Assessment of Prediction Capability of MARS-KS Code for Convection Heat Transfer from Horizontal Tube in Crossflow

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1. Introduction

In the Advanced Power Reactor Plus (APR+), a Passive Auxiliary Feedwater System (PAFS) is installed as one of passive safety systems (see Fig. 1). In order to increase the working time of the PAFS to more than 72 hours, KAERI proposed a new passive air-water combined cooling system as shown in Fig. 1 [1]. The Air Cooling Heat Exchanger (ACHX) is installed above the PAFS pool. It is expected that the ACHX condenses the steam vented from the PAFS pool and delays the depletion time of the water in the PCCT.

Jeon et al. [2] carried out the modeling of the ACHX and the performance analysis on the PAFS connected with the ACHX using MARS-KS1.4 [3]. MARS predicted the behavior of main thermal-hydraulic variables of ACHX reasonably. Then, it was found that the long term cooling of APR+ PAFS could be achieved by the installation of the ACHX in which the tube length is 6 m and the number of tubes is 8000.

For the reliable design of the number of tubes, the validation study for the heat transfer model is required. The heat removal performance of the ACHX is governed by the convection heat transfer from the horizontal tubes in the crossflow. Therefore, this study assesses the MARS-KS1.4 prediction capability on the crossflow convection heat transfer using ACHX related experimental data.

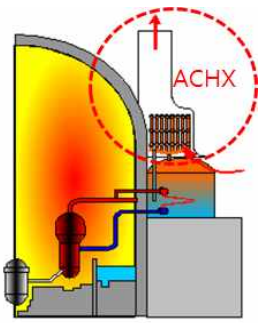

Fig. 1 Conceptual design of combined cooling system [1]

2. MARS Simulation of Air Cooling Experiments

In Kyungpook National University (KNU), the experimental investigation of air-cooled condensation in slightly inclined circular tubes without fins has been conducted [4]. In order to assess the effects of the essential parameters, variable air velocities and steam mass flow rates were given to the test section.

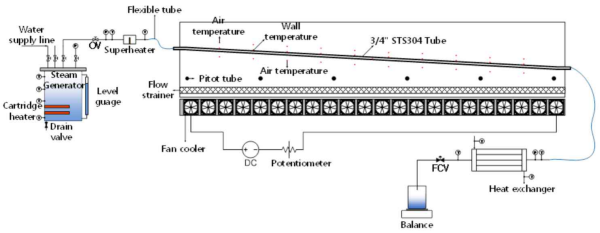

Fig. 2 Schematic diagram of KNU experimental facility [4]

Fig. 3 shows the MARS nodalization. The time dependent volume C002 and the time-dependent junction C003 were used to provide the inlet boundary condition for the steam. The time dependent volume C100 and the time-dependent junction C105 were used to provide the chimney inlet boundary condition for the air. The pipe component C004 was used to model single tube. The heat structure, HS004, was used to calculate the heat transferred from the steam to the cold air in the chimney (C200) through the tube wall.

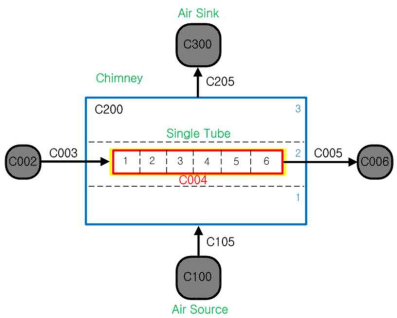

Fig. 3 MARS nodalization of KNU experiment

Fig. 4 shows the MARS simulation results. Reference calculation of MARS was performed based on the Dittus-Boelter correlation as the default convective correlation of MARS. MARS under-predicted the removal heat compared to the data. In order to improve the prediction capability of MARS-KS1.4, this study implemented the following Zukauskas correlation [5] for cross flow over horizontal tube bank:

$$h = 0.64\left[0.35\left(\frac{S_T}{S_L}\right)^{0.2} Re_D^{0.6} Pr^{0.36}\left(\frac{Pr}{Pr_s}\right)^{0.25}\frac{k}{D}\right]$$

The MARS code based on the Zukauskas correlation also under-predicted the data but the difference between the data and the prediction decreased significantly. It is found that the Zukauskas correlation is more appropriate to predict the removal heat of the KNU experiment.

