MARS-KS Code Assessment for UCB-Kuhn Condensation Test

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1. Introduction

Since condensation plays a key role in heat transfer of many passive heat removal facilities such as SMART PRHRS and APR+ PAFS, its prediction is very important. It is well known that the condensation heat transfer is significantly reduced in the presence of non-condensable gas and this situation can occur in various design basis accidents of nuclear power plants. Therefore, there have been some efforts to calculate the local heat transfer coefficient of the condensation heat transfer with and without non-condensable gases by a thermal-hydraulic system codes such as RELAP and TRACE etc.

In this respect, the performance of MARS-KS (Multi-dimensional Analysis of Reactor Safety KINS Standard) code which has been developed for the realistic multi-dimensional system to estimate and evaluate the thermal hydraulic phenomena of nuclear power plants is assessed in the present study by simulating local condensing heat transfer experiments of UCB-Kuhn including non-condensable gas effect. For this, original and modified MARS-KS codes were used for calculations and the results were compared with tests in addition to those of TRACE code.

2. Calculation Model Description

In order to verify capability of the MARS-KS code including the modified MARS-KS code, condensation heat transfer experiments with and without non-condensable gas conducted by Kuhn et al. were modeled and simulated in the present study.

2.1 UCB-Kuhn Test Apparatus

The UCB-Kuhn test apparatus consists of the steam and gas supplies, condensing test section, condenser end section, cooling system and so on. Figure 1 shows the UCB-Kuhn condensing test section. The mixture of steam and non-condensable gases is directed downward through the inner tube (condenser section) and the cooling water passes through the outer pipe. The condensation of water occurs as heat is removed from the mixture through the condenser tube wall by an upward flow of the cooling water in the outlet annulus. The test section is cooled over a length of 241.8 cm.

2.2 Nodalization of MARS-KS

A nodalization diagram of the MARS-KS model for calculating the UCB-Kuhn condensation test section is shown in Fig. 1. It consists of two time dependent volumes (inlet and outlet), two pipes (one for test section and one for end section), and heat structure. The main pipe for test section is divided by 12 cells to model the condensing section of UCB test facility. The axial wall temperature distribution from the tests employed as the boundary condition on the outer surface of the heat structure component. The boundary condition for steam inlet flow rates and the mass fraction of the non-condensable gases applies to the pipe inlet and total of 6 tests were selected for MARS-KS verification and assessment, as given in Table 1.

2.3 Modification of MARS-KS code

For condensation wall-to-fluid heat transfer coefficient of vertical geometry, the original MARS-KS code uses Nusselt correlation for laminar flow, Shah correlation for turbulent flow and Colburn-Hougen diffusion method for non-condensable gas treatment [2]. These correlations were changed to Lee and Kim's [4] correlation in the modified MARS-KS code. The new heat transfer coefficient developed from degradation factor methodology with experimental data has the following forms

For pure steam:

$$\mathrm{h} = h_{Nu} \times 0.8247(\tau^*_{mix})^{0.3124}$$

For steam with non-condensable gas:

$$\mathrm{h} = h_{Nu} \times (1 - 0.9641W_{nc}^{0.402})(\tau^*_{mix})^{0.3124}$$

where h is heat transfer coefficient, h_{Nu} is heat transfer coefficient based on Nusselt theory, τ_{mix}^* is non-dimensional shear stress.

Table 1. Test Matrix for MARS-KS Assessment

Exp. Number	Pressure (bar)	Steam Inlet Flow (kg/h)	NC Inlet Mass Fraction (%)
1.1-1	1	60	pure steam
1.1-5	5	60	pure steam
2.1-9	4	60	20
3.2-4	4	60	5
3.4-3	3	60	20
4.3-2	2	30	10

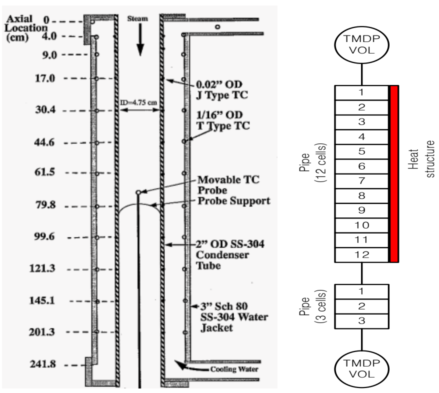

Fig. 1. UCB-Kuhn Test Section and Nodalization Diagram for MARS-KS code.

