A Summary of Interfacial Heat Transfer Models and Correlations

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1. Introduction

A long term project has been launched in October 2006 to develop a plant safety analysis code. 5 organizations are joining together for the harmonious co-working to build up the code. In this project, KAERI takes the charge of the building up the physical models and correlations about the transport phenomena. The momentum and energy transfer terms as well as the mass are surveyed from the RELAP5/MOD3, RELAP5-3D, CATHARE, and TRAC-M does. Also the recent papers are surveyed. Among these resources, most of the CATHARE models are based on their own experiment and test results. Thus, the CATHARE models are only used as the comparison purposes.

In this paper, a summary of the models and the correlations about the interfacial heat transfer are represented. These surveyed models and correlations will be tested numerically and one correlation is selected finally.

2. Interfacial Heat Transfer

The interfacial heat transfer is the phenomena that the mass and energy are transferred through the phase interface. The possible interface forms that may happen in the fluid flow are the continuous liquid-gas interface and the dispersed liquid-gas interface. For both of the interfaces, the temperatures of the liquid and gas phases determine the manners and the amounts of the transferring heat and phase change. Another important parameter to determine the interfacial heat transfer is the flow regime. The flow regimes directly determine the interface area. Thus, the surveyed model and correlations are arranged by the flow regimes.

2.1 bubbly Flow

In the bubbly flow regime, major interface is induced at the bubble and the continuous liquid. The bubble size or size distribution is key parameter to measure the interfacial area. In the RELAP5-3D codes, the mean diameter is used to describe the bubble size, which comes from the bubble size distribution functions[1]. The maximum bubble size is restricted by the Weber number. In addition, Ishii [2], Hibiki [3], Yun [4] models are surveyed, too.

The heat transfer coefficients between the super heated liquid and the interface include the Plesset and Zwick model[5], Lee-Ryley model[6]. These models describe the combined effect of bubble growth rate and interfacial heat transfer. Lucic model [7] is a recent model.

For the subcooled liquid, Unal model[8] is used in RELAP5-3D code. Chen and Mayinger [9] model is used in TRAC-M code. Recentrly, Chen and Mayinger[10], and Zeitoun[11], Warrier [12] suggested the correlation including the refrigerant fluids.

For both of the superheated gas and subcooled gas, the interfacial heat transfer is provided as a constant. Only the amounts are different for all codes.

2.2 Slug Flow

The interfacial area of slug flow is considered by the sum of the large Taylor bubble interface and small bubble interface. For the Taylor bubble, Ishii and Mishima [13] correlation is widely used for all codes. The interfacial area model of bubbly flow is used for the small bubbles. RELAP5-3D code assumes the cylindrical Taylor bubbles and uses the Sauter mean diameter. TRAC-M includes the cap bubble shape. It is important to determine the fraction of the Taylor bubble because the Taylor bubble interfaces occupy the enormous portion of the total interfacial area.

For the superheated liquid, RELAP5 uses large constant, 3×10^6 W/m^{2}K for the heat transfer coefficient of large Taylor bubble interface. By using the large constant, the unstable superheated liquid phase rapidly disappears from the governing equation.

For the subcooled liquid, the Chen and Mayinger model is used in TRAC-M code, the same to bubbly regime. Recent research about the subcooled liquid heat transfer, Hetzron and Rozenblit [14] and Elamvaluthi and Srinivas [15] suggested a correlation for the large Taylor bubble.

For the superheated gas, modified Lee-Ryley model is used in RELAP5-3D. In TRAC-M code, a constant is used like the liquid interface case.

The larger constant values are used for the heat transfer coefficient at the interface of subcooled gas bubbles than superheated gas.

2.3 Annular-Mist Flow

Annular-mist flow is characterized by the liquid film located along the wall and the droplets at the core region of the flow. All traditional codes use the total interfacial area rather than dividing the film and the droplet interface. However, when the droplet filed is considered another one independent phases, the interfacial area should be separated. RELAP5-3D, MARS, and TRAC-M postulate the simple geometrical assumptions by Ishii and Mishima[13] for the continuous liquid film interface. In addition, film wave effects are considered as a multiplying factor.

The interfacial area between dispersed droplet and gas is determined by the number and the size of the droplets. In RELAP5, the entrainment fraction is calculated by the model of Ishii and Mishima [16]. From the dispersed liquid fraction, the interfacial area is calculated with the assumptions of droplet shape. RELAP5-3D and TRAC-M assume the spherical bubbles.

For the superheated liquid film interface, RELAP5 uses a constant 3×10^6 W/m^{2}K for the interfacial heat transfer coefficient. The Brown model [17] is used for the droplet interface.

In TRAC-M, the Bankoff model [18] is used for the superheated liquid film heat transfer coefficient. The Skelland model[19] is used for the droplet interface.

RELAP5-3D uses the Theofanous correlation [20] for the subcooled liquid interface heat transfer coefficient. For the droplet interface, Brown model[17] is used again. In TRAC-M, the Bankoff model[18] and Pasamehmetoglu and Nelson correlation[21] are used for the subcooled liquid film and the droplet interface, respectively. Both correlations are induced from the transient conduction heat transfer solutions.

For the superheated gas interface, the Dittus-Boelter correlation is widely used for the turbulent and larminar cases. The Ryskin model [22] is used for the droplet interface in TRAC-M code.

Both the RELAP5-3D and the TRAC-M use the very large constants for the heat transfer coefficient of the subcooled gas interface. Because it is an unstable phase, strong prevention logic is applied.

2.4 Stratified Flow

For the stratified flow regime, the Dittus-Boelter equation and McAdams model [23] are applied for almost all phasic temperature ranges in codes. However, in the subcooled liquid stratified interface, recent researches like Lee, et. al.[24], Kim, et. al.[25], are suggested for the effects of the reverse flow and surface wave, respectively.

3. Conclusion

A literature survey work about the interfacial heat transfer has been performed for the wide range of the traditional thermal hydraulic codes and recent papers. Numerical tests and smoothing works will be prepared for the several selected models for the next work step. Finally, a well adjusted interfacial heat transfer package, which works as the source terms in the governing equations describing the 3-field, 2-phase fluid system.

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