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Assessment of RELAP5/MOD3 with Condensation Experiment for Pure Steam Condensation in a Vercal Tube

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Abstract

The film condensation models in RELAP5/MOD3.1 and RELAP5/MOD3.2 are assessed with the data of experiment performed in the scaled down condensation experimental facility with a single vertical tube of inner diameter of 46 mm in the range of pressure 0.1 ~ 7.5 MPa for the PSCS(Passive Secondary Condenser System). Both MOD3.1 and MOD3.2 don't shows any reliable predictions of the experimental data. The RELAP5/MOD3.1 overpredicts the heat transfer coefficients of experiment, whereas the RELAP5/MOD3.2 underpredicts those data. It is recommended that the film condensation model in RELAP5/MOD3.2 should be modified to have a larger heat transfer coefficient than those of the present model to give the reliable predictions.

1. Introduction

Passive reactors, such as CP-1300(CARR PASSIVE-1300MWe), are characterised by the simplification in the design and by the presence of passive systems. CP-1300 has many passive systems, such as PSCS(Passive Secondary Condenser System) for the decay heat removal in the secondary loop, PCCS(Passive Containment Cooling System) for the cooling of the containment[1]. The PSCS is composed of vertical tube-and-shell type heat exchangers residing in a pool located outside the containment. The steam supplied from the main steam line is condensed in the condenser tube of the PSCS and returned to the condensate line as a condensate by gravity.

The condensation rate in a vertical condenser is a key parameter in the performance anlysis of PSCS by RELAP5/MOD3 thermal hydraulic code and the exact estimation of condensation heat transfer rate in the secondary condenser tube shoud be performed before the design of PSCS. For the evaluation of the performance of PSCS, the RELAP5/MOD3 thermal hydraulic code is used. It is known that the RELAP5/MOD3 Code has much uncertainties in the modeling the condensation phenomena[3]. Recently, the modified film condensation heat transfer model is used in the RELAP5/MOD3.2. The film condensation heat transfer model in the RELAP5/MOD3.1 and the RELAP5/MOD3.2 are assessed with the data of experiment performed in the range of pressure, 0.1 ~ 7.5

MPa.

2. Previous Works

The key physical phenomena in the PSCS is the condensation inside a vertical tube and the pool boiling outside the tube. In this work, the film condensation heat transfer model in the RELAP5 code are only assessed. For the film condensation heat transfer, many analytical and experimental studies were done for the various flow conditions which include the laminar and turbulent film condensation in a vertical and horizontal geometries[3].

Form the previous works, it should be known that the key parameters in the film condensation is Nusselt number (Nu), film Reynolds number (Re_f), Prandtl number ($\Pr_f$) and nondimensional shear stress (τ_i^*). Therefore, many correlations composed of those numbers, such as the Nusselt correlation and the Chen correlation, are proposed in the film condensation heat transfer in a vertical plate wall[3]. On the other hand, the two-phase annular flow correlation, such as the Shah correlation[4] which extended the single phase annular flow model to the two-phase region, is used in RELAP5/MOD3.2.

In the RELAP5/MOD3.1, the Nusselt correlation with the turbulent enhance factor (f_1) is adopted in the film condensation because the Nusselt correlation generally shows the smaller value of the heat transfer coefficient[3]. The film condensation heat transfer coefficient (h_c) used in the RELAP5/MOD3.1 as follows[2];

$$h_c = f_1 h_{nss}, \tag{1}$$

$$\text{where,} \quad h_{nss} = 0.943\left[\frac{\rho_f(\rho_f-\rho_g)g i_{fg} k_f^3}{\mu_f L_c (T_s - T_w)}\right]^{\frac{1}{4}}, \tag{2}$$

$$f_1 = \min[2, 1+2.88\times 10^{-5} Re_g^{1.18}]. \tag{3}$$

However, the maximun heat transfer coefficient of the Nusselt and the Shah model is used in RELAP5/MOD3.2 as the film condensation heat transfer coefficient as follows[2];

$$h_c = \max(h_{nss}, h_{shah}) \tag{4}$$

$$\text{where,} \quad h_{nss} = \frac{k_f}{\delta} = \frac{k_f}{0.9086\left[\frac{\mu_f^2 Re_f}{g\rho_f \Delta\rho}\right]^{\frac{1}{3}}} \tag{5}$$

$$\text{and} \quad h_{shah} = h_{dittus}(1.0-x)^{0.8}\left(1+\frac{3.8}{Z^{0.95}}\right), \tag{6}$$

$$Z = (p/p_{crit})^{0.4}(1/x-1.0)^{0.8}, \tag{7}$$

$$h_{dittus} = 0.023\ k_f Re^{0.8} \Pr^{0.4}/D. \tag{8}$$

Also, Kim et al.[5] showed the RELAP5/MOD3.1 has a node effect(as the node size decrease, the heat transfer coefficients calculated by the code increase) in the simulation of the condensation heat transfer because the film condensation heat transfer coefficient include local condensation length(L_c). Therefore, in the RELAP5/MOD3.2, the heat transfer coefficients are calculated from the liquid film Reynolds number(Re_f) to remove the node effect and the Shah[4] correlation is adopted for the better estimation of the turbulent condensation heat transfer.