3. Simulation Results

Among total of 6 cases simulated by MARS-KS (Table 1), results of 2 cases are provided in this paper. Figure 2 and 3 show the heat flux on the condenser wall surface for experiment 1.1-1 and 3.4-3, respectively. The former has pure steam inlet and the latter has 20% of air mass fraction. As shown in the figures, the MARS-KS code shows large deviation from experimental data for both cases. The prediction always keeps lower value (i.e. less heat removal from the tube wall) than experimental data. This tendency can be identified for all other experiments other than 1.1-1 and 3.4-3 presented in this paper. Otherwise, prediction by the TRACE code represents more favorable results. Note that predictions made by the MARS-KS code and the modified MARS-KS code are the exactly same for the pure steam case experiment.

Figure 4 and 5 also show the simulated heat transfer coefficient for experiment 1.1-1 and 3.4-3, respectively. The predicted heat transfer coefficient using the MARS-KS code is fairly higher than experimental data. Similar to heat flux, prediction made by TRACE code also shows good agreement with experimental data.

Predictions made by the modified MARS-KS code for experiments with non-condensable gas are shown in the Fig. 3 and 5. The simulated heat flux from the modified MARS-KS code shows even larger deviation from experimental data than the original code. However, when calculating the heat transfer coefficient using the modified code, the relatively reliable estimation was obtain as shown in Fig. 5.

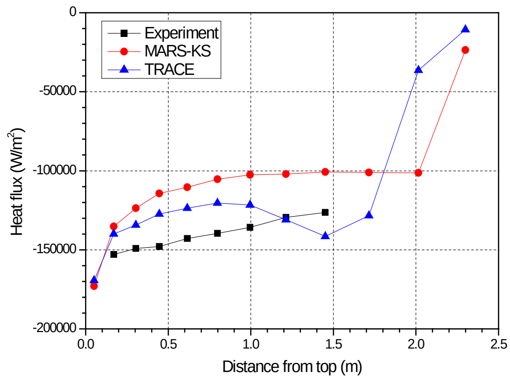

Fig. 2. Heat flux for Exp. 1.1-1 (NC=0%)

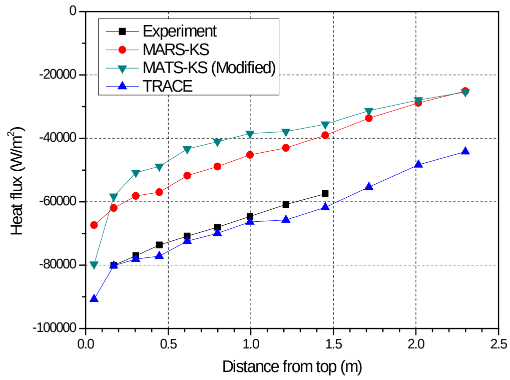

Fig. 3. Heat flux for Exp. 3.4-3 (NC=20%)

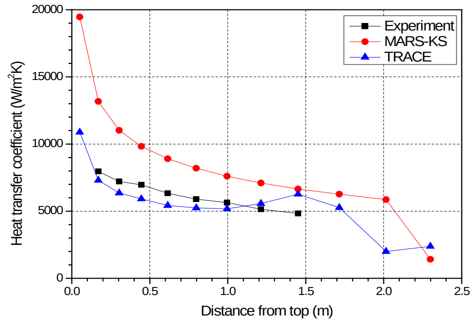

Fig. 4. Heat transfer coefficient for Exp. 1.1-1 (NC=0%)

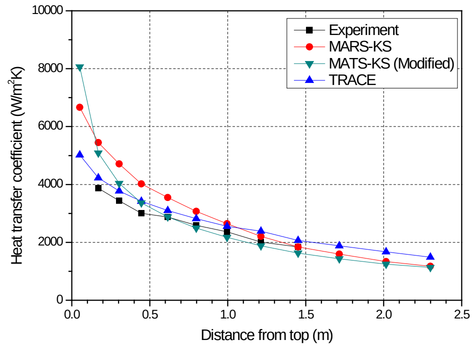

Fig. 5. Heat transfer coefficient for Exp. 3.4-3 (NC=20%)

4. Conclusion

The condensing heat transfer problem over the vertical wall was simulated by the MARS-KS code. The UCB-Kuhn test results were used to validate the calculation results from the MARS-KS code and the modified MARS-KS code. Simulated values from TRACE code were also used to compare the results.

The predicted heat flux over the condensing tube wall from the MARS-KS is fairly lower than experimental data. And the heat transfer coefficients from the MARS-KS are higher than those of tests. However, simulation data from the TRACE shows more favorable results. Furthermore, predictions made by the modified MARS-KS code show fairly improved behavior for estimating the heat transfer coefficient. In spite of this improvement, calculated heat flux over the wall by the modified MARS-KS code shows larger deviation than the original code. Therefore, MARS-KS code needs more development to improve its simulating ability for vertical wall condensing problem if it can have good prediction capability just like TRACE code.

REFERENCES

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