Thermal Hydraulic Analysis for CFVS Depending on Outlet Orifice Size

J. W. Lee [a*], H. S. Kim [a], W. S. Kim [a]
[a] *R&D Center, BHI Co., LTD., 122, Janngbaek-ro, Gunbuk-myeon, Haman-gun, Gyeongsangnam-do, Korea*
[*] *Corresponding author: jwlee@bhi.co.kr*

1. Introduction

In the case of a severe accident at a nuclear power plant (NPP), Containment venting, mass removal from the containment, as an effective mitigation measurement of over pressurization, can prevent the containment from uncontrolled failure [1,2,3,4]. Containment Filtered Venting System (CFVS) is one action that can be used to protect the containment and the facility while mitigating radioactivity releases to the environment [5]. The Containment Filtered Vented System (CFVS) is installed in nuclear power plant to protect the integrity of containment building against the over pressurization and to remove fission products which are in aerosol from the fuel into the containment during severe accidents. The presently considered filtration system is a wet system for which some general specification of design criteria can be exposed:

(a) The pressure in the containment will be reduced from approximately the design pressure to half of that value before 24hr [6].

(b) At least, the CFVS must contain enough scrubbing water to cover the so called “autarky time”, which is usually defined at 72 hours venting operation without any refurbishment. The permanently installed reserves of scrubbing water pool additives on site shall allow for a CFVS autonomy after the accident initiating event. For that reason the scrubbing water pool is essential for the robust process by providing safe decay heat transfer (cooling by evaporation) and highest aerosol loading capability for applications with high decay heat requirements.

For Korea OPR-1000 pressurized water reactor NPP, the CFVS is designed with venturi scrubber’s wet type and metallic fiber filter. During the venting process, mixture involved radiative nuclide is quantitatively divided to iodine and aerosol in the throats of venturi scrubber and stored in the scrubbing water pool. But scrubbing water volume is continuously reduced by evaporation due to the high temperature steam and the decay heat due to fission products. Therefore, the orifice design such as size that affects steam flow rate from containment building is important design parameter in CFVS, to maintain performance passively over 72 hours after accident.

This study analysed the thermal hydraulic characteristic using the FLOWNEX about CFVS design criteria under accident condition according to four different orifice’s outlet size: 0.13 m, 0.15 m, 0.2 m and 0.3 m.

2. Methods and Results

2.1 Modeling and Boundary condition

Fig. 1 shows the schematic of the CFVS. The CFVS is connected at one end to the containment via vent piping and isolation valves and at the other end to the exhaust stack via a line equipped with the orifice. The pressure relief pipe is closed by two manual isolation valves, and by a rupture disk ahead of the exhaust air stack. When the containment pressure rises to the design value or above, the operator can open the isolation valves manually.

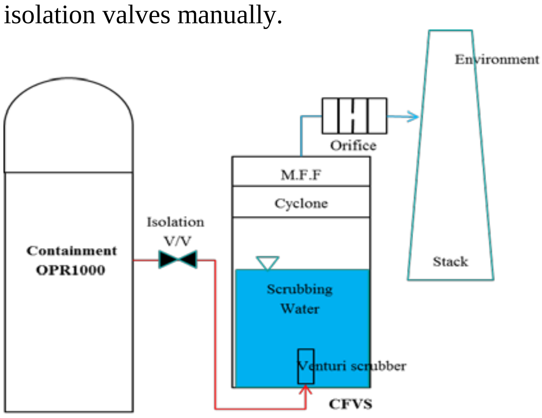

Fig. 1. Schematic of CFVS

This study investigated the thermal hydraulic characteristic in the CFVS for a long operating time using the FLOWNEX v8.4 [7] which is 1D simulation software. The reference plant is OPR1000, which is a pressurized water reactor with a thermal power of 2,815 MWt, and a Station Blackout (SBO) was chosen as an accident scenario.

The modelling of the CFVS, including the models for the venturi scrubber, scrubbing water pool, the cyclone, the metal fiber filter and orifice, a vessel for the CFVS was modelled as a control volume of 110.8 m^3 and including about 50 tons of scrubbing water. The CFVS was connected with the containment building and the environment through a venting pipe and an exhaust pipe, respectively, as a flow path with 0.3048 m (12 in) and 0.3556 m (14 in) diameter. The tank of CFVS was applied to 300 kW of decay heat by fission products. The pressure drop of the scrubber, filter and cyclone is shown in Fig. 2. Initial and boundary condition are summarized in Table 1. The isolation valves open/close set-point is 9/2.5 bar for the containment pressure. The simulation calculated the thermal hydraulic conditions in the CFVS for a long operating time of about 72 hours according to three different orifice size on the exhaust pipe: 0.13 m, 0.15 m, 0.2 m and 0.3 m.

