# Evaluation of the Horizontal Condensation Heat Exchanger Analysis Methodology

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## 1. Introduction

The use of the passive safety systems has emerged for safety in the accident of the Nuclear Power Plant (NPP). And many passive safety systems use the natural circulation, which is formed by the residual heat from the core as the heat source and the heat exchanger as a heat sink. The Passive Auxiliary Feedwater System (PAFS) and Passive Containment Cooling System (PCCS) are typical passive safety systems that remove heat from the core or cool down the inside of the containment building. In both systems, there is a characteristic that complex two-phase flow and condensation heat transfer phenomena occur in the inside of the condensation heat exchanger tube. Therefore, it is necessary to accurately predict the horizontal in-tube condensation to evaluate the performance and design passive safety systems such as PAFS.

In previous study, a verification analysis was performed on a single horizontal tube condensation experiment at Purdue University using the SPACE code. Through this, the SPACE code was evaluated as underestimating the condensation heat transfer inside the condensation heat exchanger tubes compared to the experiment [1]. In this study, the effect of the analysis result by simulating the secondary side of the condensation heat exchanger tube was evaluated.

## 2. Experiment

Purdue University conducted the single tube experiments (Purdue-Single) [2]. Figure 1 shows the schematic diagram of the test section of Purdue-Single experiment. The primary side is condensed with water jacket. The primary side single tube has an OD 31.7 mm, and ID 27.5 mm with 3.0 m heat transfer length. Steam and non-condensable gas (NC gas) flows into the tube. The experimental conditions are summarized in Table 1.

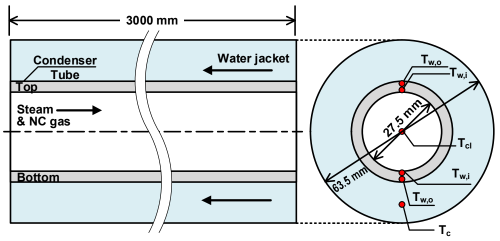



Fig. 1. Schematic of Purdue-Single test section

Table. 1. Purdue-PCCS experimental conditions

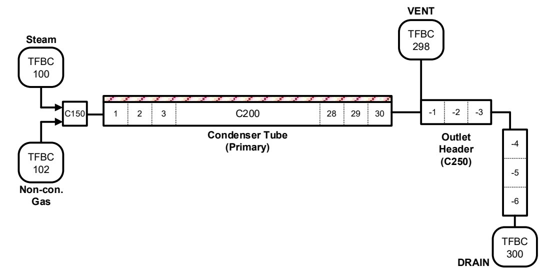
| Parameter | Range |
|---|---|
| Primary Side (Steam/Air) | |
| Pressure (bar) | 1 – 4 |
| Steam flow rate (g/s) | 6.0 – 46.0 |
| NC gas mass fraction (%) | 0 – 20 |
| Secondary Side (Water) | |
| Pressure (bar) | 2 |
| Flow rate (kg/s) | 1.48 |
| Temperature (℃) | 45.0 |

## 3. Simulation of the experiment

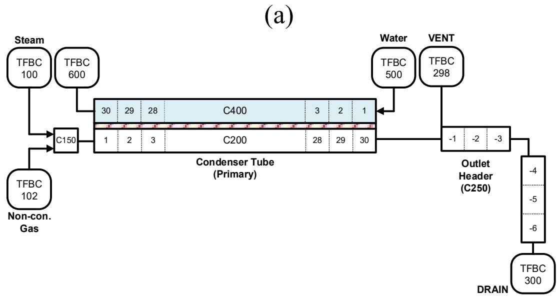
### *3.1. SPACE nodalization*

In this study, two types of inputs were developed for each experiment to check the effect of whether the secondary side was simulated.

Figure 3(a) and (b) represent the SPACE code nodalization of the Purdue-Single experiment. In Figure 3(a), the secondary was simulated by the temperature boundary conditions with wall temperature from the experimental data (Reference). By the way, in Figure 3(b), the secondary side was simulated with pipe component.




