Evaluation of the PRHRS Performance Degradation due to Non-Condensible Gas for the Small and Medium Reactor using MARS-KS code

Sook Kwan Kim[a*], Suk Ku Sim[a], Ju Yeop Park[b], Kwang Won Seol[b], and Yong Ho Ryu[b]
[a] *en2t, Room 213, R&D Building 2, 100 Sinseong-dong, Yuseong-Gu, Daejeon, 305-804, Korea*
[b] *KINS, 34, Gwahak-ro, Yuseong-Gu, Daejeon, 305-338, Korea*
[*] *Corresponding author: skkim@en2t.com*

1. Introduction

The effect of non-condensible gas on the performance of PRHRS (Passive Residual Heat Removal System) of the Small and Medium Reactor(SMR) was evaluated during a loss of flow event. Since the TMI accident in 1979, the passive systems have been considered in the advanced reactors as a feature of design improvement because the passive system simplifies the system and thus increases the reliability of the system. The Westinghouse received the design certification from the USNRC for the AP600 and AP1000 passive type pressurized water reactors. The APR+ under development by KEPCO considers the use of PAFS (Passive Auxiliary Feedwater System). And the PRHRS is adopted as a passive secondary heat removal system for the SMART (System-integrated Modular Advanced ReacTor) [1].

These passive systems use horizontal or vertical-tube type of heat exchangers where condensation heat transfer occurs. When the non-condensible gas exists in the tube, it has been known that there is a considerable degradation of heat transfer. Therefore, an accurate prediction of heat transfer with non-condensible gas existing in the system is important to predict system response during a transient. In order to evaluate the effect of the non-condensible gas on the performance of PRHRS, analyses were performed using MARS-KS code [2] with non-condensible condensation heat transfer model and the results are compared with those of the original MARS-KS code.

2. Analysis and Results

2.1 Analysis

The MARS-KS condensation heat transfer coefficients in the tube side where condensation heat transfer may occur are Nusselt model(1916) and Shah model(1979) for laminar and turbulent flow, respectively. In order to account for the effect of the non-condensible gas on the heat transfer the POSTECH condensation heat transfer model uses the following correlations[3].

$$f = \frac{h_{\exp,mix}}{h_{Nu}} = \tau_{mix}^{*\ 0.3124}\left(1 - 0.964 \cdot W_{nc}^{0.402}\right)$$

$$\tau_{mix}^{*} = \frac{\tau_{mix}}{g\rho_f L} = \frac{1/2\rho_{mix}u_{mix}^2 f_{fric}}{g\rho_f L}$$

where, f : degradation factor
h : heat transfer coefficient
τ : dimensionless shear stress
W : non-condensible gas mass fraction.
exp : experiment
Nu : Nusselt theory
τ_{mix}^{*} :dimensionless shear stress

As shown in the Fig. 1, there are large uncertainties in the original condensation model of the MARS-KS code. Of the models, modified MARS-KS incorporating POSTECH model predicts the experiment result relatively well.

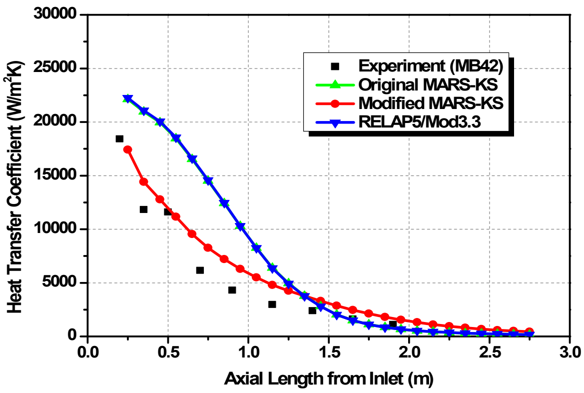

Fig. 1. Comparison of condensation models

Fig. 2 shows a schematic diagram and nodalization of the PRHRS for a typical small and medium reactor. In the analysis it is conservatively assumed that non-condensible gas, that is air, is present at the upper part of the PRHRS. Following loss of flow event due to loss of power to RCPs, the primary and secondary sides of the plant undergo natural circulation cool-down process. The ECTs (Emergency Cooling Tank) in the PRHRS act as the final heat sink during the transient.

