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Assessments of UCB-Kuhn Condensation Tests by Various Thermal-Hydraulic Codes

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1. Introduction

Recently, Korea Hydro & Nuclear Power (KHNP) submitted a topical report on "Safety and Performance Analysis CodE (SPACE) for nuclear power plants" [1] to Korea Institute of Nuclear Safety (KINS) and KINS is reviewing the topical report at present.

To validate and verify a new Thermal-Hydraulic (T-H) code such as SPACE, a lot of code calculations should be done with respect to a systematic validation and verification matrix which is composed of analytical problems or physical experiments related to various thermal-hydraulic phenomena. One of these T-H phenomena is condensation heat transfer with and without non-condensable gas.

To validate SPACE code ability for condensation heat transfer prediction, KHNP performed some calculations on UCB-Kuhn condensation experiment [2]. Originally, UCB-Kuhn condensation experiment was performed to quantify the reduction of condensation due to non-condensable gas by S. Z. Kuhn of the University of California at Berkeley in developing the simplified boiling water reactor. And this experiment has been referenced frequently as a representative experiment on condensation heat transfer with and without non-condensable gas.

However, KHNP only presents a comparison between SPACE code calculation and the experimental data in the topical report, therefore, it is very difficult to decide whether SPACE code performance is good or not. Therefore in the present study, various other T-H codes such as RELAP, MARS and TRACE calculations are made for the same UCB-Kuhn condensation tests which were solved by SPACE code and comparisons among various T-H codes results including SPACE are made to see if SPACE code is reasonable enough to predict the condensation heat transfer with and without non-condensable gas.

2. UCB-Kuhn Condensation Test Facility and Its Modeling for T-H Codes Calculations

2.1 UCB-Kuhn Condensation Test Facility

Figure 1 shows a schematic of condensation pipe with some dimensions which was used for UCB-Kuhn condensation test. Pure steam or mixture of steam and non-condensable gas are introduced from the above of the condensation pipe and are directed downward during test. Otherwise, coolant for cooling the condensation pipe is introduced from the bottom of the peripheral of the condensation pipe and is directed above. The total length of the condensation pipe is 2.418m long, the inner diameter of the condensation pipe is 0.0475m and the outer diameter is 0.0508m. The material of the condensation pipe is SS-304.

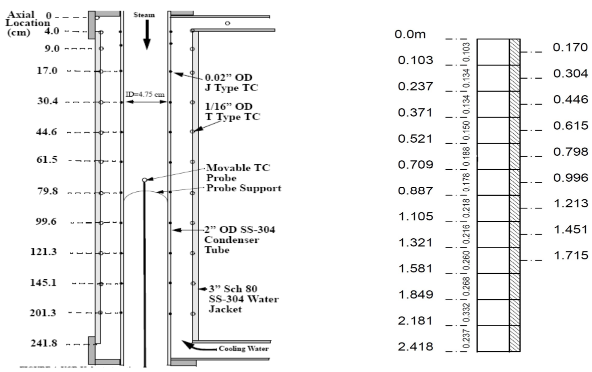

Fig. 1. Schematic of condensation pipe and axial dimensions for thermocouples of UCB-Kuhn condensation test.

Although a lot of tests had been done with this experimental facility, only two of them which were used for SPACE code validation are calculated in the present study. They are RUN 1.1-1 and RUN 4.3-3, respectively. RUN 1.1-1 test deals with pure steam condensation test. Otherwise, RUN 4.3-3 test deals with mixture of steam and non-condensable gas. The non-condensable considered in RUN 4.3-3 is air. Specific values of test conditions used for simulations of these two tests are given in Table I.

Table I: Test Conditions for Calculations

Test RUN Number	W_s (kg/hr)	W_g (kg/hr)	P_in (bar)	AMF (%)
RUN 1.1-1	60.2	0	1.139	0
RUN 4.3-3	31.3	3.2	2.798	9.3

Here, W_s and W_g represent mass flow rates of steam and non-condensable gas (in the present study, air), respectively, P_in represents pressure value at the inlet region of the condensation pipe and AMF is Air Mass Fraction, defined $W\_g/(W\_s+W\_g)\times 100$.

Figure 1 also shows various axial dimensions of the condensation pipe at which thermocouples are installed to measure temperature distribution along the pipe. To make a direct comparison between experimentally measured data and T-H codes calculations results possible, these axial locations (e.g. 0.170, 0.304, 0.446 etc.) are used as center points of each node of the condensation pipe in nodalizations for various T-H codes. Therefore all T-H codes including SPACE share a common nodalization structure for the condensation pipe.

