Preliminary Assessment of the KAERI 6x6 Reflood Experiment for the SPACE Code Using General Wall Heat Transfer Models

Sang-Ki Moon[a*], Jungwoo Kim[a], Kyung-Doo Kim[a], Ki-Yong Choi [a], Hyun-Sik Park[a], Seok Cho[a]
[a]*Korea Atomic Energy Research Institute (KAERI), 1045 Deadeokdaero, Yuseong-gu, Daejeon, 305-353, Korea*
[*]*Corresponding author:skmoon@kaeri.re.kr*

1. Introduction

The SPACE code (Safety and Performance Analysis Code) which is based on a multi-dimensional two-fluid, three-field model is under development for a licensing application of pressurized water reactors [1]. A reflood heat transfer can be dealt with the general wall heat transfer model or a separate reflood heat transfer model by an user option. The reflood heat transfer package is incorporated into a heat transfer model that takes account of the two-dimensional heat conduction effects near the quench fronts. A detailed description of the overall heat transfer models as well as the reflood heat transfer model can be found in the design document [2]. This paper briefly introduces the wall heat transfer models of the SPACE code regarding the reflood heat transfer phenomena, and the preliminary assessment results with KAERI 6x6 reflood heat transfer experiments using the general film boiling model. A companion paper deals with the same assessment using the reflood heat transfer model instead of the general wall heat transfer model. The objectives of these assessments are to examine the prediction capabilities of general wall heat transfer models against the reflood phenomena, and to suggest future improvement directions.

2. Wall Heat Transfer Model of the SPACE Code

The reflood heat transfer model is implemented into the wall-to-fluid heat transfer package of the SPACE code as one of 13 heat transfer models. When the reflood flag is off, the wall heat transfer coefficient is calculated using the general wall heat transfer correlations instead of the separate reflood model.

The differences between the reflood heat transfer and the general wall heat transfer models are the use of film boiling and the transition boiling models beyond the post-CHF region. The general wall heat transfer model uses the film boiling look-up table by Groeneveld et al. [3]. The look-up table is basically a normalized data bank of the heat transfer coefficients for discrete values of pressure, mass flux, quality and wall superheat. The heat transfer coefficient and the total heat flux for a fully-developed film boiling can be predicted with diameter correction factor as follows:

$$h_p = h_{table}\left[P, G, X_e, (T_w - T_{sat})\right](0.008/D)^{0.2} , \quad (1)$$

$$q_p^{''} = h_p (T_w - T_{sat}) . \quad (2)$$

The total heat flux predicted by the look-up table was partitioned into three fields proportional to phase volumetric fraction times phase density as follows:

$$q_{p,i}^{''} = q_p^{''} \times \alpha_i \rho_i / \left(\sum_i \alpha_i \rho_i \right) . \quad (3)$$

3. Assessment of the Wall Heat Transfer Model

The reflood heat transfer model of the SPACE code was assessed using KAERI 6x6 reflood heat transfer experiment [4]. Cho et al. [4] conducted reflood heat transfer experiments with 6x6 rod bundle using ATHER (Advanced Thermal Hydraulic Evaluation of Reflood phenomena) test facility. The experiments cover a flooding velocity of 2 ~ 6 cm/s, an inlet subcooling of 20 ~ 80 °C, a system pressure of 0.2 ~ 0.6 MPa, and an initial maximum wall temperature of 500 ~ 700 °C. The test section consists of 30 heater rods, 2 unheated rods, and a guide tube in the center of the bundle. The heater rods have the heated length of 3.81 m and the outside diameter of 9.5 mm. The heater rods simulate the symmetric chopped cosine axial power profile. Among the various experimental data, several tests are selected for the assessment of the general wall heat transfer model of the SPACE code as shown in Table 1.

Table 1. Assessment test matrix

Parameter	EP22-50030	EP22-70030	EP26-70030	EP62-70030
Initial max. wall temperature (°C)	499.5	701.9	699.1	699.0
System pressure (MPa)	0.2	0.2	0.2	0.6
Flooding velocity (cm/s)	2.0	2.0	6.0	2.0
Reflood water temperature (°C)	31.6	31.5	31.0	32.6
Total power (kW)	10.45	10.61	10.57	10.82

As shown in Fig. 1, the 6x6 rod bundle reflood experiment was modeled with a pipe with 20 hydrodynamic cells and a heat structure with 20 axial meshes. All cold walls such as unheated rods, guide tube and the test section housing were also modeled with the same number of axial meshes. A time dependent flow boundary at the inlet and a time dependent pressure boundary at the outlet were imposed in order to give appropriate initial and boundary conditions. In the present assessment, one-dimensional heat conduction without fine mesh was used and the heat transfer enhancement by the spacer grids was not simulated.

