Assessment of Condensation Models in SPACE in the Presence of Noncondensable Gas

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1. Introduction

The condensation phenomena play an important role in heat removal of reactor coolant system, especially the PRHRS(Passive Residual Heat Removal System) in SMART. During the PRHRS operation, nitrogen gas might be generated because of evaporation in the steam generator. It will act as a noncondensable gas in the condensation heat exchanger. It is known that even a small amount of noncondensable gas can reduce the condensation heat transfer considerably. SPACE adopted condensation models through the experimental studies for those condition. In order to analyze the heat transfer in the steam generator of next generation NPP by using SPACE, verification of its condensation model is essential. In this study, assessment of condensation models in the SPACE in the presence of noncondensable gas is performed by validation with a benchmark experiment.

2. Condensation Models of SPACE

The condensation heat transfer models in SPACE consist of default model, alternative model and temporary model. The default model uses Nusselt(1916), Chato(1962), Shah(1979) correlation and Colburn-Hougen(1934) model. In the condition of pure steam and laminar flow, Nusselt correlation is used for vertical tube and Chato correlation for horizontal tube. Shah has developed the condensation heat transfer correlation considering turbulent flow. So when the calculation results performed by the Shah correlation is larger than Nusselt or Chato model, SPACE selects Shah's results for the pure steam cases. Based on the Shah correlation, if the noncondensable gas exists, the Colburn-Hougen model is used. The basic principle of the Colburn-Hougen model is that the total heat transfer through steam-noncondensable gas layer to liquid-steam interface is equivalent to the heat transfer through the condensation film. This energy balance equation is represented as:

$$h_c(T_{vi} - T_w) = h_m i_{fgb} \rho_{vb} \ln\left(\frac{1 - p_{vi}/p}{1 - p_{vb}/p}\right) \quad (1)$$

The No-Park(2002) model is adopted as alternative model and the Vierow-Schrock(1991) model as temporary model. The both are used for the in the presence of noncondensable gas cases. However, the No-Park(2002) model is not treatd in this paper. Vierow and Schrock in UCB has proposed the correction factor for Nusselt and Chato correlation to simulate the effect of noncondensable gas. The total correction factor *f* is the ratio of local condensation heat transfer coefficient obtained from the experimental data and calculation result from Nusselt correlation. It is expressed by multiplying f_1 and f_2.

The heat transfer enhancing factor, f_1, is as follows:

$$f_1 = 1 + 2.88 \times 10^{-5} \mathrm{Re}_{mix\,2}^{1.18} \quad (2)$$

The heat transfer reducing factor, f_2, is as follows:

$$f_2 = \begin{cases} 1 - 10 \cdot M_a, & M_a < 0.063 \\ 1 - 0.938 \cdot M_a^{0.13}, \quad \text{for} & 0.063 < M_a < 0.6 \\ 1 - M_a^{0.22} & M_a > 0.6 \end{cases} \quad (3)$$

3. Benchmark Experiment

POSTECH has performed the experiment to investigate the local condensation heat transfer coefficients in the presence of noncondensable nitrogen gas in a vertical tube. The experimental facilities consisted of a steam generator, steam flow rate control system, steam/nitrogen gas mixing system, test section, and data acquisition system. Figure 1. shows the schematic diagram of the experimental apparatus.

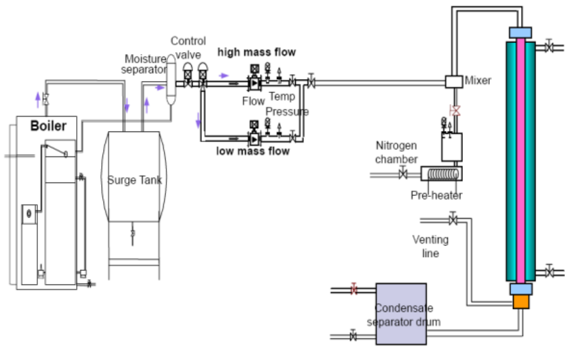

Fig. 1. Schematic diagram of the experimental apparatus

The steam flow from the gasoline boiler to the steam/nitrogen gas mixing system and then flow into test section. The test section consisted of an inner condenser tube and an outer cooling jacket. The mixture is condensed as it flows down along the tube. By measuring the temperature of test section at different locations, the heat transfer coefficient was calculated by using them.

4. Modeling and Results

4.1. SPACE modeling

The experiment is selected to evaluate the condensation models in SPACE in the presence of noncondensable gas. The test section of the experiment is modeled by using SPACE. To avoid unnecessary external effect, in this modeling, the outer cooling jacket of test section was replaced by outer wall temperature. The pipe component was used to simulate the condenser tube. Inlet and outlet conditions were modeled by using TFBC(Temporal Face Boundary Condition). The inlet had flow boundary condition, whereas the outlet had pressure boundary condition.

4.2. Results and discussion

In accordance with steam flow rate and inlet mass fraction of noncondensable gas, code calculations for six cases were carried out. Because calculating the heat transfer coefficient directly in the code is not available, the bulk temperature is used for the comparative parameter. The high temperature gradient indicates that the heat transfer coefficient is large. Among the six cases, the two are illustrated in figure 2 and figure 3. The Vierow-Schrock model cannot follow the experimental data, whereas the Colburn-Hougen model predicts the tendency of the temperature well till the middle of the axial location. This discrepancy is caused by different ranges of condensation correlations in the two models. In other words, the diameter and quality range of the experiment belong to the Shah correlation in the Colburn-Hougen model, not the UCB correlation in the Vierow-Schrock model. The other cases show similar results. Therefore, that results indicate that the results of the SPACE calculations are valid. However, the gap between the experiment and the Colburn-Hougen model increased as the axial location increased. It demonstrates that the Colburn-Hougen model is vulnerable at the condition of the low quality.

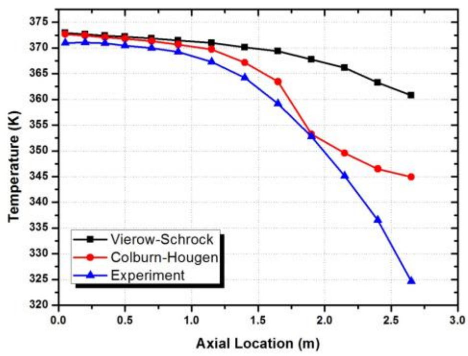

Fig. 2. Bulk temperature for case MB32
(M_s=11.2kg/h, W_{N2}=10%)

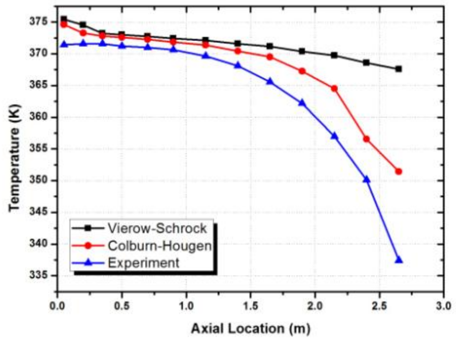

Fig. 3. Bulk temperature for case MB42
(M_s=13.8kg/h, W_{N2}=10%)

5. Conclusions

The experimental data was compared with SPACE calculation to assess the condensation model in the presence of noncondensable gas in SPACE. As mentioned earlier, the discrepancy between the Colburn-Hougen and the Vierow-Schrock indicates that the SPACE calculation is reasonable. However, the Colburn-Hougen model did not fit as the axial location increase. It means that Colburn-Hougen model do not proper at the condition of low quality. The modified condensation model for this condition will improve the capability of SPACE.

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