# Validation of Two-group IAT (Interfacial Area Transport) Model for Droplet Field in SPACE Code

B. U. Bae, S. W. Lee, S. W. Bae, K. D. Kim

*Korea Atomic Energy Research Institute, 111 Daedeok-daero, 989 Beon-gil, Yuseong-gu, Daejeon*
*Corresponding author: bubae@kaeri.re.kr

## 1. Introduction

SPACE (Safety and Performance Analysis Code for Nuclear Power Plant) code has been developed for thermal hydraulic safety analysis of nuclear power plants, dealing with the various fluid flow features. It adopts a three-dimensional three-field model, which treats the transport of continuous liquid, vapor, and droplet field separately.[1] In this model, interfacial area concentration of the droplet field is of importance for estimation of the interfacial momentum and heat transfer between the droplet and the vapor phases. In this study, to enhance the prediction capability for the interfacial area and reflect the dynamic behavior of interface between the droplet and the spacer grid, IAT (Interfacial Area Transport) model was implemented in the SPACE code.

## 2. IAT Model Implementation

### *2.1 IAT Equation for Droplet Field*

IAT model for the droplet field estimates the interfacial area concentration (IAC) with solving IAT equation, rather than using a static correlation for the IAC. It treats the variation of the interfacial area of the droplet by considering several source terms. An important source term of the equation is the droplet breakup by a spacer grid, which induces increase of the interfacial area of the droplet. When the droplet makes impact on the spacer grid surface, small droplet can be generated by the breakup and it affects the increase of the interfacial area and the amount of droplet evaporation. In particular, the breakup on the spacer grid surface can produce very small droplets, which is distinguished by the large droplets.[2] Considering the existence of the small and large droplets, SPACE code adopts a two-group IAT equation for the droplet field as follows.

$$\frac{\partial A'''_{i,LD}}{\partial t} = -\nabla \cdot \left( A'''_{i,LD} \overline{U}_e \right) + \frac{3S'''}{\rho_l r_s} + S_{\Gamma,LD} + S_{grid} \quad (1)$$

$$\frac{\partial A'''_{iSD}}{\partial t} = -\nabla \cdot \left( A'''_{iSD} \overline{U}_e \right) + S_{\Gamma,SD} + S_{SD1} + S_{SD2} \quad (2)$$

Equation (1) estimates the variation of interfacial area concentration for the large droplet ($A'''_{i,LD}$), where the source term in the right-hand-side includes convection of the interfacial area, entrainment and de-entrainment, phase change, and the breakup by the spacer grid. Transport of the interfacial area concentration for the small droplet ($A'''_{i,SD}$) is calculated by Eq. (2). Similarly to the large droplet field, the source term for transport equation of the small droplet is composed of the convection, phase change and the breakup. Details for the source term of the breakup in two equations ($S_{grid}$, $S_{SD1}$, $S_{SD2}$) will be discussed in next section. After calculating two transport equations, total interfacial area concentration is estimated as a summation of $A'''_{i,LD}$ and $A'''_{i,SD}$.

### *2.2 Breakup Model in IAT Equation*

When large droplet flow collides with the spacer grid surface, the amount of the breakup flow ($m_{DB}$) is estimated as follows.[2]

$$m_e = \frac{\alpha_d \rho_d v_d \cdot Area}{Volume} \quad (3)$$

$$m_{DB} = \eta_e \left( \frac{A_G}{A_C} \right) m_e \quad (4)$$

In above equations, $m_e$ is the mass flux density of the large droplet impacting on the spacer grid. $A_G / A_C$ is a ratio of the grid surface to the cell area and $\eta_e$ is a breakup efficiency assumed to be 0.6. The breakup flow from Eq. (4) is considered as the source term for the droplet breakup in the transport equation of both groups. Depending on the droplet Weber number ($We_D = \rho_d V_{DI}^2 D_I / \sigma$), some of the breakup flow contributes to the source term in the large droplet and the other is regarded as the small droplet field as follows.[2]

1) $We_D < 30.9$ : Assumed as no breakup
2) $30.9 < We_D < 150$ : All breakup flow is regarded as the source term of the large droplet flow
$$fluxl = m_{DB} \quad (5)$$
3) $150 < We_D < 250$ : Both to the large and small droplet fields
$$fluxl = (1-\xi) m_{DB} \quad (6)$$

$$fluxm = \xi m_{DB} \quad (7)$$

$$\xi = \frac{We - 150}{250 - 150} \quad (8)$$

4) $250 < We_D$ : All breakup flow is regarded as the source term of the small droplet flow

$$fluxm = m_{DB} \quad (9)$$

*fluxm* and *fluxl* in above equations mean the droplet breakup flow for the large and small droplet, respectively. From the definition of the droplet breakup flow, the source terms for the breakup by the spacer grid ($S_{grid}$ for the large droplet field and $S_{SD1}$ for the small droplet field) are estimated as follows. $D_{SD1}$ is a diameter of the broken droplet, and $D_I$ is a diameter of the large droplet impacting on the grid surface.

