition is shown below. Q is flow rate, L is pipe length, d is pipe diameter, and V_t is turbulent inertial deposition velocity.

$$\eta_{\text{turb inert}}(d_a) = \exp\left(-\frac{\pi d L V_t}{Q}\right)$$

$$V_t = \frac{(6\times10^{-4}(0.0395\ Stk\ Re^{3/4})^2 + 2\times10^{-8} Re)U}{5.03\ Re^{1/8}}$$

From the above equation, the transport efficiency is in proportion to the flow rate. Thus particle loss from turbulent deposition decreased in case of high flow rate.

5. Conclusion

Preliminary calculation with Igor Pro was conducted and simple sensitivity calculation was also performed. Expected results were obtained and it is confirmed that the calculation tool could be used in the aerosol loss calculation in the KAERI’s experiment. Next step is that sensitivity calculation will be performed with considering other uncertain factors to find out the effect of the factors. After that, aerosol loss in aerosol sampling system also will be followed.

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