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Effect of Bubble Size Distribution in Retention of Aerosol Particles during Pool Scrubbing − Part II: Application to LACE-ESPAÑA Experiments

Yoonhee Lee[1)*], Yong Jin Cho[1)], and Inchul Ryu[2)]
1) Korea Institute of Nuclear Safety
62 Gwahak-ro, Yuseong-gu, Daejeon, Korea 34142
2) KEPCO Engineering & Construction Company Inc.
269 Hyeoksin-ro, Gimcheon-si Gyeongsangbuk-do, Korea 39660
[*]Corresponding author: yooney@kins.re.kr

1. Introduction

In the first part of the study [1], based on the derivation of the deposition velocities which are functionalized over the bubble sizes, we proposed the calculational procedure for the bubble-size-dependent decontamination factors (DFs) for more realistic analyses on the amount of fission products (FPs) released from the pool scrubbing. The bubble-size-dependent DFs were implemented in I-COSTA coupled with the calculation module for bubble-hydrodynamics and bubble-thermodynamics to obtain thermophysical conditions of the bubbles.

With I-COSTA, two sensitivity analyses were performed: one was on the various retention mechanisms of the aerosol particles, and the other was on the various size distributions of the bubbles. From the sensitivity analyses, we found that the centrifugal deposition is the dominant mechanism of the retention, since ~90% of the net deposition velocities came from the centrifugal deposition. We also found that the steam fraction has large effects on the DFs. The results were attributed to that most steam condenses before the globule completely breaks up into small bubbles.

In this part of the study, we apply I-COSTA to analyses of LACE-ESPAÑA experiments [2] in order to validate the calculational procedure. We then, compare the numerical results to those from SPARC-90 [3] and the experimental results. In the comparison, calculations by SPARC-90 [3] are performed with default sensitivity coefficients for the average equivalent diameter of the bubbles and modification of the sensitivity coefficients to make the average equivalent diameter equal to that in the distributions considered in I-COSTA, in order to show the effect of the distribution itself.

2. Application of I-COSTA to Numerical Analyses on LACE-ESPAÑA Experiments

2.1 Comparison of DFs to those from SPARC-90 and Experiments

I-COSTA is applied to analyses of LACE-ESPAÑA experiments to validate the calculational procedure for the bubble-size-dependent DFs proposed in the first part of the study [1]. Among the various tests in LACE-ESPAÑA experiments, we compare the tests listed in Table 1, which are performed using a single injector with a globular regime; i.e., the Weber number at the nozzle exit of the experiments is less than 10^5. In the experiments, CsI aerosol particles are used.

Table 1. Information of the aerosol particles

Tests	AMMD*	GSD**	Steam fraction
RT-SB-00/01	3.4E-06	2.6	0.90
RT-SB-02/03	5.0E-06	3.8	0.87
RT-SB-04/05	3.4E-06	5.4	0.58
RT-SB-06/07	4.2E-06	3.3	0.56
RT-SB-08/09	5.5E-07	1.6	0.38
RT-SB-10/11	7.2E-06	1.6	0.35
RT-SB-12/13	3.0E-06	2.3	0.11
RT-SB-14/15	5.8E-06	3.5	0.15

*AMMD : Aerosol Mass Mean Diameter
**GSD : Geometrical Standard Deviation

As computation conditions, the size distribution of the aerosol particles is divided into 10 discretized sections. The region between the nozzle exit and the top of the pool where the globules and the bubbles rise is divided into 10 sub-regions. In the case of calculations by SPARC-90, they use a SINGLE value for the average bubble equivalent diameter. The DFs are compared in Fig. 1.

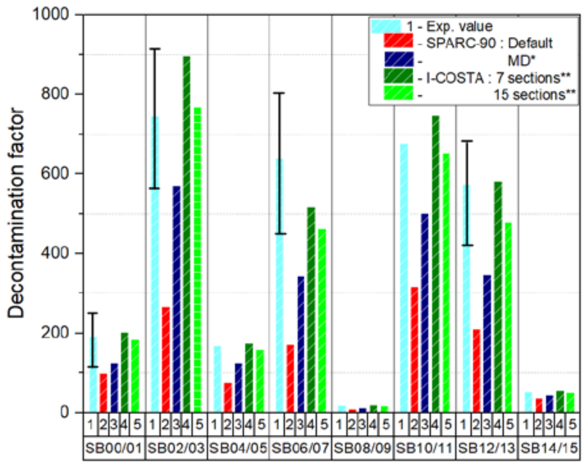

Fig. 1. Comparison of the DFs for various LACE-ESPAÑA experiments

* Modification of sensitivity coefficients to make the average equivalent diameter equal to that in I-COSTA
** Number of sections in the bubble size distributions

As shown in Fig. 1, for the most cases of the tests, I-COSTA shows that DFs are within the range of uncertainty in the tests. The DFs obtained by SPARC-90 with default sensitivity coefficients, however, are much lower than the experimental results, i.e., 3.7 times lower than the experimental results for the RT-SB-06/07 test. The results are due to SPARC-90 employing conservative calculations in the DFs; i.e., the average equivalent diameter of the bubble in SPARC-90 is ~0.7 cm, which may give 32.5 times lower net deposition velocity, as shown in the first part of the study [1].

The results of SPARC-90 with modification of sensitivity coefficients gives enhanced DFs compared to the results of SPARC-90 with default sensitivity coefficients; i.e., the DF for the RT-SB-06/07 by SPARC-90 is 1.85 times lower than the experimental results. However, compared to the results of I-COSTA and the experimental results, the DFs are still underestimated. The results are attributed to that the net deposition velocity of the aerosol particles used to calculate the DFs is not a simple linear function of the equivalent diameters of the bubble. Instead, it increases dramatically as the equivalent diameter of the bubbles approaches zero as shown in Fig. 5 in the first part of the study [1]. Computing times of I-COSTA and SPARC-90 are compared in Table 2.