3. Pure Steam Condensation Experiment in a vertical tube

For the validation of the performance of PSCS, the small scale experiment is performed. The experimental facility is designed with the maximum pressure of 7.5 MPa and the temperature of 300 ℃. The main components of experimental facility is the steam generator which supply the steam with the maximum capacity of 200 kWe, the condenser tube with the outer diameter of 50.8 and the length of 1.8 m, and other auxiliary equipments such as temperature and pressure sensors, the data acquisition system and the control system[6].

The local temperatures of condenser tube wall are measured to find the heat removal rate of the PSCS tube as shown in figure 1.

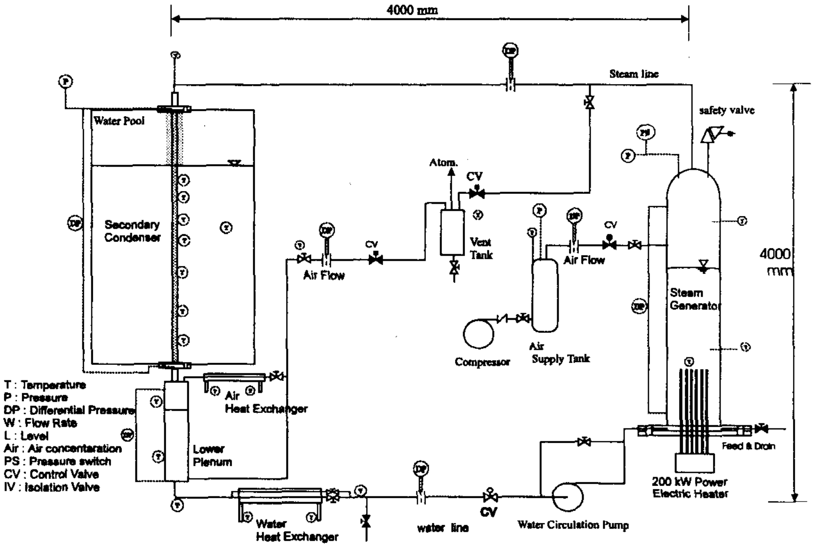

Figure 1 Schematic diagram of the KAIST Secondary Condenser experimental facility

The local temperatures, the heat fluxes, and the heat transfer coefficients of tube are used for the assessment of the RELAP5/MOD3 code in the range shown in Table 1.

Table 1. The range of experimental parameters

Unit	Pressure (MPa)	Re_f -	h (W/m^2K)	Pr_f -	Nu -	tube diamter (ID)	tube length
Minimum	0.1	100	30	0.83	0.05	46 mm	1.8 m
Maximum	7.5	17,000	20,000	1.55	0.2		

The measurement errors of temperature and heat transfer coefficient are 20% and 25.4 %, respectively.

4. Results and Discussion

Nodalization of experimental facility is performed to compare the results of experimental results with the simulation results of the RELAP5 code as shown in figure 2.

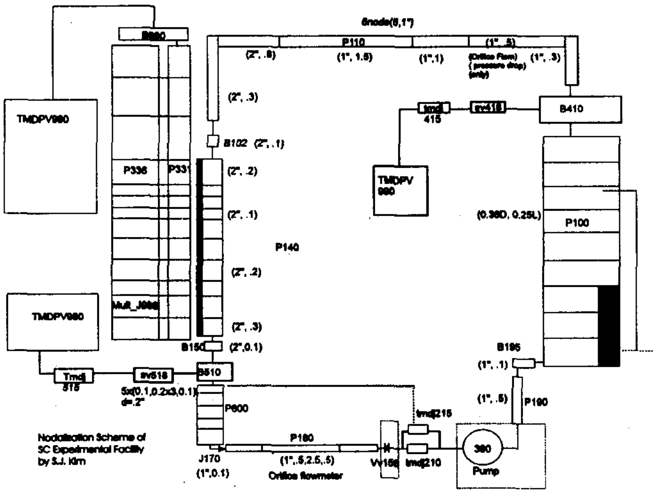

Figure 2 Nodalization scheme of the condensation experimental facility

The heat fluxes calculated in the RELAP5/MOD3.1 are greater than those of the experiment as shown in figure 3 and the temperatures of tube wall are overestimated than those of the experiment in figure 4. It should be noted that the RELAP5/MOD3.1 is not applicable for the simulation of the PSCS due to the node effect.

The RELAP5/MOD3.2 shows the lower value of heat fluxes than those of the experiment[figure4]. For the local temperatures of tube wall, only the inner wall temperatures calculated by the RELAP5/MOD3.2 slightly underpredict those of the experiment due to the lower estimation of the film condensation heat transfer coefficients as shown in figure 5.

