Evaluation of the Heat Removal Performance of the Passive Containment cooling System using MARS-KS with an Empirical Condensation Correlation

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1. Introduction

The Passive Containment Cooling System (PCCS) that will be introduced in the next generation Korean nuclear power plant to guarantee the safety of the nuclear power to utilize the condensation heat transfer phenomenon. The condensation heat transfer phenomenon plays a key role in the event of the loss of coolant accident (LOCA) or main steam line break (MSLB) in suppressing the pressurization of the containment. Therefore, the heat removal performance of the PCCS is an important factor for the integrity of the containment.

In this study, the heat removal performance of the conceptual PCCS design is evaluated by using MARS-KS 1.4[1]. After the simulation, the result of this study is compared with the Lim's data[2] for validation. An empirical condensation correlation [3] is applied to the MARS-KS to replace the embedded condensation model by Colburn and Hougen.

2. Empirical Condensation Correlation

The condensation experimental results were obtained by using 10 mm and 40 mm outer diameter vertical cylinder tubes in the Jeju National University(JNU) [3][4]. Based on the condensation experimental results, the empirical condensation correlation was developed by using parameters which affects the condensation heat transfer coefficient, such as the pressure, the wall subcooling non-condensable gas mass fraction and aspect ratio to consider the geometry of the condenser tubes.

The form of proposed correlation is as following:

$$\frac{h_{nc}}{h_{Nu}} = a \cdot e^{b \cdot W_{nc}} \cdot \left(L/D\right)^{c} \cdot P^{*\cdot d} \cdot T^{*\cdot e}. \qquad (1)$$

where, $P^* = P_s/P_c$, $T^* = T_{wallsub}/T_c$, h_{nc}, h_{Nu}, D, P_s, P_c, $T_{wallsub}$, and T_c denote the condensation heat transfer coefficient in the presence of the non-condensable gas(W/m^{2}K), the Nusselt's heat transfer coefficient(W/m^{2}K), the outer diameter of condenser tube(m), the partial pressure of steam(bar), the critical pressure(bar), the wall subcooling(K), and the critical temperature(K), respectively.

The coefficients in Eq. (1) are determined by the non-linear regression analysis from the JNU and Dehbi's experiments. The proposed correlation is as following:

$$\frac{h_{nc}}{h_{Nu}} = 0.165 e^{-1.852 W_{nc}} \left(L/D\right)^{0.529} P^{*0.36} T^{*-0.219}. \qquad (2)$$

The proposed correlation is valid over the ranges:
$0.096 < W_{nc} < 0.890$
$25 < L/D < 100$
$0.253\ bar < P_s < 4.687\ bar$
$18.00\ K < T_{wallsub} < 68.72\ K$
The adjust R2 value for the data fit was 0.986.

3. MARS-KS Analysis

3.1 Models and Conditions

Figs. 1, 1(a) and 1(b) represent the containment nodalization and the PCCS loop nodalization, respectively. The containment nodalization consists of single volumes and pipe components. Containment dome(400) and heat transfer area(310, 320) are modeled as a single volume and other part of containment are modeled as pipe components. The heat structures are modeled between the outer surface of Passive Containment Cooling Heat Exchanger(PCCHX) and containment volume(310, 320) for the heat transfer between the PCCS and containment. PCCT is modeled as pipe component with 10 volumes. Each train of PCCS consists of 10 assemblies of PCCHX. The assembly of PCCHX has 8 bundles of PCCHX and each bundle has 488(8 61) tubes. The bundle of PCCHX is modeled as a lumped pipe component with 10 volumes. Passive heat sinks(PHS) such as stainless steel, carbon steel, concrete wall, and miscellaneous steels are modeled as heat structures[2]. The mass and energy release data due to LBLOCA are modeled as time-dependent volumes and time-dependent junction[2]. The time-dependent junction is connected with the 110-2 volume.

3.2 Analysis Results and Discussions

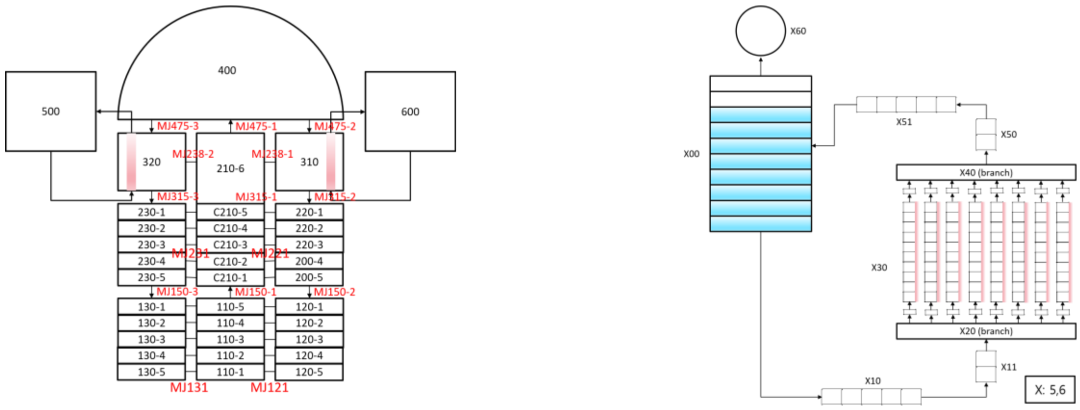

Fig. 1. Nodalization scheme for PCCS: (a) Containment with PCCS, (b) PCCS loop.

