# Use of the MARS-KS Code for the Prediction of Condensation Heat Transfer in a Passive Cooling Heat Exchanger

Byung Soo Shin, Jong Chull Jo, Sang Kyoon Lee, Kyu Sik Do
*Korea Institute of Nuclear Safety*
bsshin@kins.re.kr

## 1. Introduction

The Passive Auxiliary Feedwater System (PAFS) is new conceptual design of auxiliary feedwater system in APR+ nuclear power plan. Although PAFS is relatively a simple system composed of one heat exchanger and several valves, it is designed to be capable of performing safety functions of which the conventional Auxiliary Feedwater System (AFS) did by active components. Furthermore, PAFS carry out safety functions during the period of the total loss of electrical power (i.e. SBO).

PAFS provides cooling water into a steam generator to remove the residual heat under transient and accident conditions. During operation of PAFS, the phase change occurs at the Passive Cooling Heat Exchanger (PCHX) which located at the inside of the Passive Condensation Cooling Tank (PCCT). Then, the condensate water flows into the steam generator by gravity and it evaporates in the steam generator again. Therefore, the characteristics of heat transfer inside the PCHX is a main issue of PAFS. The schematic diagram of PAFS is in Figure 1.

This paper addresses a preliminary investigation of the applicability of the thermal-hydraulic system analysis code "MARS-KS" for predicting the thermal-hydraulic characteristics of PCHX and PCCT in the PAFS. In addition, the heat transfer performance of PCHX during operational transients has been investigated.

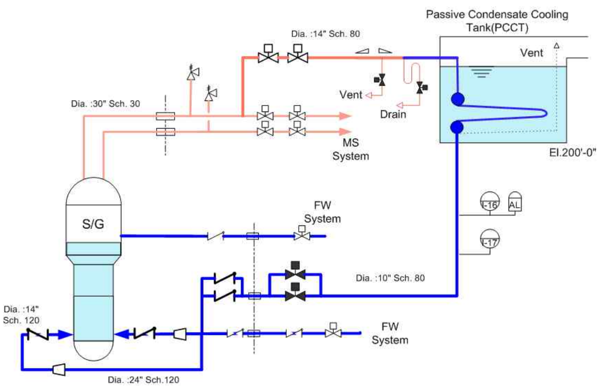



Figure 1 Schematic Diagram for PAFS

## 2. Numerical Methods

In PCHX, a major phenomenon is a wall condensation. MARS-KS have some kinds of condensation models for geometrical features. Wall condensation is the process of changing a vapor near a cold wall to a liquid on the wall by removing heat.

The method of calculating the heat transfer coefficient is given below. Once it is known, it is used to calculate the total heat flux:

$$q_t'' = h_c\left(T_w - T_{sppb}\right) \quad (1)$$

Where $q_t''$ is total heat flux, $h_c$ is predicted condensation heat transfer coefficient, $T_w$ is wall temperature, $T_{sppb}$ is saturation temperature.

The correlation for condensation heat transfer coefficient of almost horizontal tube such as PCHX tube (show figure 2) takes the form

$$h_c = F\left[\frac{g\rho_f \Delta\rho h_{fg} k_f^3}{D_h \mu_f \left(T_{sppb} - T_W\right)}\right]^{\frac{1}{4}} \quad (2)$$

The $F$ term corrects for the liquid level in the tube bottom with the form

$$F = \left(1 - \frac{\Phi}{\pi}\right)F' \quad (3)$$

The development by Chato (1962) indicates that a value of 0.296 for F is an average value appropriate for free flow from a horizontal tube, with the liquid level controlled by the critical depth at the exit. [1]

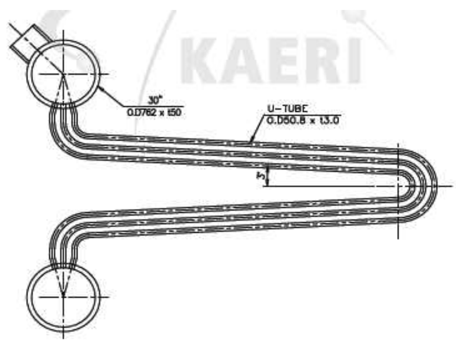



Figure 2 PCHX tube bundles in PAFS

## 3. Results

To estimate the thermal-hydraulic characteristics of PCHX, the piping including PCHX and PCCT is nodalized as shown in figure 3. In the simulation, the saturated steam flow with specific mass flow is supplied into PCHX. The PCCT contains the saturated water at the atmospheric pressure.

