Preliminary Assessment of the Interfacial Source Terms in SPACE Code

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1. Introduction

The development program for a nuclear reactor safety analysis code which will be used by utility bodies has been launched supported by the Ministry of Knowledge Economy. The code, named as SPACE, has been designed to solve the multi-dimensional 3-field 2 phase equations. The target power plant type is restricted to PWR's and does not include advanced reactor types, like gas cooled or liquid metal reactors.

KAERI, KOPEC, KNF, KEPRI and KHNP are participated in the development project. KAERI has been assigned to develop the physical models and correlations which are required as the closure relationships. The assigned work can be divided into four parts, i.e, (i) the flow regime determination, (ii) the wall heat transfer, (iii) the wall and interfacial friction, and (iv) the interfacial heat and mass transfer. The interfacial heat and mass transfer correlations used in RELAP5, TRAC-M, CATHARE, etc. are reviewed with respect to the simplicity and the range of validity. The recent suggestions are also reviewed. The intellectual property ownerships are proved before an adaptation to the development of the SPACE code. The selected models and correlations are already represented by reference [1]. This paper shows the preliminary assessment results obtained by using the SPACE code.

2. Separate Assessment

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. **Table 1** shows the selected models and correlation for the interface area. Some models are changed from the first selection as in the reference [1]. Interfacial area concentration models for the post-CHF flow conditions are also included.

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 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 except the interpolation regimes

3. Integrated Assessment

Although the choking model is not implemented yet in SPACE, a flashing phenomenon was assessed. One end of a horizontal pipe component is connected to ambient at the start of calculation.

Two-phase pressure drop of the horizontal or vertical pipe flows are also assessed. The pressure drop amounts are directly related to the interfacial area concentration. The results are compared to the MARS calculation results.

The vaporization and condensation in the vertical pipe flow also have been assessed. In this assessment, all 6 interfacial heat transfer source terms are activated. The results show the reasonable temperature increase and interfacial mass transfer behaviors.

4. Conclusion

Further detail tests are continuously required for various flow regimes and volume conditions. The interfacial area and heat transfer models are successfully implemented to the SPACE code.

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REFERENCES

[1] S. Bae, Y. J. Lee, Y. J. Chung, H. C. Kim, K. D. Kim, Interfacial Area and Heat Transfer Models and Correlations for the SPACE Code, Transactions of the Korean Nuclear Society Spring Meeting, May 29-30, 2008, Gyengju, Korea.
[2] Hibiki, T., Lee, T. H., Lee, J. Y., Ishii, M., 2006, Interfacial Area Concentration in Boiling Bubbly Flow Systems, Chem. Eng. Sci., Vol. 61, pp. 7979-7990.
[3] Kataoka, I., Ishii, M. and Mishima, K., 1983, "Generation and Size Distribution of Droplet in Annular Two-Phase Flow," Trans. ASME, J. Fluid Engineering, 105, 230-238.
[4] Kitscha, J. and Kocamustafaogullari, G., 1989, "Breakup Criteria for Fluid Particles," Int. J. Multiphase Flow, 15, 573-588.

