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Correlation Confirmation on Removal Rate for Coagulating and Depositing Aerosols

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1. Introduction

The severe accident analysis code, so called CINEMA, is being developed in the Korea. Among the various modules necessary for the severe accident simulation, SIRIUS tracks the fission product behavior in the plant. The key role of this code is to provide the quite accurate information about the radioactive materials such as the mass, size distribution, decay heat, activity and so on. For instance, once we get the aerosol size distribution for radioactive materials, the size-dependent decontamination factors may be calculated for the fission product release to the environment. So predicting the size distribution for aerosols is important to mitigate the radioactive releases [1].

In the situation of severe accidents, the radioactive materials retained in the pellet inside of the cladding can be released to the outside. The radioactive materials then have a tendency to transform their phase into an aerosol from a gaseous form. Hence the transport of these material in aerosol form is very important in the analysis of the safety of a nuclear power plant [2].

Fundamentally, there are two representative approaches for the simulation of aerosol transport: a sectional method and lumped model. In the early stage of the development of aerosol dynamics, a lumped model was generally used. These days, however, owing to an increase in available computational power and the faster calculation time of CPUs, a sectional method has been highlighted. The current severe accident codes use both methods for their development philosophy.

Purpose of this paper is to regenerate the correlation between the dimensionless mass and the removal rate which was already provided by Epstein [3]. The procedures performed by Epstein was reviewed first and then the same procedure were undertaken to get the correlation using the MAEROS computer code [4]. These results can be used as an option in SIRIUS to provide the aerosol mass behavior without solving the sectional method based on aerosol size distribution information.

2. Procedure for Calculating Dimensionless Mass and Removal Rate

What we want to know is the relationship between the dimensionless mass and the removal rate. Epstein already defined the dimensionless mass, M and the removal rate, Λ [3].

$$\Lambda = \left(\frac{\gamma\varepsilon_0\chi^2\mu h^2}{\alpha K_0 g\rho}\right)^{1/2}\cdot\lambda \equiv \Lambda\left[\left(\frac{\gamma^9 g h^4\varepsilon_0^5}{\alpha^3 K_0\rho^3\mu}\right)^{1/4}\cdot m\right] \tag{1}$$

$$\mathrm{M} = \left(\frac{\gamma^9 g h^4\varepsilon_0^5}{\alpha^3 K_0\rho^3\mu}\right)^{1/4}\cdot m \tag{2}$$

The follows are the actual removal rates in continuous and discrete forms with the effective height of the system, h.

$$\lambda(t) = \frac{\int_0^\infty v n(v,t) u(v) dv}{h\int_0^\infty v n(v,t) dv} \tag{3}$$

$$\lambda(t) \approx \frac{\sum_{j=1}^{M} v_j u(v_j) n_j}{h\sum_{j=1}^{M} v_j n_j} \tag{4}$$

where the deposition velocity is

$$u(v) = \frac{2}{9}\left(\frac{3}{4\pi}\right)^{2/3}\cdot\frac{\alpha^{1/3} g\rho v^{2/3}}{\chi\mu} \tag{5}$$

$$u(v) = Bv^b \tag{6}$$

The MAEROS code is based on the sectional method which is dividing the size spectrum into finite number of groups [5]. Average representation about each size group is made for expression about conservation laws between size groups. In this paper, to calculate dimensionless removal rate the in eqn. (1), the actual removal rate should be calculated as eqn. (4). In the eqn. (4) the number density for each size group is required for corresponding numerical simulation. Because the MAEROS code can calculate the average values for each size group such as number density, density and so on, its result is provided into the eqn. (4). Also, in eqn. (2), the dimensionless system mass requires the actual system mass. The MAEROS code can give us the actual system mass as well. Thus the MAEROS code is utilized in this research to provide us with number density for every size group and actual system total mass.

3. Summary of Experiments for Numerical Simulation of the MAEROS Code

3.1 MAEROS Input Preparation

Five cases are for ABCOVE5, 6, and 7, and one additional case for an analysis of the zero source term are taken as the samples for the correlation generation. Because AB6,7 deal with two aerosol components, those these experiments were separated into two case, each. The following are the variables for the simulation of each case. In addition, to provide a sufficient size spectrum, the size of the aerosol ranges from 0.01 μm to 250 μm.

