MARS-KS Code Assessment for Condensation Heat Transfer in Horizontal Tube with the Presence of Non-Condensable Gas using Purdue Experiment

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1. Introduction

In South Korea, advanced power reactor plus (APR+), as a Korean specific reactor, is currently under development for the export strategy. In order to raise competitiveness of the APR+ in the world market, it is necessary to develop the original technology for the improved technology, economics, and safety features. For this purpose, a passive auxiliary feedwater system (PAFS) was adopted as an improved safety design concept of APR+; and then there have been many efforts to develop the PAFS.

According to PAFS design concept [1], PAFS can completely replace the auxiliary feedwater system. When the design basis accident, in which feedwater is unavailable, occurs, the PAFS can remove the residual heat in the core and then prevent the core damage.

In the PAFS with the horizontal type heat exchanger, two-phase natural circulation, condensation heat transfer in tube, boiling heat transfer in pool, natural convection in pool, etc. are considered as very important thermal-hydraulic phenomena (see Fig. 1). Compared with the vertical heat exchanger from these phenomena, the major difference of the horizontal heat exchanger is the condensation heat transfer phenomena in the tube side.

There have been many efforts to understand the condensation heat transfer with in the presence of NC gas in tube but most researches focused on the condensation heat transfer in vertical tube. Therefore the details of the condensation heat transfer in the presence of NC gas in horizontal condenser tubes are not well understood.

In order to develop the safety evaluation system for APR+ PAFS, it is required to evaluate the capability and applicability of the MARS-KS code for modeling the condensation heat transfer in the horizontal tube with NC gas because many heat transfer correlations in MARS-KS are known to have much uncertainty. In particular, there is no reliable model for the condensation phenomena in horizontal tube with NC gas. In order to assess the MARS-KS code results and identify the uncertainty bounds, the assessment of the model should be provided by comparison with experimental data.

In this study, the condensation experiment performed in Purdue University [2], which was selected as a first validation experiment, was simulated by using MARS-KS. By comparing MARS-KS predictions with the experimental data, the accuracy and applicability was investigated.

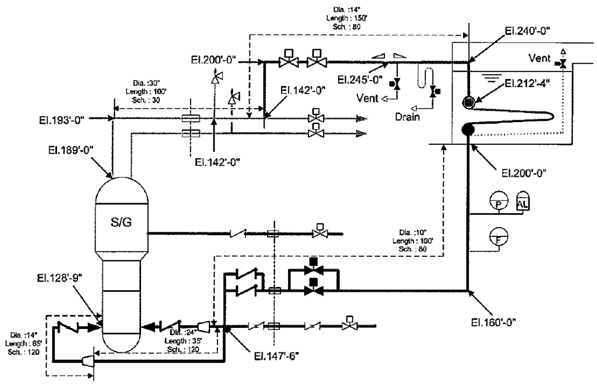

Fig. 1 Schematic of PAFS

2. Review of the Condensation Experiment in Purdue University

2.1 Condensation experiment

The condensation experiment performed in Purdue University was initially conducted to support the horizontal PCCS (Passive Containment Cooling System) design and was extended for general application to other horizontal heat exchangers. In the experiments, the local heat transfer coefficient profiles along the condenser tube were measured to provide a comprehensive database for the phenomena.

As shown in Fig. 2, the test facility is composed of the steam generator, the NC gas supply line, the coolant water supply, the test section, the condensate collection system, the associated piping and water storage tanks, the instrumentation and the data acquisition system. The steam/air mixture enters the condenser tube and steam is condensed by the coolant water flowing in the coolant annulus.

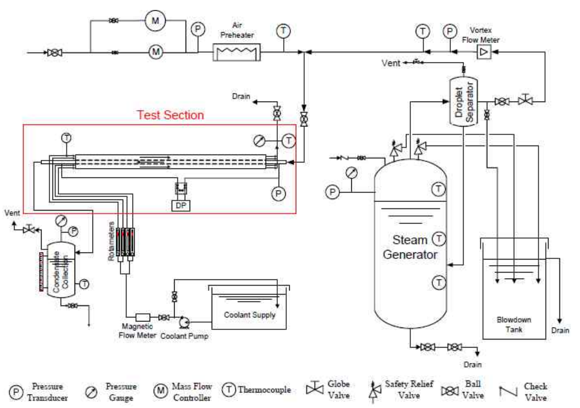

Fig. 2 Test Facility Layout of Purdue University Experiment

The test section is a double pipe, countercurrent flow, concentric-tube heat exchanger. The inner tube is the condenser tube and the secondary-side coolant water flows through the surrounding coolant annulus countercurrent to the primary fluid. The condenser tube is a 4.5 m long SS304 tube of 31.7 mm OD and 2.1 mm wall thickness with a heat transfer length of 3.0 m. The coolant annulus outer diameter is 63.5 mm.

