Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Prediction of Void Fraction in Subcooled Boiling

Kwi- Seok Ha, Hae-Young Jeong, Young-Min Kwon, Won-Pyo Chang, Eui-Kwang Kim, and Yong-Bum Lee
Researchers
Korea Atomic Energy Research Institute, P.O. Box 105, Yuseong, Daegeon 305-600
E-mail:ksha@kaeri.re.kr

1. Introduction

The various subcooled boiling models were investigated through the published experimental data. In the process of investigation, we developed two models related to the subcooled boiling. First, the Saha and Zuber correlation predicting the point of the net vapour generation was modified to consider the thermal and dynamic effects at the high velocity region. Second, the pumping factor model based on parameters related to bubble generation mechanism was developed. The proposed models were evaluated against a series of subcooled flow boiling experiments at the pressure range from 1 bar to 146.8 bar. The implementation of the developed models into RELAP5/MOD3.3 brought about the improved results compared to those of the default model of the code.

2. Subcooled Boiling Models in RELAP5/MOD3.3

RELAP5/MOD3.2 code used the Saha-Zuber method of predicting the conditions necessary for net voids to exist [1]. Then Lahey's pumping factor model of Eq. (1) has been used to assign a fraction of the total heat flux to liquid. The Saha-Zuber correlation of Eq. (2) assumes that the bubble detachment is thermally controlled and occurs at a fixed Nusselt number at the low flow rates. At the high flow rate bubble departure is hydro-dynamically induced and occurs at a fixed Stanton number. At some point, as the liquid flows axially over a heated wall, the enthalpy may become close enough to the saturation enthalpy that bubbles generated at the wall will not be condensed. The enthalpy necessary is the critical enthalpy.

$$\varepsilon = \frac{\rho_f}{\rho_g} \cdot \frac{h_f^{sat} - h_f}{h_{fg}} \tag{1}$$

$$h_{cr} = h_f^{sat} - \frac{q_f''}{0.0065 \cdot G} \quad \text{for } Pe > 70000$$
$$= h_f^{sat} - \frac{q_f'' \cdot D \cdot C_{pf}}{455 \cdot k_f} \quad \text{for } Pe \le 70000 \tag{2}$$

Recently, a number of research activities for the subcooled flow boiling at the low pressures have been done in the past few years, focused on the safety analyses of the research reactors operating near atmospheric pressure [2] and the improvement of the best estimate thermal-hydraulic code [3, 4]. Most of the above models are applicable to their developed ranges.

3. Proposed models of the subcooled boiling model

Two physically based models were modified to improve the prediction of void fraction in the subcooled flow boiling. The critical enthalpy correlation that determines the point of net vapour generation was modified. As shown in Eq. (2), the correlation developed by Saha and Zuber takes two forms, depending on the value of the Peclet number. For the Peclet numbers less than 70000, thermal effects govern the onset of significant void only. For the Peclet numbers greater than 70000, the onset of significant void is governed by dynamic force only. According to Rogers [5], the trend of the bulk liquid temperatures at the onset of significant void was opposite to those predicted by the Saha and Zuber correlation. Thus, the data cited by Saha and Zuber were newly fitted to two correlations depending on the Peclet number of 52000.

$$h_{cr} = \begin{cases} h_f^{sat} - \dfrac{\mathrm{St}' \cdot \mathrm{Pe}^{0.124} \cdot C_{pf}}{0.0287} & \text{for Pe} \ge 52000 \\ h_f^{sat} - \dfrac{\mathrm{St}' \cdot \mathrm{Pe}^{1.08} \cdot C_{pf}}{918.525} & \text{for Pe} < 52000 \end{cases} \tag{2'}$$

The second proposed model is associated with the pumping factor model. According to the reference [4], the pumping factor is the function including following variables, e.g. $\varepsilon = \varepsilon\left(\rho_g, \rho_f, C_{pf}, k, H, G, d_{Bw}, h_{fg}, f, \Delta T_w\right)$. Here, k is the liquid conductivity and H is the wall heat transfer coefficient. Using the pi-theorem with above variables, Eq. (3) can be derived. The above two relations (Eqs. (2') and (3)) are implemented into the RELAP5/MOD3.3.

$$\varepsilon = (1.514K) \cdot F \cdot \frac{\rho_f}{\rho_g} \frac{C_{pf}\left(T_w - T_f\right)}{h_{fg}} \frac{\sqrt{k_f / \rho_f C_{pf} f}}{d_{Bw}} (666.5 \cdot \mathrm{Bo}) \tag{3}$$

4. Simulation results for the experiments

A various experimental data were obtained from the literatures [5,6,7,8] for comparing the subcooled boiling models. Table 1 summarizes the experiments used in the evaluation of the subcooled boiling models.

In all cases of simulations, the inlet boundary conditions are the liquid velocity and temperature and the outlet boundaries are the pressure.