Table I: Common Input Data for Sample Cases

	ABCOVE 5, 6, 7 and Additional Case (Case 1, 2, 3, 4, 5 and 6)
α	1.000E+00
μ (kg/(m*s))	1.565E-05
ε_o	1.000E+00
k(J/K)	1.380E-23
C_m	1.370E+00
g(m/s^2)	9.800E+00
B	2.222E-01
b	6.667E-01

Table II: Different Input Data for AB5,6 and 7

	γ	h (m)	χ	V (m^3)
AB5,6,7 (Case 1,2,3,4 and 5)	2.25	9.649	1.5	852
Zero Source (Case6)	1.0	10.0	1.0	1000

Table III: Initial Aerosol Data

	Initial GSD	Initial GMD (μm)	Initial Mass (kg/m^3)
AB5,6,7 (Case1,2, 3,4 and 5)	N/A	N/A	0.0
Zero Source (Case6)	1.05	0.5	8.6487E-03

The material densities, ρ (kg/m^3), for these cases are 2500, 2450, 3670, 2130, 3670, and 1000, respectively. In Table III, it can be seen that there are initially no aerosols for the ABCOVE experiments [6],[7],[8].

3.2 Numerical Result

Using the MAEROS outputs and the definition of the dimensionless number by Epstein, the pairs of the dimensionless mass and removal rate can be calculated. In addition, the MAEROS outputs are compared with the MELCOR simulation. As a result, the consistency was found for both results [7]. The suggested function relationships between the dimensionless mass and the removal rate based on the Epstein number for sedimentation as the follows.

$$\Lambda_{SED}^{SS} = 0.266\mathrm{M}^{0.282}(1+0.189\mathrm{M}^{0.8})^{0.695} \quad (7)$$

$$\Lambda_{SED}^{D} = 0.528\mathrm{M}^{0.235}(1+0.473\mathrm{M}^{0.754})^{0.786} \quad (8)$$

Using equation (7), (8) and the results obtained from the MAEROS simulation, the following results were obtained. It can be verified that the starting points for each case are almost exactly lie on the steady state curve suggested by Epstein. It is easily found that the development of the each case in the aging circumstance lie on the aging state curve suggested by Epstein as well. In Fig 1, the key physical phenomenon that the removal rate increase instantly if the source is turn off and slowly decrease with the fast disappearance of large size particle and decrease of actual total system mass can be confirmed.

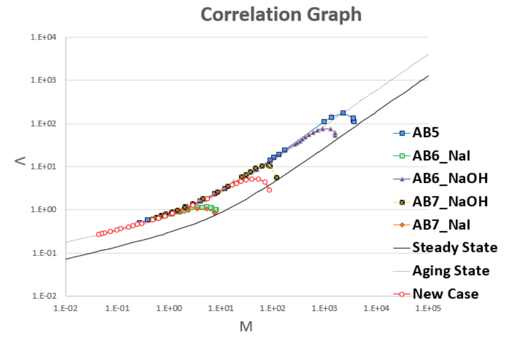

Fig. 1. Correlation Graph

4. Conclusions

The Epstein's correlation was confirmed from the sample runs. Based on the current work, new correlations can be suggested based on the numerical simulations. Final goal will be to develop new dimensionless parameters and correlations without solving the complicated size distribution equations.

NOMENCLATURE

b	Exponent in particle deposition velocity law, eqn. (6);
B	coefficient in particle deposition velocity law, eqn. (6);
C_m	particle slip coefficient;
g	gravitational acceleration;
h	effective height of the particle cloud; volume of particle cloud (compartment) divided by deposition area;
k	Boltzmann constant.
m	density of particle cloud; mass per unit volume of particle cloud;

M	dimensionless density of particle cloud. particle size distribution function.
$n(v,t)$	particle size distribution function;
$u(v)$	deposition velocity for particles of volume v;
v	particle volume;
V	system volume.

Greek symbols

α	density correction factor;
γ	collision shape factor;
ε_o	adjustable particle capture efficiency constant;
λ	removal rate contant, eqn. (3);
Λ	dimensionless aerosol removal rate constant;
μ	gas viscosity
ρ	density of particle material
χ	particle settling shape factor.

Subscripts

SED	pertain to particle removal by sedimentation,
D	refers to a pure decaying aerosol (no source),
SS	refers to a source-reinforced aerosol in steady-state.

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