Transactions of the Korean Nuclear Society Autumn Meeting
Pyeong Chang, Korea, October 30-31, 2008

Investigation and Selection of Entrainment-Deposition Correlations for the Development of SPACE code

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1. Introduction

Since 1970s, various safety codes have been developed to predict the thermal-hydraulic phenomena in nuclear power plant and many studies have been performed to improve the prediction performance and accuracy. One of the most important issues to develop and to improve the safety codes is the droplet entrainment and deposition (En-Dep) behavior in the safety analysis and design of a nuclear power plant.

Until now, most of the thermal-hydraulic system code, such as TRAC and RELAP5, have been developed based on the liquid phase deal with a single set of average equation and with the averaged liquid phase equation (a two-field model), so that the behavior of a droplet cannot be described accurately. On the other hand, COBRA-TF provides a two-fluid, three-field representation of two-phase flow in which continuous liquid and entrained liquid drops and described separately.

At the present time, SPACE (Safety & Performance Analysis CodE) has been being developed in Korea based on a three-field model for predictions and analyses of general thermal-hydraulic phenomena in a nuclear power plant.

In this paper, investigation and selection of En-Dep correlations are performed to develop an En-Dep module in SPACE code.

2. Flow Regime for Entrainment-Deposition Correlations in SPACE code

The phenomena of droplet entrainment mainly take place when the relative velocity between gas and liquid is very high in two phase flow such as ‘annular-mist flow regime’ and most of researches have been investigated En-Dep of droplet for annular-mist flow regime.
However En-Dep could occur in hot/cold leg and reactor core (vertical and horizontal stratified flow regime) during loss of coolant accident (LOCA) in a nuclear power plant, therefore it is needed to develop En-Dep module in SPACE code for these flow regime.

3. Selection of Entrainment-Deposition Correlations

3.1 Vertical annular-mist flow regime

Correlations for the deposition and entrainment rate of droplets in vertical annular-mist flow regime were selected from Okawa-Kataoka (2005) study. They suggested the deposition rate and entrainment rate of droplet correlations investigated with more extensive databases than the previous works [1].

3.2 Vertical stratified flow regime

There are little studies of En-Dep correlations for vertical stratified flow regime. In COBRA-TF, however, an entrainment model similar to one proposed for droplet entrainment by vapor bubbling through liquid pools is used for bottom reflood condition [2, 3] and base on this approach, the entrainment rate correlation is selected for vertical stratified flow regime.

Droplet deposition correlation in this flow regime is defined base on the simple physical phenomenon (when droplet move towards water surface, it deposit).

3.3 Horizontal annular-mist/stratified flow regime

There are little studies of droplet En-Dep rate correlations for horizontal flow regime and especially droplet entrainment rate correlation not founded in present study.

Pan et al. (2002) considered that entrainment is considered to result from a balance between the rate of atomization of the liquid layer flowing along the pipe wall and the rate of deposition of drops, and they suggested the local rate of atomization correlation which is selected as droplet entrainment correlation for horizontal annular-mist flow regime [4].

Paras-Karabelas (1991) developed droplet deposition rate correlation based on 50.8mm inner diameter horizontal pipe experiment [5]. This correlation is based on more advanced physical theory than other studies (considered a deposition rate constant as a constant or as a simple linear equation related to gas velocity) and is investigated with extensive experimental databases

There are no studies for correlations of droplet En-Dep rate in horizontal stratified flow but the mechanisms of En-Dep in this flow regime are similar to the mechanisms in horizontal annular-mist flow regime. Therefore, the droplet En-Dep rate correlations in horizontal stratified flow and in horizontal annular-mist flow are selected as the same.

3. Summary

The selected correlations of droplet En-Dep rate are summarized in table I.

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Table I: Selected Correlations of Droplet Entrainment-Deposition for SPACE code

Flow regime	En-Den	Correlations	Range	Founded Ref.
Vertical annular-mist flow	Entrainment	$m_E = \rho_l \times \min(k_{e1}\pi_{e1}, k_{e2}\pi_{e1}^{0.5}, k_{e3})$ $(k_{e1}, k_{e2}, k_{e3}) = (3.8, 1.2, 1.2)\times 10^{-3} m/s$ $\pi_{e1} = \frac{\delta f_i \rho_g (j_g^2 - j_{gc}^2)}{\sigma}$	i.d.: 5-57 mm Air-water / Steam-water j_g: 20-110m/s	Okawa-Kataoka (2005)
	Deposition ($m_D = k_d C$)	$k_d = \min(0.19C^{*-0.2}, 0.105C^{*-0.8})$ $for\ C^* > 0.2$ $k_d = 0.17u_f$ $for\ C^* < 0.2$ $C^* = \frac{C}{\rho_g}$	i.d.: 5-57 mm Air-water / Steam-water j_g: 20-110m/s	Okawa-Kataoka (2005)
Vertical stratified flow	Entrainment	$S_E = (\alpha_g v_g / u_{crit})^2 W_G$	-	NRC Steam Generator Workshop (1979)
	Deposition ($m_D = k_d C$)	For the droplets move downward, $S_D = \rho_d V_{cell} \alpha_d \frac{\lvert v_d \rvert}{\Delta z(\alpha_g + \alpha_d)}$ The other case, $S_D = 0$	-	Based on the physical phenomena
Horizontal annular-mist flow/stratified flow	Entrainment	$m_E = MAX\left(0, \frac{k_A' v_g^2 (\rho_g \rho_l)^{1/2}}{\sigma} \frac{(W_{LF} - W_{LFC})}{P}\right)$ $k_A' = 3\times 10^{-6}$	i.d. 23.1-95.3 mm j_g: 11-131 m/s	Pan-Hanratty (2002)
	Deposition ($m_D = k_d C$)	$k_d = 20.7U^*(\tau^+)^{-0.5}$ $\tau^+ = \frac{d_d^2 U^{*2} \rho_g \rho_l}{18\mu_g^2}$ $U^* = v_g \sqrt{\frac{f_w}{2}}$	j_g: 30.1-65.5 m/s	Paras-Karabelas (1991)