TRACE5-patch01 Assessment of POSTECH Local Condensation Experiment

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1. INTRODUCTION

The TRACE[1] code is a thermal-hydraulic system code, introduced from United States Nuclear Regulatory Commission (USNRC), through international cooperative research program Code Application and Maintenance Program (CAMP). Korea Institute of Nuclear Safety (KINS) has performed TRACE assessments since 2004, as a part of thermal-hydraulic research.

In order to evaluate the design of a PRHRS[2] condensation heat exchanger designed for SMART (System-integrated Modular Advanced ReacTor), the experimental and theoretical study had been performed by investigating its heat transfer characteristics. Although the PRHRS operates at 3.5MPa in real situations, the experimental data were obtained at atmospheric pressure, i.e., 0.1MPa.

The main objective of this study was to assess TRACE5 code using the PRHRS condensation heat exchanger experimental data, and compare the results of TRACE5 film condensation correlation to that of Lee-Kim's correlation.

2. BACKGROUND

The TRAC/RELAP Advanced Computational Engine (TRACE - formerly called TRAC-M) is the latest in a series of advanced, best-estimate reactor systems codes developed by the U.S. Nuclear Regulatory Commission for analyzing transient and steady-state neutronic-thermal-hydraulic behavior in light water reactors. It is the product of a long term effort to combine the capabilities of the NRC's four main systems codes (TRAC-P, TRAC-B, RELAP5 and RAMONA) into one modernized computational tool. TRACE Version 5.0 represents the initial release of this analysis code.

<u>*Condensation Model in TRACE[1]*</u>

Condensation model in TRACE was consisted of major two sets of correlations. First, for laminar flow, Kuhn-Schrock-Peterson empirical correlation is used, as eq.(1) ;

$$Nu_{cond} = 1 + 1.83 \times 10^{-4} \bullet \mathrm{Re}_f \qquad (1)$$

where, Nu_{cond} is Nussult number for condensation, and Re_f is film Reynolds number.

For turbulence, Gnielinski correlation (eq.(2)) is used ;

$$Nu_{turb} = \frac{(f/2)(\mathrm{Re}_f - 1000) \bullet \mathrm{Pr}}{1 + 12.7 \bullet (f/2)^{1/2}(\mathrm{Pr}^{2/3} - 1)} \qquad (2)$$

where, $f = \left[1.58 \bullet \ln(\mathrm{Re}_f) - 3.28\right]^{-2}$, and this correlation is valid for $2300 \le \mathrm{Re}_f \le 5 \times 10^6$ and $0.5 \le \mathrm{Pr} \le 2000$.

This Kuhn correlation was replaced with Lee and Kim correlation[3] and the two results are compared.

<u>*Experiment Description[3]*</u>

A schematic of the experimental apparatus is shown in figure 1. The experimental facilities consisted of a steam generator, steam flow rate control system, steam/nitrogen gas mixing system, test section, and data acquisition system. Test conditions were shown in table 1.

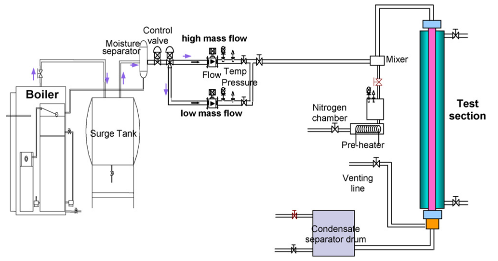


Figure 1. Schematic Drawing for Experiment

Table 1. Previous steam condensation experiments in a vertical tube with noncondensable gas [3]

	Vierow and Schrock (1991)	Siddique et al. (1993)	Araki (1995)	Kuhn et al.(1997)	Park and No (1999)	Kim (2000)	Oh and Revankar (2005)	Lee and Kim (2006)
Tube len.(m)	2.1	2.54	2	2.4	2.4	1.8	0.984	2.8
Tube ID (mm)	22	46	49.5	47.5	47.5	46.2	26.6	13
Thickness(mm)	1.65	2.4	5.5	1.65	1.65	2.3	3.38	2.5
Jacket ID (mm)	50.8	62.7	159.2	76.2	100	-	-	40
N.C. gas	Air	Air/He	Air	Air/He	Air	Air	Air	N_2
Secondary cooling	Forced convection	Pool boiling	Pool boiling	Forced convection				
Steam flow(kg/h)	5.9-24.95	7.9-31.9	9.0-58.0	28.3-61.9	7.6-40.0	-	9.0-19.8	6.5-28.2
Inlet NCG mass frac. (%)	0-14	10-35	0-24	0-40	10-40	0-30	0-10	0-40
Pressure (MPa)	0.03-0.45	0.1-0.5	0.15-0.25	0.1-0.5	0.17-0.5	0.3-7.5	0.1-0.4	0.1-0.13
HTC (W/m^2K)	0-16,000	100-25,000	-	500-13,000	100-7,000	4,000-7,400	3,500-6,500	300-27,900

3. CODE MODEL

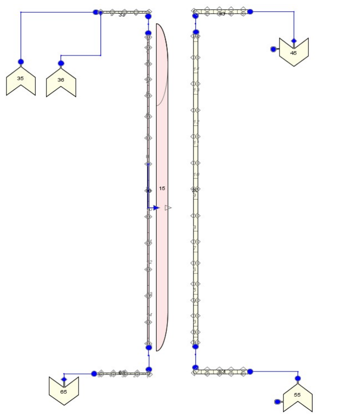


Figure 2. TRACE Nodalisation

The test section and cooling jacket were divided into 15. Inlet boundary condition was set as mass flowrate boundary condition and Outlet boundary condition did as pressure boundary. The schematic nodalization was shown in Fig.2. As boundary conditions, the inlet/outlet was modeled by FILL/ BREAK component. In order to focusing on condensation phenomena inside condenser tube, the cooling channel side boundary conditions of heat structure were modeled as constant temperature conditions.