The MARS-KS result from the this study was compared with the Lim's data[3] for validation of the this study as shown in Fig. 2. The overall trend is analogous to Lim's data but the difference between the data was started after about 100 seconds. This difference is the difference of the heat removal rate by the PCCS. In this study, the heat removal rate of the PCCS is more efficient in the beginning of the event. However, the performance of PCCS suddenly gets worse near the 1000 sec as shown in Fig. 3. Thus, containment pressure of this work is higher than that of Lim. The difference of total heat removal capacity of PCCS makes the difference of the containment pressure. The total heat removal capacity of PCCS of this study is bigger than that of Lim. thus, since the PCCS is the long-term heat sink, it affects the pressure in the containment after about the 2000 seconds.

Fig. 3 represents the released energy into the containment and heat removal rate by PCCS and Passive Heat Structure(PHS) using the MARS-KS and MARS-KS with empirical correlation. The energy consists of the energy of the steam and liquid. The released steam is the main parameter to increase the containment pressure. From the results, the heat removal rate by PCCS shows the different aspects. From 2 seconds to 40 seconds, the heat removal rate calulated by MARS-KS is larger than that computed from MARS-KS with empirical correlation. The air mass fraction is relatively high at the beginning of the event. After 40 seconds, the PCCS of the MARS-KS with empirical correlation is effective to dwindle the pressure in the containment.

Fig. 4 shows the comparison of containment pressure obtained by MARS-KS and MARS-KS with empirical correlation for evaluation the condensation model in the MARS-KS. Based on the result, overall trend is almost same. The difference of the pressure in the containment appears after about 100 seconds. The heat removal rate of PCCS affects the pressure in the containment. This indicates that the Colburn-Hougen used in MARS-KS tends to under-estimate the condensation heat transfer coefficient. However, since the empirical condensation correlation is based on the condensation experimental

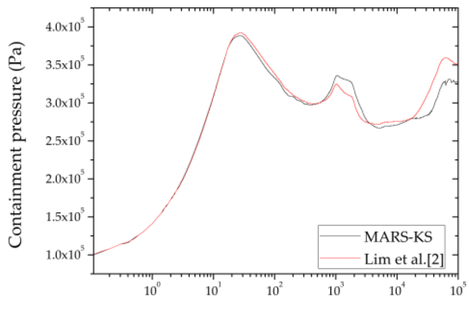

Fig. 2. Comparison of the containment pressure obtained by the this study and Lim[2].

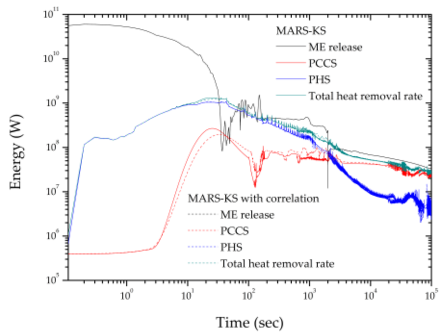

Fig. 3. Comparison results between the MARS-KS and MARS-KS with empirical correlation.

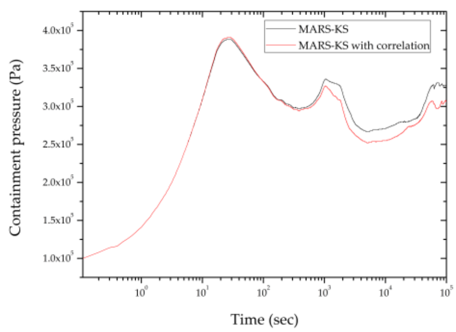

Fig. 4. Comparison of the containment pressure between the MARS-KS and MARS-KS with empirical correlation.

results, it is more realistic than the existing Colburn-Hougen model.

4. Conclusions

The heat removal performance of the conceptual PCCS design was modeled by using MARS-KS 1.4. The result of this study was compared with the Lim's data for validation. The empirical condensation correlation was applied to the MARS-KS for evaluation of the existence condensation model.

The overall trend is analogous to Lim's data but the difference between the data was started after about 100 seconds. It happens two reasons: condenser tube length and the total heat removal capacity of PCCS.

At the beginning of the event, the heat removal rate by PCCS in the MARS-KS result shows the good performance compared with that of MARS-KS with empirical correlation until 40 seconds. However, the heat removal rate by PCCS in the result of MARS-KS with empirical correlation is more helpful to decrease the pressure in the containment due to the empirical condensation correlation which is derived from the experimental results.

This study will be a good option to determine the realistic heat removal capacity of the PCCS.

ACKNOWLEDGEMENTS

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