Improvement of the Subchannel Flow Mixing Model of the Best-Estimate System Code, MARS 3.0

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1. Introduction

The MARS code is a best-estimate multi-dimensional system analysis code, where the COBRA-TF code was adapted as a three-dimensional (3D) T/H module. The COBRA-TF code was developed to predict the reactor vessel thermal-hydraulics (T/H). It uses a three-dimensional, two-fluid, three-field model for two-phase flows on rectangular Cartesian coordinates or subchannel coordinates. Also, the COBRA-TF code has a subchannel flow mixing model. All these features of the COBRA-TF code can be fully exploited in the MARS code. Therefore, the MARS code can be used for the subchannel analysis of light water reactors

In this paper, the MARS 3D module is assessed using rod bundle test data that were performed to investigate single- and two-phase flow distribution in rod bundle geometries. In particular, the void drift model was improved.

2. Turbulent Mixing and Void Drift Model in the MARS 3D Module

Generally, the fluid flow in the subchannels is an axially dominant one-dimensional flow. However, there is flow mixing between adjacent channels and, in the case of two-phase flow, the rate of flow mixing significantly increases. This flow mixing phenomena are generally divided into three components [1]; diversion cross flow, turbulent mixing, and void drift. In the MARS 3D 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 was employed and has been modified [1], based on the works of Kelly [2] and Hwang *et al.* [3]. In the modified model, the net mass flux of gas phase from subchannel *i* to *j* due to the turbulent mixing and void drift is

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

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

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

For the entrained-liquid phase in the MARS 3D module, the mixing model is not applied. Equations (1) and (2) are added to the right-hand sides of the continuity equations for vapor phase and continuous liquid phase, respectively. In addition, energy and momentum exchange terms due to the turbulent mixing and void drift are also taken into account in the governing equations.

3. The Assessment Results

The subchannel flow mixing model of MARS was assessed using the ISPRA 16-rod bundle test and the GE 9-rod bundle test data. These tests represent typical PWR and BWR core T/H conditions, which were conducted at the pressures of 16.0 MPa and 6.9 MPa, respectively. The power distributions in the rod bundles for the selected tests were axially and radially uniform. Subcooled water enters the test section at the bottom. A mixture of steam and water leaves the channel at the top. Then, steady-state enthalpy and mass flow rate distributions at the outlet of the test section were measured. Detailed descriptions on the experimental conditions and the MARS input model are given in Reference 4. In Figures 1 and 2, the calculated exit qualities at the corner, side, and inner subchannels are compared with the measured data of the ISPRA and the GE tests, respectively.

From the results of this assessment, it was found that the optimum void drift coefficient depends on the system pressure. In order to confirm the effect of pressure on the void drift phenomena, subchannel mixing tests that were performed under atmospheric pressure conditions [5] were also simulated. The experiments were performed in two laterally inter-connected subchannels using air-water two-phase flows. 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 (from 0.33 m to 1.65 m above the inlet). Void distribution and axial flow distribution were measured along each channel. Two experiments, SV-1 and SV-2, were used in the MARS assessment.

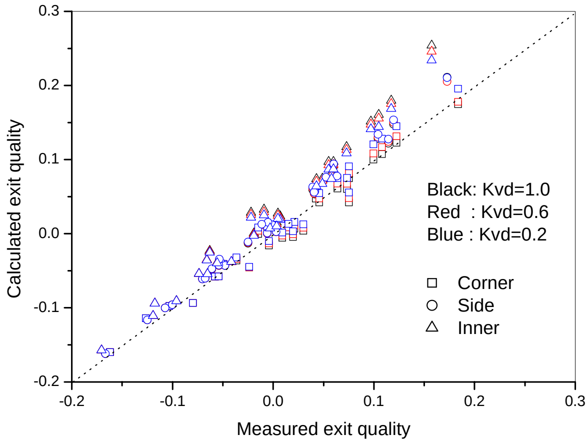

Figure 1. Comparison of the exit qualities: ISPRA 16-rod test.