(a)




(b)

Fig. 3. Purdue-Single experiment nodalizations (a) temperature boundary (b) simulating secondary side

### *3.2. Analysis results*

The results of the analysis are represented in Figure 4 to 7 for the typical case. Figure 4 is the result of local heat flux result along the axial direction. As shown in the figure, SPACE predicts the local heat flux lower than the experimental data. Also, at the entrance of the condensation tube (less than 1.0 m), calculation result of the simulating cooling jacket is lower than the temperature boundary type (Reference type).

However, local heat transfer results in Figure 5, the reference type is lower than the simulating cooling jacket type at the entrance region. For this, lower condensation heat transfer causes low temperature difference, because of the high saturation temperature, and this makes the high calculated local heat transfer coefficient.

For this, the default wall condensation model in the SPACE code uses the condensation heat transfer coefficient as a maximum value of the Chato (1962) [3] and Shah (1979) [4] models, for horizontal tube. Chato (1962) model considered the heat transfer through the thick condensate layer at the bottom of horizontal tube. And Shah (1979) model predicting heat transfer coefficient during the film condensation based on the Dittus and Boelter (1930) correlation with the vapor quality. So, the default model predicts low condensation heat transfer than experiment and its prediction results are near to the bottom region in the tube.

Therefore, the local centerline temperature of the reference type analysis in Figure 6 decreases faster than the cooling jacket simulated analysis.

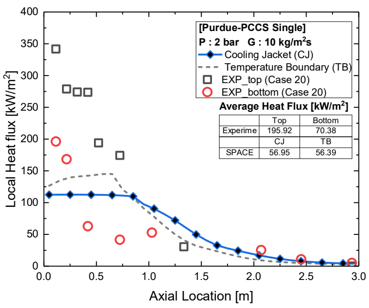



Fig. 4. Local heat flux result (2 bar, 10 kg/$m^2$s)

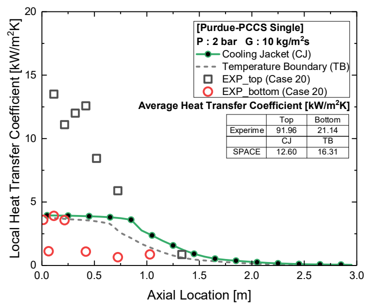



Fig. 5. Local heat transfer coefficient result (2 bar, 10 kg/$m^2$s)

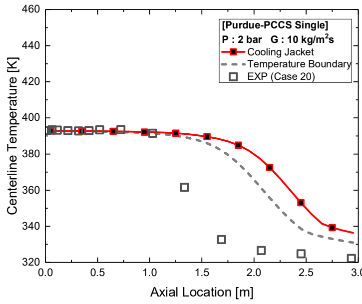



Fig. 6. Local centerline temperature result (2 bar, 10 kg/m2s)

Figure 7 shows the overall heat transfer rate calculation results. The cooling jacket simulated calculation data are lower than the reference type analysis. And the reference type analysis results are more accurate than the cooling jacket simulated.

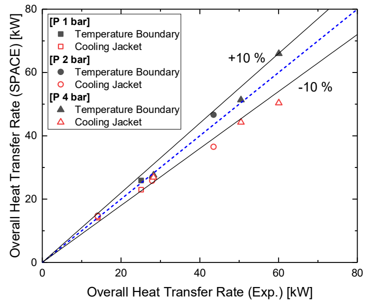



Fig. 7. Comparison of the overall heat transfer rate between secondary side simulation methodologies

## 4. Conclusion

In this study, the evaluation of the horizontal in-tube condensation heat transfer according to the simulating secondary side using SPACE code was performed and the following conclusions are drawn.

(1) The analysis method with simulate cooling jacket predicts condensation heat transfer lower than the secondary side simulated by temperature boundary.

(2) The analysis method which simulate the secondary side with temperature boundary is more accurately for prediction of overall heat transfer rate.

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