Study on the Injection Region for Pool Scrubbing

Yu Jung Choi [a*], JaeHwan Park [a], Hyeong-Taek Kim [a]
[a]*KHNP-CRI, 70,1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, Korea, 305-343*
[*]*Corresponding author: yujung.choi@khnp.co.kr*

1. Introduction

Pool scrubbing is one of the ways to remove aerosol by injected gas rising through water pools. As a result of the Fukushima Daiichi nuclear incident in 2011, Containment Filtered Vent Systems (CFVSs) are being installed at Nuclear Power Plants (NPPs) to enhance the integrity of containment under severe accident conditions in Korea. The main role of CFVS is not only to ensure the integrity of containment, but also to protect uncontrolled radioactive materials released to the environment after a severe accident. Therefore, it is crucial for CFVSs to decontaminate fission products appropriately. The wet type CFVSs are mainly composed of a liquid pool and filters. Gases of high temperature and pressure are injected into the liquid pool by nozzles from a containment when the CFVS starts to operate in a severe accident. According to previous studies [1, 2], pool scrubbing for fission products occurs effectively when gases enter the pool at a very high velocity. In other words, the velocity of injection gas is a key parameter in the injection region for pool scrubbing. Therefore, in this study, the criteria of the injection regime were examined and a preliminary review was performed for the injection zone with a hypothetical scenario case.

2. Methods and Results

2.1 Injection zone of pool scrubbing

A scrubbing pool divided into three regions: an injection zone, bubble rise zone, and pool surface zone. Gases with high temperature and high pressure enter the liquid pool from containment when the CFVS operates under a severe accident condition. The injection zone is the first region for injected gases to be met in the pool. The gases leaving from nozzles experienced thermal and mechanical gas-liquid interaction in the pool.

At the injection zone, the dimensionless nozzle Weber number (We) was used to define the regime [3]:

$$\mathrm{We} = \frac{\rho_{l} \; D_{inj} U_{inj}^{2}}{\sigma_{l}} \qquad (1)$$

Where ρ_{l} : Pool density [kg/m^3]
D_{inj} : Injection nozzle diameter [m]
U_{inj} : Injection flow velocity through D_{inj} [m/s]
σ_{l} : Surface tension of pool against

When the inlet gas is in the globule regime (We <10^5), a globule forms. In this regime, a globule is detached and moves upward to the surface of pool in the bubbly flow. While the inlet gas is in the jet regime (We ≥10^5), the continuous jet flows are formed at the injection zone. More effective decontamination can occur during the pool scrubbing in this regime compared to the globule regime. Therefore, to remove fission products more effectively, it is necessary to control the injection flow rate in the pool of the CFVS.

2.2 Calculation of a hypothetical scenario

To review the effects of injection gas velocity at the injection zone of the CFVS liquid pool, a sequence from Station Black Out (SBO) was chosen as a hypothetical case. The case calculation was performed by MAAP5 for the APR1400. To organize a more severe condition, a failure of recovery of AC power was assumed during the entire evaluation period (72hrs).

The performance of CFVS was calculated by GOTHIC 8.1[4, 5]. Results of the MAAP were used as boundary conditions. Operation set points of the CFVS were chosen arbitrarily. When the containment pressure reached 600kPa, the CFVS started to operate. In contrast, when the containment pressure drops to 400kPa, the CFVS stopped operating.

