Development of Physical Model for TRACE to simulate Downcomer Boiling Phenomena of APR1400

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1. Introduction

The reactor vessel wall is one of important heat source during large break LOCA. In APR1400, there is a passive flow regulator, i.e., the fluidic device, in safety injection tanks and sufficient water is injected to the downcomer until ~200 sec. After that time, however, injected water is reduced to the capacity of two safety injection pumps and the effect of vessel wall could be more meaningful. The subcooling margin of the water will be reduced by the interaction with super heated steam and, therefore, the water in the downcomer could be boiled off by heat addition in vessel wall. [1] When the voids are generated in lower downcomer, the interaction between void and liquid become important. The interfacial drag models in the system codes such as TRACE and RELAP handle this phenomenon. TRACE code has a special interfacial drag model, Blasius model, which is applied in the downcomer only. However, it is well known that the Blasius model predicts axial vapor velocity too fast because it calculates the interfacial drag coefficient too small.

To quantify the interaction between vapor and liquid, KAIST performed a separate effect test on the downcomer boiling phenomena based on the APR1400 lower downcomer annulus geometry at late reflood period. In this paper, we developed interfacial drag model in TRACE code and we assessed this model using the experiments performed by KAIST.

2. Experimental Facilities and Results

The test facility models the APR1400 lower downcomer with rectangle geometry [2]. The major parameters including the gap size, reactor vessel wall thickness are scaled down based on the APR1400 configuration. After the initial wall temperature reaches to the assumed reflood condition (~300℃), the cooling water (~95℃) is injected into the downcomer during ~30sec until the bottom of cold leg is filled with water, and the transient data is gathered. Test results show that the void generation is observed in the near wall surface, but it does not propagates to the bulk liquid. In the wall surface region, the water and the steam are uprising co-currently and the bulk liquid flows down, and overall internal circulation is formed. The steam and water velocities at the near wall surface are ~0.8m/sec and ~0.4m/sec, respectively. No sudden level drop and transient is observed.

3. Assessment using TRACE with Blasius model

The basic idea of Blasius model is reducing interfacial drag in the downcomer. The logic diagram of Blasius model is shown in Fig. 1.

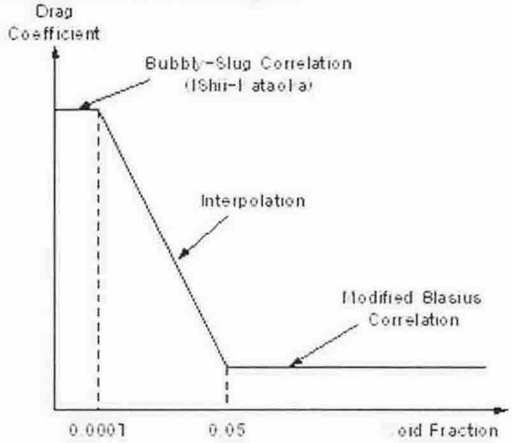


Fig. 1 Logic diagram of Blasius model

As shown in the Fig. 1, the drag coefficient is sharply reduced when the average void fraction is greater than 0.05 and, therefore, axial vapor velocity become too fast. Fig. 2 shows vapor velocity predicted in TRACE. As shown in the Fig. 2, vapor velocity in TRACE is too much fast compared to that of experiment.

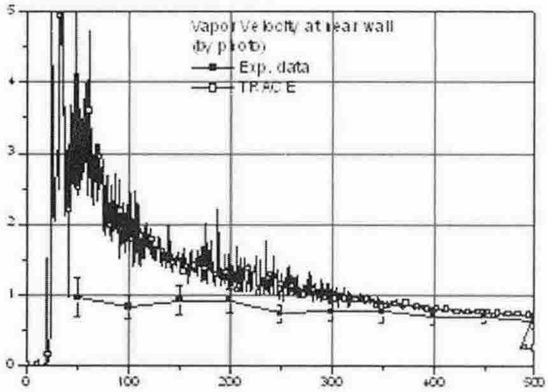


Fig. 2 Vapor velocity (TRACE w/ blaius vs. Experiments)

4. Downcomer boiling model and its assessment

General interfacial drag models in bubbly-slug flow regime have been developed based on the experiments using non-heated vertical round tube. However, downcomer geometry is a kind of channel and voids are generated at the side wall. The fuel channel has a similar geometry with the downcomer and the voids are generated at fuel surface. In RELAP5/Mod3.3 code, Bestion model is used for calculating interfacial drag in the fuel channel.