Fig. 2 compares the predicted wall temperatures with the experimental data for test EP62-70030. The SPACE code reasonably predicts the wall temperature behavior and the quenching time. Similar predictions were obtained for EP22-50030 and EP22-70030 experiments. However, for high flooding velocity case, EP26-70030, the SPACE code shows earlier quenching than the experiment as shown in Fig. 3. This early quenching is due to the faster water accumulation along the test section than the experiment as shown in Fig. 4. This might be affected by physical models such droplet entrainment, interfacial drag, and droplet diameter during the reflood.

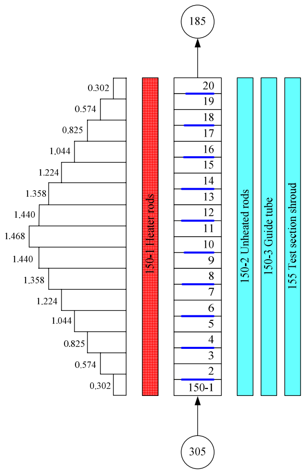
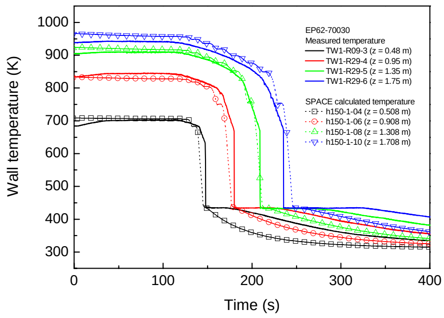
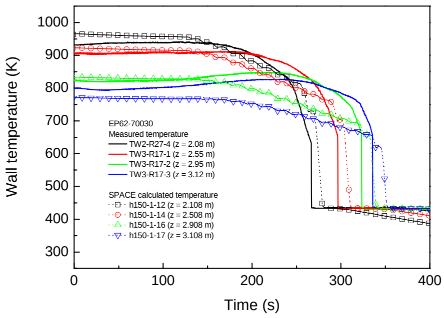


Fig. 1. SPACE model for the 6x6 reflood experiment

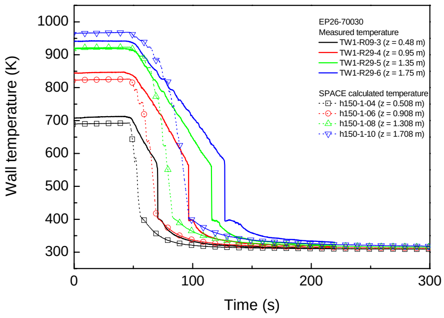


(a) Lower part

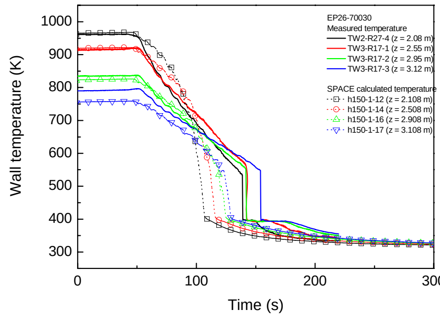


(b) Upper part

Fig. 2. Wall temperature (EP62-70030)



(a) Lower part



(b) Upper part

Fig. 3. Wall temperature (EP26-70030)

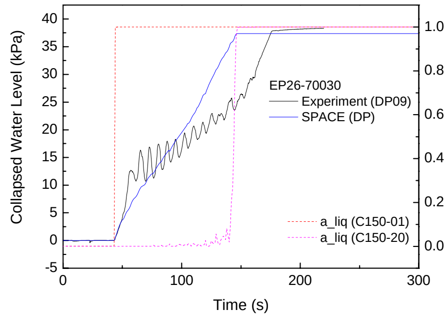


Fig. 4. Collapsed water level (EP26-70030)

4. Conclusions

The general wall heat transfer models of the SPACE code were assessed using KAERI 6x6 reflood experiment. The SPACE code predicts well the wall temperature behavior and quenching time. However, for higher flooding rates, the SPACE code showed the early quenching because of faster water accumulation in the test section than the experiment. Thus, physical models such as droplet entrainment, interfacial drag, and droplet diameter should be checked and improved for the high flooding rates.

ACKNOWLEDGEMENT

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