Radiation Heat Transfer Effect on Thermal Sizing of Air-Cooling Heat Exchanger of Emergency Cooldown Tank

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1. Introduction

An attempt has begun to extend the life time of emergency cooldown tank (ECT) by Korea Atomic Energy Research Institute (KAERI) researchers [1]. Moon et al. [1] recently reported a basic concept upon how to keep the ECT in operation beyond 72 hours after an accident occurs without any active corrective actions for the postulated design basis accidents. When the SMART (System-integrated Modular Advanced Reac-Tor) received its Standard Design Approval (SDA) for the first time in the world [2], hybrid safety systems are applied. However, the passive safety systems of SMART are being enforced in response to the public concern for much safer reactors since the Fukushima accident occurred.

The ECT is a major component of a passive residual heat removal system (PRHRS), which is one of the most important systems to enhance the safety of SMART. It is being developed in a SMART safety enhancement project to contain enough cooling water to remove a sensible heat and a decay heat from reactor core for 72 hours since an accident occurs. Moon et al. [1] offered to install another heat exchanger above the ECT and to recirculate an evaporated steam into water, which enables the ECT to be in operation, theoretically, indefinitely. An investigation was made to determine how long and how many tubes were required to meet the purpose of the study. In their calculation, however, a radiation heat transfer effect was neglected.

The present study is to consider the radiation heat transfer for the design of air-cooling heat exchanger. Radiation heat transfer is normally ignored in many situations, but this is not the case for the present study. Kim et al. [3] conducted thermal sizing of scaled-down ECT heat exchanger, which will be used to validate experimentally the basic concept of the present study. Their calculation is also examined to see if a radiation heat transfer effect was taken into consideration.

2. Methods and Results

2.1 Basic Concept

An air-cooling heat exchanger is proposed to be installed at the top of the ECT as shown in Fig. 1 [4]. The cooling water contained in ECT is heated by the heat released from an immersed heat exchanger. When water reaches at a saturation point, it starts to evaporate from the surface. A steam duct is designed to collect the

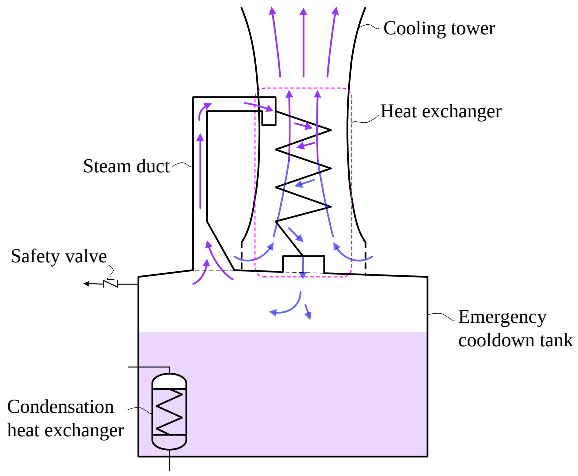

Fig. 1. Modification by installing an air-cooling heat exchanger above the ECT

evaporated steam and to deliver them to air-cooling heat exchanger, where the heat is dumped to an environment air flow and finally the steam will be condensed inside the tube wall.

2.2 Heat Transfer Correlations

Main calculation procedure is same as the previous study, except for heat balance equation. Therefore, details are not repeated here. Table 1 summarizes the heat transfer correlations used for the present study. Descriptions for each correlation can be found in Moon et al. [1].

2.3 Heat Transfer Area

The decay heat to be removed per train was obtained as 576.7 kW [1]. The required heat transfer area can be estimated using the above correlations. The number of tubes, N_{tube} is investigated by the following heat balance equation, where radiation heat transfer term is now included:

$$N_{tube} = Q/[\bar{h}(\pi DL)\Delta T + \varepsilon(\pi DL)\sigma(T^4 - T_{sur}{}^4)],$$

where Q is the decay heat, $\bar{h}$ is the average heat transfer coefficient, ΔT is the temperature difference between the tube wall and the ambient air, ε is the emissivity, and σ is the Stefan-Boltzmann coefficient.

