Review and Preliminary Evaluation of Pool Scrubbing Models

Hyun-Joung Jo[a*], Kwang Soon Ha[a], Sang Mo An[a], Hwan Yeol Kim[a], Dong Soon Jang[b]
[a] *Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea*
[b] *Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon, Korea*
[*]Corresponding author: *Jhj1225@kaeri.re.kr*

1. Introduction

If a severe accident occurs in a nuclear power plant (NPP), the aerosol and gaseous fission products might be produced in the reactor vessel and the reactor cavity during a core meltdown and molten corium-concrete interaction (MCCI) process, and then released to the environment after the containment failure [1]. FCVS (Filtered Containment Venting System) is one of the equipments for retaining the containment integrity by discharging the high-temperature and high-pressure fission products to the environment after passing through the filtration system.

In general, the FCVS is categorized into two types, wet and dry types. A conceptual schematic of wet type FCVS is shown in Fig. 1. The scrubbing pool could play an important role in the wet type FCVS because a large amount of aerosol is captured in the water pool [2]. The pool scrubbing phenomena have been modelled and embedded in several computer codes, such as SPARC (Suppression Pool Aerosol Removal Code), BUSCA (BUbble Scrubbing Algorithm) and SUPRA (Suppression Pool Retention Analysis). These codes aim at simulating the pool scrubbing process [3] and estimating the decontamination factor (DF) in the water pool, which is defined as the ratio of initial specific radioactivity to final specific radioactivity after passing through the water pool.

In the present paper, the pool scrubbing models in the SPARC and BUSCA codes were reviewed and the pool scrubbing parameters such as globule diameter and bubble diameter were evaluated preliminarily.

2. Status of Pool Scrubbing Codes

In this section, the pool scrubbing phenomena of aerosols and models in the SPARC and BUSCA codes are reviewed.

2.1 Pool scrubbing phenomenon

Figure 2 shows the typical configurations of a water pool during pool scrubbing. When gas is injected from a vent into a water pool, large gas bubbles (globule) are formed initially and then broken into many small bubbles (swarm). While the bubbles rise up under gravity to reach the gas-vapor space, the aerosols within the bubbles are removed at the gas-liquid interface [3]. Figure 3 shows several aerosol removal mechanisms in each bubble such as a gravity sedimentation, diffusional deposition, inertial deposition, and steam condensation, etc. When an aerosol particle reaches the gas-liquid interface by theses mechanisms, it is trapped in the liquid by surface tension and van der Waals forces [1].

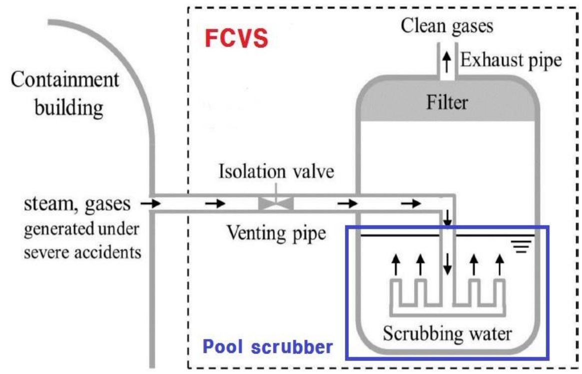

Fig. 1. A conceptual schematic of the wet type FCVS [2]

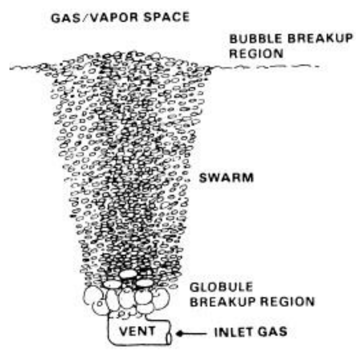

Fig. 2. A schematic of water pool during scrubbing of inlet gas [5]

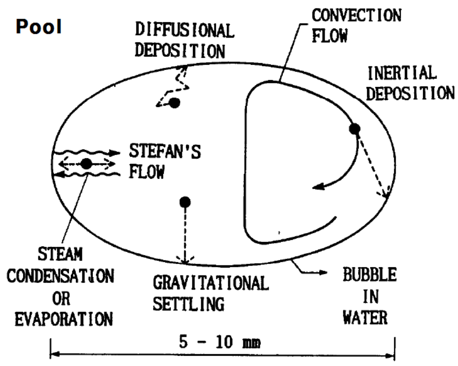

Fig. 3. Aerosol removal mechanisms [6]

In the SPARC and BUSCA codes, the decontamination factor of aerosols is calculated in two regions: gas injection and bubble rising regions. The total decontamination factor is obtained by a product of the values calculated in those regions.

2.2 Comparisons of pool scrubbing models

The SPARC has been embedded in the MELCOR code which has been used to predict and estimate the postulated severe accidents [5]. BUSCA is a mechanistic code designed originally to determine the decontamination factor in the water pool. These codes include hydrodynamics, thermo-hydraulics, and aerosol removal models, and the model characteristics and assumptions are compared in Tables I ~ III.