Table 1. The test conditions for evaluation of the subcooled boiling models

Exp.	No. of tests	Heat Flux(kW/m^2)	Pressure(Bar)	Subcooling(K)	Mass flux(kg/m^2-s)	Type	D_h (mm)
Zeitoun	11	210.0~603.2	1.1~1.68	11.4~23.5	161.2~403	Annular	12.7
Donevski	6	481.4~723.7	1.53~2.11	18.5~29.2	315.1~450	Annular	12.7
Dimmick	4	472.0~1164.0	1.65	27.5~61.0	620.2~1115.5	pipe	12.29
Bartolomy	8	780.0~1130.0	30.1~146.8	24.0~136.9	405~1000	pipe	12
Christensen	1	160.5	11.18	3.6	1516.7	Rect.tube	17.76
Marchaterre	1	496.6	55.12	12.5	907.3	pipe	10

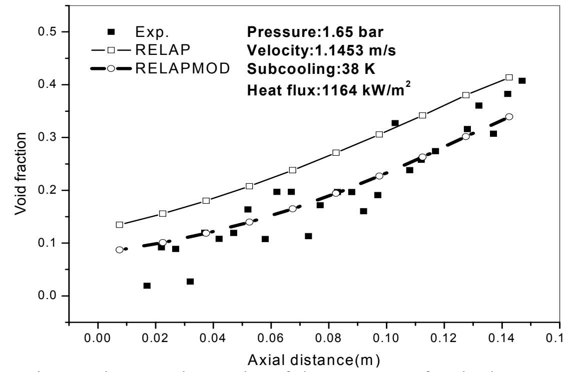

Fig. 1. The sample results of the RELAP5 for the low P.

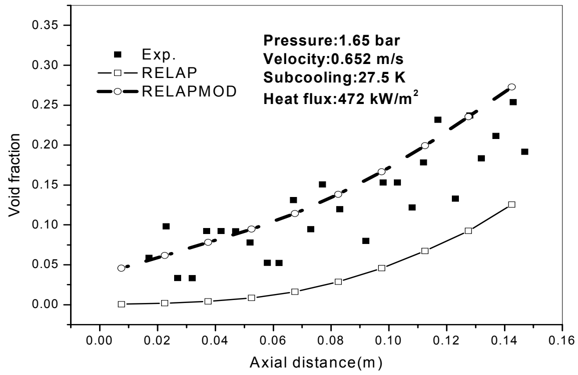

Fig. 2. The sample results of the RELAP5 for the low P.

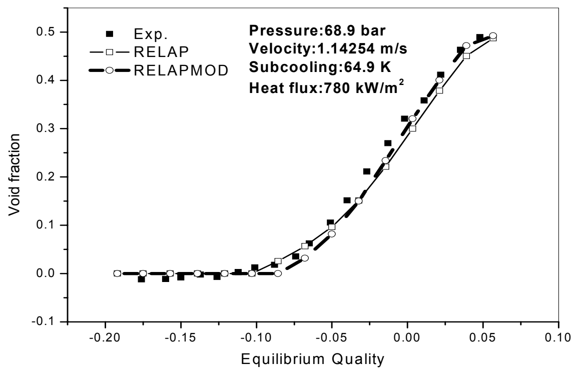

Fig. 3.The sample results of the RELAP5 for the high P.

The above two models were implemented into the RELAP5/MOD3.3. Figs. 1 ~ 3 compare the results of the current model and the default model of RELAP5/MOD3.3 (SRL model). All simulations using the proposed models for the cases of low pressure conditions were improved. The results for high pressure cases also confirm the fact that the current model dose not has any adverse effect on the void fraction prediction.

5. Conclusions

The proposed models were evaluated against a series of subcooled flow boiling experiments at low pressures (1 ~ 2 bar) and high pressures (11.18 ~ 146.8 bar). the application of the models to the RELAP5/MOD3.3 brought about the improved results in comparison with those of default model of the code and it verified the validity of the models.

ACKNOWLEDGMENTS

This work has been performed under the nuclear R&D Program supported by the Ministry of Science and Technology of the Korean Government.

REFERENCES

[1] RELAP5/MOD3 CODE MANUAL Vol. I~IV, NUREG/CR-5535 (1998).

[2] Eckhard Krepper, "CFD Modelling of Subcooled Boiling", NURETH-10, Seoul, Oct. 5-9 (2003).

[3] S. Hari, Y. A. Hassan, "Improvement of the subcooled boiling model for low-pressure conditions in thermal-hydraulic codes", Nucl. Eng. Des. 216, pp. 139-152 (2002).

[4] B. Koncar and B. Mavko, "Modelling of low-pressure subcooled flow boiling using the RELAP5 code", Nucl. Eng. Des. 220, pp. 255-273 (2003).

[5] O. Zeitoun, M. Shoukri, "Axial void fraction profile in low pressure subcooled flow boiling", Int. J. Heat Mass Transfer 40, pp. 869-879 (1997).

[6] A. S. Devkin and A. S. Podosenov, "RELAP5/MOD3 Subcooled Boiling Model Assessment", NUREG/IA-0025, U.S. NRC (1998).

[7] V. Prodanovic, D. Fraser, M. Salcudean, "Bubble behavior in subcooled flow boiling of water at low pressures and flow flow rates", Int. J. of Multiphase Flow 28, pp. 1-19 (2002).