The centerline, tube and coolant thermocouples were placed at 14 axial locations along the test section. The thermocouple locations at each of the 14 crosssections are shown in Fig. 3. Test condition is listed in Table I.

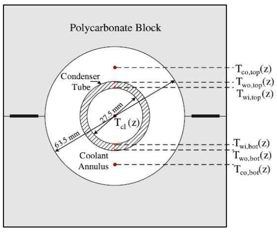

Fig. 3 Temperature Measurement Cross-section

Table I. Test conditions

Parameter	Range
Primary side pressure (MPa)	0.1, 0.2, 0.4
Steam inlet flow rate (g/s)	6.0 – 11.5
Steam/air mixture inlet velocity (m/s)	8.7-17.6
Noncondensable gas inlet mass fraction (%)	0 – 15
Secondary side pressure (MPa)	0.2
Secondary side coolant water flow rate (kg/s)	0.38, 0.76, 1.48
Secondary side coolant inlet temperature (°C)	14.0 – 18.0, 45.0

Figure 4 shows the temperature profiles along the test section for one of the tests. Using these data, local heat transfer coefficients were obtained as shown in Fig. 5.

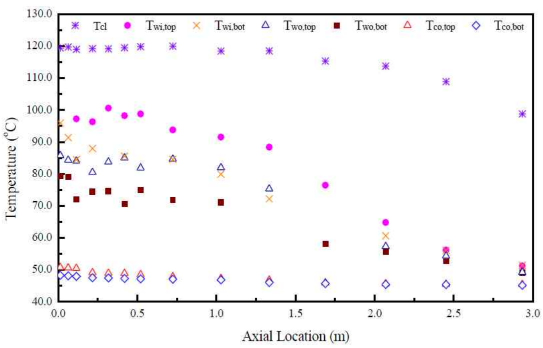

Fig. 4 Temperature Profile (Steam mass flow rate: 11.5 g/s, air mass fraction: 5 %, inlet pressure: 200 kPa, coolant water flow rate: 1.48 kg/s, coolant inlet temperature: 45 ℃)

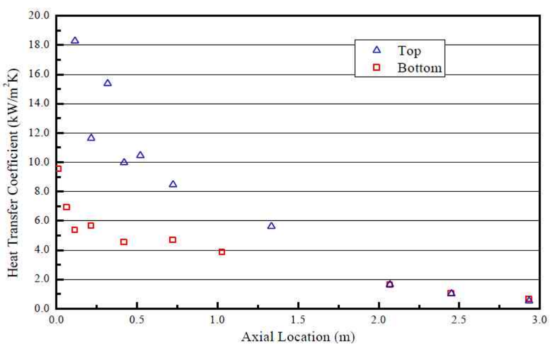

Fig. 5 Local Heat Transfer Coefficient Profile

2.2 RELAP5 Calculation for Condensation Experiment

In addition to the condensation experiment, Purdue University performs the RELAP5 calculation for the experiment. The test section nodalization is shown in Fig. 6. The heat transfer length is divided into 30 control volumes, the length of each control volume is 0.1 m. Inlet steam flow rate, inlet pressure, inlet air mass fraction, coolant flow rate, coolant inlet temperature are specified at the same value as in the experiment.

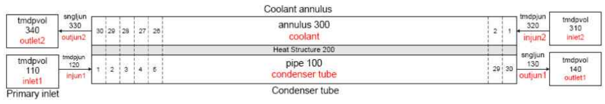

Fig. 6 Test Section Nodalization

As shown in Fig. 7, the experiment results corresponding to the test conditions in Fig. 4 are compared with RELAP5 predictions. The data compared are the local heat fluxes.

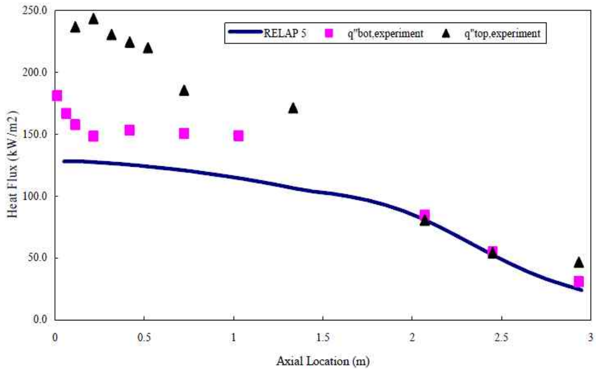

Fig. 7 Comparison of Experiment Result and RELAP5 Prediction for Heat Flux along the Axial Location

3. Future Work

In this paper, the condensation experiment and RELAP5 calculation for the condensation with the presence of NC gas in the horizontal tube performed in Purdue University were reviewed. In this study, the capability of the MARS-KS code for this experiment will be assessed. Unfortunately, all calculations were not completed. All results and important findings will be presented in the conference.

ACKNOWLEDGMENTS

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