$$S_{grid} = \frac{fluxl}{\rho_d \frac{\pi}{6} D_{SD1}^3} \cdot \pi D_{SD1}^2 = \frac{6 \cdot fluxl}{\rho_d D_{SD1}} \quad (10)$$

$$S_{SD1} = \frac{6 \cdot fluxm}{\rho_d D_{SD1}} \quad (11)$$

$$D_{SD1} = D_I \cdot 6.167 We_D^{-0.53} \quad (12)$$

$S_{SD2}$ is corresponding to the breakup of the small droplet on the grid surface. It is modeled similarly to the large droplet breakup as follows.

$$S_{SD2} = \frac{6 \cdot fluxs}{\rho_d D_{SD2}} \quad (13)$$

$$fluxs = \eta_e \left( \frac{A_G}{A_C} \right) \rho_d \frac{\pi}{6} D_{SD}^3 n_{SD} \quad (14)$$

## 3. Validation of IAT Model

### *3.1 FLECHT-SEASET Experiment*

In order to validate the IAT model implemented in the SPACE code, experimental result of FLECHT-SEASET is utilized, which simulates reflood phenomena in a rod bundle geometry.[3] Figure 1 and Table 1 show nodalization of the facility for the SPACE code calculation and the benchmark test matrix, respectively. The flow channel, the heater rods, the fillers, the thimbles, and the housing was modeled to have 20 nodes in the vertical direction. The inlet and the outlet of the flow channel were connected to the flow and the pressure boundary conditions, respectively.

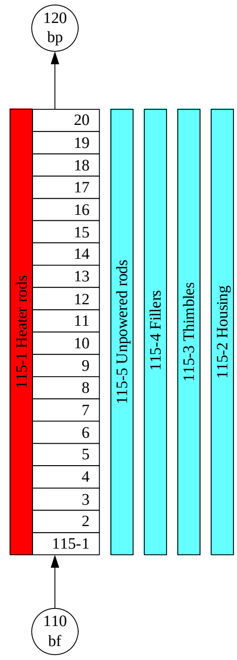


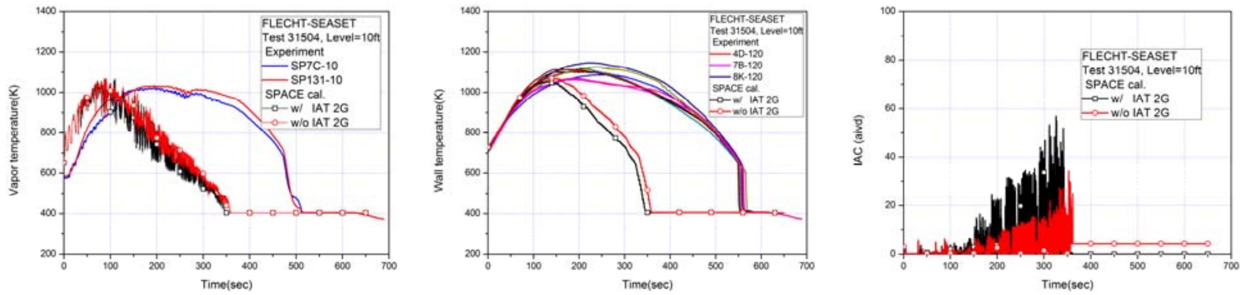

Fig. 1 Nodalization of FLECHT-SEASET experiment

Table 1 Test matrix of FLECHT-SEASET experiment

| Test Case | 31504 | 31302 | 31701 |
|---|---|---|---|
| Flooding rate (cm/s) | 2.40 | 7.65 | 15.50 |
| Upper plenum pressure (MPa) | 0.28 | 0.28 | 0.28 |
| Reflood water temperature (°C) | 51 | 52 | 53 |
| Initial rod peak power (kW/m) | 2.3 | 2.3 | 2.3 |