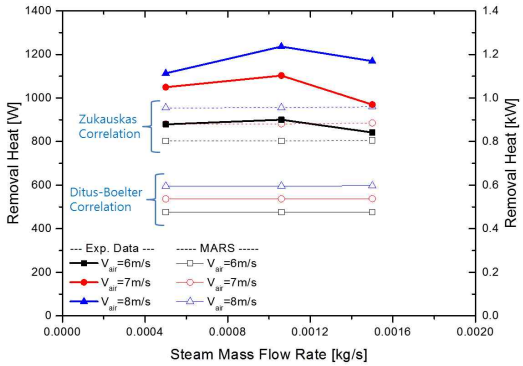

Fig. 4 MARS simulation results of KNU experiment

3. MARS simulation results of ACHX with PAFS

This study conducted the performance analysis on the PAFS connected with the ACHX by implementing the ACHX input model to the APR+ PAFS input model (see Fig. 5). Instead of Dittus-Boelter correlation, Zukauskas correlation was applied.

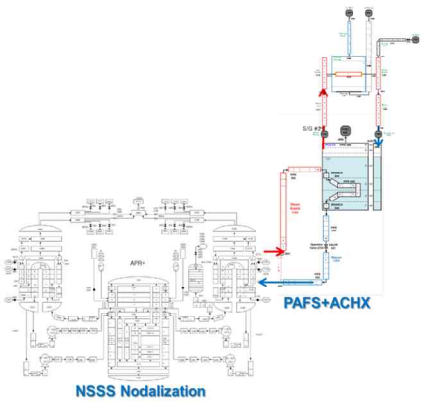

Fig. 5 MARS nodalization of APR+ PAFS-ACHX

For the feed line break analysis, MARS simulation results are as follows (see Fig. 6 and Fig. 7). The long term cooling of the PAFS was achieved by the ACHX (see Fig. 6). Compared to the use of Dittus-Boelter correlation, the number of tubes decreased from 8000 EA to 7000 EA by using the Zukauskas correlation. The water in the PAFS pool was not exhausted during 72 hours (see Fig. 7).

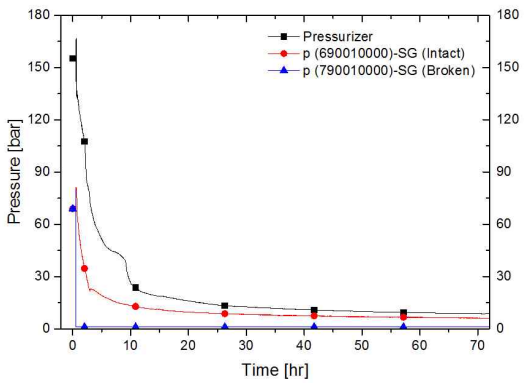

Fig. 6 Pressurizer and steam generator pressure

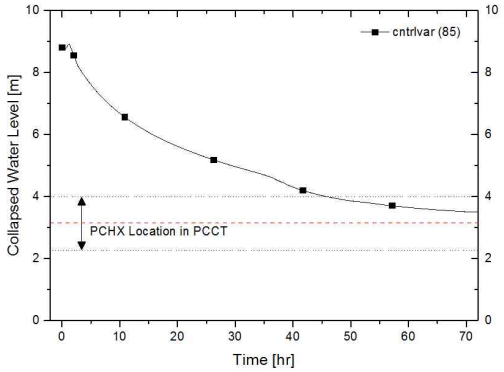

Fig. 7 Water level in PAFS pool

4. Conclusions

This study assessed the MARS-KS1.4 prediction capability on the crossflow convection heat transfer using four ACHX related experimental data. Compared to the default convection correlation by Dittus-Boelter, Zukauskas correlation predicted the experimental data well. At present, the additional validation study against various experimental data is in progress. It is expected that the Zukauskas correlation contributes to the reliable design and the safety analysis of the ACHX.

ACKNOWLEDGEMENT

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