Simulation of the KAERI PASCAL Test with MARS-KS and TRACE Codes

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1. Introduction

In order to validate the operational performance of the PAFS, KAERI has performed the experimental investigation using the PASCAL (PAFS Condensing heat removal Assessment Loop) facility [1-3]. In this study, we simulated the KAERI PASCAL SS-540-P1 test with MARS-KS V1.4 and TRACE V5.0 p4 codes to assess the code predictability for the condensation heat transfer inside the passive auxiliary feedwater system.

2. Test Facility Description

Figure 1 shows the schematic diagram of the PASCAL facility. The main components of the facility are the test section of PCHX, the steam-supply and condensate-return line, and the PCCT as shown in Fig. 1(a). To simulate the geometry of the PAFS, a single U-shaped PCHX tube with the length of 8.4 m is submerged in the PCCT. The tube has an inclination of 3 degrees to prevent the water hammer from occurring. The dimension and material of the tube are the same as the prototype. The inner and outer diameters of the PCHX are 44.8 mm and 50.8 mm, respectively. The PCHX is made of stainless steel 304.

The width and depth of the PCCT are 6.7 m and 0.112 m, respectively. The height of the PCCT is 11.484 m. The steam generator with 540kW thermal power provides the steam to the PCHX. The condensate flows back to the steam generator.

To evaluate the local heat fluxes and the heat transfer coefficients, the temperatures of fluid and tube surface are measured at 11 points along the PCHX length as shown in Fig. 1(b). A total of 9 thermocouples are installed at each measurement point as shown in Fig. 1(c).

3. Input Model Description

Figure 2 shows the MARS-KS input model. In the MARS-KS model, the PCHX is modeled using the PIPE component with the 28 nodes. The angle of inclination of each node is determined in consideration of the tube shape. The steam-supply line and the condensate-return line are modeled using the time dependent volumes and the single volumes. The PCCT is modeled using the multi-dimensional component with one node in x coordinate direction (x1), 16 nodes in y coordinate direction (y1~y16), and 22 nodes in z coordinate direction (z1~z22). The steam discharge line is connected to the upper side of 1st-16th-22nd node. The heat structure component is used to model the heat transfer between the PCHX and the PCCT.

The TRACE input model has the same nodalization as the MARS-KS input model. The steam-supply line is modelled using the FILL component. The condensate-return and the steam discharge lines are modeled with the BREAK components. The PCCT is modeled with the 3-D vessel component with x(1)-y(16)-z(22) nodes.

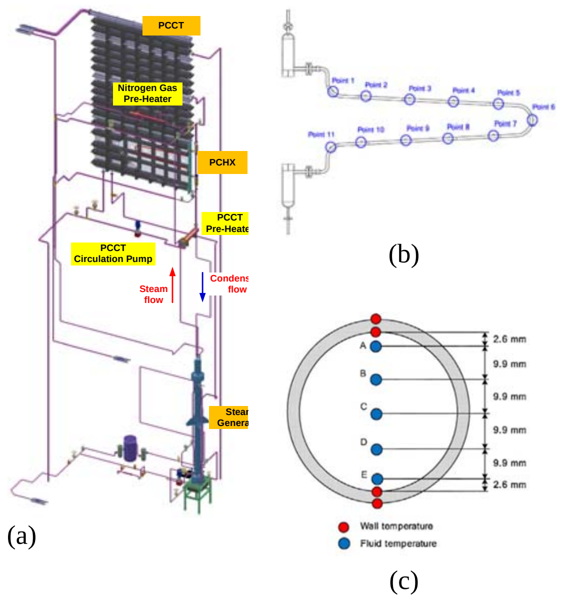

Fig. 1 Schematic of PASCAL Facility

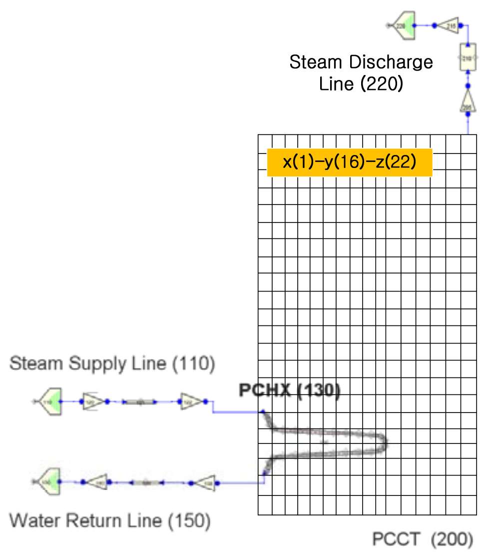

Fig. 2 MARS-KS model of PASCAL facility

The form loss coefficients at each junction of PCCT are determined by the sensitivity test so that the calculated temperature distribution of fluid in the PCCT is similar to the measured data. In both input models, the heat structure thermal properties and boundary conditions are the same.

