The Evaluation of the MARS Code by using the Downcomer Boiling Test (DOBO) Data

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1. Introduction

The reflood rate in the core is an important parameter for the 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 capability. KAERI performed the separate effect test program for simulating the phenomena in the reactor downcomer during the LBLOCA reflood period. 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 major parameters are summarized in Table 1.

Table 1. Major Experimental Data

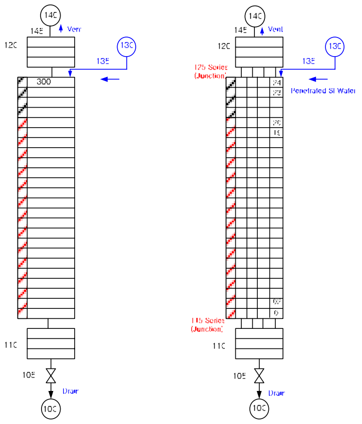
Heat Flux (kw/m^2)	50.2	69.7	82.0	91.1
Pressure at the Bottom of the Test Section (MPa)	0.219	0.217	0.222	0.227
DP in the Test Section (kPa)	50.7	50.7	50.8	50.6
Safety Injection Flow (kg/s)	1.22	1.16	1.20	1.20
Temp. of Injected Water (^{o}C)	110.1	110.2	109.6	109.5
Temp. of Drain Water (^{o}C)	117.8	118.2	119.4	120.2

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. MARS is a best-estimate thermal-hydraulic system code developed by KAERI.[3] The used code version is MARS 3.0.

2. Methods and Results

The downcomer boiling tests showed a strong multi-dimensional phenomena including a definite bubbly boundary layer near the wall. To reflect the phenomena effectively, a four-channel model is applied as well as the single-channel model, where the test section is simulated by 4X24 nodes as shown in figure 1. The heated wall has the 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. The analyses are performed by using the following five models based on the nodalization:

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
5) Multi-D Component with Equilibrium Crossflow Velocity Option



(a) (b)

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

Figure 2 shows the simulated void fraction profiles of the various models for the 82kw/m^2 of the heat flux condition. According to the results, a 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 sets the horizontally stratified flow regime for the low velocity condition at less than a critical velocity. Therefore, the lateral steam motion becomes very active, which leads to a flat lateral void fraction profile. The active lateral bubble motion can be reduced by applying an equilibrium velocity model to the crossflow junction as shown in figure 2(c), 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 2(d). The Multi-D component with an equilibrium crossflow velocity option yields an excessive definite bubbly boundary layer as shown in figure 2(e).

Figure 3 shows the axial void distribution and the average void fraction in the heated section. The single channel model overestimates the void fraction throughout entire the channel since the excessive energy of the generated steam is transferred to liquid. The four-pipe model also overestimates the void fraction although the degree is lower than that of the single channel model. The four-pipe model with an equilibrium crossflow velocity option has a similar axial void profile to that of the experiment. The multi-d models follow the trend of the four-pipe models. The average void fraction of the heated section is shown in Figure 3(b). The results reflect well the axial void profiles of each model.

In respect of the axial and lateral void profile, the models with an equilibrium velocity option agree well with the experiment. However, the models yield a higher subcooling than the experiment as shown in figure 4. The models with a nonequilibrium velocity option 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 the separated model evaluation for the subcooled boiling including the wall nucleation and condensation. The single channel model underestimate the subcooling of the drain water due to the excessive heat transfer of the steam to the liquid.

3. Conclusions

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

1) The single channel model overestimates the void fraction and underestimates the subcooling of the drain water since the excessive energy of the generated steam is transferred to liquid.

2) The 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 the wall nucleation and interfacial condensation.

Acknowledgement

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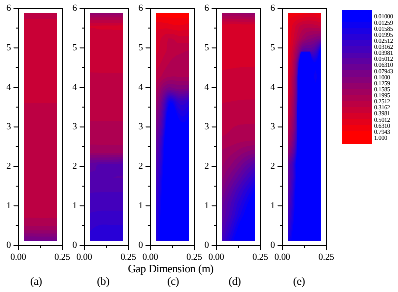
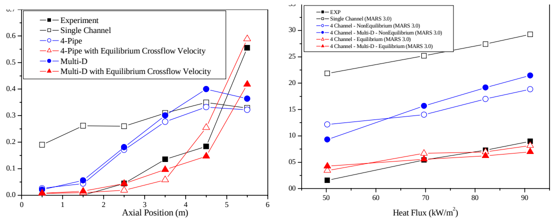


Fig. 2. Simulated Void Profile for 82kw/m^2: (a) Single Channel Model (b) Four-Pipe Model (c) Four-Pipe Model with Equilibrium Crossflow Velocity (d) Multi-D Model (e) Multi-D with Equilibrium Crossflow Velocity



(a) (b)

Fig. 3. (a) Axial Void Profile and (b) Average Void Fraction in the Heated Section for 82kw/m^2

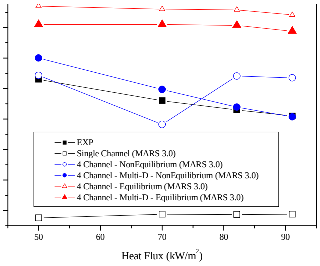


Fig. 4. Liquid Subcooling at the Bottom of the Test Section