Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

Simulation of DEBORA Experiments for Subcooled Boiling Flow by the EAGLE code with One-group Interfacial Area Transport Equation

V.T. Nguyen [a,b], C.-H. Song [a,b*], B.U. Bae [b], I.-C. Chu [b], D.J. Euh [b]
[a] *University of Science and Technology, 217 Gajungro, Yuseong, Daejeon, 305-350, Rep. of Korea*
[b] *Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong,Daejeon, 305-353, Rep. of Korea*
[*] *Corresponding author:chsong@kaeri.re.kr*

1. Introduction

In this study, the capability of the EAGLE code, which is an in-house CFD code for two-phase flow, to simulate local boiling flow processes over a wide range of operating conditions, including those close to CHF, has been assessed. The implementation of interfacial area transport (IAT) equation with advanced models such as bubble coalescence, breakup and nucleation site density is indispensable for predicting accurately the bubble size distribution. The DEBORA experiments, performed at CEA using dichlorodifluoro-methane (R12) as the working fluid, were selected to analyze a subcooled boiling flow. The aim of this work is to investigate the applicability of the state of the art physical models for interfacial area concentration (IAC).

2. Modeling of Boiling at a Heated Wall

In boiling flow, the mechanisms of a heat transfer from the wall consist of the surface quenching (q_q), evaporative heat transfer (q_e), and single-phase convection (q_c). Accordingly, the given external heat flux (q_{tot}), applied to the heated wall, is written as a sum of three parts:

$$q_{tot} = q_q + q_e + q_c \qquad (1)$$

The individual components in this heat flux partitioning are then modeled as functions of the wall temperature and other local flow parameters. Equation (1) can be solved iteratively for the local wall temperature T_W , which satisfies the wall heat flux balance. Denoting the fraction of area influenced by the bubbles as A_W , the heat flux components are given as follows:

$$q_q = A_W h_Q \left(T_W - T_L\right) \qquad (2)$$

$$q_e = \dot{m}_W H_{LG} \qquad (3)$$

$$q_c = \left(1 - A_W\right) h_C \left(T_W - T_L\right) \qquad (4)$$

$$A_W = \pi \left(a \frac{d_W}{2} \right)^2 N \qquad (5)$$

Here a is the so-called bubble influence factor, which means the ratio of the area influenced by a nucleate boiling heat transfer to the projected area at a bubble departure. Various models for the active nucleate site density (N), the bubble departure diameter (d_W) and bubble departure frequency (f) were assessed in this study. The generated vapor mass is expressed as follows:

$$\dot{m}_W = \rho_G \frac{\pi}{6} d_W^3 fN \qquad (6)$$

where f is the bubble generation frequency.

3. Interfacial Area Transport Equation

In the present thermal-hydraulic system analysis codes, the IAC is given by empirical correlations based on traditional two-phase flow regimes and the regime transition criteria. The flow regime transition criteria are algebraic relations for steady-state, fully developed flows. They do not fully reflect the true dynamic nature of changes in the interfacial structure, and then the effects of the entrance and developing flow can neither be taken into account correctly nor the gradual transition between regimes. To solve such problems, the introduction of the interfacial area transport equation has been recommended. For boiling flow, the interfacial area transport (IAT) equation is given as follows:

$$\frac{\partial a_i}{\partial t} + \nabla \cdot \left(a_i \vec{u}_g\right) = -\frac{2}{3}\frac{a_i}{\alpha}\left[\frac{\partial \alpha}{\partial t} + \nabla \cdot \left(\alpha \vec{u}_g\right)\right] + \frac{36\pi}{3}\left(\frac{\alpha}{a_i}\right)^2 \left(\Phi_n^{CO} + \Phi_n^{BK}\right) + \Phi_n^{NUC} \qquad (7)$$

where the first term on the right-hand side (RHS) is the gas expansion term, and Φ_n^{CO} , Φ_n^{BK} are the IAC variations induced by the coalescence and breakup phenomena. The coalescence and breakup terms induced by turbulence can be written in the following general forms:

$$\Phi_n^{CO} = -\frac{1}{T_c} n \eta_c , \quad \Phi_n^{BK} = -\frac{1}{T_b} n \eta_b , \qquad (8)$$

where T_c and T_b are the coalescence and breakup times of single bubble, η_c and η_b are the coalescence and the breakup efficiencies, and n is the bubble number per unit volume.

The last term on the right-hand side in Eq. (7) denotes an increase in IAC by a bubble nucleation at the heated wall.

$$\Phi_n^{NUC} = \pi d_W^2 \frac{N \cdot f \cdot A_W}{V_b} \qquad (9)$$

Here V_b is the volume of bubble detached from the wall.

4. Results and Discussion

It was found that the implementation of appropriate bubble coalescence and breakup models can improve the prediction capability of void fraction and bubble size distribution (Figs. 1 and 2). Comparisons of our results with the prediction results of the commercial CFD STAR-CD code, which implemented S_γ equations, showed a very similar dynamic behavior of local parameters. Typical results for void fraction and liquid temperature distribution were presented in Figs. 3 and 4.