4. Condensation Models

For the steam condensation without noncondensable gas at inclined surface, the MARS-KS uses the maximum of Nusselt (laminar) model and Shah (turbulent) model [4]. The TRACE uses the Kuhn-Schrock-Peterson empirical correlation (laminar) and modified Gnielinski's correlation (turbulent) [5].

5. Results and Discussion

The transient calculation were run for the SS-540-P1 test. The calculated values are taken at the quasi-steady state condition when the collapsed water level of PCCT reaches 9.3 m. The calculated results of heat flux, inner wall surface temperature, fluid temperature inside PCHX, and steam mass flow rate are compared with the experimental data. The measured values are extracted from Ref. [2].

5.1 Heat Flux

Figure 3 shows the calculated and measured distribution of heat flux at tube inner surface along the PCHX length.

In the experiment, the measured heat flux of the top region inside tube was larger than that of the bottom region. This is due to the fact that the top part of the tube is filled with the steam flow and the condensate flows in the bottom region. The distribution of heat flux at the upper half of PCHX was almost uniform, and the values gradually decreased at the lower half of PCHX along the tube length.

With the similar trend of inclination, the MARS-KS generally under-predicts the heat flux. The maximum difference is observed at the bent region in the middle (measurement point 6 in Fig. 1(b)). The TRACE, on the other hand, overestimates the heat flux at the upper half of PCHX and under-predicts it at the lower half of tube. The difference between the TRACE prediction and the data at the PCHX inlet region is about 30%. When compared with the MARS-KS results, the change rate of heat flux along the tube is relatively large.

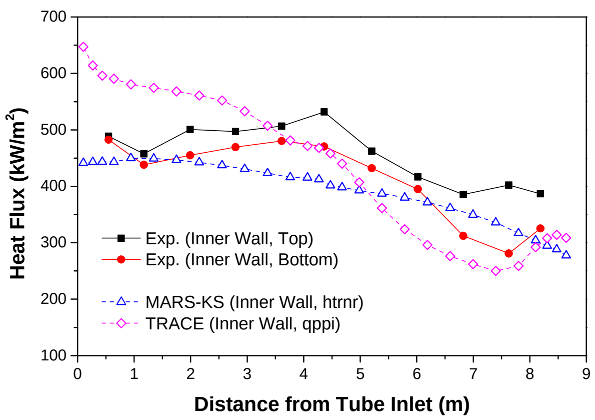

Fig. 3 Heat fluxes along the PCHX length

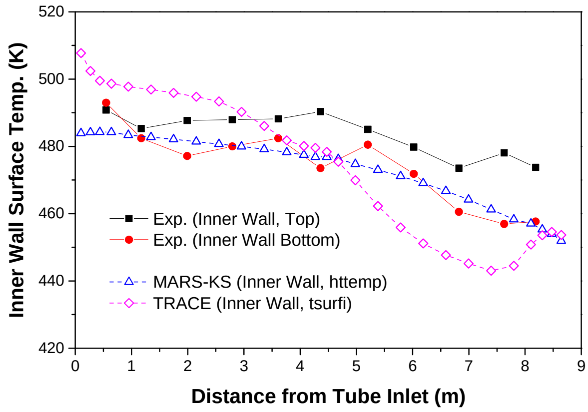

Fig. 4 Inner wall surface temperature along the PCHX length

5.2 Inner Wall Surface Temperature

Figure 4 shows the distribution of tube inner wall surface temperature. In the experiment, the trend of surface temperature distribution was similar to that of heat flux.

As expected from the temperature results, the MARS-KS does a good job of approximating the temperature distribution of inner surface with it being a little more close to the bottom side temperature. However, similar to the results of heat flux, the TRACE overestimates the inner wall surface temperature at the upper half of PCHX and under-predicts the temperature at the lower half of PCHX.

