Experimental research on aerosol decontamination performance of the filtered containment venting system in ARIEL test facility

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1. Introduction

The containment of nuclear power plant should be able to withstand during severe accident in order to prevent the release of radioactive fission product into environment. The molten corium, in case of core melt accident, may generates fission products, steam, hydrogen and non-condensable gases by interaction with reactor vessel, concrete pit, core catcher and coolant[1,2]. Consequently, the aerosol concentration and the pressure inside the containment increases and the containment may be threatened.

Filtered containment venting is one action to prevent an uncontrolled release of radioactive fission products caused by an overpressure failure of the containment[3]. Filtered containment venting system releases the high temperature and pressure gas from the containment into the environment and mitigates release of radioactive fission product. After the Fukushima-Daiichi accident which was demonstrated the containment failure, many countries to consider the implementation of filtered containment venting system on nuclear power plant where these are not currently applied[4]. The reactors in Korea (19 PWR, 4PHWR) are planned to be installed the filtered containment venting system.

In this study, the evaluation for aerosol removal performance of the filtered containment venting system is verified by the experiments with various thermal-hydraulic conditions such as pressure, flow rate and gas composition. In general decontamination factor, which is yield from aerosol mass concentrations at inlet and outlet of the filtered containment venting system, is used to show the aerosol removal performance[5]. This study presents the decontamination factors of aerosol removal experiments in various thermal-hydraulic condition. Experiments are conducted with the full height filtered containment venting system test facility called Aerosol Removal & Iodine Elimination(ARIEL) at Korea Atomic Energy Research Institute(KAERI).

2. Methods and Results

2.1 Design features of the FCVS

The main concept of the Korean filtered containment venting system is combination of wet and dry filtrations. It consists of venture scrubbers, cyclones, metal fiber filter, molecular sieve. A comprehensive review for the Korean filtered containment venting system can be found in Song. Et al.(2016)[1].

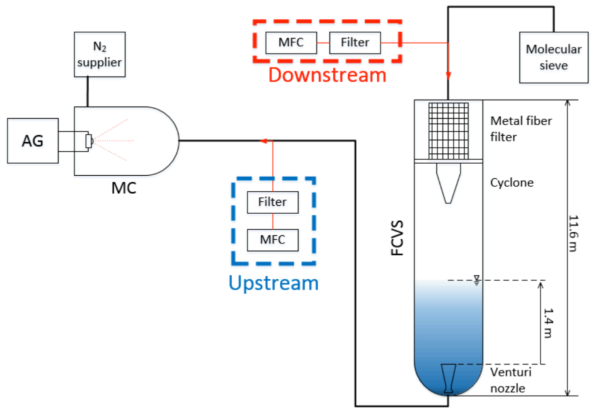

Fig. 1. Schematic of AREIL facility set for aerosol removal test showing locations for aerosol generation and measurements.

In summary for aerosol removal process in the FCVS, while the mixture gas including aerosols passes the venturi nozzle, most of the aerosols are removed in the pool due to impaction occurred between the gas and the droplet. Following the gas passing the pool, the cyclone screens entrained water droplets which contain aerosols in its and the metal fiber filter removes tiny aerosols and droplets.

2.2 Aerosol removal test on ARIEL

Figure 1 shows schematic of ARIEL test facility set for aerosol removal test. Aerosol is generated by air atomizing nozzle in the mixing chamber. For an aerosol, well-shaped spherical SiO_2 (0.7 µm of diameter) is used[6]. The suspension of SiO2 in the ethanol is atomized by nitrogen gas and the ethanol evaporated in the mixing chamber to generate the aerosols.

Aerosol mass concentration is measured with filter method. The filter measurements are conducted at upstream and downstream within the isokinetic sampling condition. Aerosol is collected on glass fiber filter (GF/F 47 mm, Whatman), which were mounted on a specially made stainless steel filter holder. The isokinetic sampling condition is achieved by controlling the inhalation flow rate with the mass flow controller through the isokinetic sampling probe(DEKATI). In case of the mixture gas that contains steam, steam is collected as condensed water by using the heat exchanger to measure sampling volume. The mass of collected aerosols is weighted by micro-balance (XP6, Mettler Toledo).

Table 1 Thermal-hydraulic conditions for aerosol removal tests

#	1	2	3	4	5	6
Total flow rate (kg/s)	0.07	0.21	0.29	0.08	0.14	0.20
N2 flow rate (kg/s)	0.07	0.21	0.29	0.04	0.07	0.11
Steam flow rate (kg/s)	-	-	-	0.04	0.07	0.10
Pressure (bar)	2.00	4.94	7.05	3.01	5.01	6.98
Gas temperature (oC)	140	135	150	160	165	170

Table 2 Aerosol mass concentrations and decontamination factors with various thermal-hydraulic conditions

	N2 gas					
#	1		2		3	
location	upsteam	downsteam	upsteam	downsteam	upsteam	downsteam
sampling flow rate (lpm)	5.48	4.95	16.85	39.19	17.39	24.38
sampling period (s)	1799	2550	9614	9612	7498	7497
accumlated aerosol mass (mg)	99.72	<0.01	341.05	<0.01	309.62	<0.01
aerosol concentration (mg/m3)	606.89	<0.05	126.32	<0.0016	142.49	<0.0033
Decontamination factor, DF	> 12000		> 78000		> 43000	
	N2 + steam mixture gas					
#	4		5		6	
location	upsteam	downsteam	upsteam	downsteam	upsteam	downsteam
sampling flow rate (lpm)	2.17	3.05	3.92	5.91	5.84	8.19
condensated water mass (kg)	1.43	0.85	0.85	0.95	1.83	1.18
sampling period (s)	14664	14664	11139	11138	10923	10920
accumlated aerosol mass (mg)	3876.65	<0.01	511.59	<0.01	274.03	<0.01
aerosol concentration (mg/m3)	1189.98	<0.008	236.94	<0.0037	156.67	<0.0052
Decontamination factor, DF	> 149000		> 63000		> 30000	

2.3 Thermal-hydraulic conditions

Six aerosol removal experiments were conducted within different thermal-hydraulic conditions. Table 1 is summarized the flow rate for nitrogen and steam, pressure at the inlet of FCVS, and gas temperature. Case 1 – 3 used only nitrogen gas which simulates non-condensable gas in severe accident. Case 4 – 6 are conducted with steam and nitrogen mixture gas with 1:1 mass flow rate. To verify the aerosol decontamination performance with various pressure conditions, three different pressure condition were tested. The temperature of gas is set above the saturated vapor temperature corresponds to each pressure in order to avoid condensation at the pipe.

2.4 Aerosol decontamination factor

Decontamination factor is the ratio of the aerosol mass concentrations at upstream and downstream. Table 2 is summarized sampling flow rate, condensed water mass, sampling period, measured aerosol mass on the filter, aerosol mass concentration at upstream and downstream and decontamination factors. In all cases, at the downstream, the aerosol mass was not measureable due to limitation on microbalance even though the aerosol mass concentration at the upstream is high enough. Therefore, the decontamination factors that determined in this study are influenced by the aerosol mass concentration at the upstream and sampling volume at the downstream.

3. Conclusions

This paper presents an experimental investigation for aerosol removal performance of the filtered containment venting system with various thermal hydraulic conditions. Decontamination factor determined by filter measurement for the FCVS is above 10,000.

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