2.2 Specific Nodaliztions for Various T-H Codes

Figure 2 shows various nodalizations employed for simulations of UCB-Kuhn condensation test by various T-H codes in the present study. A nodalization of Fig. 2(a) is used for RELAP and MARS codes calculations, Fig. 2(b) and 2(c) are two nodalizations tested for TRACE code. And Fig. 2(d) shows a nodalization adopted in SPACE code validation. As for TRACE code, a nodalization of Fig. 2(c) is used in the present study. This is because TRACE code was identified to need additional nodes for stabilization of calculations. [3] Without the introduction of some artificial nodes (in the present study, 3 nodes), TRACE code calculation based on Fig. 2(b) nodalization shows unusual prediction near the end of condensation pipe. It is interesting that SPACE code also employed this kind of artificial nodes in their nodalization. [See, Fig. 2(d)] Figure 3 shows that effect of introduction of these artificial nodes in TRACE calculation is pretty large in terms of wall heat flux.

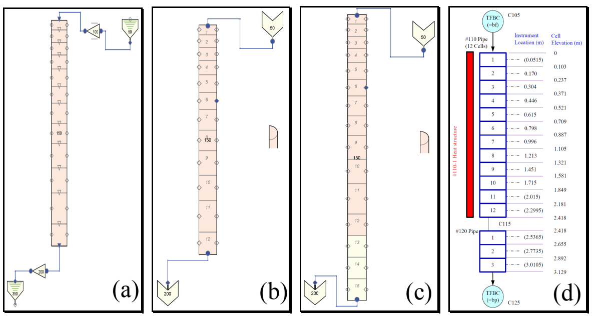

Fig. 2. Nodalizations for various T-H codes calculations.

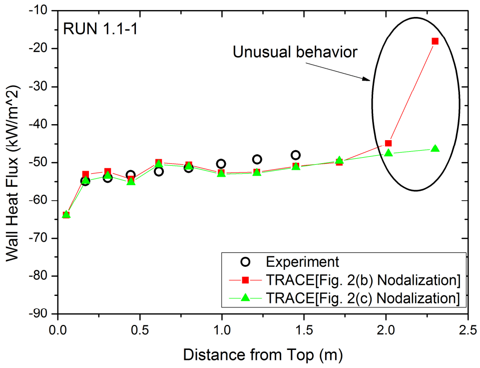

Fig. 3. Nodalization Dependency of TRACE Calculations.

3. Calculations of UCB-Kuhn Condensation Tests

3.1 Boundary Conditions for Calculations

Table II shows measured outer wall temperatures distributions along the condensation tube for RUN 1.1-1 and RUN 4.3-3 tests. Here, outer wall temperatures mean that these values were measured at the radially outmost position of the condensation pipe wall. One can verify this fact through Fig. 4.[4] Since these specific outer wall temperatures of the condensation pipe were given, they are used as specified temperature boundary condition of heat structures(i.e. the condenser pipe wall) for all T-H codes calculations.

Table II: Measured Outer Wall Temperatures Distributions for RUN 1.1-1 and RUN 4.3-3.

Node Number	Distance from Top(m)	RUN 1.1-1 T_wall(K)	RUN 4.3-3 T_wall(K)
1	0.0515	366.15	371.65
2	0.170	366.15	371.65
3	0.304	365.45	369.15
4	0.446	364.25	365.85
5	0.615	364.45	364.15
6	0.798	363.75	360.45
7	0.996	362.55	357.05
8	1.213	362.05	352.25
9	1.451	361.85	348.05
10	1.715	361.85	348.05
11	2.015	361.85	348.05
12	2.2995	361.85	348.05

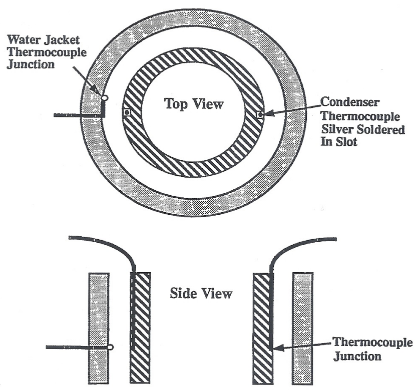

Fig. 4. UCB-Kuhn thermocouple attachment.

Constant mass flow rates of 60.2kg/hr for pure steam case (RUN 1.1-1) and 34.5kg/hr for steam-air mixture case (RUN 4.3-3) can be also considered specific boundary conditions when T-H codes calculations are made.