4. ASSESSMENT RESULTS

In this paper, five cases were analyzed as shown in Table 2. The selection criteria were total and each component mass fluxes. MB11 had smallest mass flux and MB82 has largest.

Table 2. Analyzed Experiment Cases

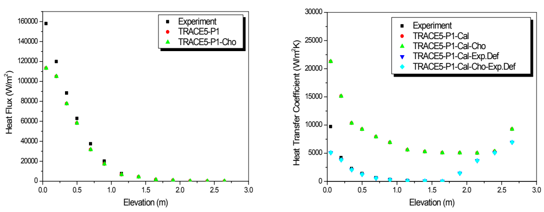
Experiment I.D	Inlet Flow (Steam/ NCG) (kg/hr)	Pressure (In/Out) (kPa)	Inlet Temperature (^oC)
MB11	6.53/0.23	103.21/103.75	99,91
MB25	8.53/5.72	116.72/117.76	93.97
MB42	13.75/1.56	105.48/106.38	98.93
MB81	28.139/0.8775	116.27/ 115.60	102.76
MB82	26.86/3.20	132.17/130.51	105.10

In these experiments, the mixture fluid entered and instantaneously liquid film is covered on the condenser tube inside. After the condenser tube inside is covered by liquid film, all heat transfer occurred between liquid film surface and steam. Therefore, liquid film interface area is one of the important parameter for this experiment.

In figures, the elevation was measured from condenser tube entrance and in real, the entrance elevation is 3.0m and outlet is 0.0m. But for convenience, entrance elevation is set to 0.0m, and outlet is 3.0m.

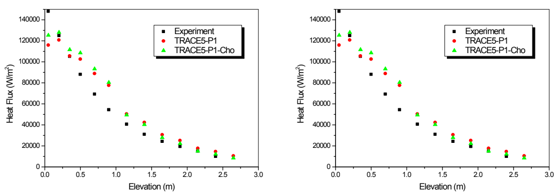
The MB11 case is characterized by small steam flow and small nitrogen flow. In this case, Heat flux and heat transfer coefficient were predicted well by TRACE5 except the first point from test section entrance. In figure 3, calculated heat flux result shows good agreement and the calculated HTCs show different behavior. One of the HTCs, which was calculated based on $(T_{wall,i}\text{-}T_{gas})$, shows good agreement with experimental results. This means that the measured bulk temperatures in experiment are almost same as gas temperature. The other HTCs have very different values.

The MB25 case shows almost same behavior with experiments.



a) Heat Flux b) Heat Transfer Coefficient

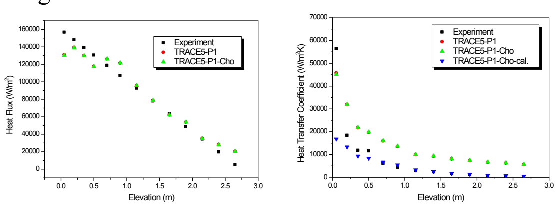
Figure 3. MB11 Results



a) Heat Flux b) Heat Transfer Coefficient

Figure 4. MB-25 Results

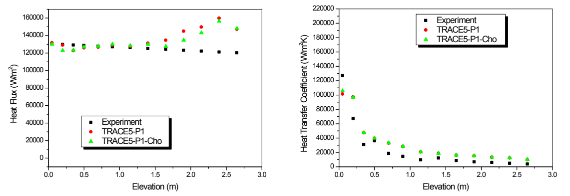
The results of MB42 were shown in figure 5 and the results have same characteristics with MB25. The calculated heat flux shows good agreement with experiment and the HTCs are predicted well by TRACE5 after 1.0m. This may be regarded as entrance effects.



a) Heat Flux b) Heat Transfer Coefficient

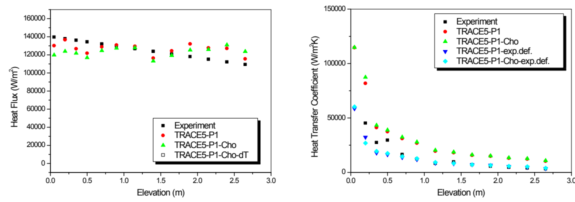
Figure 5. MB-42 Results

In MB81 and MB82, almost same behaviors are shown in figure 6, and 7. The calculated heat flux shows slightly lower than that of experiment and calculated HTCs are almost same.



a) Heat Flux b) Heat Transfer Coefficient

Figure 6. MB-81 Results



a) Heat Flux b) Heat Transfer Coefficient

Figure 7. MB-82 Results

For the modified TRACE5 results, the significant differences were not observed.

5. CONCLUDING REMARKS

The TRACE5-patch01 condensation model was assessed against the POSTECH local condensation heat transfer experiment. Two correlations, Kuhn and Lee-Kim were used to predict the heat flux and HTC in the experiments.

The calculated results showed that both correlations in TRACE5-patch01, although they have been developed from the conditions different each other, give good predictions of the heat flux and the HTC.

These results provide a justification of TRACE5 film condensation logics, which can be used to develop a single correlation applicable to laminar and turbulent flow.

Acknowledgments

This work was supported by Nuclear Research & Development Program of the National Research Foundation (NRF) grant funded by the Korean government (MEST).

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[2] Lee, K.Y, and Kim, M.W., “Experimental and empirical study of steam condensation heat transfer with a noncondensable gas in a small-diameter vertical tube,” Nuclear Engineering and Design, 238 207–216, (2008)

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