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Identification of Major Phenomena on Aerosol Retention in Pool with High Speed Jet

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1. Introduction

A steam generator tube rupture (SGTR) in a pressurized water reactor (PWR) may cause accidental release of radioactive aerosol into the environment [1, 2]. Its specific significance is in its potential to bypass the containment thereby providing a direct pathway of the radioactivity from the primary circuit to the environment [3].

There are a number of possible scenarios in which the capture of fission products in pool might also occur under the jet injection regime, in which radioactive aerosol particles laden gases may enter the water at very high velocities resulting in a submerged gas jet. It is not easy that to evaluate the behavior and decontamination of aerosol in pool with high velocity jet regime.

This paper introduces the fundamentals of hydrodynamics of jet flow regime and aerosol removal mechanisms in order to estimate aerosol removal during gas injection in pools under jet regimes. The key variables in the modeling are considered such as injection gas velocity, droplet size, and aerosol diameter. Sensitivity studies on the key variables were performed and the most important factor affected on aerosol removal efficiency was identified in pools under jet regimes.

2. Modeling method

2.1. Hydrodynamics of jet flow region

A submerged gas jet whose the weber number is over 10^5 is usually expressed by Fig.1. The aerodynamics forces of the surrounding high speed gas might cause the deformation and fragmentation of the entrained droplets [3]. Both gas-liquid and droplet-particle interactions should be considered to evaluate the jet hydrodynamics and aerosol removal efficiency.

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2.2. Aerosol removal mechanisms

The aerosol removal on the droplet occurs as shown in Fig.2. Aerosol removed by liquid drops may arise through several mechanisms such as inertial impaction, interception, diffusion.

2.2.1. Inertial impaction

As the gas stream approaches the drop, the fluid streamlines spread around it, while a particle suspended in the gas stream tends to move in a straight line due to its inertia. Therefore, as the gas flows around the drop, the particle keeps moving toward the drop [5].

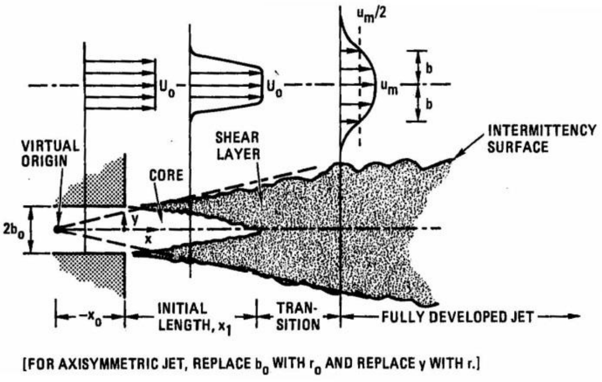

Fig. 1 Schematic of simple turbulent jet [4].

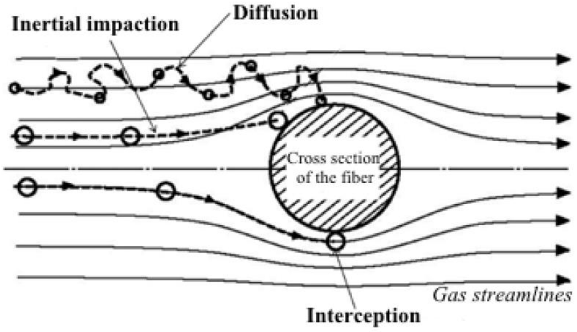

Fig. 2 Diffusion, inertial impaction and interception mechanisms of particle deposition on a fiber [4].

Due to the fluid drag of some particles, especially the larger ones shall be deflected from their path toward the drop and carried by the gas around the droplet [4].

Among the available expressions about collection efficiency by inertial impaction, Yung et al.[6] has proposed:

$$\eta_{impact} = \left(\frac{stk_a}{stk_a+0.35}\right)^2 \quad , \tag{1}$$

where stk_a is the aerosol Stokes number [7]

$$stk_a = \frac{C_c \rho_a d_a^2 (u_g - u_d)}{9\mu_g d_d}$$

and C_c is the Cunningham slip-correction factor which is chosen as 1.2.

2.2.2. Interception

Aerosol interception on the droplet takes place when the radius of the aerosol is larger than the distance between the gas streamline followed by the aerosol and the surface of the obstacle. Jung and Lee [8] proposed aerosol interception efficiency as follows:

$$\eta_{interception} = c(\frac{R}{1+R} + \frac{1}{2}(\frac{R}{1+R})^2 d) \qquad (2)$$

Where a = $(\frac{r_d}{r_g})^3$, b = $\frac{\mu_l}{\mu_g}$, R = $\frac{d_a}{d_d}$, $c = \frac{1-a}{J+bk}$,
d = $(3b+4)$, J = $1 - \frac{6}{5}a^{\frac{1}{3}} + \frac{1}{5}a^2$, k = $1 - \frac{9}{5}a^{\frac{1}{3}} + a + \frac{1}{5}a^2$