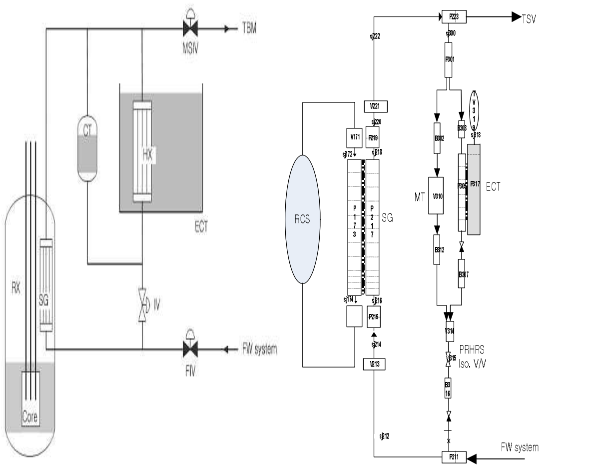

Fig. 2. Schematic diagram and nodalization of PRHRS

2.2 Results

The Fig. 3,4,5 and 6 show behaviors of PRHRS flow, ECT temperature, RCS temperature, and SG secondary pressure during loss of flow event for the case of 3.6 kg (about 0.092% of total mass per 1 PRHRS train) of air present in the PRHRS, respectively. As shown in the figures, Modified MARS-KS code with POSTECH condensation heat transfer models predicts the system parameters less conservatively due to degraded heat transfer in the PRHRS heat exchangers. Especially the degradation effect is significant in the later part of the transient.

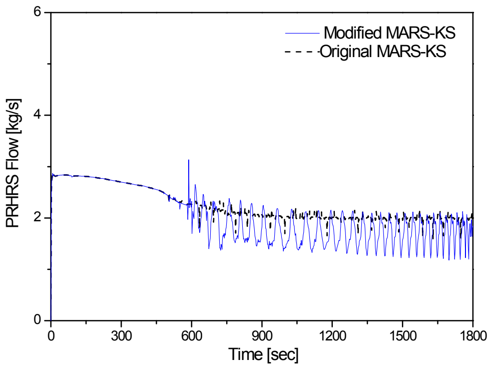

Fig. 3. Behavior of PRHRS flow

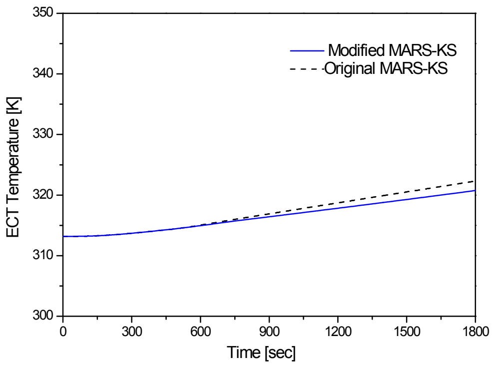

Fig. 4. Behavior of ECT temperature

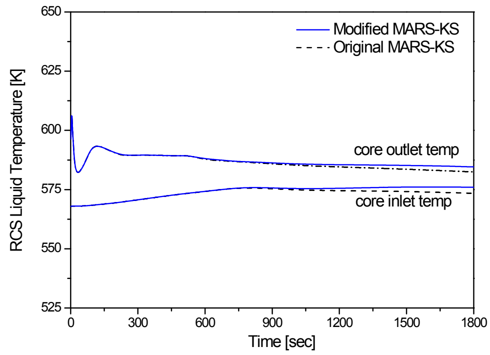

Fig. 5. Behavior of RCS temperature

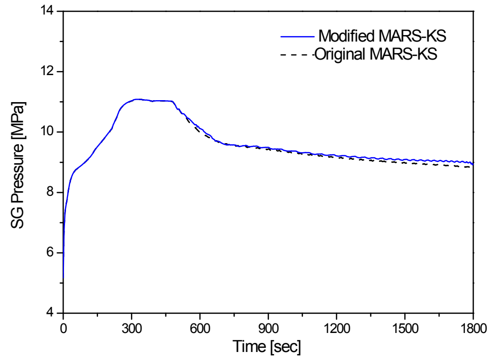

Fig. 6. Behavior of SG pressure

3. Conclusions

The effect of non-condensible gas on the performance of the PRHRS was evaluated using MARS-KS code with non-condensible condensation heat transfer model and the results are compared with those using original MARS-KS code. The non-condensible gas in the PRHRS degrades the performance of the PRHRS of small and medium reactor during a loss of flow event.

Thus, it is advisable to eliminate the source of the non-condensible gas in the PRHRS design. And the elimination of the Nitrogen Accumulator make-up tank and the adoption of the steam make-up tank in the SMART PRHRS design seem to improve the PRHRS performance.

REFERENCES

[1] K. W. Kim, et al., SMART System Description, Korea Advance Institute of Atomic Energy, 000-PL403-001, 2010.
[2] MARS-KS 1.2, Korea Institute of nuclear Safety, 2010.
[3] K.Y.Lee, “The Effects of Noncondensable Gas on Steam Condensation in a Vertical Tube of Passive Residual Heat Removal System”, Ph.D. Thesis, Pohang University of Science and Technology, 2007.