Table 2. Comparison of computing time of I-COSTA and SPARC-90

Tests	SPARC-90 [sec]		I-COSTA [sec]	
	Default	MD	7	15
RT-SB-00/01	1.5E-02	1.5E-02	4.6E-02	9.3E-02
RT-SB-02/03	3.1E-02	3.1E-02	3.1E-02	7.8E-02
RT-SB-04/05	1.5E-02	1.5E-02	7.8E-02	9.4E-02
RT-SB-06/07	4.6E-02	4.6E-02	6.2E-02	7.8E-02
RT-SB-08/09	3.1E-02	3.1E-02	1.1E-01	2.0E-01
RT-SB-10/11	3.1E-02	3.1E-02	4.6E-02	9.3E-02
RT-SB-12/13	3.1E-02	3.1E-02	7.7E-02	7.8E-02
RT-SB-14/15	2.9E-02	2.9E-02	4.7E-02	7.8E-02

Even though the computing time of I-COSTA is two times longer than that of SPARC-90, the order of computing time is around 10^{-2} sec. Therefore, it would not be a huge burden when we calculate the bubble-size-dependent DFs coupled with a severe accident analysis code such as MELCOR [4].

2.2 Importance of DFs for various zones of the pool scrubbing

In the analyses, importance in the injection zone, in the transition zone, and in the bubble rise zone are compared. The length of the transition zone is defined by the distance between the point where the initial globule is located and the point where the critical Weber number of the globule is 15. The importance is defined by Eq. (1) such that the summation of the importance for all regions is 1. The importance for the various tests of LACE-ESPAÑA experiments is shown in Fig. 2.

$$IMP_k = \frac{\log(DF_k)}{\sum_k \log(DF_k)}, \quad (1)$$

where k is the zone index.

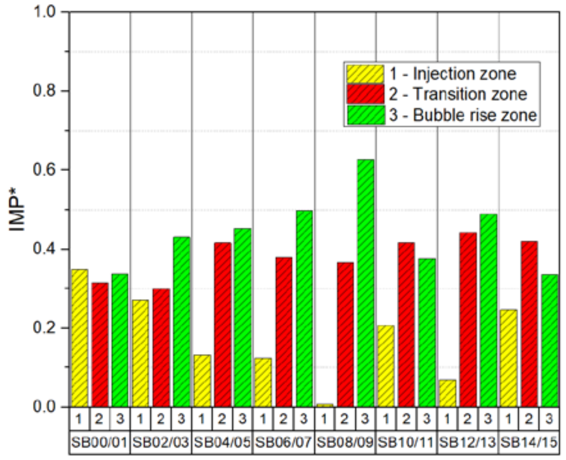

Fig. 2. Importance of DFs for each zone of pool scrubbing

As shown in Fig. 2, the importance of the transition zone is not negligible. The difference in importance between the transition zone and the bubble rise zone when the ultimate size distribution is reached within 2% for RT-SB-00/01. The results are attributed to that the volume fraction of the bubbles in the transition zone is significant and consequently there is noticeable retention of aerosol particles in this zone. Therefore, it is necessary to measure the size distributions of the bubbles in the transition zone to consider the retention of the aerosol particles in the transition zone more realistically. Note that in this study, we assume that the size distributions of the bubbles remain static for entire region due to lack of information on the size distribution of the bubbles.

3. Conclusions

In this study, for more realistic calculations on the retention of aerosol particles during the pool scrubbing, we derived the calculational method for the bubble-size-dependent DFs and we implemented it into I-COSTA. In the first part of the study, we discussed on the derivation of the deposition velocities functionalized over the bubble sizes to obtain the bubble-size-dependent DFs. We also discussed on the sensitivity analyses on the retention mechanisms as the change of bubble size and various size distributions of the bubbles.

In this part of the study, we applied I-COSTA to analyze LACE-ESPAÑA experiments for validation of the calculational procedure. We then compared the numerical results of I-COSTA to those obtained by SPARC-90 as well as to the experimental results. DFs obtained by I-COSTA were within the uncertainty range of the experiments. However, SPARC-90 showed much lower DFs than those of the experiments, i.e., the DFs in the analysis of the RT-SB-06/07 test was 3.7 times lower than that of the experiment. The results were attributed to that SPARC-90 employs conservative calculations in DFs by selecting the average equivalent diameter of the bubbles as ~0.7 cm.

Even though there was modification on the sensitivity coefficients to make the average equivalent diameter of the bubble equal to that in I-COSTA, DFs were still underestimated. The causes of the results was that the net deposition velocity of the aerosol particles is not a simple linear function of the equivalent diameters of the bubbles. Instead, it increases dramatically as the equivalent diameter approaches zero.

In the case of computing time, even though the computing time of I-COSTA is two times longer than that of SPARC-90, the order of computing time is around 10^{-2} sec. Therefore, it would not be a huge burden when we calculate the bubble-size-dependent DFs coupled with severe accident analysis code such as MELCOR.

For the analyses on the importance of the DFs in the various zones of the pool scrubbing, we found that the DFs in the transition zone were not negligible compared to those in the bubble rise zone where ultimate size distributions of the bubbles were achieved. Therefore, for more realistic evaluation, it is necessary to perform experiments to measure the size distribution of the bubbles in the transition zone.

As future work, we will apply I-COSTA to experiments available for validation of the calculational method. We will then extend the method to pool scrubbing of gaseous form of iodine, which is also important for evaluation of the source term during a severe accident.

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