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MARS Predictability for a Multi-Dimensional Boiling Flow in a Large Slab Geometry

D.J.Euh*, B.J.Yun. C.-H.Song
**Korea Atomic Energy Research Institute, P.O.Box 105, Yuseong, Daejeon, 305-600, KOREA*
**djeuh@kaeri.re.kr*; *http://theta.kaeri.re.kr*

1. Introduction

The reflood rate in the core is an important parameter for a core cooling during the LBLOCA reflood period, which strongly depends on the multi-dimensional thermal hydraulics in the downcomer. However, the results of the safety analysis for the LBLOCA of the APR1400 plant are different according to the codes used.[1][2] It may be due to the difference in the various models composing the code. Therefore, it is necessary to investigate the boiling phenomena in the downcomer during the LBLOCA reflood period and to improve the code's capability. KAERI performed the separate effect test program for simulating the phenomena in the reactor downcomer during the LBLOCA reflood period.[3] The facility is designed so as to meet a full scale for the height and gap of the reactor downcomer. The facility simulates a 1/47.08 azimuthal part of the prototype downcomer section area. The measured two-phase flow data were compared with the results of the safety analysis code, MARS, to investigate the modeling capability and to find the weak-points to be improved in the thermal hydraulic models of the safety analysis code. The used code version is MARS 3.0.

2. Methods and Results

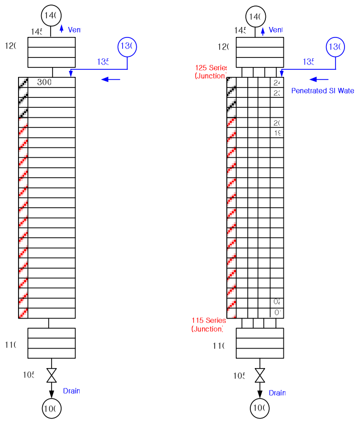
The downcomer boiling tests showed strong multi-dimensional phenomena including a definite bubbly boundary layer near the wall. To reflect the phenomena effectively, a four-channel model with 24 axial nodes is applied as well as the single-channel model as shown in figure 1. The heated wall has a length of 5.0m, which is simulated by 20 axial nodes. The temperature and flow rate of the injected water from the upper side of the test section and the bottom pressure are modeled as boundary conditions, which are determined from the experimental data.(Table 1) The analyses are performed by using the following four models:

1) Single Channel Model for the Downcomer
2) Four-Pipe Model for the Downcomer
3) Four-Pipe Model with Equilibrium Crossflow Velocity Option
4) Multi-D Component for the Downcomer

Figure 2 shows the axial void distributions. The single channel, four-pipe, and multi-D models overestimate the void fraction throughout the entire channel. However, the four-pipe model with an equilibrium crossflow velocity has a similar axial void profile to that of the experiment. The average void fraction of the heated section of Table 2 reflects well the axial void profiles of each model.

Table 1. Major Boundary Data

Heat Flux (kw/m^2)	70.5
Pressure at the Bottom of the Test Section (MPa)	0.212
Safety Injection Flow (kg/s)	1.33
Temp. of Injected Water (^{o}C)	110.7



(a) (b)

Fig. 1. MARS Model for Simulation: (a) Single Channel Model (b) Four-Channel Model

Figure 3 shows the void profiles of the various models. According to the results, the four-pipe model does not predict well the lateral void profile shown in the experiment. The discrepancy comes from the misleading flow regime at the crossflow junction. The MARS predicts a horizontally stratified flow for the lateral steam motion, which leads to a flat lateral void fraction profile. The active lateral bubble motion can be suppressed by applying an equilibrium velocity model to the crossflow junction as shown in figure 3(d), which is similar to the experimental test. The problem of the flow regime map is solved in the Multi-D component as shown in figure 3(e). However, it shows a large void amount in the test section. On the other hand, the four-pipe model with equilibrium crossflow velocity results in an excessively high upward steam motion near the wall, which is unlike the experiments shown in figure 4. In respect of the axial momentum, the four-pipe model shows better results.

In respect of the axial and lateral void profile, the models with an equilibrium velocity agree well with the experiment. However, the models yield a higher subcooling than the experiment as shown in Table 2. The models with a nonequilibrium velocity approximate the drain subcooling although they overestimate the void fraction in the test section. The characteristics of the multi-channel models show the necessity of a separated model evaluation for a subcooled boiling including a wall nucleation and condensation. The single channel model underestimates the subcooling of the drain water due to the excessively high void fraction in the lower part of the test section.

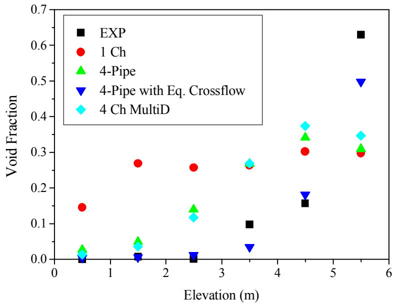


Fig. 2. Axial Void Profile in the Heated Section

3. Conclusions

Four models are used for the analysis of the downcomer boiling phenomena. From the investigation of the results, we could obtain the following findings:

1) MARS overestimates the void fraction in the downcomer boiling problem. 2) An improvement of the flow regime map at the crossflow can solve the misleading problem of the lateral void profile. 3) The subcooled boiling model of MARS should be improved in respect of a wall nucleation and an interfacial condensation.

Acknowledgement

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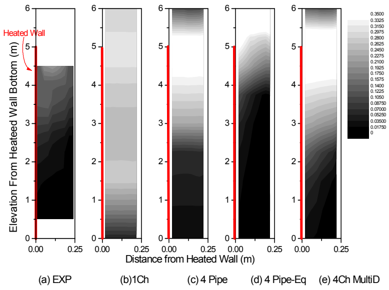
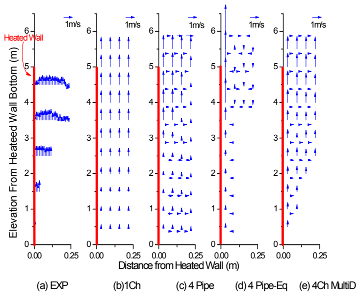
Table 2. Average Parameters

	Average Void Fraction in Heated Section	Lower Subcooling (K)	Temperature Rise (K)
Exp	0.053	4.42	6.88
1Ch.	0.248	0.84	10.45
4Pipe	0.166	4.51	6.71
4Pipe-Eq	0.049	8.01	3.21
4Ch.MultiD	0.164	4.96	6.26



(a) EXP (b)1Ch (c) 4 Pipe (d) 4 Pipe-Eq (e) 4Ch MultiD

Fig. 3. Void Profile: (a) Experiment (b) Single Channel Model (c) Four-Pipe Model (d) Four-Pipe Model with Equilibrium Crossflow Velocity (e) Multi-D Model



(a) EXP (b)1Ch (c) 4 Pipe (d) 4 Pipe-Eq (e) 4Ch MultiD

Fig. 4. Velocity Profile: (a) Experiment (b) Single Channel Model (c) Four-Pipe Model (d) Four-Pipe Model with Equilibrium Crossflow Velocity (e) Multi-D Model