Interfacial Area and Heat Transfer Models and Correlations for the SPACE code

Sunwon Bae*,Young Jin Lee, Young Jong Chung, Hee Chul Kim and Kyung Du Kim
Korea Atomic Energy Research Institute, 150 Dukjin-dong, Yuseong-gu, Teajon, Korea 305-353
*bswon@kaeri.re.kr

1. Introduction

A safety analysis code, named as SPACE, for a pressurized water reactor is under development to obtain licensing to be used for the PWR design and to hold entire proprietary rights. The task of KAERI is to develop the physical models and correlations which are required to solve the field equations. It can be divided into four parts; i) flow regime determination, ii) wall heat transfer, iii) wall and interfacial friction, iv) interfacial heat and mass transfer. This paper will describe the process to develop the models for the interfacial area and heat transfer models and correlations which are used for the SPACE code.

2. Model Selection

2.1 Interfacial Area Concentration

SPACE code has been designed to have the 3 field analysis capability. 3 field means that the continuous liquid, vapor and droplet behaviors are independently calculated and monitored in the thermo-hydraulic view point. Thus the interfacial area between droplet and vapor is important to analysis the interfacial transport of the heat and mass as well as the interface between the continuous liquid and vapor. **Table 1** shows the selected models and correlation for the interface area between the continuous phase and droplets

2.2. Interfacial Heat Transfer Model

As noted earlier, the governing equation set of SPACE code should have the additional mass and energy transfer terms related to the droplet field. The names and the meanings of the interfacial heat transfer terms are as followings, i) h_ivl, the heat transfer to the vapor at the vapor-liquid interface, ii) h_il, the heat transfer to the liquid at the vapor-liquid interface, iii) h_ivd, the heat transfer to the vapor at the droplet-vapor interface, iv) h_id, the heat transfer to the liquid of droplet at the droplet-vapor interface, v) h_ln, the direct heat transfer to the liquid at the non-condensible gas interface, vi) h_dn, the direct heat transfer to the liquid of droplet at the non-condensible gas interface.

Table 2 shows the interfacial heat transfer models and correlations for the bubbly and slug flows only. It should be noted that the bubble and droplet interfaces are considered separately with depth. The Taylor bubbles and small bubbles are separately considered in slug flow. The liquid film and the droplets are considered separately in stratified flow when the interfacial area and heat transfer terms are calculated. The interfacial area concentration and heat transfer models are completely selected for other flow regimes and used to make the source relationships for the SPACE code.

3. Code Structure

C++ compiler environments are used to build the SPACE code interfacial source terms. The final requirement is not the interfacial area itself but the product of the interfacial area and heat transfer.

Table 1. Flow regime transition criteria used in various codes.

	Form	Valid range	Uncertainty	
bubbly	$N_{a_i} = 3.02\eta N_{Lo}^{0.335}\alpha N_{Re_b}^{0.239}$ $N_{a_i} = a_i Lo$ $Lo = \sqrt{\frac{\sigma}{g\Delta\rho}}$		adiabatic 21% boiling 31%	Hibiki (2006)
slug	Taylor : $a_i = \left(\frac{C^*}{D^*}\right)\frac{\alpha-\alpha_{gs}}{1-\alpha_{gs}}$ Small: Hibiki	Churn flow limit		TRAC-M & RELAP5 method Flowmap function $\alpha_{gs} = \alpha_{BS}F_9$
annular	Film: $a_i = C_\gamma\left(\frac{4}{D_H}\right)\sqrt{1-\alpha_l}$ $C_\gamma = \frac{D_H(1-\alpha_g)}{l_{min}} \le 10$ Droplet: $a_i = \frac{6\alpha_d}{d_d}$	Churn flow limit		d_d: minimum of Kataoka (1983)and Kitscha(1989) droplet diameter
H-stratified	Continuous interface: $\frac{4\sin\theta}{\pi D}$ Droplet: annular flow model $a_i = \frac{6\alpha_d}{d_d}$			Angle determined by flowmap function
V-stratified	Continuous interface : $\frac{1}{L}$ Droplet: annular flow model $a_i = \frac{6\alpha_d}{d_d}$			