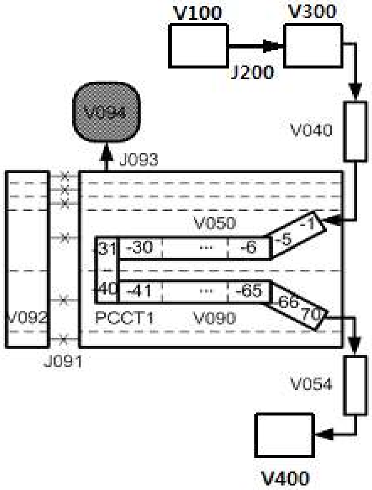
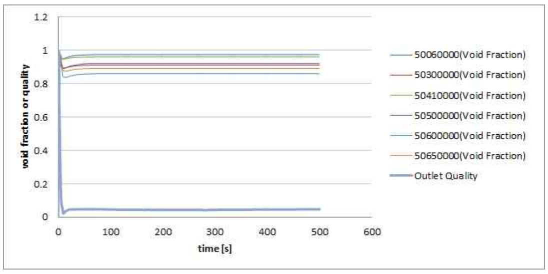
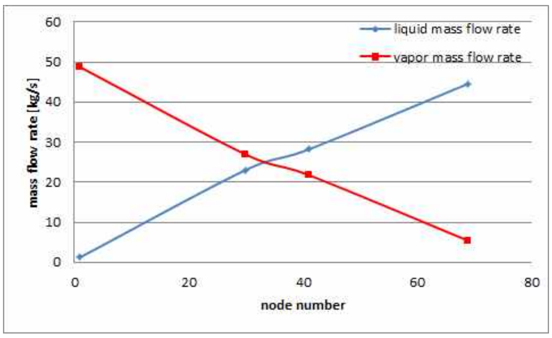



Figure 3 Nodalization for the PCHX and PCCT

The designed and expected operational range of PAFS is approximately from 30 kg/s to 100kg/s on mass flow rate and from 2MPa to 7MPa on operating pressure according to previous works [2, 3] and this study considered the ranges in the simulations. The typical variation of void fraction and mass flow rate inside the PCHX tube with time and length is shown as figure 4. According to the results on the typical case, the high void fraction of over 0.8 inside the PCHX tubes, the change of mass flow rate verifies the condensation phenomena. Furthermore, the values of equilibrium quality at the outlet of PCHX have less than 0.15 in the most cases. However, it is possible for saturated steam to exist at the downstream of PCHX.




(a) Void fraction and quality




(b) mass flux

Figure 4 Variation of void fraction and mass flux inside the PCHX tubes

In PAFS design, a heater installed inside the PCCT maintains the PCCT temperature in saturated temperature. It is a way to control the condensation rate constantly. However, external disturbances such as mixing with cold water from other water source by failing or breaking isolation valve could change the temperature. Therefore, we assumed that PCCT temperature is 20°C and simulated the cases. According to Figure 5, lower PCCT temperature increases the condensation rate slightly and the effect of PCCT temperature on the condensation rate is enhanced as the mass flow rate decreases. At the same time, we observed that the level of PCCT decreases linearly.

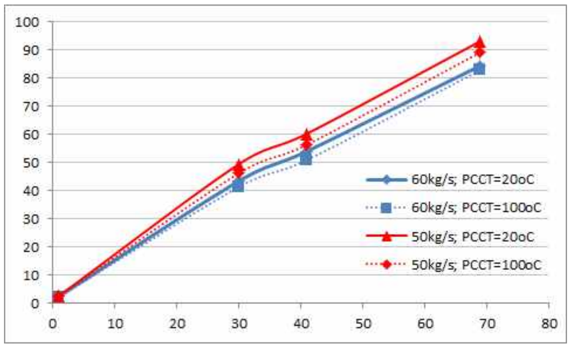



Figure 5 Condensation rate

The MARS-KS show a good convergence about the condensation heat transfer phenomenon on PCHX in PAFS if the mass flow rate is enough large to avoid zero void fractions at the tube outlet. Under the mass flow rate, it oscillates rapidly. As further study, that problem needs to be deal with.

## 3. Conclusions

Based on the results of this study, the MARS-KS code seems to work for predicting the condensation heat transfer in the PCHX of PAFS. However, further in-depth study should be followed to confirm if the code is applicable for conservative safety analyses of the PAFS during operational transients.

## REFERENCES

[1] MARS-KS Manual volume V: Model and Correlations, 2009

[2] KINS, Design basis accident assessment for the safety evaluation of APR+ passive auxiliary feedwater system, KINS/HR-1068, 2011

[3] H.J. Sung, Design and Assessment of PAFS, KNS fall workshop, 2010