Table I: Assumptions of hydrodynamic conditions [4]

	SPARC	BUSCA
Initial globule size	Decreases linearly	Disappear instantaneously
Swarm shape	Plume	Plume & Cluster
Bubble size	Constant	Depends on pool conditions
Bubble shape	Sphere & ellipsoid	Sphere, ellipsoid and cap

Table II: Thermo-hydraulics conditions [4]

	SPARC	BUSCA
Bubble pressure	Water pressure	Water pressure + Surface tension
Thermal equilibrium	Instantaneous gas-liquid	consequently
Heat and mass transfer	Gas-Liquid side	Gas side
Heat and mass balance	Change in internal energy	Bubble enthalpy Bubble temperature

Table III: Aerosol removal mechanisms [4]

	SPARC	BUSCA
Injection zone	Steam condensation	
	Jet impaction	
	Settling Impaction Diffusion	-
Rise zone	Settling Impaction Diffusion Evaporation Diffusiophoresis Break up	Settling Impaction Diffusion Convection Thermophoresis Diffusiophoresis Break up
Aerosol shape	Sphere	Non-sphere

In injection zone, SPARC considers only Stokes number in jet impaction while BUSCA includes SPARC correlations and additional correlations. SPARC is more sensitivity to the initial steam condensation because the condensation onto particle leads to the particle growth and higher DF. SPARC considers the settling, centrifugal deposition, and diffusion if the gas comes into the pool through small orifices. BUSCA does not simulate these phenomena.

In rise zone, BUSCA calculates diffusion velocity higher than SPARC due to the different bubble shapes. Namely, BUSCA code seems to be more efficient to remove small particles than SPARC [10]. However, SPARC does not consider the thermophoresis contributions in the rise zone.

Low total decontamination factors were consistently predicted by both codes as shown in Table IV. The discrepancy was not simply quantitative but qualitative as well [10].

Table IV: Limitations of the pool scrubbing models

	SPARC	BUSCA
Particle agglomeration	Non considered	
Chemical effects	Non considered	
Bubble behavior	Neglected oscillations as bubbles collapse and reform	
Flow range	Bubbly flow	
DF	BUSCA < SPARC < Experiment	

3. Preliminary Evaluation of Globule and Bubble Diameter

The globule diameters and bubble diameters were evaluated by SPARC code. The input data for each experiment were taken from the LACE-España report as shown in Table V.

Table V: Experimental conditions [12]

Pool		Gas	
Temperature	110 ℃	Temperature	150 ℃
Depth	2.5 m	Composition	N_2 / steam
Absolute pressure	3 bar	Inlet pressure	3.25 bar
Vent type	horizontal	Orifice diameter	1 cm

The initial globule diameters were compared and others hydrodynamics parameters were calculated such as the initial globule volume, stable bubble size and shape, bubble rise velocity and bubble swarm velocity. The length of the globule region depends on the initial globule diameter. As the globule diameter increases, the swarm region decreases considerably and the bubble residence time in the pool decreases.

In SPACRC code, the globule diameter is estimated by equation (2). In equation (2), the normalized globule volume V_n is related to the weber number. The SPARC provides a variety of expressions to calculate the normalized globule volume related to the vent type. The injection velocity is the dominant factor of globule diameter.

$$D_g = \left(\frac{3}{2} V_n D_0^2 \sqrt{\frac{\sigma}{\rho_p g}} \right)^{1/3} \quad (1)$$

$$V_n = a\mathrm{We}^b \quad (2)$$

$$\mathrm{We} = \frac{\rho_p D_0 V_0^2}{\sigma} \quad (3)$$

where, ρ_p is pool liquid density; σ pool liquid surface tension; D_0 vent diameter; V_0 gas injection velocity; *a* 0.857 at a horizontal vent; *b* 0.73 at a horizontal vent; D_g globule diameter.

The globule diameters in the breakup zone are calculated along with steam faction and inlet velocity on LACE experimental conditions as shown in Fig. 4. In equation (3), the Weber number is defined by a non-condensable gas. Therefore, the globule diameter has dependence on injection velocity and steam fraction when the orifice diameter and vent type are fixed. The calculation results on the globule diameters are compared with SPARC code data as shown in Fig. 5. The discrepancy between the current calculations and SPARC codes would be due to the gas properties, pressure difference, etc.

Passing through the breakup zone, unstable globule is broken and small bubbles are stabilized. The SPARC code assumes a single diameter distribution. The diameter is assumed as 0.72cm if only non-condensable gas is ejected in the inlet, and as equation (5) if some steam is accompanied [5].

$$d_E = 0.72\exp(2.303(-0.2265 + 0.0203 + 0.0313X_{nc})^{1/2}) \quad (4)$$

where, d_E is volume mean diameter; X_{nc} volume mean diameter molar fraction of non-condensable gas in inlet gas

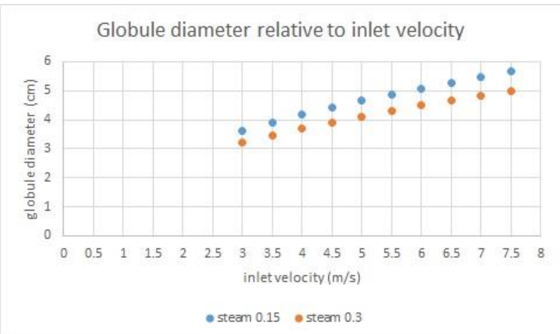

Fig. 4. Globule diameter relative to inlet velocity [4]