[5] Lucic, A., Emans, M., Mayinger, F. and Zenger, C., 2004, “Interferomtric and numerical study of the temperature field in the boundary layer and heat transfer in subcooled flow boiling, Int. J. of heat and Fluid Flow”, Vol. 25, pp. 180-195.
[6] Unal, H. C., 1976, Maximum bubble diameter, maximum bubble-growth time and bubble growth rate during the subcooled nucleate flow boiling of water up to 17.7MN/m2, Int. J. Heat Mass Transfer, 19, 643-649.
[7] Vierow, K.M. and Schrock, V.E., 1992, “Condensation in a natural circulation loop with noncondensable gas present,” Japan-U.S. Seminar on Two-Phase Flow Dynamics, Berkeley, California, USA.
[8] Hetsroni, G. and Rozenblit, R., 2000, Thermal patterns on a heated wall in vertical air-water flow, int. J. Multiphase Flow, Vol. 26, pp. 147-167.
[9] Ryley, D.J., 1961, Phase Equilibrium in Low-Pressure Steam Turbines, Int. J. Mech. Sci. Vol. 3, pp. 28-46.
[10] Bankoff, S. G., 1980, "Some Condensation Studies Pertinent to Light Water Safety,”" Int. J. Multiphase Flow 6, 51-67.
[11] Pasamehmetoglu, K. and Nelson, R., 1987, "Transient Direct-Contact Condensation on Liquid Droplets," Nonequilibrium Transport Phenomena, American Society of Mechanical Engineers, New York, HTD-Vol. 77, 47-56.
[12] Ryskin, G., 1987, "Heat and Mass Transfer from a Moving Drop−.Some Approximate Relations for the Nusselt Number," Int. Comm. Heat Mass Transfer 14, 741-749.
[13] Linehan, J. H., Petrick, M. and El-Wakil, M. M., 1972, "The Condensation of Saturated Vapor on a Subcooled Film During Stratified Flow,”" Chem. Eng. Symp. Series 66, 11-20.
[14] K.W. Lee, I.C. Chu, S. O. Yu, H.C. No, 2006, “Interfacial condensation for countercurrent steam-water stratified wavy flow in a horizontal circular pipe,” Int. J. Heat and Mass 49, pp.3231-3129.
[15] McAdams, W. M., 1954, Heat Transmission, 3rd ed., McGraw-Hill Book Co., New York.

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

Regimes		Models	Descriptions
Bubbly	bubble	Hibiki et. al. (2006)[2]	bubble to liquid
Slug	Taylor bubble	Ishii & Mishima (1980)[3]	fraction determined by Ishii and Mishima (1980)
	Small bubble	Hibiki et. al. (2006)	
Annular-mist	Film	Ishii & Mishima(1980)	wave effect included
Horizontal stratified	Film	Ishii & Mishima(1980)	wave effect included
Vertical stratified	Film	geometrical consideration	wave effect included
Inverted annular	Film	Geometrical consideration	Fraction determined by linear divide assumption
	Bubble	Hibiki et. al. (2006)	
Inverted slug	Liquid plume	Geometrical consideration	Liquid plume diameter limitation considered
Dispersed	Film	Ishii & Mishima(1980)	Droplet area dominant
Droplet	Droplet	sphere assumption	Kataoka and Kitscha[4] correlation for diameter

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

Regimes and thermal states			Models	Descriptions
Bubbly	Liquid	superheat	Lucic et al. (2004)[5]	diffusion heat transfer
		subcool	Unal (1976)[6]	general subcooled water correlation[7]
	Vapor		Constant	mitigate the existence of unstable phase
Slug	Liquid	superheat	Lucic et. al. (2004)	diffusion heat transfer
		subcool	Hetsroni and Rozenblit (2000)[8]	Pecklet number involved
	Vapor	superheat	Lee and Ryley (1968)[9]	flashing consideration
		subcool	Constant	mitigate the existence of unstable phase
Annular -mist	Liquid		film: Bankoff (1980)[10] droplet:Pasamehmetoglu (1987)[11]	assumed droplet temperature profile
	Vapor		film: Bankoff (1980) droplet: Ryskin (1987)[12]	rapid diffusion of droplet liquid
Horizontal stratified	Liquid	superheat	Linehan (1972)[13]	wave effect included
		subcool	Lee et. al. (2006)[14]	wave effect considered
	Vapor		Constant	mitigate the existence of unstable phase
Vertical stratified	Liquid		McAdams (1954)[15]	laminar extent to turbulence
	Vapor		modified McAdams (1954)	Surface temperature required
Inverted annular	Liquid	superheat	Lucic et. al. (2004)	diffusion heat transfer
		subcool	Unal (1976)	general subcooled water correlaion
	Droplet		Constant	mitigate the existence of unstable phase
	Vapor		Constant	mitigate the existence of unstable phase
Inverted slug	Liquid	superheat	Lucic et. al. (2004)	diffusion heat transfer
		subcool	Hetsroni and Rozenblit (2000)	Pecklet number involved
	Droplet		Pasamehmetoglu (1987)	assumed droplet temperature profile
	Vapor		Same to slug flow	flashing consideration
Dispersed	Liquid		Constant	mitigate the existence of unstable phase
	Droplet		Pasamehmetoglu (1987)	assumed droplet temperature profile
	Vapor		Dittus-Boelter	General convective heat transfer
All	noncondensible		Dittus-Boelter & Bankoff	