However, for TRACE code, a special care was required to implement this inflow boundary condition.

For TRACE code, application of "Fill" component with constant mass flow rate type to the inflow boundary condition generates unusual behavior of calculation results at the entrance region of the condensation pipe. Therefore, "Fill" component with constant generalized state type was used as the inflow boundary condition to eliminate this unusual behavior. Therefore, in the present study, specific vapor velocities of 15.5m/sec and 3.4m/sec were used to define "Fill" component with constant generalized state for RUN 1.1-1 and RUN 4.3-3 tests calculations, respectively.

3.2 Calculation Results of various T-H codes

Based on previously developed nodalizations and boundary conditions, code specific calculations for RUN 1.1-1 and RUN 4.3-3 tests were made. Each T-H code versions employed in the present study are as follows. For RELAP, RELAP5/Mod3.3patch4 is used. For TRACE, TRACEV5.0patch4 is used with falling film condensation option for the condensation pipe is activated. MARS KS1.3(subversion79) is used for MARS. As for SPACE, SPACE 2.14 version was used for its validation.

Figure 5 through 8 show some important physical properties of condensation heat transfer calculation for RUN 1.1-1. And Figure 9 through 12 show same things for RUN 4.3-3. For experimental data such as wall heat flux and heat transfer coefficient, error bars are also displayed in the corresponding figures. Average relative uncertainties for wall heat flux and heat transfer coefficient are ±10.4% and ±18.7%, respectively [4].

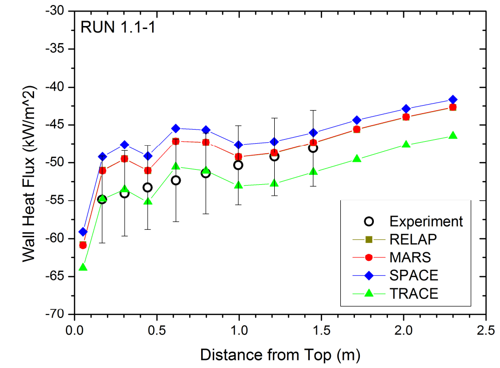

Fig. 5. Comparisons of Wall Heat Flux for RUN 1.1-1.

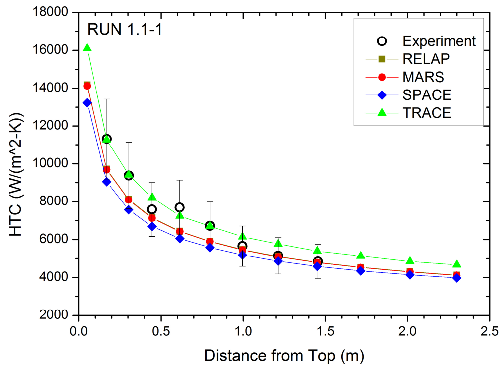

Fig. 6. Comparisons of Heat Transfer Coefficient for RUN 1.1-1.

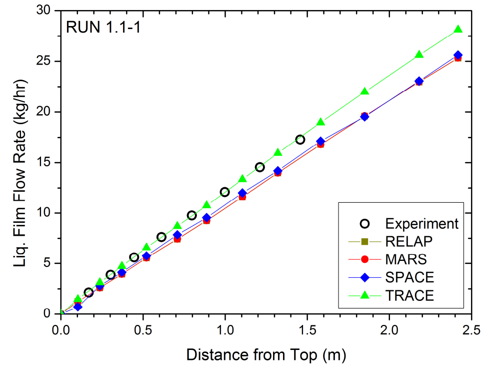

Fig. 7. Comparisons of Liquid Film Flow Rate for RUN 1.1-1.

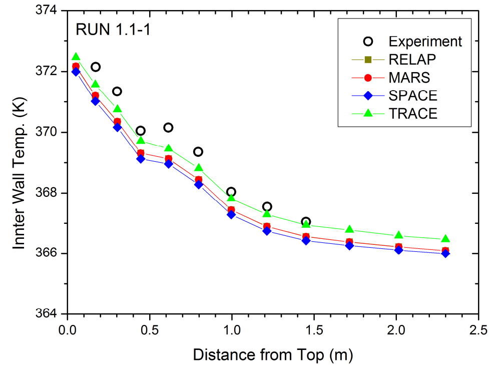

Fig. 8. Comparisons of Inner Wall Temperature for RUN 1.1-1.