2.2.3. Brownian diffusion

Brownian motion is the random movement of aerosol suspended in a fluid. From the equation (3)-(5), we obtain the diffusion efficiency [4].

$$\eta_{diffusion} = 0.7(\frac{4\sqrt{c}}{\sqrt{3Pe}} + 2(\frac{\sqrt{3}\pi}{4Pe})^{\frac{2}{3}} \frac{1}{(cd)^{\frac{1}{3}}} \qquad (3)$$

$$\mathrm{Pe} = \frac{d_d u_d}{D_{diff}} \qquad (4)$$

$$D_{diff} = \frac{KTC_c}{3\pi\mu_g d_a} \qquad (5)$$

2.2.4. Overall aerosol collection efficiency

The overall efficiency and decontamination factor of aerosol removal by the droplet can be obtained as following equation (6), (7).

$$\eta_{total} = 1 - (1-\eta_{impact})(1-\eta_{inter})(1-\eta_{diff}) \qquad (6)$$

$$\mathrm{DF} = \mathbf{1} - \frac{\mathbf{1}}{\mathbf{1}-\boldsymbol{\eta_{total}}} \qquad (7)$$

3. Results

Parametric studies were performed to evaluate the influence of selected parameters on the aerosol collection efficiency. The following parameters were selected: droplet diameter, aerosol diameter, and gas injection velocity. The common and variable parameters for parametric studies are listed in Table I ~ Ⅱ.

Table I: The common parameters for parametric studies

Parameters	Unit	Gas	Liquid
Temperature	℃	150	100
Density	g/cm^3	0.0017	1
Volumetric flow rate	cc/s	2000	
Orifice diameter	cm	1	

Table Ⅱ: The variable parameters for parametric studies

Parameters	Unit	Value
Aerosol diameter (AMMD)	μm	0.1, 1.0, 5.0
Droplet diameter	cm	0.001, 0.01, 0.1
Volumetric flow rate	cc/s	600, 1000, 1500, 2000, 2500, 3000

3.1. Parametric study of droplet & aerosol size

Figure 3 shows that the calculated results on the decontamination factor by droplet of each mechanism according to the droplet and aerosol diameter. As shown in Fig. 3, the collection efficiency increases as droplet size decreases and aerosol diameter increase.

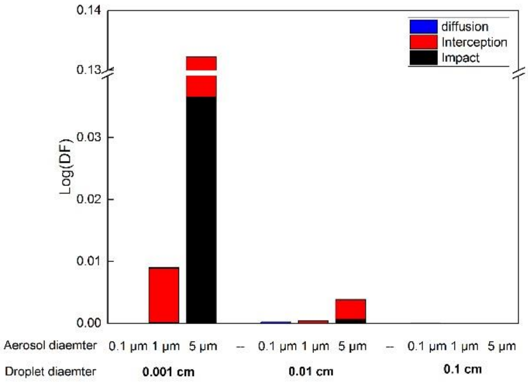

Fig. 3 Decontamination factor by impaction, interception, and diffusion according to aerosol and droplet diameter.

3.2. Sensitive study of injection velocity

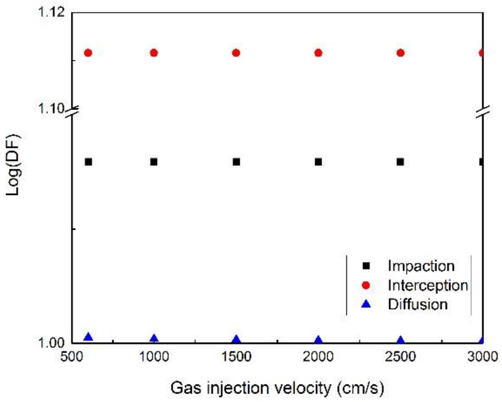

Fig. 4 Decontamination factor according to gas injection velocity.

Figure 4 shows that the calculated results on the decontamination factor by droplet according to the gas injection velocity. As shown in Fig. 4, the gas injection velocity is less affected on aerosol collection efficiency.

4. Conclusion

To evaluate the aerosol collection efficiency in pool with high speed jet flow, several the aerosol removal mechanisms on droplet such as inertial impaction, interception, Brownian motion were evaluated according to the aerosol and droplet diameter and gas injection velocity. The collection efficiencies increase as aerosols diameter and inverse droplet diameter increases. The gas injection velocity had not much affected on the aerosol collection efficiency.

NOMENCLATURE

C_c	Cunningham correction factor
d_a	aerosol diameter
d_d	droplet diameter
D_{diff}	diffusion coefficient
K	Boltzmann constant
r_a	radius of aerosol
r_g	boundary radius (jet radius)
Stk_a	stokes' number
u_a	velocity of aerosol
u_a	velocity of aerosol
u_d	droplet density
ρ_a	aerosol density
η_{impact}	efficiency by inertial impaction of aerosol
η_{inter}	efficiency by interception of aerosol
η_{diff}	efficiency by inertial impaction of aerosol
η_{total}	total efficiency of aerosol by droplet

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