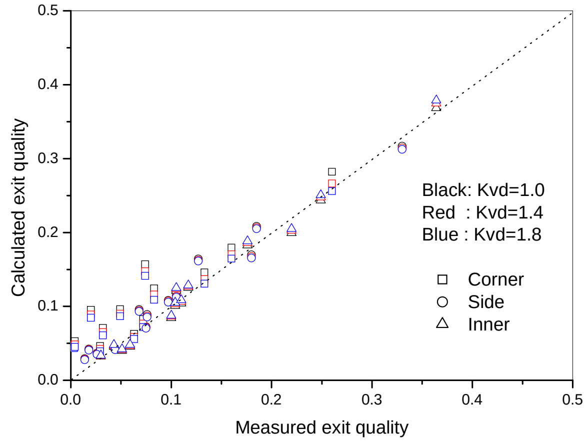

Figure 2. Comparison of the exit qualities: GE 9-rod test.

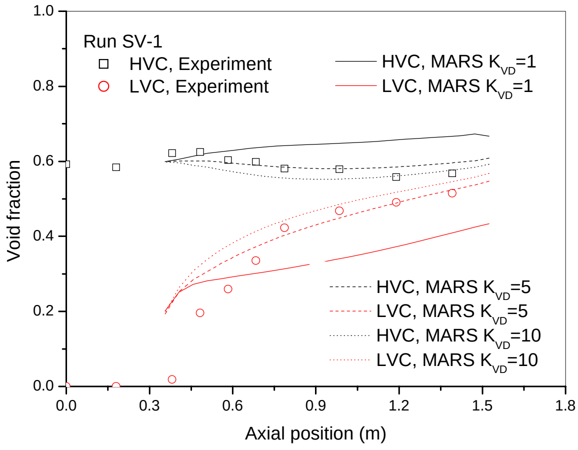

Figure 3. Axial void distribution of Run SV-1.

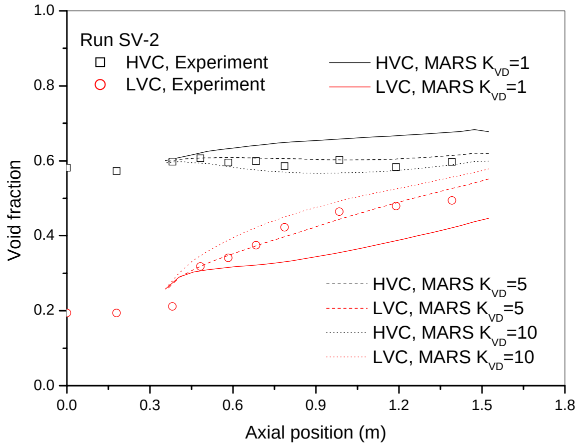

Figure 4. Axial void distribution of Run SV-2.

In Figures 3 and 4, the results of calculations with the void drift coefficient of 1, 5, and 10 are illustrated, where "HVC" is high void channel and "LVC" is low void channel. Both Figures 3 and 4 show the void prediction is strongly dependent on the void drift coefficient. When the coefficient is 5.0, the results are most accurate among the three calculations.

From the results shown in Figures 1 through 4, the void drift coefficient was represented as a function of pressure:

$$K_{VD} = 6.2e^{-0.215P} \qquad (3)$$

where P is pressure in MPa. This coefficient was chosen so as to minimize the root-mean-square error in the predictions of the void fractions from the three test facilities. The physical background of Eq. (3) is still under discussion.

4. Conclusions

The MARS code is a best-estimate multi-dimensional system analysis code. Also, the code has the subchannel analysis capability. In this work, the turbulent mixing and void drift model was assessed using ISPRA 16-rod test, GE 9-rod test, and the two experiments under atmospheric pressure. The results of the calculations 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.

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