In this study, basic form of Bestion model is used as downcomer boiling model as follows;

$$C_{i,dc} = M_{dc} \frac{65.0 \times \alpha(1-\alpha)^3 \times \rho_g}{D_h} \times v_r$$

We added relative velocity effects in the original Bestion model to consider non-uniform velocity profile. The multiplier, M_{dc} is a tuning factor.

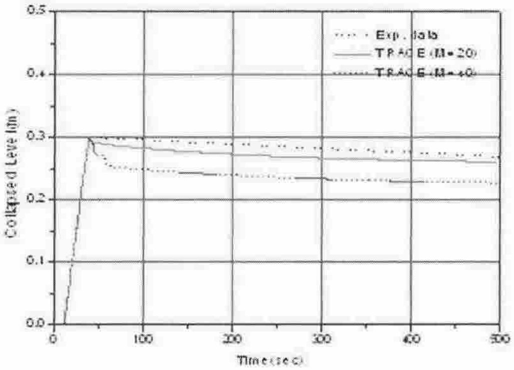


Fig. 3 Water lever according to the multiplier

Figure 3 shows the collapsed water level in the downcomer according to the variation of the multiplier. As shown in the graph, we can observe sudden level drop when the multiplier is too large. So, we determined the value of multiplier as 20.0.

For M_{dc}=20.0, the axial vapor velocity is as follows;

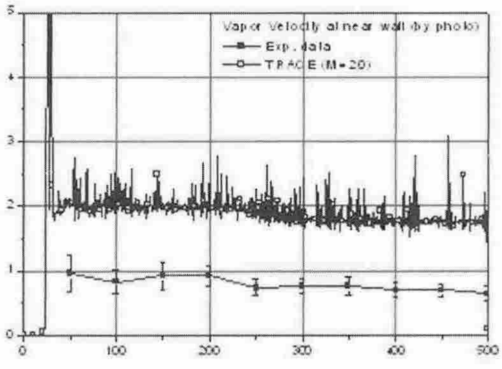
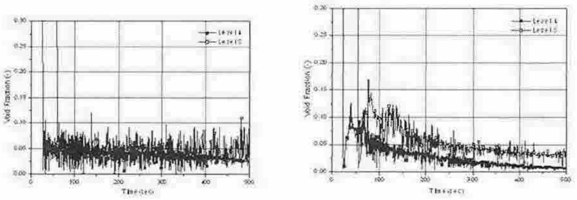


Fig. 4 Comparison of vapor velocity

Fig. 4 is the vapor velocity of the middle of the chamber. As shown in the graph, the predicted velocity of TRACE is ~ 2m/s. TRACE code using new downcomer boiling model over predicts the vapor velocity compared to the velocity of the experiments. However, the vapor velocity using the new model (Fig. 4) shows more reasonable behavior than vapor velocity behavior using the Blasius model (Fig. 2). These differences between two models can be found in void fraction distribution. Fig. 5 shows void distribution at 14 and 18 cm from chamber bottom.



(a) Blasius model (b) New Model

Fig. 5 Void fraction Distribution

In prediction results using Blasius model, there is no difference of void fraction according to the elevation. It is not matched with the experimental results. However, the new model shows reasonable void fraction distribution with the elevation.

For the wall temperature distribution, we can not find any meaningful differences between two models and TRACE predicts wall temperature distribution precisely.

5. Conclusions

In this paper, we developed new model to predict downcomer boiling phenomena. This model has been imported into TRACE code instead of Blasius model and assessed using downcomer boiling experiments performed by KAIST. Until now, we have only one preliminary experimental result. Therefore, we have to perform more assess to finalize the new downcomer boiling model using more experimental data.

ACKNOWLEDGEMENT

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