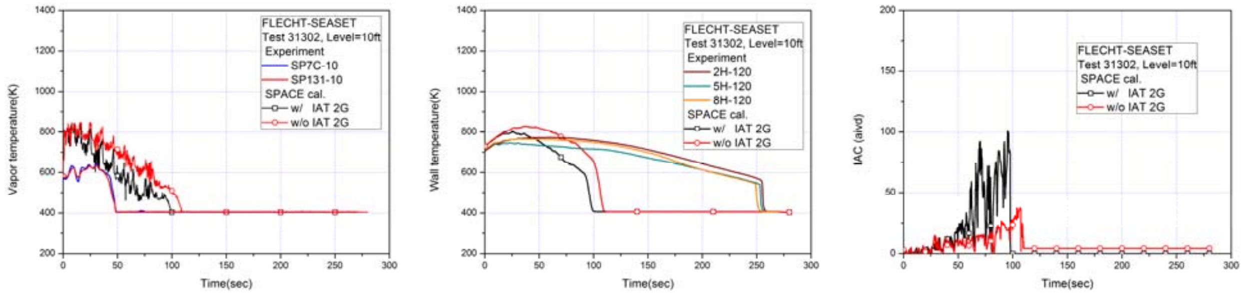
### *3.2 SPACE Code Calculation*

Figures 2, 3, and 4 show the calculation result of SPACE code with implementing the two-group IAT equation for three FLECTHT-SEASET test cases. They are compared to the result without the IAT for the droplet field. As shown in the result, the SPACE code predicted quenching time earlier than the actual test. When the IAT model was implemented for the droplet field in the SPACE code, interfacial area concentration of the droplet was predicted higher than the calculation result without the IAT in all test cases. It means that the breakup by the spacer grid effectively increased the interfacial area of the droplet by adopting the IAT model. A larger interfacial area of the droplet contributed to decrease vapor temperature as shown in the figures, due to enhanced amount of the vaporization. Effect of the IAT equation and the breakup model is more remarkable in the test case with a higher flooding rate (Test 31302 and 31701), since more droplets are generated in the high flooding rate and they increase the amount of the entrainment and the breakup by the spacer grid.



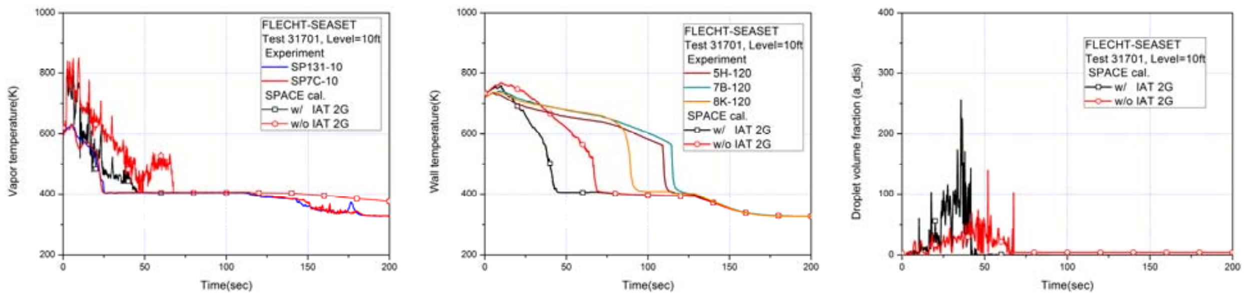

(a) Vapor temperature (L=10ft) (b) Wall temperature (L=10ft) (c) IAC (L=10ft)

Fig. 2 Calculation result for test 31504




(a) Vapor temperature (L=10ft) (b) Wall temperature (L=10ft) (c) IAC (L=10ft)

Fig. 3 Calculation result for test 31302




(a) Vapor temperature (L=10ft) (b) Wall temperature (L=10ft) (c) IAC (L=10ft)

Fig. 4 Calculation result for test 31701

## 4. Conclusion

Two-group IAT equation model was implemented in the SPACE code to mechanistically estimate dynamic behavior of the interfacial area for the droplet. The breakup of the droplet by impacting on the spacer grid was considered as major source terms in the equation. Variation of the interfacial area for the large and small droplets could be quantitatively estimated with separated transport equations for two groups. The IAT model for the droplet field in the SPACE code was validated with comparison to FLECHT-SEASET experiment. The calculation result proved that the droplet IAT model has estimated the dynamic behavior of the droplet interfacial area and reduced the vapor temperature by increasing the amount of the vaporization. For the further study, development of more precise model for the droplet breakup is required with comparison of the droplet size to the test result.

## REFERENCES

[1] KAERI, SPACE code manual- Models and Correlations, 2012.

[2] EPRI, Analysis of FLECHT-SEASET 163-Rod Blocked Bundle Data Using COBRA-TF, NUREG/CR-4166, 1985.

[3] USNRC, PWR FLECHT-SEASET Unblocked Bundle, Forced and Gravity Reflood Task Data Report, NUREG/CR-1532, 1980.