Proceedings of the Korean Nuclear Society Spring Meeting
Seoul, Korea, May 1998

Assessment of RELAP5/MOD3.2 with Condensation Experiment in the Presence of Noncondensables in a Vertical Tube

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Abstract

The standard RELAP5/MOD3.2 code were assessed with the condensation experiment in the presence of noncondensable gas in a vertical tube of PCCS of CP-1300. There are two wall film condensation models, the default model and the alternative model, in RELAP5/MOD3.2. The experimental apparatus was modeled with the two models, and simulations were performed for several sub-tests to be compared with the experimental results. In overall sense the simulation results showed that the default model of RELAP5/MOD3.2 under-predicts the heat transfer coefficients, while the alternative model over-predicts them throughout the condensing tube.

1 Introduction

As a passive engineered-safety-feature the external condenser concept[1] is adopted to be applied as a PCCS of CP-1300[2]. It utilizes the condensation of steam in condensing tubes, which are located in a water pool outside a containment. Several experiments on the local heat transfer phenomena in a vertical tube with noncondensable gases have been performed recently and several correlations have been developed based on their own experimental data[3, 4, 5, 6]. However, it was noticed that the existing correlations had limited applicable operating ranges because of their development from their own experimental database generated with limited operating range.

A new experimental apparatus with a venting line was set up to make the coolant flow uniform at the inlet using honeycomb and to reduce the multi-dimensional effect at the exit of the coolant jacket. In the present experiment the coolant bulk temperature was calculated by a simple numerical method using measured two surface temperatures of the annulus and the coolant flow rate to provide more reliable heat flux. The operating range of the present experiment is similar to Siddique[5]'s one. The experimental data were compared with the predictions from the previously developed correlations, and the effects of the various parameters on steam condensation with noncondensable gas were investigated.

The simulation capability to deal with steam-noncondensable gas mixtures in vertical tubes of PCCS is also an important technical problem in the design of the PCCS. Here, the RELAP5/MOD3.2 code[7] is selected as a simulation tool, which does not show the dependency of the nodal size for wall condensation heat transfer. A simulation of the loss of residual heat removal system during mid-loop operation was also performed using the RELAP5/MOD3.1[8] which shows the dependency on the nodal size for wall condensation heat transfer, and the calculations showed that the model for calculating condensation heat transfer coefficients in the presence of noncondensables is inadequate and needs modification. Here, there are two wall film condensation models, the default model and the alternative model, in RELAP5/MOD3.2, The default model is to use the maximum of Nusselt's and Shah's with the Colburn-Hougen's diffusion calculation when noncondensable gases are present. The alternative model is the Nusselt model with UCB multipliers, which is revised to include the effects of the interfacial shear and the presence of the noncondensable gas in a vertical tube

Also, it was known that those heat transfer models in RELAP5/MOD3.2 had much uncertainties in predicting condensation phenomena in the presence of noncondensable gas[9]. The test facility was modeled with RELAP5/MOD3.2 and the numerical simulations were performed to compare results from two wall film condensation models of RELAP5/MOD3.2 with those from the present experiment.

2 Assessment of Two Wall Film Condensation Models

The steam condensation experiments in the presence of noncondensable gas in a vertical tube of PCCS were performed at KAIST[10]. The schematic diagram of the experimental facility is shown in Figure 1, and the nodalization scheme of the RELAP5/MOD3.2 code of the present experimental facility is shown in Figure 2. The present RELAP5/MOD3.2 nodalization used for this simulation contains 41 control volumes, 6 junctions, a valve and a heat structure. Time-dependent volumes acting as infinite sources or sinks are used to represent boundary conditions both for the steam-noncondensable gas mixture flow in a condensing tube and for the coolant flow in a coolant jacket. For the simulation of the coolant jacket, two time-dependent volumes 200 and 280 are connected to the annulus 240 with 11 volumes via a time-dependent junction 210 and a single junction 270. Similarly, for the simulation of the steam-noncondensable gas mixture flow two time-dependent volumes 100 and 180, a pipe with 13 volumes, a time-dependent junction 105 and a single junction 151 are also used. A branch 120 is used to simulate an upper plenum and three pipe volumes, 150, 160 and 157, are used to simulate a lower plenum, a drain tank and a connecting pipe between the lower plenum and the drain tank, respectively. The above three pipes are connected using single junctions 155, 156 and 158. A valve 175 is used to regulate the venting of the mixture of the residual steam and the noncondensable gas. A heat structure 140 with 11 volumes is used to represent the heat transferred from the steam-noncondensable gas mixture to the coolant through the condensing tube.

For base case calculations, three sub-tests, *E4d*, *E12b*, and *E13b*, were simulated by RELAP5/MOD3.2 to determine whether or not it could describe properly the steam condensation experiments in the presence of noncondensables in a vertical tube of PCCS. These simulations used both the default model and the alternative model of the RELAP5/MOD3.2 code, and two simulation results of each steady-state calculation were compared with each other, and they were also compared with the experimental data. The simulation results of the experimental data of *E13b* were compared in Figures 3 through 6.

