Assessment of the Inter-channel Mixing Model of the MARS Code

J.-J. Jeong*, D. H. Hwang, S. W. Bae, and B. D. Chung
Korea Atomic Energy Research Institute, Dukjin 150, Yuseong, 305-353 Daejeon
*E-mail: jjjeong@kaeri.re.kr

1. Introduction

The MARS code is a best-estimate multi-dimensional thermal-hydraulic system code. In the MARS code, the COBRA-TF code was adapted as a three-dimensional (3-D) thermal-hydraulic module, which was originally developed for the reactor vessel thermal-hydraulics including the reflood heat transfer and hot channel behavior. The COBRA-TF code has a flow mixing model between adjacent subchannels in rod bundles. These features of the COBRA-TF code have been well conserved in the MARS code. In addition, the critical heat flux correlation of the AECL lookup table has been implemented in the MARS 3-D module. Thus, the MARS 3-D module can be used for the hot channel analysis.

In this paper, the inter-channel mixing model of the MARS 3-D module is assessed using well known rod bundle test data.

2. Inter-channel Flow Mixing Model in the MARS 3-D Module

In the MARS 3-D module, a two-fluid, three-field formulation is adopted for a two-phase flow. The three fields are vapor, continuous liquid, and entrained liquid. Each field is treated in three dimensions on rectangular Cartesian or subchannel coordinates.

As mentioned earlier, the MARS 3-D module has a special model for inter-channel flow mixing phenomena, which are generally divided into three components; diversion cross flow, turbulent mixing, and void drift. In the MARS 3-D module, the diversion cross flow is modeled by solving the transverse momentum equations. For turbulent mixing and void drift between adjacent subchannels, the Lahey's model [1] was employed and it has been improved [2, 3].

In the modified Lahey's model [2, 3], the net mass flux of gas phase from subchannel i to j due to the turbulent mixing and void drift is represented by

$$w''_{g,i-j} = \left(\frac{\varepsilon}{l}\right)_{1\phi} \theta \left\{ (\alpha\rho)_{g,i} - (\alpha\rho)_{g,j} - K_{VD} \frac{G_i - G_j}{\bar{G}_{i,j}} \rho_{g,i-j} \right\}, \qquad (1)$$

where ε is eddy diffusivity and l is the subchannel mixing length. $(\varepsilon/l)_{1\phi}$ has the unit of velocity and is sometimes called single-phase "turbulent velocity." θ is a two-phase multiplier for the turbulent velocity. α and ρ are void fraction and density, respectively. G_i is the total mass flux at channel i. K_{VD} is the void drift coefficient. Similarly, the net mass flux of liquid phase from subchannel i to j due to the turbulent mixing and void drift is represent

$$w''_{l,i-j} = \left(\frac{\varepsilon}{l}\right)_{1\phi} \theta \left\{ (\alpha\rho)_{l,i} - (\alpha\rho)_{l,j} + K_{VD} \frac{G_i - G_j}{\bar{G}_{i,j}} \rho_{l,i-j} \right\}. \qquad (2)$$

For the entrained-liquid phase in the MARS 3-D module, the mixing model is not applied.

3. The Results of Assessment and Discussions

The inter-channel flow mixing model of the MARS 3-D module has been assessed using the ISPRA 16-rod bundle test and the GE 9-rod bundle test data [2, 3].[1] These tests represent typical PWR and BWR core thermal-hydraulic conditions, which were conducted at the pressures of 16.0 MPa and 6.9 MPa, respectively. In these tests, steady-state enthalpy and mass flow rate distributions at the outlet of the test section were measured. In Figures 1 and 2, the calculated exit qualities at the corner, side, and inner subchannels are compared with the measured data. As can be seen in Figs. 1 and 2, the optimum void drift coefficients for the ISPRA and the GE tests are 0.2 and 1.8, respectively.

To investigate the effect of pressure on the void drift phenomena, subchannel mixing tests that were performed under atmospheric pressure conditions [4] were also simulated. The experiments were performed in two laterally inter-connected subchannels using air-water two-phase flows (See Fig. 3). Air-water mixture was injected into the bottom of each subchannel at a predetermined rate. In the interconnected region, flow mixing occurs by lateral flow exchanges. The length of interconnected region is 1.32 m. Void and axial flow distributions were measured along each channel. Two experiments, SV-1 and SV-2 [4], were simulated.

In Figs. 4 and 5, the results of calculations with the void drift coefficient of 1, 8, and 16 are illustrated, where "HVC" is high void channel and "LVC" is low void channel. Both Figures 4 and 5 show that the void prediction is strongly dependent on the void drift coefficient. When the coefficient is 16.0, the results are most accurate among the three calculations.

"Void drift" is known to occur due to the strong tendency of the vapor phase to drift towards the higher

[1] This assessment was performed in 2004. Recently, a critical coding error in the MARS 3-D module (related with the inter-channel flow mixing model) was fixed and, thus, the assessment was conducted again.

