Development and Assessment of Multi-Dimensional flow model in MARS Compared with the RPI Air-Water Experiment

Seok Min Lee,[a] Un Chul Lee,[a] Sung Won Bae,[b] Bub Dong Chung[b]
a Dept. Nuclear Engr. Seoul Nat'l Univ., Shillim-dong, Kwanak-gu, Seoul, 151-744, Korea. seokmin2@snu.ac.kr
b Korea Atomic Energy Research Institute, 150 Dukjin-dong, Yuseong,Daejeon, 305-353,Korea.

1. Introduction

The Multi-Dimensional flow models in system code have been developed during the past many years. RELAP5-3D, CATHARE and TRACE has its specific multi-dimensional flow models and successfully applied it to the system safety analysis. In KAERI, also, MARS(Multi-dimensional Analysis of Reactor Safety) code was developed by integrating RELAP5/MOD3 code and COBRA-TF code. Even though COBRA-TF module can analyze three-dimensional flow models, it has a limitation to apply 3D shear stress dominant phenomena or cylindrical geometry. Therefore, Multi-dimensional analysis models are newly developed by implementing three-dimensional momentum flux and diffusion terms. The multi-dimensional model has been assessed compared with multi-dimensional conceptual problems and CFD code results. Although the assessment results were reasonable, the multi-dimensional model has not been validated to two-phase flow using experimental data. In this paper, the multi-dimensional air-water two-phase flow experiment was simulated and analyzed.

2. Model and Experiment description

2.1 MARS, Multi-dimensional flow Model

The multi-dimensional flow models in MARS are developed by considering 3D convection and diffusion terms. The terms in Cartesian coordinate are as follows.

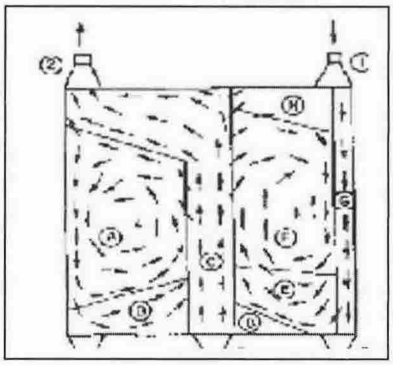
$$\vec{V}\bullet\nabla\vec{V}=\begin{cases} u\dfrac{\partial u}{\partial x}+v\dfrac{\partial u}{\partial y}+w\dfrac{\partial u}{\partial z} \\ u\dfrac{\partial v}{\partial x}+v\dfrac{\partial v}{\partial y}+w\dfrac{\partial v}{\partial z} \\ u\dfrac{\partial w}{\partial x}+v\dfrac{\partial w}{\partial y}+w\dfrac{\partial w}{\partial z} \end{cases}$$
(1)

$$\nabla\underline{\underline{\tau}}=\begin{cases} \mu'\left[\dfrac{\partial^2 u}{\partial y^2}+\dfrac{\partial^2 u}{\partial z^2}\right] \\ \mu'\left[\dfrac{\partial^2 v}{\partial x^2}+\dfrac{\partial^2 v}{\partial z^2}\right] \\ \mu'\left[\dfrac{\partial^2 w}{\partial x^2}+\dfrac{\partial^2 w}{\partial y^2}\right] \end{cases}$$
(2)

Equation (1) and (2) was implemented in the MARS momentum equations as explicit form. The equations in the cylindrical coordinate systems were also modeled and implemented.

2.2 RPI Air-water Experiment

Air-water experiments were performed in a two-dimensional test section in a low pressure loop at RPI. This test section simulates a two-dimensional slice through the core of a pressured water reactor. Figure 1 shows the test section geometry and qualitative flow patterns. Port 1 supplied single-phase liquid to the upper right corner, Port 2 and 3 received two-phase flow mixtures from upper left and lower right corners. Port 4 supplied a two-phase mixture to the bottom center of the test section. Port 5 was closed during these tests. Void fractions were measured with a traversing single-beam gamma densitometer.



Region
(A) bubbly/slug
(B),(D) single-phase
(C) slug
(E)bubbly
(F)Bubbly/slug
(G)Pure liquid
(H)Air-pocket

Figure 1. RPI Test section and qualitative flow pattern

The test procedure was to fill the test section with liquid, then supply liquid flow to Port 1 and 4, and establish the air flow to Port 4. The flow rates were adjusted with flow control valves.

