Modification of Two Phase Friction Multiplier Model in MARS Vessel Module

Sung Won Bae, Jae-Jun Jeong, Bub Dong Chung
Korea Atomic Energy Research Institute, 150 Dukjin-dong, Yuseong,Daejeon, 305-353,Korea, bswon@kaeri.re.kr

1. Introduction

The fundamental two phase pressure drop calculation methods in MARS vessel module were reviewed in this paper. Around the high void fraction region of two phase flows, simple approximated two phase friction multiplier was a source of unreasonable discrepancies. Therefore, basic Lockhart-Martinelli [1] correlation was adapted and implanted in to the MARS vessel module. The two phase multiplier was calculated under various mass flow rate conditions and compared to the simple method.

2. Pressure Drop Discrepancy

There are three ways to calculate the wall-liquid film frictions. The first way is that by applying the velocity gradient based on an approximate correlation for the velocity profile in the liquid film. Second way is that by assuming as $\tau_i = \tau_w$, thus neglecting the gravitational force term in the liquid film momentum conservation equation. Finally, the third way is to use an empirical correlation to calculate the two phase friction pressure gradient and to assume that wall friction is imposed directly on liquid film. Among these, the third approach, which has been widely applied in two-fluid modeling is currently utilized in most of the best-estimate thermal-hydraulic code for nuclear reactor transient analyses.

MARS vessel module has been utilized the third way of calculating wall friction. The friction factors for laminar and turbulent regime are as follows.

$$f_k = 64/\mathrm{Re}_k, \qquad \mathrm{Re}_k \le 2200 \tag{1}$$

$$\frac{1}{\sqrt{f_k}} = -2\log_{10}\left\{\frac{\varepsilon}{3.7D} + \frac{2.51}{\mathrm{Re}_k}\left[1.14 - 2\log_{10}\left(\frac{\varepsilon}{D} + \frac{21.25}{\mathrm{Re}_k^{\,0.9}}\right)\right]\right\}, \qquad \mathrm{Re}_k \ge 3000 \tag{2}$$

Where, subscript k means each phase. D and ε represent the hydraulic diameter of flow channel and wall roughness, respectively. In the turbulent region, the engineering approximation to the Colebrook-White correlation was used. The friction factor in the transient regime is calculated by interpolation. These friction factors are the same to those of RELAP5 [2].

MARS vessel module has utilized the friction multiplier with a simple approximation of annular flow regime [3]. In the moderate void fraction value, the multiplier was

$$\phi_f^2 \approx \frac{1}{(1-\alpha)^2} \tag{3}$$

In order to check the validity of this approximation, vertical channel flow was postulated as in the Figure 1.

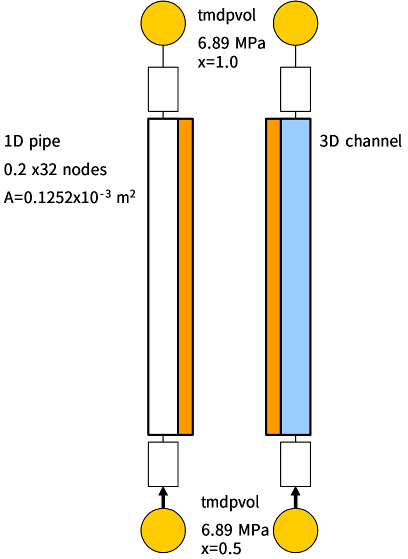


Figure 1. Schematic of vertical channel flow

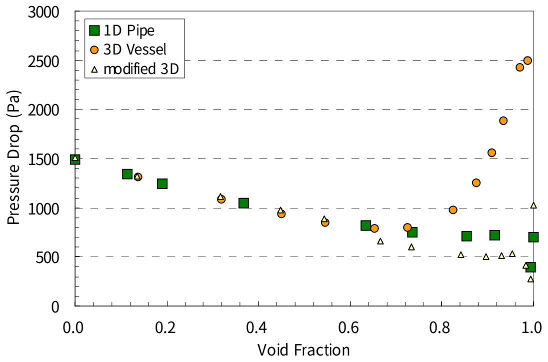
First, 3 mass flow rate cases are tested to investigate the pressure drop amounts under non-heating and heating cases. The degree of subcool is maintained at 18K for 6.89 MPa.

