

Development of a three-field model for two-phase annular-mist flow

Sang Ik Lee, Hee Cheon NO

Korea Advanced Institute of Science and Technology, Yusong-Gu 373-1, Daejeon, Korea, 305-701
silee@nsys.kaist.ac.kr

1. Introduction

The widely used safety analysis codes such as RELAP5 [1,2] and TRAC [3,4] use two-phase, two-field representation to describe the thermal-hydraulic phenomena of nuclear power plant. But the averaged description of liquid phase is significantly different from actual phenomena especially when droplet entrainment exists.

On the other hand, COBRA-TF [5], which describes the entrainment field as a separate one from continuous liquid film, is showing the advanced features for the thermal-hydraulics codes but its applicability is highly restricted to the reactor core.

Recently, USNRC is developing a thermal-hydraulic analysis code that consolidates the capabilities of various codes and TRAC-M is the base of the efforts. [6]

With this situation, the implementation of three-field modeling into TRAC-M/F90 is necessary and as for the first application, the implementation into one-dimensional component is presented.

2. Implementation of a three-field model

2.1 The development of a three-field model

To describe the behavior of droplet entrainment, additional governing equations for mass, momentum, and energy conservation are required. The governing equations are developed based on the thermal equilibrium assumption and result in three mass, three momentum, and two energy equations. After the development of governing equations, the finite difference forms are derived. Constitutive relations from COBRA-TF are used in the most of the necessary correlations as summarized in Table I. The correlations are for the annular-mist flow regime and therefore are only applicable to this regime.

2.2 The implementation into TRAC-M/F90

The developed 3-field model is implemented into TRAC-M/F90. The implementation is started adding new variables for describing the droplet entrainment behavior. The initial and boundary conditions of the new variables are designed to be input in the original TRAC input file. The primary variables added are the velocity and the volume fraction of entrained liquid. As the same with the original TRAC-M, the solution matrix is constituted by linearization of the finite difference equations of mass and energy conservation.

The solution matrix which was originally 5×5 is now extended to 6×6 . The new time velocities of each phase are obtained by solving finite difference form of momentum equations. These expressions are used in substituting the velocity terms in mass and energy equations.

Table 1. Constitutive relations used in the present study (Annular-mist flow regime)

Constitutive relations	Correlations used
Interfacial friction	$\tau_i = \frac{1}{2} \rho_g (V_g - V_l)^2$ $f_i = \frac{0.079}{\text{Re}_g^{0.25}} (1 + 300 \frac{\delta}{D})$ [7-9]
Droplet drag	$C_d = \frac{24}{\text{Re}_d} (1 + 0.15 \text{Re}_d^{0.687})$ $+ \frac{0.42}{1 + 4.25 \times 10^4 \text{Re}_d^{-1.16}}$ [7]
Wall friction	$f_w = \max \left(\frac{16}{\text{Re}_l}, 0.001375 \right.$ $\left. + 0.01375 \text{Re}_l^{-1/3} \right)$ [5]
Drop size	$d = \frac{1.5 \sigma}{\rho_g (V_g - V_d)^2}$ [2]
Entrainment rate	$S_E^m = 2.0 \frac{\tau_i k_s}{\sigma} \left(\frac{V_g \mu_l}{\sigma} \right) \frac{\Delta x P_w}{vol}$ $k_s = 0.57 \delta + 21.73 \times 10^3 \delta^2 - 38.8 \times 10^6 \delta^3$ $+ 55.68 \times 10^9 \delta^4$ [5]
De-entrainment rate	$S_D^m = \frac{k_d C}{vol} \Delta x P_w, k_d = 0.15 m/s$ [5]

2.3 Results

To test the behavior of the newly developed TRAC-M, simple tests with constant entrainment rate are performed and the results are the same with analytic predictions. The simulation of Collier and Hewitt's air/water experiment [10] is performed and the results show reasonable agreement with experimental data as shown in Fig. 1.

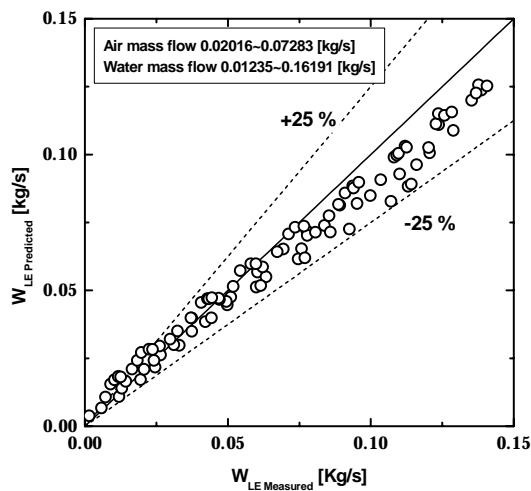


Figure 1. Predicted entrained liquid mass flow rate with Collier and Hewitt's experimental data.

3. Conclusion

A three-field model is developed based on the previous studies [5, 7, 8, 9] and is implemented into 1-D components of TRAC-M/F90. The results show reasonable agreement with experimental data. With this, it can be concluded that the capability of predicting entrainment behavior in TRAC-M/F90 is successfully created.

In the present study, the entrainment/de-entrainment rate correlations from COBRA-TF are simply used. The simulation of steam/water flow is not performed here because the experimental data of air/water flow are more easily available and contain sufficient information for validation. To test the applicability of the present work in nuclear power plant, it is necessary to simulate steam/water experiments. The numerical tests of steam/water flow are left on coming work.

REFERENCES

- [1] RELAP5 Code Development Team, RELAP5/MOD3 Code Manual Vol.1: Code Structure, System Models, and Solution Methods, NUREG-CR5535, 1995.
- [2] RELAP5 Code Development Team, RELAP5/MOD3 Code Manual Vol.5: Models and Correlations, NUREG-CR5535, 1995.
- [3] J. W. Spore, et al, TRAC-PF1/MOD2 Vol.1: Theory Manual, LA-12031-M, NUREG/CR-5673, 1993.
- [4] B. T. Adams et al, TRAC-M/FORTRAN 90 (version 3.0) Programmer's Manual, NUREG/CR-6725, 2001.
- [5] M. Thurgood et al, COBRA/TRAC-A Thermal-Hydraulic Code for Transient Analysis of Nuclear Reactor Vessels and Primary Coolant Systems, Vol.1: Equation and Constitutive Models, NUREG/CR-3046, PNL-4385, 1983.
- [6] J. Mahaffey et al, Architecture of the USNRC Consolidated Code, ICON-8, April, 2000, Baltimore, USA.
- [7] V. Stevanovic, M. Studovic, A simple model for vertical annular and horizontal stratified two-phase flows with liquid

- entrainment and phase two-phase flows with liquid entrainment and phase transitions one-dimensional steady state conditions, Nucl. Eng. Des., Vol. 154, p. 357-379, 1995.
- [8] S. Sugawara, Y. Miyamoto, FIDAS: detailed subchannel analysis code based on the three-fluid model, Nucl. Eng. Des., Vol. 122, p. 147-161, 1990.
 - [9] S. Sugawara, Droplet deposition and entrainment modeling based on the three-fluid model, Nucl. Eng. Des., Vol. 122, p. 67-84, 1990.
 - [10] J. G. Collier, G. F. Hewitt, Data on the vertical flow of air-water mixture in the annular and dispersed flow regimes, Part II: Film thickness and entrainment data and analysis of pressure drop measurements, Trans. Inst. Chem. Engrs. Vol. 39, p. 127-136, 1961.