Preliminary Thermal Sizing of PRHRS Heat Exchanger for Innovative Next Generation SMART Plus

Joo Hyung Moon[a*] and Seungyeob Ryu[a]
[a]*Korea Atomic Energy Research Institute,*
111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea
[*]*Corresponding author: moonjooh@kaeri.re.kr*

1. Introduction

Recently, the Korea Atomic Energy Research Institute (KAERI) and the King Abdullah City for Atomic and Renewable Energy (K.A.CARE) had established a Joint R&D Center to conduct a joint project. The main goal of this project is to propose a preliminary design of innovative next generation SMART (System-integrated Modular Advanced ReacTor) Plus to enhance its economic efficiency and safety by uprating reactor power and by introducing innovative element technologies, such as printed circuit steam generator (PCSG), internal control rod drive mechanism (CRDM), an improved reactor vessel module, and so on. In the project, a preliminary design of passive residual heat removal system (PRHRS) will be performed. In the present study, the heat transfer area of PRHRS heat exchanger (PHX) for SMART Plus will be estimated.

2. Description of PRHRS Heat Exchanger

The PRHRS consists of four independent trains and each train is composed of one emergency cooldown tank (ECT), one PHX and one PRHRS makeup tank (PMT).

The PHX consists of inlet header, vertical once-through type heat transfer tube, and outlet header, and performs the function to remove the residual heat of the core and the sensible heat in the reactor coolant system (RCS) through the cooling water in the ECT. The PHX locates inside of the ECT, and the RCS is cooled down as the coolant circulates naturally through the inside of the heat transfer tube of the PHX. The heat removal capacity of the PHX is calculated such that the RCS reaches the safe shutdown condition within 36 hours after an accident initiation. In the calculation of the heat removal capacity of the PHX, the heat transfer degradation effects by non-condensable gases are considered. The heat transfer tubes of the PHX are submerged in the ECT cooling water.

3. Design Requirements of the PRHRS

The performance of the PRHRS shall meet the following requirements:

A. The temperature of the RCS shall be lowered below that of the safe shutdown condition within 36 hours after the accident initiation and the PRHRS shall maintain this condition until at least 72 hours without an operator's intervention or an emergency AC power.

B. The cooling rate of the RCS shall not exceed the design limitations of the RCS and connecting equipment.

The heat transfer area of the PHX shall be determined to meet the above requirements satisfactorily.

4. Thermal Sizing of PRHRS Heat Exchanger

4.1 Assumptions

It is assumed that majority of design parameters remains unchanged from the previous design of PHX for SMART, except that nominal thermal power of SMART Plus is uprated to 970 MWth. Even though the design change for steam generator (SG) is under consideration, it is assumed that the thermal performance of SG remains unchanged, which is acceptable for the preliminary calculation. The ANS-71 [1] decay heat curve with additional 20% of margin, is employed to obtain data for the decay heat over time. In this paper, modeling of the PMT is omitted, which is allowable for the preliminary study.

4.2 Modeling of the PRHRS

In this paper, the homogeneous flow model [2] is adopted. It considers the two phases to flow as a single phase possessing mean fluid properties. It is assumed that the two-phase flow discharged from the outlet of the SG is maintained along the vertical and horizontal steam line until it reaches the inlet of the PHX. Even though this assumption does not reflect a real phenomenon precisely, it is practical for the preliminary design since the homogeneous flow model is faster and converged relatively well. Calculation procedures are identical to the previous ones for SMART [3].

4.3 Estimation of the Heat Transfer Area

The heat transfer area shall be determined to meet the design requirements of the PRHRS, as mentioned in Section 3. The heat transfer area is dependent upon diameter, length and the number of heat transfer tubes. Therefore, a parametric study is conducted with the

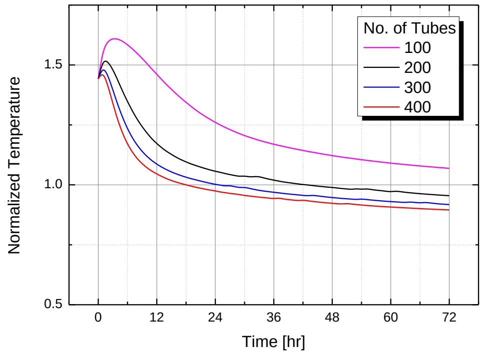

Figure 1. Normalized RCS temperature (3 Trains)

