Summary of Interfacial Heat Transfer Model and Correlations in SPACE Code

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1. Introduction

The first stage of development program for a nuclear reactor safety analysis code named as SPACE which will be used by utility bodies has been finished at last April 2010. During the first stage, main logic and conceptual sculpture have been established successfully under the support of Korea Ministry of Knowledge and Economy. The code, named as SPACE, has been designed to solve the multi-dimensional 3-field 2 phase equations [1].

From the begining of second stage of development, KNF has moved to concentrate on the methodology evaluation by using he SPACE code. Thus, KAERI, KOPEC, KEPRI have been remained as the major development organizations. In the second stage, it is focused to assess the physical models and correlations of SPACE code by using the well known SET problems.

For the successful SET assessment procedure, a problem selection process has been performed under the leading of KEPRI. KEPRI has listed suitable SET problems according to the individual assessment purpose. For the interfacial area concentration, the models and correlations are continuously modified and verified.

2. Interfacial Heat Transfer Models

2.1 Interfacial Area Concentration

SPACE includes the interfacial area between vapor and droplet in addition to the gas-(continuous) liquid interfacial area. The interfacial area between droplet and vapor is important to analysis the interfacial transport phenomena like the spray injection in the pressurizer, the steam binding in the steam generator, and the core reflood in the LBLOCA accident. The Azzopardi model [2] has been selected to modify the current droplet diameter model in SPACE code.

Vertical stratification regime has been treated to contain the small bubbles under the interface level. By doing this, the transition between vertical stratified regime and other regimes shows intentionally smooth behavior. The vertical stratified regime is not permitted for the vapor generating flow condition.

In the post-CHF hot wall flow regime, it has been assumed that liquid and droplet phases are totally mixed up. The droplet amounts become significant in the inverted slug flow and the dispersed flow. As the current entrainment and de-entrainment models are not matured, the liquid and droplet mixed up assumption is temporally used in SPACE for the post-CHF flow regime. **Table 1** shows the selected models and correlation for the interface area. Some models are changed and modified from the first selection in the reference [1].

2.2. Interfacial Heat Transfer

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 follows: 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. The superheated liquid flashing model is designed by using the Plesset and Zwick model [3]. The maximum bubble growth rate is assumed at the heterogeneous interfacial surface of superheated liquid.

The modified Lee and Ryley model [4] is mainly used for the interfacial heat transfer around the spherical surface. The vapor heat transfer of superheated droplet interface is also modeled by the modified Lee and Ryley model. The interfacial heat transfer in the superheated droplet liquid is models by the Lucic *et. al*. model [5]. At that application, the characteristic length scale is droplet diameter. The direct heat transfer derived by the sensible temperature difference between gas and liquid is modeled by using the Dittus-Boelter correlation.

Table 2 shows the interfacial heat transfer models and correlations except the interpolation regimes

3. Conclusion

The current status about the interfacial heat transfer related models and correlations in the SPACE code are summarized. During the second stage of development, the smooth transition and robust model behaviors are main interests. SPACE shows better results about the conceptual and separate effect problems.

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Table 1. Summary of the models for the interfacial area concentration

Regimes		Models	Descriptions
Bubbly	bubble	Hibiki et. al. (2006)[6]	bubble to liquid
Slug	Taylor bubble	Ishii & Mishima (1980)[7]	fraction determined by Ishii and Mishima (1980)
	Small bubble	Hibiki et. al. (2006)	
Annular-mist	Film	Ishii & Mishima(1980)	wave effect included. Core internal bubble considered.
Horizontal stratified	Film	Ishii & Mishima(1980)	wave effect included.
Vertical stratified	Film	geometrical consideration	small bubble under level considered.
Inverted annular	Film	Geometrical consideration	fraction determined by square divide assumption
	Bubble	Hibiki et. al. (2006)	
Inverted slug	Liquid plume	Geometrical consideration	liquid and droplet mixed up
Dispersed	Film	Ishii & Mishima(1980)	inverted slug without liquid. Droplet area dominant
Droplet	Droplet	sphere assumption	Azzopardi[2] correlation for droplet diameter

Table 2. Summary of the models for the interfacial heat transfer

Regimes and thermal states			Models	Descriptions
Bubbly	Liquid	superheat	max of Lee-Ryley[4] and Lucic et al. (2004)[5]	diffusion heat transfer. Flasing
		subcool	Unal (1976)[8]	general subcooled water correlation
	Vapor		constant	mitigate the existence of unstable phase
Slug	Liquid	superheat	constant, Lee-Ryley	diffusion heat transfer. Flashing
		subcool	Dittus-Boelter and Unal (2000)	Pecklet number involved
	Vapor	superheat	Lee and Ryley (1968)[4]	flashing consideration
		subcool	constant	mitigate the existence of unstable phase
Annular -mist	Liquid		film: constant and Theofanous[9] droplet: Lee-Ryley and Nelson (1987)[10]	assumed droplet temperature profile
	Vapor		film: Dittus-Boelter and constant droplet: Lee-Ryley[4]	rapid diffusion of droplet liquid
Horizontal stratified	Liquid	superheat	Dittus-Boelter and regime combine	wave effect included
		subcool	Dittus-Boelter	wave effect considered
	Vapor		Dittus-Boelter and constant	mitigate the existence of unstable phase
Vertical stratified	Liquid		McAdams (1954)[11] and bubbly combine	laminar extent to turbulence
	Vapor		modified McAdams (1954)	surface temperature required
Inverted annular	Liquid	superheat	Lee-Ryley and bubbly combine	diffusion heat transfer
		subcool	Unal (1976) and Dittus-Boelter	general subcooled water correlaion
	Droplet		Lee-Ryley and Nelson, Lucic	mitigate the existence of unstable phase
	Vapor		constant	mitigate the existence of unstable phase
Inverted slug	Liquid	superheat	constant and Dittus-Boelter	diffusion heat transfer
		subcool	constant and Dittus-Boelter	Pecklet number involved
	Droplet		Lee-Ryley and Nelson, Lucic	assumed droplet temperature profile
	Vapor		Dittus-Boelter	flashing consideration
Dispersed	Liquid		Dittus-Boelter	mitigate the existence of unstable phase
	Droplet		Lee-Ryley and Nelson, Lucic	assumed droplet temperature profile
	Vapor		Dittus-Boelter	General convective heat transfer
All	Direct heating		Dittus-Boelter	