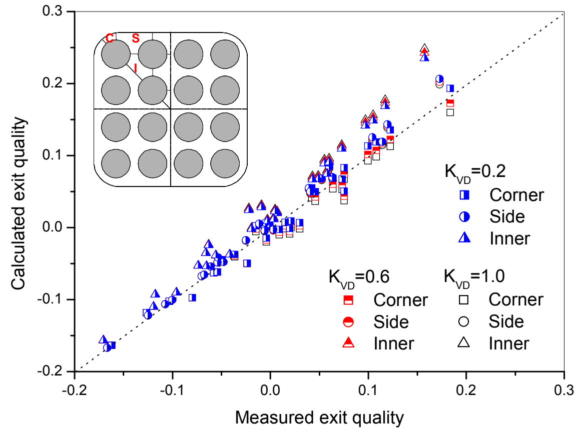

Fig. 1. Exit qualities: ISPRA 16-rod test.

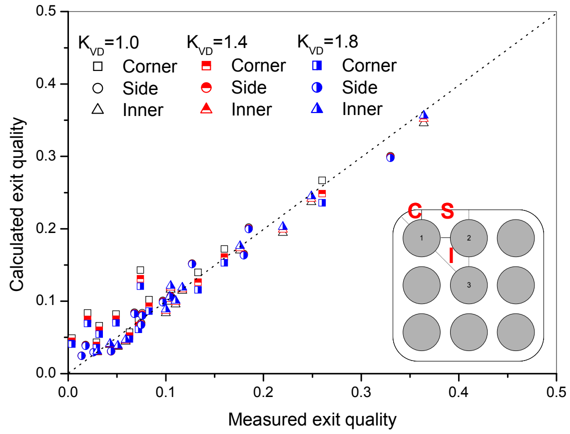

Fig. 2. Exit qualities: GE 9-rod test.

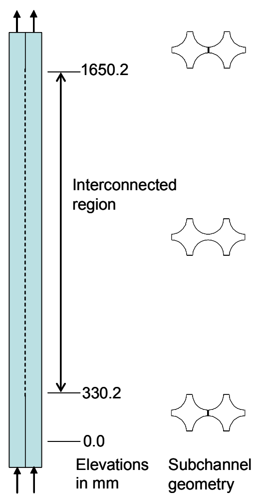

Fig. 3. The schematic of Tapucu's experiment.

velocity regions. However, the fundamental mechanism of the void drift is still unknown. Although various mechanisms for the void drift phenomena have been proposed, they have a common feature; the lateral drift force increases by decreasing the pressure. That is, "void drift" is more apparent under low pressure conditions. This is consistent with the assessment results. As a result, an optimum void drift coefficient, which can minimize the root-mean-square error of the local quality (or void fraction) predictions, was derived

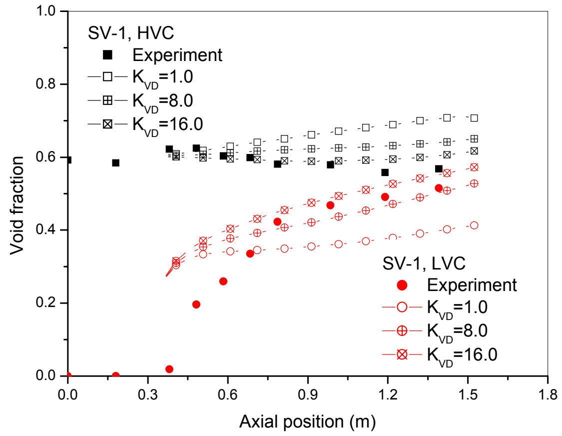

Fig. 4. Axial void distribution of Run SV-1

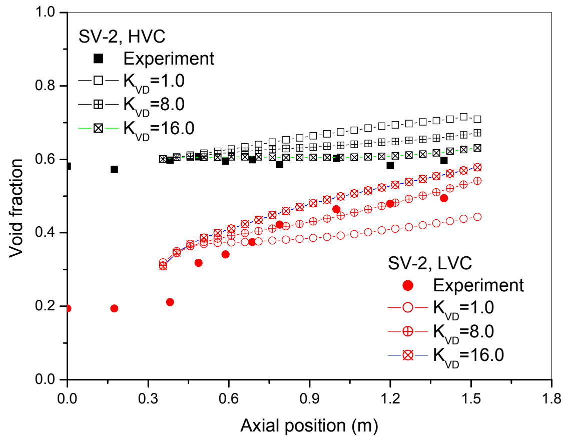

Fig. 5. Axial void distribution of Run SV-2

as a function of the system pressure:

$$K_{VD} = 0.112 + 16.4e^{-0.329P} \tag{3}$$

where P is the pressure in MPa.

4. Concluding Remarks

The turbulent mixing and void drift model of the MARS 3-D module was assessed. The results of the assessment clearly show that the MARS code can predict single- and two-phase flow distributions in rod bundles well. The effect of the void drift coefficient was also examined. As a result, the optimum void drift coefficient was represented as a function of the system pressure.

References

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