2.3 MARS Modeling

Figure 2 shows a MARS modeling which consist of 17 x 17 rectangular 2D Multi-dimensional slab and 4 time dependent junction and one inlet 1D pipe for Port 4. The simulation case of the test is 2AN4. Total liquid flow rate is 1.18kg/s and flow split fraction of port 1 and 4 is 0.5. air flow rate is 0.00547kg/s in Port 4.

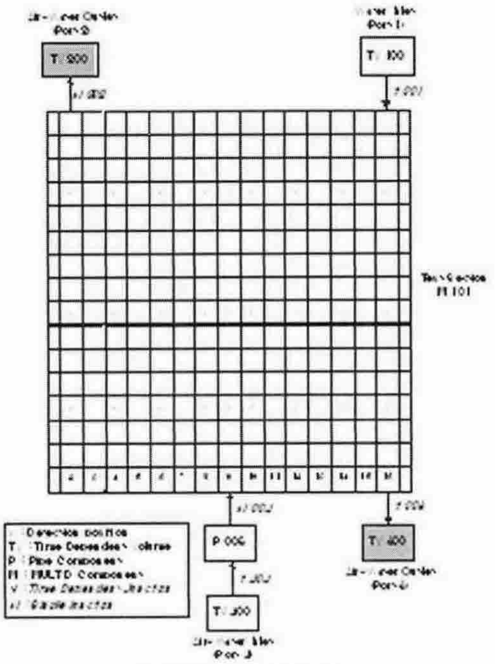


Figure 2. MARS Nodalization

3. Results

The results of first time run were not successful. The calculated void-fraction distribution is highly dispersed and diffusive. It was revealed that main reason is horizontal stratified force in horizontal stratified flow regimes. Since stratified flow regime is not expected in multi-dimensional flow, the horizontally stratified flow regimes are deleted. However, level gradient terms are always set to be active resulted from the horizontally different void fraction.

Obtained results after modification are shown in Figure 3 and Figure 4. Void fraction profile and vector plot is similar to observation of test. The Calculated void fractions are compared with measured void fraction in Figure 4.

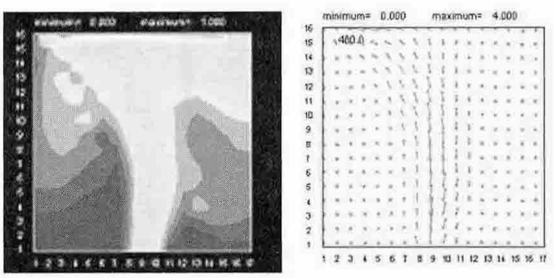


Figure 3. Void fraction profile and Flow pattern vector plot

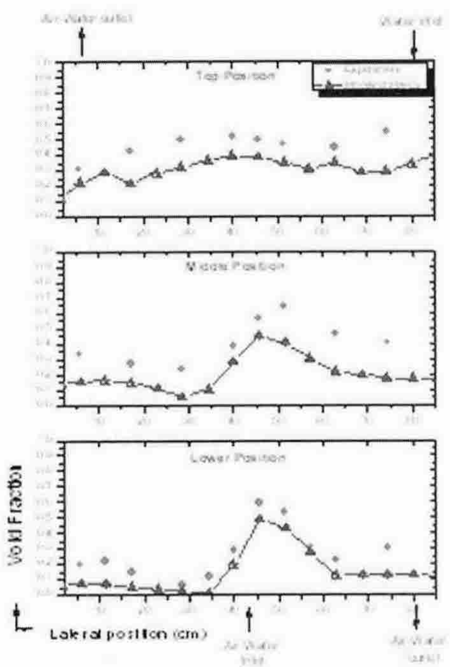


Figure 4. Comparison of Void fraction

4. Conclusion

Two-phase multi-dimensional models in MARS are assessed with the simulation of RPI air-water test. It was found that the modification of horizontal flow regime map is needed in multi-dimensional model. With the modification of flow regime, the predicted flow patterns and void fraction profiles are in good agreement with measured data.

Acknowledgement

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