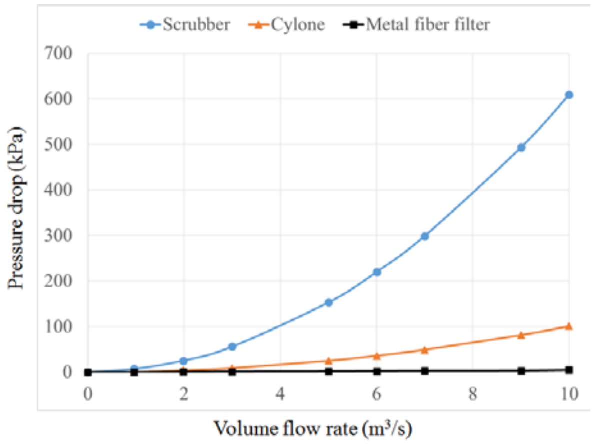

Fig. 2. Pressure drop of the scrubber, filter and cyclone

Table I: Initial and boundary condition

Modeling Component	Parameter	Unit	Value
Containment building	Power	MWth	2815
	Free volume	m^3	77,280
	Design pressure	bar.a	5
	Ultimate pressure	bar.a	10.1
CFVS	Opening / Closing pressure	bar.a	9 / 2.5
	Volume	m^3	110.8
	Initial scrubbing water level	m	3.6
	Initial scrubbing water weight	ton	50
	Initial scrubbing water temperature	℃	20
	Decay heat	kW	300
	Venting / Exhaust pipe diameter	m	0.3048 / 0.3556
	Orifice size	m	0.13, 0.15, 0.2, 0.3

2.2 Depressurization in the Containment Building and CFVS tank

Fig. 3 shows the pressure variation in the containment building during the operation of the CFVS. The orifice size is more than 0.15 m, dramatically decreased in the containment building after operating the CFVS and satisfied the design criteria which the depressurization in the containment building dropped to 50 % of the design pressure within 24 hours. The pressure for the case of 0.13 m in orifice size does not decrease as soon as the CFVS operates at the closing set-point of 2.5 bar.

With the operating of the CFVS, the pressure in the tank of CFVS is higher and longer because the small area of orifice make the increment of the discharge resistance of gases as shown in Fig. 4.

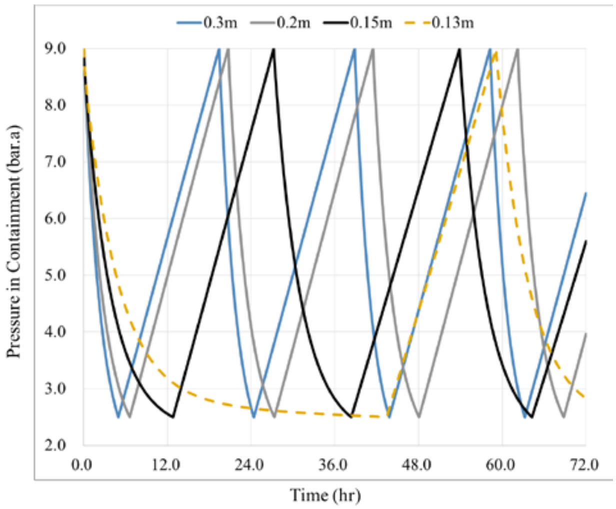

Fig. 3. Pressure in containment

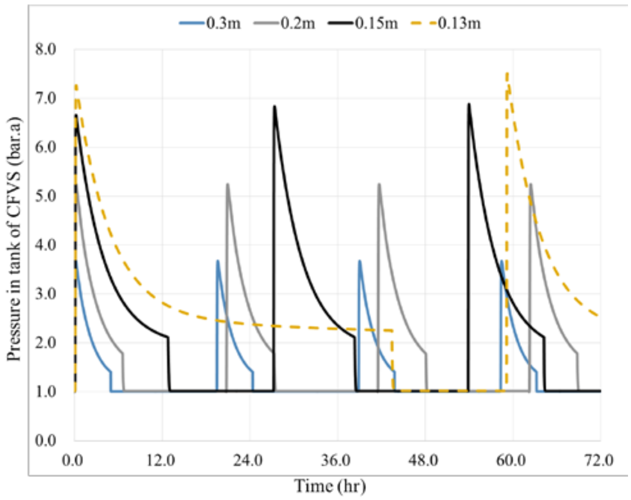

Fig. 4. Pressure in tank of CFVS

2.3 Evaporation of Scrubbing Water Pool

It is necessary to maintain the scrubbing water level to make a region for decontamination. If the scrubbing solution is fully evaporated, the fission products could then be discharged into the environment without decontamination. The initial water level of the scrubbing solution in the CFVS was 3.6 m from the bottom of the vessel. The minimum water level to meet the filtration performance of the venture scrubber in the designed CFVS is 1.4 m and the maximum water level is 6m to avoid inflow in the inlet of cyclone.