Table 1. Summary of heat transfer correlations for the present study

References	Heat transfer correlations	Range of Ra_L
Churchill & Chu [5]	$\overline{\mathrm{Nu}_L} = \left[0.825 + \frac{0.387 {Ra_L}^{1/6}}{[1+(0.492/Pr)^{9/16}]^{8/27}}\right]^2$	
McAdams[6]	$\overline{\mathrm{Nu}_L} = 0.13 {Ra_L}^{1/3}$	$4\times10^9 \le Ra_L \le 2.5\times10^{10}$
Eigenson [7]	$\overline{\mathrm{Nu}_L} = 0.148 {Ra_L}^{1/3}$	$4\times10^9 \le Ra_L \le 2.5\times10^{10}$
Al-Arabi & Khamis [8]	$\overline{\mathrm{Nu}_L} = 0.47 {Ra_L}^{1/3} / {Gr_D}^{1/12}$	$2.7\times10^9 \le Ra_L \le 2.95\times10^{10}$
Yang [9]	$\overline{\mathrm{Nu}_L} = \left[0.60 \left(\frac{L}{D}\right)^{1/2} + 0.387 \left(\frac{Ra_L}{[1+(0.492/Pr)^{9/16}]^{16/9}}\right)^{1/6}\right]^2$	Complete range of Ra_L

2.4 Results

Figure 2 compares the results of number of tubes for several models. It is evident that the larger the value of *L/D*, the fewer number of tubes that are required. As seen in the figure, when radiation heat transfer is accounted for, the numbers of tubes required were reduced to almost half values. This is because the contribution of convective heat transfer and that of radiation is at the similar order of magnitude.

Figure 3 shows the difference between convection and radiation. In most case radiation heat transfer per unit area is larger than that of convection. It is why the deviation among several convection models is diminished in Fig. 2 when the radiation term is included. Radiation is comparable to convection in the present study. Therefore it can be concluded that radiation should not be ignored in the design of air-cooling heat exchanger.

Kim et al. [3] reported that the length and the number of tubes required for their air-cooling heat exchanger were 1.687 m and 25. Table 2 shows the comparison among several models when the same boundary conditions were applied as those of Kim et al. [3]. It shows good agreement among Kim et al. [3], Al-Arabi & Khamis [8] and Yang [9]. Therefore it can be drawn that Kim et al. [3] also ignored the radiation heat transfer. As seen in the table, only 12 tubes will be required when radiation heat transfer is adequately considered.

Table 2. Number of tubes required for the same boundary condition of Kim et al.[3]

	w/o radiation	w/ radiation
Kim et al. [3]	25	n/a
Churchill & Chu [5]	34	15
McAdams[6]	30	14
Eigenson [7]	27	13
Al-Arabi & Khamis [8]	22	12
Yang [9]	23	12

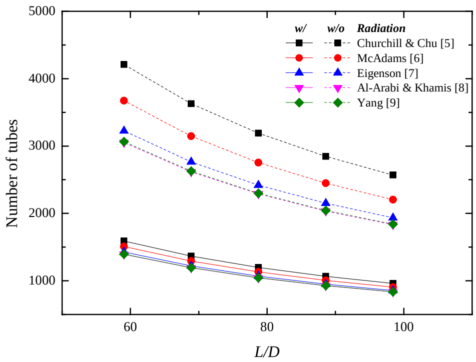

Fig. 2. Radiation heat transfer effect on the number of tubes required for several models

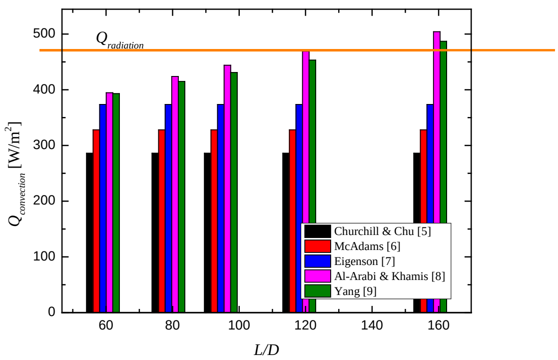

Fig. 3. Comparison between convection and radiation heat transfer

3. Conclusions

The thermal sizing of an air-cooling heat exchanger was conducted including radiation heat transfer. Investigations were made using several heat transfer correlations for natural convection of the vertical tubes and also the radiation heat transfer term. It is revealed that the radiation should not be neglected for the present air-cooling heat exchanger. This work will contribute to evaluate the feasibility of the basic concept upon an extension of the cooling period of ECT to longer than

72 hours, which will enhance the passive safety systems of SMART.

Acknowledgement

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