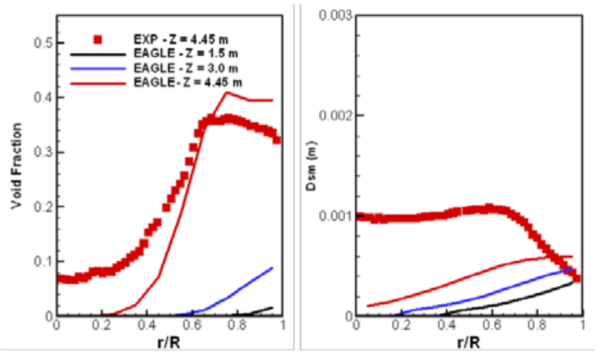

Fig. 1. Prediction of EAGLE without implementation of bubble coalescence and breakup models (DEB10 case)

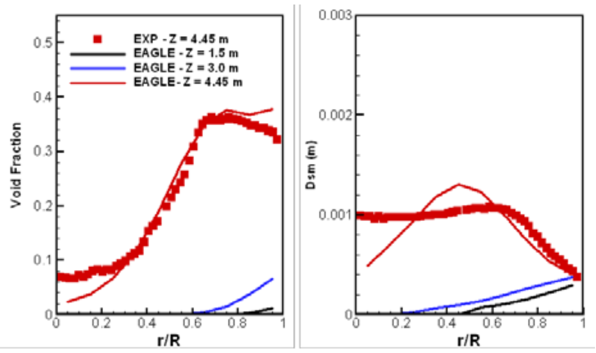

Fig. 2. Prediction of EAGLE with implementation of bubble coalescence and breakup models (DEB10 case)

5. Conclusions

Results clearly showed that the EAGLE code has a good capability of simulating the subcooled boiling as well as the implementation of bubble and coalescence models is indispensable for predicting accurately the bubble size distribution.

ACKNOWLEDGEMENTS

This work was supported by the Nuclear Research & Development Program of the National Research Foundation (NRF) grant funded by the Korean government (MEST). (grant code: M20702040003-08M0204-00310).

The authors are thankful to Prof. Byong-Jo Yun at Pusan National University for providing the DEBORA experimental data.

REFERENCES

[1] B.U. Bae, H.Y. Yoon, D.J. Euh, C.-H. Song, G.C. Park, Computational analysis of a subcooled boiling flow with a one-group interfacial area transport equation. Journal of Nuclear Science and Technology, Vol. 45, pp. 341-351, 2008.

[2] J. Garnier, E. Manon, G. Cubizolles, Local measurements on flow boiling of refrigerant 12 in a vertical tube. Multiphase Science and Technology, Vol. 13, pp. 1-111, 2001.

[3] S. Lo, CFD modeling of boiling flows in nuclear reactor fuel assemblies, ICONE17, Brussels, Belgium, 2009.

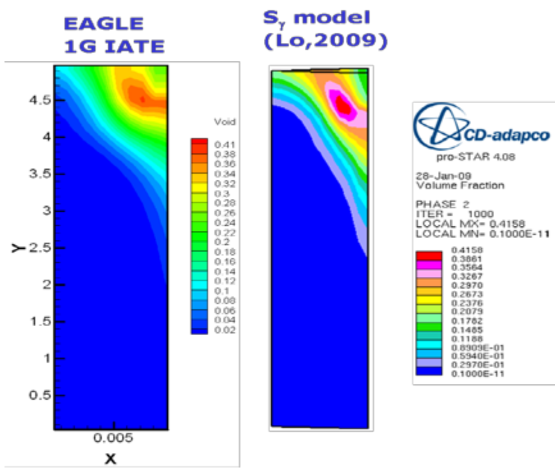

Fig. 3. Comparison of void fraction distribution prediction

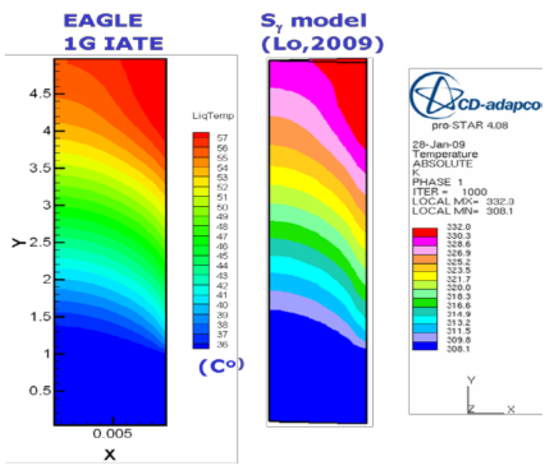

Fig. 4. Comparison of liquid temperature distribution prediction