Fig. 5 shows the effect of the orifice size on level of the scrubbing water in the CFVS. When the isolation valve is opened, the pressure and saturation temperature increase in the CFVS tank, and the water level rises as the water density decreases. Every orifice sizes are satisfied for scrubbing water level of design criteria during 72 hours of operation time, excluding 0.3m. The pressure drop of 0.3m in the orifice is lower, so there is a large amount of evaporation that flows out to the outlet as shown in Fig. 6.

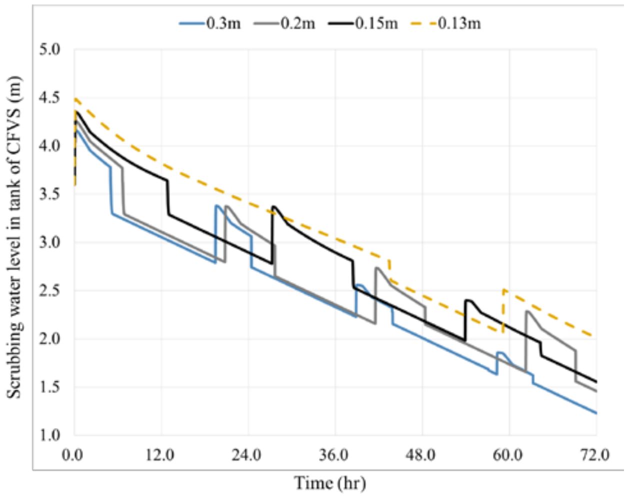

Fig. 5. Scrubbing water level in tank of CFVS

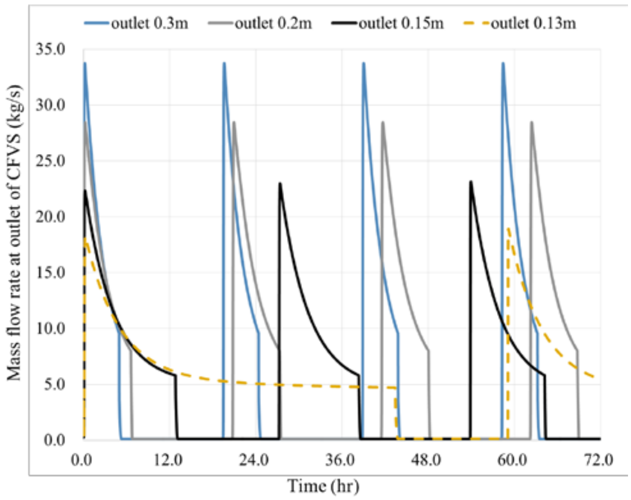

Fig. 6. Mass flow rate in CFVS (operating time: 72 hours)

The simulation results depending on the size of orifice are summarized in Table Ⅱ. The larger for the orifice size is lower for the total amount of gas flowing out into the atmosphere from the viewpoint of the total amount of outflow gas, because the valves are frequently closed. It is also necessary to select an appropriate orifice size from the viewpoint of proper level maintenance during operating.

The 0.15 m of orifice size can reduce control manually isolation valve opening and closing during a long term operating period compared to 0.2 m.

Table Ⅱ: Summary of results depending on the size of the orifice during 72 hours of operation time in CFVS

Parameter	Unit	Design criteria	Value			
Orifice size	m	-	0.3	0.2	0.15	0.13
Max. Water level	m	< 6	4.2	4.2	4.4	4.5
Min. Water level	m	> 1.4	1.2	1.5	1.6	2
CFVS isolation V/V 1st closing time	hr	< 24	5	6.6	13	43
Number of time for isolation V/V opening		The less is better	4	4	3	2
Total discharge steam mass	10^6 kg		1.346	1.348	1.355	1.467

3. Conclusions

This study analysed the thermal hydraulic characteristic using the FLOWNEX about design criteria of under accident condition according to four different orifice size, such as 0.13, 0.15, 0.2 and 0.3m.

The orifice size of 0.1 m and 0.3 m are satisfied for design criteria at the level of scrubbing water and depressurization, respectively. The optimum orifice size is 0.15 m because the operator can less open the isolation valves manually.

ACKNOWLEDGEMENTS

This work was supported by the Nuclear Research & Development of the Korea Institute of Energy Technology and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry and Energy. (No. 20141510101680)

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