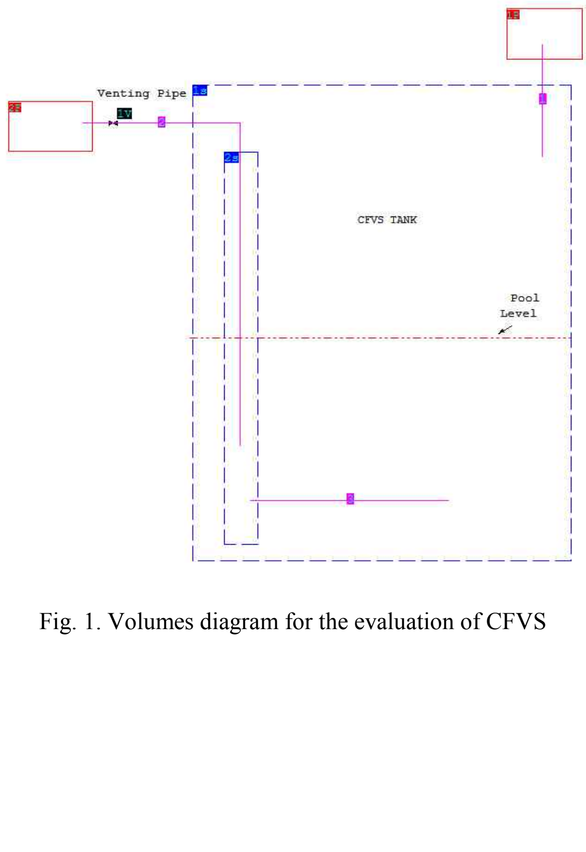

Fig. 1. Volumes diagram for the evaluation of CFVS

2.3 Results

Based on the calculation of GOTHIC 8.1, the results are as follows. Fig. 2 shows the pressure behavior of CFVS with variation in containment pressure under the accident scenario. With the operation of CFVS, the injected gas velocities changed such as those in Fig. 3. The range of injected gas velocity was generally between 100~150m/s.

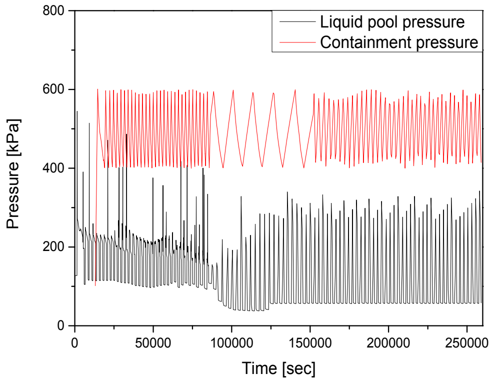

Fig. 2. Pressure behaviors of a CFVS pool and containment

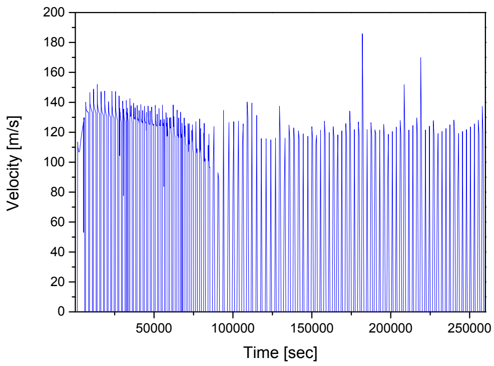

Fig. 3. Injected gas velocity in the pool of CFVS

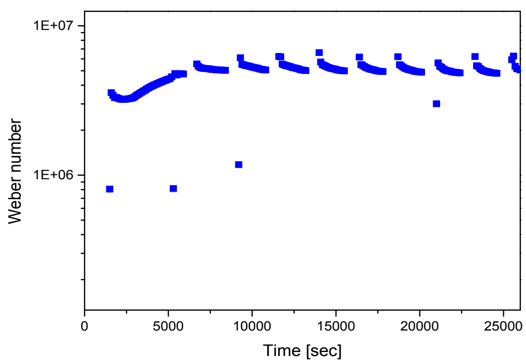

Fig. 4. Range of Weber numbers at the injection zone during the accident

Fig. 4 shows the range of Weber numbers at the injection zone during the accident scenario. The zero values of the Weber numbers were excluded due to the CFVS shutdown. All Weber numbers were over 10^5 during the entire analysis time period.

3. Conclusions

In order to study hydraulic conditions at the injection zone for pool scrubbing, the Weber numbers of the CFVS pool injection region were calculated under a hypothetical case. During the accident, all Weber numbers indicated that the injection zone of the pool was at the jet regime (We $\geq 10^5$) when the CFVS was operated. This means effective decontamination is possible during the entire period of the accident. However, future work is needed to evaluate the aerosol removals reflected in these conditions to confirm whether the decontamination was effective or not.

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