From the comparison of the simulation results with the experimental data, it is found that both RELAP5/MOD3.1 and RELAP5/MOD3.2 are not well applicable to the modeling

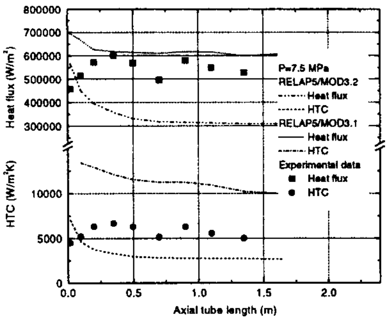

Figure 3 Comparison of measured local heat fluxs with the calculated heat flux by RELAP5/ MOD3 (P=7.5 MPa)

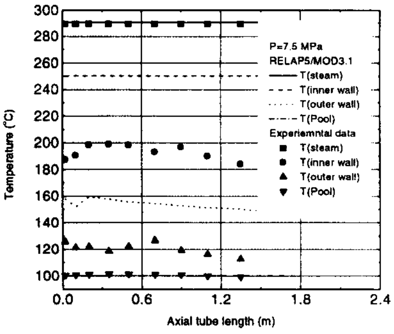

Figure 4 Comparison of the experimental temperature profile with the temperature profiles calculated by RELAP5/MOD3.1 (P=7.5 MPa)

of PSCS. The condensation model of RELAP5/MOD3.2 should be modified to give a reliable prediction of the experimental data. Figure 6 shows the comparison of Nusselt and Park[7]'s model with the experimental results. As Nusselt model underpredict the HTCs in the turbulent region where the liquid film Reynolds number (Re_f) is greater than 2400. The turbulent film condensation model of Park[7] is compared with the experimental data and shows good agreements with the experimental results in the region of higher Reynolds number(figure 6).

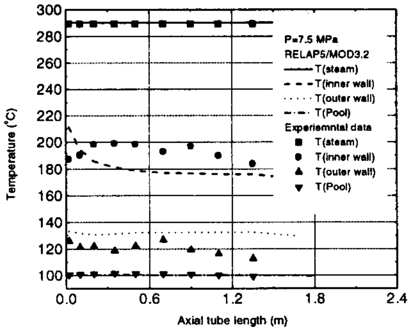

Figure 5 Comparison of the experiment al temperature profiles with the temper ature profiles calculated by RELAP5/M OD3.2 (P=7.5 MPa)

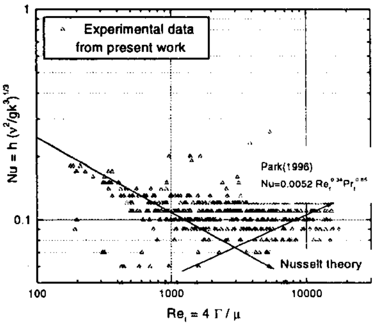

Figure 6 Comparison of film condensation correlations with the experimental data

5. Conclusions and Recommendations

The RELAP5/MOD3.1 overpredicts the present experimental data, whereas the RELAP5/MOD3.2 underpredicts the experimental results. It is due to the different scheme of film condensation models between RELAP5/MOD3.1 and RELAP5/MOD3.2. Neither of the RELAP5/MOD3.1 and RELAP5/MOD3.2 can't shows reliable prediction of the experimental data. Therefore, the condensation model in the REALP5 code should be modified to give a reliable predictions and assessed with much more experimental data.

References

[1] Chang, S. H. and NO, H. C., Baek, W. P., Lee, S. I., and Lee, S. W., "Conceptual design of CARR Passive PWR 1300 MWe(CP-1300), Nucl. Eng. Int. pp.12-16, Feb, (1997)

[2] Ransom, V. H. et al., "RELAP5/MOD3 Code Manual V.2," NUREG/CR-5535, INEL-95/0174, (1995)

[3] NO, H. C., Choi, K. Y., Park, H. S., and Kim, S. J. , "Assessment and improvement of condensation model in RELAP5/MOD3," KINS/HR-176, (1996)

[4] Shah, M. M., "A general correlation for heat transfer during film condensation inside pipes,"Int. J. Heat Mass Transfer, V.22, pp.547-556, (1979)

[5] Kim, H. T. and NO, H. C., "Modification of condensation heat transfer of RELAP5/MOD3.1 for the simulation of secondary condenser," Nuclear Technology, V.119, pp.98-104, (1997)

[6] NO, H. C. et al., "Development of technology for the evaluation of the secondary condensation system performance and the evaluation of thermal-hydraulic design of nuclar auxiliary cooling system - 2nd mid-term" KEPRI Report, (1998)

[7] Park, S. K. and Kim, M. H., "Effects of wavy interface on film condensation of steam/air mixture on vertical surface," Ph.D. Thesis, Pohang University of Science and Technology, (1992)