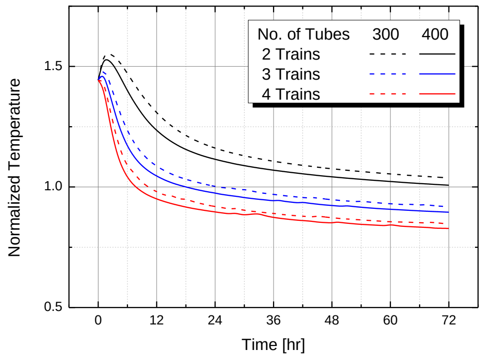

Figure 3. Normalized RCS temperature (300/400 Tubes)

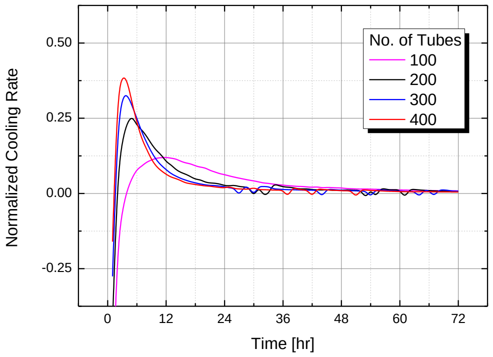

Figure 2. Normalized RCS cooling rate (3 Trains)

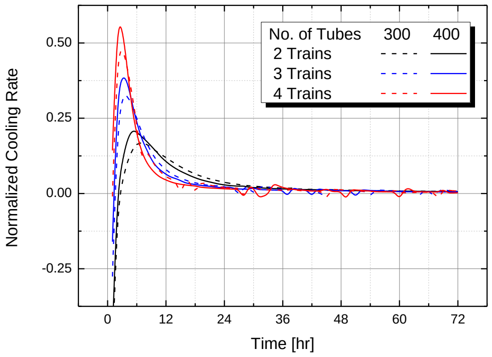

Figure 4. Normalized RCS cooling rate (300/400 Tubes)

various number of tubes, while diameter and length are fixed as same as previous values of SMART [3].

5. Results

Figure 1 shows the transient behaviors of the RCS temperature with the various number of tubes. In the figure, the number of trains in operation was chosen to be 3. Temperature is normalized to the safe shutdown temperature, which is 1.0 in the y-axis. As shown in the figure, when the number of tubes is 100 or 200, the first requirement of the PRHRS was not met. On the other hand, when the number of tubes is 300 or 400, it was satisfactorily met. Figure 2 shows the transient behaviors of the RCS cooling rate with the various number of tubes, which is normalized to its maximum limit. As shown in the figure, all cases met the second requirement of the PRHRS. Therefore, as shown in Figures 1 and 2, it may conclude that the number of tubes shall be at least 300 to reach the safe shutdown condition (temperature of the RCS shall be lower than 215℃ at the time of 36 hours since an accident occurrence and shall maintain this state until 72 hours).

Figure 3 shows the transient behaviors of the RCS temperature with the number of trains in operation, when the number of tubes is either 300 or 400. As shown in the figure, when the number of trains in operation is 2, the first requirement of the PRHRS was not met. On the other hand, when the number of trains in operation is 3 or 4, it was satisfactorily met. Figure 4 shows the transient behaviors of the RCS cooling rate with the number of trains in operation. As shown in the figure, all cases met the second requirement of the PRHRS. Therefore, as shown in Figures 3 and 4, it may conclude that the number of trains in operation shall be at least 3 to reach the safe shutdown condition.

In summary, the number of tubes shall be at least 300 and the number of trains in operation shall be at least 3 to reach the safe shutdown condition. In consideration of the thermal degradation of tubes during the operation of the PRHRS, arbitrary margin of 20% shall be added. Therefore, the final number of tubes required to reach the safe shutdown condition is determined to be 360.

6. Conclusions

The preliminary calculation for the heat transfer area of the PHX was conducted. It was predicted that the number of tubes shall be 360 and the number of trains in operation shall be at least 3 to reach the safe shutdown condition. This paper will contribute to the design of the passive safety systems of the SMART Plus.

ACKNOWLEDGEMENT

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