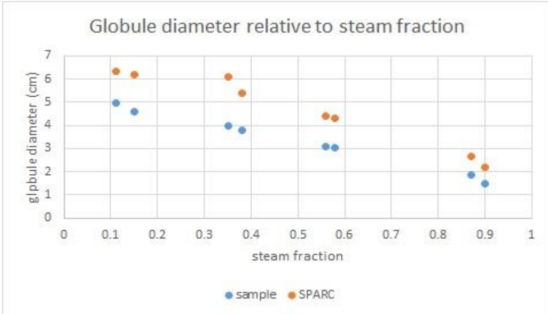

Fig. 5. Globule diameter relative to steam fraction [4]

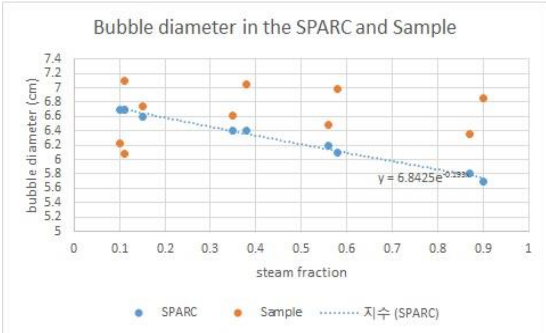

Fig. 6. Bubble diameter relative to steam fraction [4]

As shown in Fig. 6, the bubble diameters in the swarm region are calculated along with steam faction on LACE experimental conditions. The calculated bubble diameters are different from SPARC code results. It is expected that, in the SPARC code calculation, the bubble diameter at only non-condensable gas ejection as mentioned in equation (4) might be changed to 0.684cm.

3. Conclusion

To estimate the decontamination factor (DF) of radioactive aerosol in the water pool during the severe accident in a nuclear power plant, variety models and codes has been developed. The pool scrubbing models such as hydrodynamics, thermo-hydraulics, and aerosol removal models in the SPARC and BUSCA codes were reviewed. Based on the current codes hydrodynamic modelling, decontamination factor is particularly sensitive to the initial globule size which is affected on the residence time and decontaminant factor. Bubble diameter in the swarm region directly influence on decontaminant factor. Some pool scrubbing parameters such as globule diameter and bubble diameter were evaluated preliminarily.

The decontamination factor by current pool scrubbing models should be evaluated and improved.

ACKNOWLEDGMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korean government (Ministry of Trade, Industry, and Energy) (No. 20131510101700).

REFERENCES

[1] A. Powers and J. I. Sprung, A Simplified Model of Aerosol Scrubbing by Water Pool Overlying Core Debris Interacting with Concrete, NUREG/CR-5901, Sandia National Laboratories, Albuquerque, NM, October 1992.

[2] Young Su Na, Kwang Soon Ha, "Thermal Hydraulic Issues of Containment Filtered Venting System for a Long Operating Time, Nuclear Engineering and Technology, Vol.46 No.6, December 2014.

[3] S. A. Ramsdale, G. J. Bamford, S. Fishwick, and H. C. Starkie, Status of Research and Modelling of Water-Pool Scrubbing, Nuclear and Technology, November 1992.

[4] M. Escudero Berzal, M. J. Marcos Crespo, M. Swiderska-Kowalczyk, State-of-art reviews on fission products aerosol pool scrubbing under severe accident conditions, Commission of the European Communities , November 1995, Luxembourg.

[5] P. C. Owczarski and K. W. Burk, SPARC-90: a Code for Calculating Fission Product Capture in Suppression Pools, NUREG/CR-5765, 1991.

[6] I. Kaneko and M. Fukasawa, Experimental Study on Aerosol Removal Effect by Pool Scrubbing, 22nd DOE/NRC Nuclear Ari Cleaning and Treatment Conference, August 25, 1992.

[7] F. J. Moody, The Importance of Pools, Sprays, and Ice Beds in Fission Product Retention in Containment, in: Proc. of Fission Product Behavior and Source Term Research, 15-19 July 1984, Snowbird, Utah, USA.

[8] S. A. Ramsdale, BUSCA-JUN90 Reference Manual, SRD-R542, November 1992.

[9] S. Ramakrichnan, R. Kumar and N. R. Kuloor, Studies in Bubble Formation – 1: Bubble Formation Under Constant Flow Conditions, Chemical Engineering Science, 24, pp. 731-747, 1969

[10] J. López-Jiménez, L. E. Herranz and M. J. Escudero, Pool Scrubbing, Informes Técnicos Ciemat, 1996.

[11] C. M. Ruecker and P. A. Scott, Parameters Influencing the Aerosol Capture Performance of the Submerged-Bed Scrubber, PNL-6035, April 1987.

[12] M. J. Marcos Crespo, F. J. Gomez Moreno, Lace-Espana Experimental Program on the Retention of Aerosols in Water Pools, ISSN 0214-087X, 1994