5.3 Fluid Temperature inside PCHX

Figure 5 shows the fluid temperatures at tube centre (measurement point C in Fig. 1(c)) and at the vicinity of tube bottom (measurement point E) along the PCHX length.

In the experiment, while the saturated temperatures were measured at the tube centre along the PCHX length, the subcooled temperatures were measured at the vicinity of tube bottom (measurement point E). Therefore a stratified flow appeared along the whole length of tube. As the steam flowed toward the outlet, the condensate temperature gradually decreased. The temperature of bottom region at the bent region in the middle (measurement point 6 in Fig. 1(b)) jumped to about saturated temperature probably due to the thermal mixing, and then the condensate temperature gradually decreased along the tube.

Both codes provide good estimate for the steam temperatures. For the condensate temperature, the

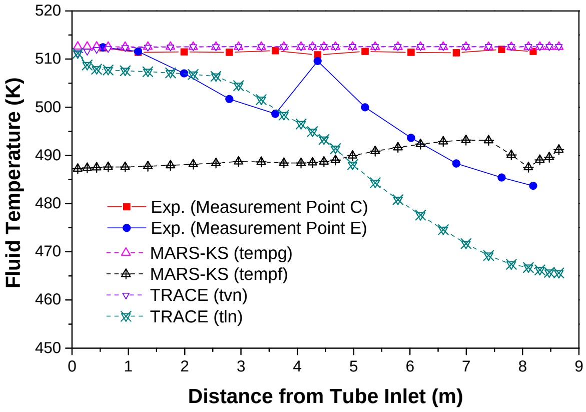

Fig. 5 Fluid temperature along the PCHX length

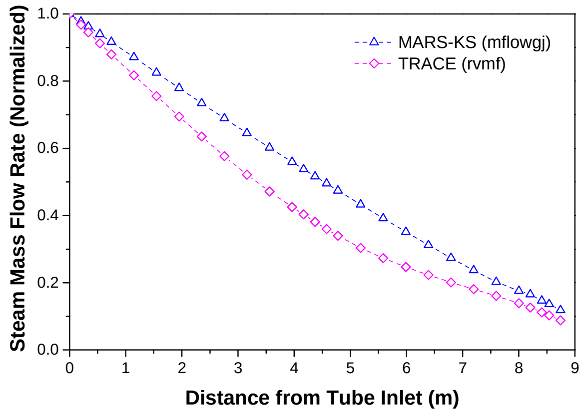

Fig. 6 Mass flow rate of steam along the PCHX length

TRACE provides reasonable temperature trend. However, the TRACE is incapable of reproduce the temperature jump at the bent region due to the fact that the one-dimensional system code does not simulate the thermal-mixing. The difference in condensate temperature between the TRACE prediction and the data at the lower part of PCHX is about 20K.

The MARS-KS result for the condensate temperature show the significant difference between the predicted values and data. The MARS-KS prediction shows very little difference in condensate temperatures throughout the PCHX, and fails to predict the decreasing condensate temperature along the tube length. It under-predicts the condensate temperature at the upper part of PCHX and over-predicts the temperature at the tube outlet region.

5.4 Condensation Rate

Figure 6 shows the MARS-KS and TRACE predictions for the mass flow rates of steam along the PCHX length. The values are normalized to the injection flow rate of steam. The TRACE prediction shows larger amount of steam condensation than the MARS-KS prediction. The MAES-KS shows that the steam flow rate is almost linearly decreased along the PCHX length. However, the TRACE results show that the condensate rate at the upper part of PCHX is larger than at the lower part of PCHX. While the TRACE result shows that about 91.2% of injected steam flow is condensed inside PCHX, the MARS-KS result shows about 88.2% of steam flow is condensed.

6. Conclusions

We simulated the KAERI PASCAL SS-540-P1 test with MARS-KS V1.4 and TRACE V5.0 p4 codes to assess the code predictability for the condensation heat transfer inside the passive auxiliary feedwater system. The calculated results of heat flux, inner wall surface temperature of the condensing tube, fluid temperature, and steam mass flow rate are compared with the experimental data. The result shows that the MARS-KS generally under-predict the heat fluxes. The TRACE over-predicts the heat flux at tube inlet region and under-predicts it at tube outlet region. The TRACE prediction shows larger amount of steam condensation by about 3% than the MARS-KS prediction.

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