Table 2. Interfacial heat transfer models and correlations

	Form of models and correlations			Valid range	Uncertainty	Consideration
Bubbly	Interface-liquid	SHL	Lucic(2004) : Nu=110.			Diffusion control model of Plesset/Zwick
		SCL	Warrier(2002): $Nu_c = \frac{h_c D_b}{k_l} = 0.6\,\mathrm{Re}_b^{1/2}\,\mathrm{Pr}_l^{1/3}\left[1 - 1.20\,Ja^{9/10} Fo_0^{2/3}\right]$	$20 < \mathrm{Re}_b < 700$ $1.8 < \mathrm{Pr}_l < 2.9$ $12 < Ja < 100$	25 %	Stagnant or convective Non-condensible gas effects: Vierow-Schrock (1992) correction factor
	Interface-vapor	SHG	10000(W/m² K)			physical assumption
		SCG	10000(W/m² K)			
	Direct		10000(W/m² K)			
Slug	Interface-liquid	SHL	Taylor : 10000(W/m² K) small : bubbly model			physical assumption
		SCL	Taylor : $Nu = 3.25 Pe^{0.4} Fr^{-0.2}$ small: bubbly model			Hetsroni/Rozenblit(2000)
	Interface-vapor	SHG	Taylor : h= $(2.0 + 0.74\,\mathrm{Re}_v^{0.5}\,\mathrm{Pr}_v^{1/3})\frac{k_v}{D_H}$ small : 10000(W/m² K)			original Lee/Ryley(1968)
		SCG	Taylor & small bubble : 10000(W/m² K)			physical assumption
	Direct		10000(W/m² K)			physical assumption

The product of the interfacial area and heat transfer is carried out at the heat transfer functions. Each heat transfer model includes the call of the interfacial area subfunctions. The heat transfer quantity multiplied by the suitable interfacial area is calculated for the horizontal and vertical flow regimes. A linear interpolation scheme is used to find the final quantity of the given inclined angle of the control volume. The interfacial heat transfer terms are prepared for the whole flow regimes and environment conditions.

4. Verification Test

Verification test procedures are performed in the manner of the void fractions and the phasic velocities. Because the SPACE code has 3 field system, the void fraction test is divided into the 2 field and the 3 field test. **Figure 1** shows the interfacial area between the vapor and continuous liquid phase along the void fraction at several pressure conditions. There is a sharp decrease of the interfacial area concentration at the transition of the bubbly-slug regime.

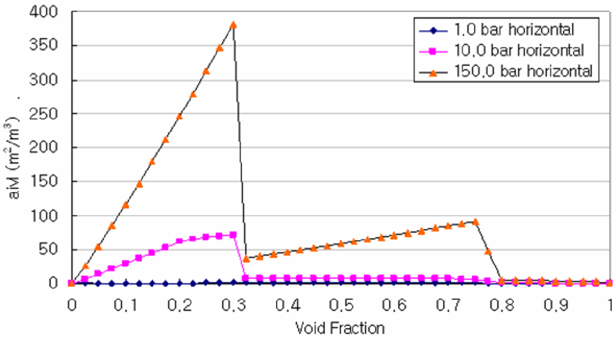

Fig. 1. Interfacial area between the continuous liquid and vapor phase along the void fraction at several pressures

Figure 2 shows the direct interfacial heat transfer to the liquid at the non-condnesible gas interface. The interfacial area strongly affects to the quantity of the heat transfer. In the vicinity of void fraction 0.8, an additional investigation is required for the cure of the abnormal peak. In the figure 1 and 2, the volume fraction of droplet field is kept as 0.

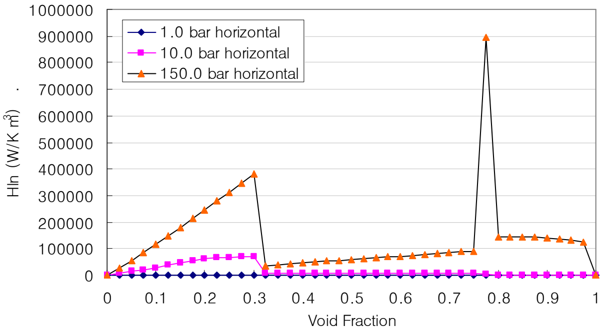

Fig. 2. Interfacial heat transfer between the continuous liquid and vapor phase along the void fraction at several pressures

5. Conclusion

Further detail tests are performed and the results show reasonable validity for the flow regimes and volume conditions. The interfacial area and heat transfer models are successfully implemented to the SPACE code.

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