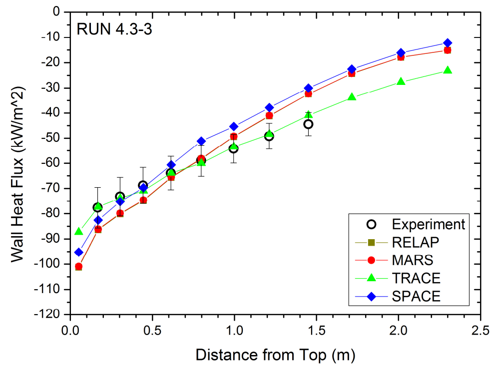

Fig. 9. Comparisons of Wall Heat Flux for RUN 4.3-3.

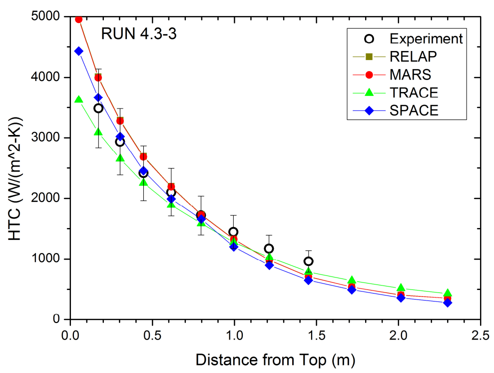

Fig. 10. Comparisons of Heat Transfer Coefficient for RUN 4.3-3.

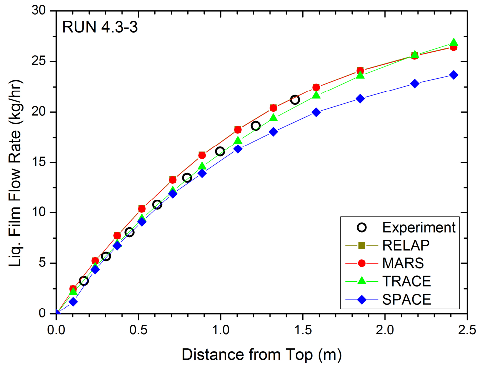

Fig. 11. Comparisons of Liquid Film Flow Rate for RUN 4.3-3.

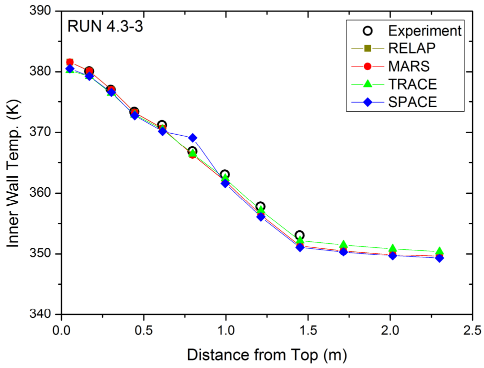

Fig. 12. Comparisons of Inner Wall Temperature for RUN 4.3-3.

Most figures show that agreements between T-H codes calculations results and experimental data are reasonably good. Especially, TRACE code simulation result gives an excellent agreement with experimental data although some special cares were needed for best prediction. Calculation results by RELAP and MARS codes show quite similar behaviors among each other and agreements with experimental data are reasonable enough although they are not as good as TRACE. However, SPACE code shows relatively poor prediction capability compared to other T-H codes although overall prediction capability for the condensation heat transfer is not so bad. Furthermore, for SPACE code, one can also identify something to be justified. They are as follows.

1) Calculation result of inner wall temperatures distribution for RUN 4.3-3 (See, Fig. 12) shows an artificial bump of temperature at 0.798m. Considering smooth temperature distributions of outer wall are used as boundary condition of calculation, this is a quite strange behavior.
2) Liquid Film Flow Rate for RUN 4.3-3 (See, Fig. 11) predicted by SPACE code is quite less than predictions by other T-H codes.
3) In its nodalization, SPACE code introduces an artificial nodes. (See, Fig. 2)

4. Conclusions

Simulations for UCB-Kuhn condensation tests (RUN 1.1-1 for pure steam test and RUN 4.3-3 for mixture of steam-air test) were performed by various T-H codes such as RELAP, MARS and TRACE and their results were compared to experimental data and SPACE code calculation result given in the topical report for SPACE.

Most of T-H codes results including that of SPACE show much similarity among them and they also show reasonable agreement with the experimental data, respectively. However, SPACE code predictability is not as good as the other T-H codes. TRACE code shows excellent prediction capability for this condensation experiment and RELAP and MARS codes shows prediction capability between TRACE and SPACE. As for SPACE, something to be justified are identified.

REFERENCES

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