As shown in Figure 3, the calculated heat flux from the default model is always lower than that from the alternative model in the upper region of the condensing tube. Moreover,

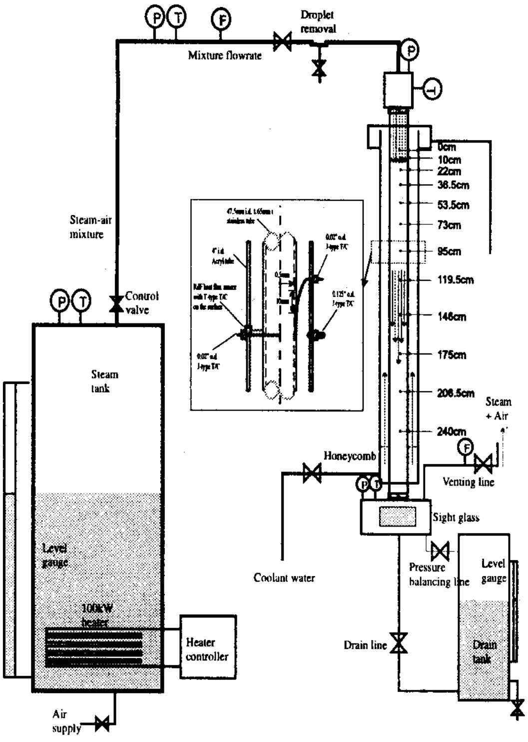

Fig. 1: A schematic diagram of KAIST condensation experimental apparatus

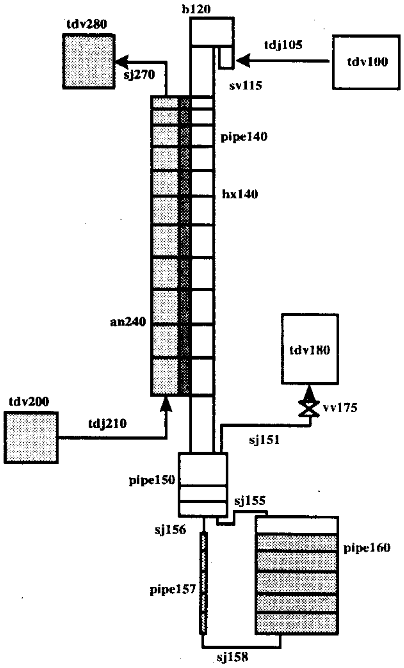

Fig. 2: Nodalization scheme of the RELAP5/MOD3.2 code for PCCS experimental facility

the condensation heat flux calculated from the default model is always much lower than the experimental data throughout the condensing tube. However, the condensation heat flux calculated from the alternative model is a little higher than the experimental data in the upper region of the condensing tube, and they crossed each other in the middle of the condensing tube.

As shown in Figure 4, the calculated air mass fraction from the default model is always lower than that from the alternative model. The calculated air mass fraction from the default model increases linearly and is always slightly higher than the experimental data. However, the calculated air mass fraction from the alternative model increases rapidly in the upper part of the condensing tube and the inclination is decreased in the lower part, and it always keeps higher values than the experimental data except for the the inlet.

The calculated condensation heat transfer coefficient from the default model is always lower than that from the alternative model throughout the condensing tube, as shown in Figure 4. Similar to the comparison results of the heat flux, the calculated heat transfer coefficient from the default model is always lower than the experimental data, while the calculated one from the alternative model is always higher than the experimental data. Three heat transfer coefficients, or two simulated results and one experimental data, are greatly different in the inlet of the test section, but they are similar in the outlet of the

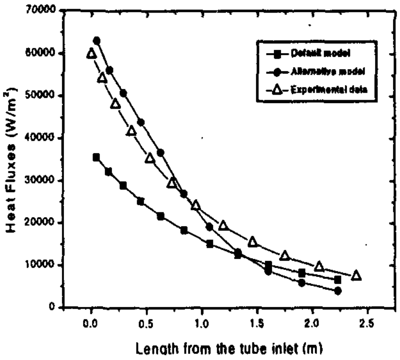

Fig. 3: Comparison of heat fluxes calculated using two condensation models with the experimental data of *E13b*

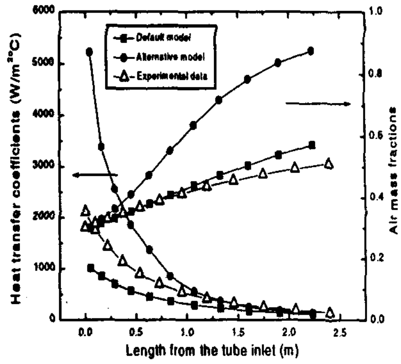

Fig. 4: Comparison of air mass fractions and heat transfer coefficients calculated using two condensation models with the experimental data of *E13b*

condensing tube, where the amount of steam is greatly reduced by condensation and the convective heat transfer is dominant.