Table1. Pressure drop calculations for vertical flow

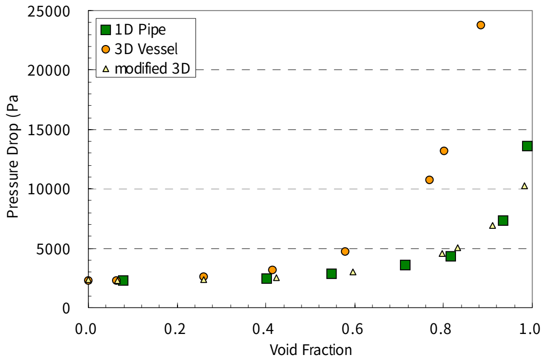
Mass flow (kg/s)	Non-heating(adiabatic)		Heating	
	1D pipe	3D vessel	1D pipe	3D vessel
0.04753	41.7	41.5	26.3	64.7
0.25	59.5	59.4	191	344
0.65	176.0	176.0	559	1080

As in Table 1, the pressure drop amounts for 1D and vessel are quite equal for the non-heating single phase flows. But in the heating cases, where the CHF occur, the pressure drops of 3D vessels are almost twice higher than those of 1D case. This result reveals that the pressure drop discrepancies are exist in the two phase region.

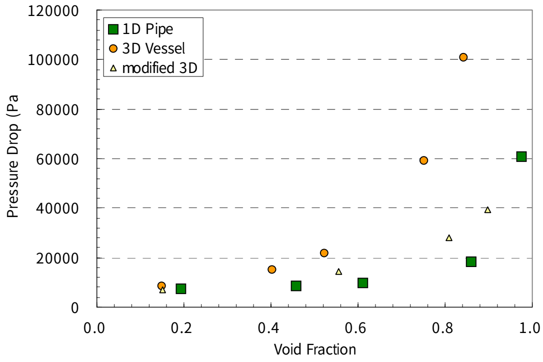
Figure 2 shows the pressure drop between two nodes located at the middle of the vertical channel for adiabatic upward flows under saturated condition at 6.89 MPa. Various combinations of vapor and liquid phase mass flow rates have been injected from the bottom of channel with the total flow rate maintained.



(a) Mass flow rate of 0.04753 kg/s (G=380 kg/s-m^2)



(b) Mass flow rate of 0.25 kg/s (G=2000 kg/s-m^2)



(c) Mass flow rate of 0.65 kg/s (G=5200 kg/s-m^2)

Figure 2. Comparisons of pressure drop across a node in adiabatic upward two phase flow

In that figures, tremendous differences have been observed after a certain value of void fraction.

3. Modification of Two Phase Friction Multiplier

In order to remove the discrepancies in the high void fraction region as in the figure 2, traditional Lockhart-Martinelli correlation was implemented in vessel module instead of Equation (3). Both the film and vapor core flow were assumed as viscous dominant flow, thus the constant C in Equation (4) and (5) was determined as 5.0.

$$\phi_f^2 = 1 + \frac{C}{X_{tt}} + \frac{1}{X_{tt}^2} \tag{4}$$

$$\phi_g^2 = 1 + CX_{tt} + X_{tt}^2 \tag{5}$$

$$X_{tt} \approx \left(\frac{1-x}{x}\right)^{0.9} \left(\frac{\rho_g}{\rho_f}\right)^{0.5} \left(\frac{\mu_f}{\mu_g}\right)^{0.1} \tag{6}$$

Based on this modification, Bennett's CHF test series are modeled both with 1D and vessel modules. This test series is a vertical channel flow experiment with uniform heating beyond the critical heat flux criteria [4]. Besides the heating case, the adiabatic upward flows at certain qualities are also investigated. As the results, the pressure drops between two nodes are represented in figure 2 with the label of 'modified 3D'.

4. Conclusion

The simple approximation of two phase friction multiplier model, which used in MARS vessel module, was a source of pressure drop discrepancies at high void fraction condition. The Lockhart-Martinelli two phase friction multiplier model has been implemented in MARS 3D vessel module. This modification makes the pressure drop of vessel module similar to 1D calculation in high void fraction region of both adiabatic and heating conditions.

Acknowledgement

This work has been carried out under the nuclear research and development program of Korea Ministry of Science and Technology

REFERENCES

[1] Lockhart, R.W. and Martnelli, R.C., Proposed correlation of data for isothermal two-phase two-component flow in pipes, Chem. Eng. Prog., **45**, p.39, 1949

[2] RELAP5/MOD3 Code Manual Vol.4-Models and Correlations, NUREG/CR-5535 INEL-95/0174, 1995

[3] Collier, J.G. and Thome, J.R., Convective boiling and condensation, 3rd Edition, Oxford Science Publications, 1994

[4] Bennett, A.W. et al., Heat Transfer to Steam-Water Mixture Flowing in Uniformly Heated Tubes in Which the Critical Heat Flux has been Exceeded, AERE-R5373, October 1976.