Experiment *E13b* was simulated for high inlet air mass fraction above 10% and low inlet steam-air mixture flow rate below $30 kg/hr$, which was shown in Figure 4. The simulation results showed that with the inlet mixture flow rate below $30 kg/hr$ and the inlet air mass fraction above 10%, predictions by both the default model and the alternative model are not good agreement with experimental data.

From experimental studies, it was known that the main parameters controlling the condensation with noncondensable gas in a vertical tube are the inlet steam-air mixture flow rate, the inlet air mass fraction, and the inlet saturated steam temperature. Simulations on experiments *E12b* and *E4d* were also performed to show the parametric effects with both the default model and the alternative model of RELAP5/MOD3.2.

For relatively high inlet steam-air mixture flow rate above $30 kg/hr$, simulation was performed for experiment *E12b*, as shown in Figure 5. The experimental air mass fraction was predicted better with the default model than with the alternative model. The tendencies were similar to those in the case of experiment *E13b*, but the calculated air mass fraction from the default model became slightly lower than the experimental data along the condensing tube. The calculated heat transfer coefficients from the alternative model are close to the experimental data both near the inlet and the outlet of the condensing tube, but higher than the experimental data in the middle of the condensing tube. The heat transfer coefficients calculated using the default model are lower than the experimental data near the inlet, and they are approaching each other along the condensing tube. This tendency of the default model is unchanged regardless of the change of the inlet mixture flow rate.

From the above simulation results it was concluded that with an increase in the inlet steam flow rate above $30 kg/hr$, the predictions by the default model are not good except for the outlet of the condensing tube, while those by the alternative model are good both in the inlet and outlet but it also predicted higher heat transfer coefficients in the middle

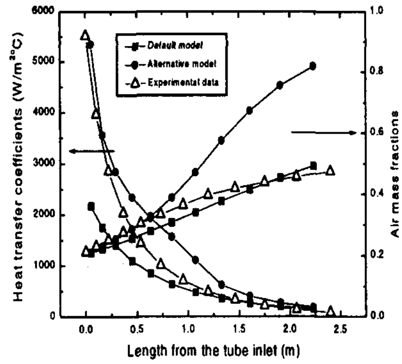

Fig. 5: Comparison of air mass fractions and heat transfer coefficients calculated using two condensation models with the experimental data of *E12b*

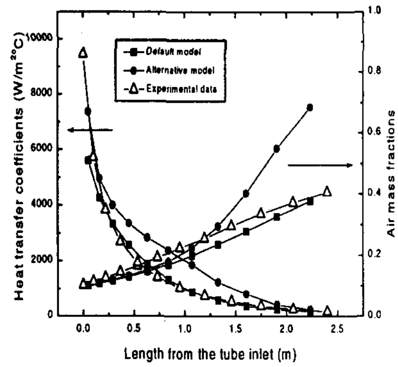

Fig. 6: Comparison of air mass fractions and heat transfer coefficients calculated using two condensation models with the experimental data of *E4d*

of the condensing tube.

For relatively low inlet air mass fraction below 10% and high inlet steam-air mixture flow rate above $30kg/hr$, simulation was performed for experiment *E4d*, as shown in Figure 6. The experimental air mass fraction was predicted well with the default model. The calculated heat transfer coefficient from the alternative model becomes similar to the experimental data both at the inlet and the outlet of the condensing tube, but it predicts higher values in the middle of the condensing tube. This tendency of the alternative model is unchanged regardless of the change of the inlet air mass fraction. The heat transfer coefficient calculated using the default model simulates well the experimental data throughout the condensing tube.

From the above simulation results it was concluded that for the condition of relatively low air mass fraction below 10% and high steam flow rate above $30kg/hr$, the default model predicts well the experimental data.

3 Conclusions and Recommendations

The capability of the RELAP5/MOD3.2 code in modeling the condensation heat transfer has been investigated for steam condensation experiment in the presence of noncondensable gas. After the experimental apparatus being modeled with RELAP5/MOD3.2, the simulation results by two wall film condensation models were compared with the experimental data.

From the studies, the followings were concluded:

1. The default model of RELAP5/MOD3.2 predicted well the experimental heat transfer coefficients for operating range with relatively low inlet air mass fraction below 10% and relatively high inlet steam flow rate above $30kg/hr$ but it always underpredicted the experimental data except for the region near the inlet.

2. The alternative model of RELAP5/MOD3.2 over-predicted the experimental data

throughout the condensing tube, but it predicted well the experimental data for operating range with relatively high inlet steam flow rate above $30kg/hr$ except for the middle part of the condensing tube.

3. It was also concluded that the effect of the inlet steam-air mixture flow rate was not properly considered in the default model, and the effect of the inlet air mass fraction in the alternative model.
4. As both wall film condensation models have limited applicable ranges, it is needed to develop a new correlation applicable over more broad operating range.

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