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Design Guideline for Primary Heat Exchanger in a Research Reactor

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1. Introduction

Research reactors should incorporate the cooling system for the cooling of the reactor core power. The Jordan Research and Training Reactor (JRTR) is also equipped with the Primary Cooling System (PCS), Secondary Cooling System (SCS), and primary heat exchanger between two systems as shown in Fig. 1. The PCS circulates demineralized water to remove the heat generated in reactor core. The heat is transferred to the cold water of the SCS through the primary heat exchanger. In JRTR, Plate-type Heat Exchanger (PHE) was used as the primary heat exchanger. The cooling tower automatically sets the SCS inlet temperature constant by fan speed control. The flow rate of SCS is adjusted to be identical with the PCS flow rate.

To design the PHE, the inlet and outlet temperatures and the flow rates for both systems should be determined. The flow rate has the allowable band for the safe operation from the lower limit to upper limit resulting in different temperature distribution in the PHE. Specially, the PCS outlet temperature which is the core inlet temperature is used for a safety parameter for the reactor shutdown. Therefore, we need to figure out which limit for the flow rate should be used from the conservative point of view. In this paper, analytical study is conducted to track the variation of the PCS outlet temperature in conditions of the constant core power and constant SCS inlet temperature

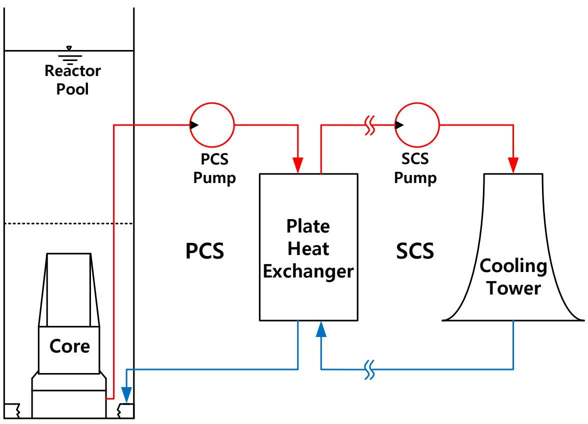

Fig. 1. Schematic diagram of system.

2. Modeling and Results

2.1 System Modeling

The system shown in Fig. 1 is modeled one-dimensionally with the commercial one-dimensional system code, FLOWMASTER 7. Fig. 4 shows the diagram of the modeled system which is composed of a PCS pump, a SCS pump, a plate heat exchanger, the reactor pool, core, cooling tower, and piping.

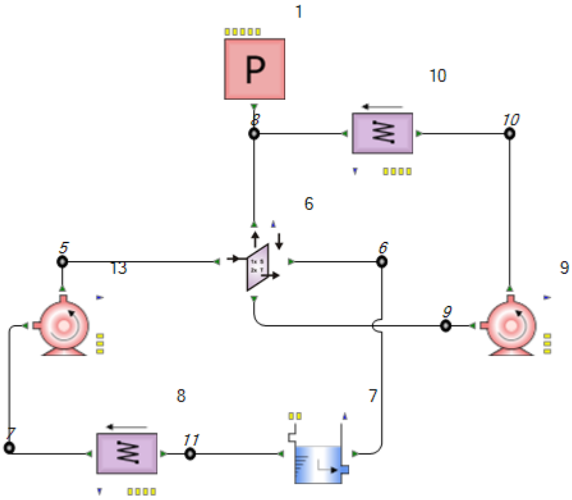

Fig. 2. System modeling.

In this paper, all the components are not specified in detail for the confidential reason. However, the main components such as the plate heat exchanger and PCS pump and SCS pump are described in 2.2 and 2.3.

During the simulation, the SCS inlet temperature in PHE and the core power were constant; 30.4 ℃, 6.1 MW respectively. Each flow rate of PCS and SCS (200kg/s, 230 kg/s) was controlled by adjusting the loss coefficient of PCS piping and SCS piping.

2.2 Plate Heat Exchanger Modeling

The cooling capacity of plate heat exchanger is a function of PCS mass flow rate ($\dot{m}_{PCS}$), SCS mass flow rate ($\dot{m}_{SCS}$), PCS inlet and outlet temperatures in PHE ($T_{PCS.in}$, $T_{PCS.out}$), SCS inlet and outlet temperatures in PHE ($T_{SCS.in}$, $T_{SCS.out}$), cross sectional area (A_{plate}), and overall heat transfer coefficient (U_{plate})

$$
\begin{aligned}
Q &= \dot{m}_{PCS} C_{p.PCS} (T_{PCS.in} - T_{PCS.out}) \\
&= \dot{m}_{SCS} C_{p.SCS} (T_{SCS.out} - T_{SCS.in}) \\
&= U_{plate} A_{plate} (LMTD) \qquad (1)
\end{aligned}
$$

The log mean temperature difference (LMTD) is defined in equation (2) below.

$$LMTD = \frac{\Delta T_2 - \Delta T_1}{ln\frac{\Delta T_2}{\Delta T_1}} \quad (\Delta T_1 \neq \Delta T_2)$$

$$= \Delta T_1 = \Delta T_2 \quad (\Delta T_1 = \Delta T_2) \qquad (2)$$

$$where, \Delta T_1 = T_{PCS.in} - T_{SCS.out}$$

$$\Delta T_2 = T_{PCS.out} - T_{SCS.in}$$

The overall heat transfer coefficient is calculated by the correlation which is a function of the several geometry parameters shown in Fig. 3. The equation (3) shows the correlation used in this paper which is most recommended.

$$Nu = [0.2668 - 0.006967\beta + 7.244 \times 10^{-5}\beta^2] \times [20.78 - 50.94\phi + 41.1\phi^2 - 10.51\phi^3] \times Re^c Pr^{1/3} \qquad (3)$$

$$where, c = 0.728 + 0.0543sin\left[\left(\frac{\pi\beta}{45}\right) + 3.7\right],$$

$$\emptyset = \frac{A_1}{(L_v - D_p)(L_h + D_p)}, Re = \frac{G_c D_h}{\mu},$$

$$G_c = \frac{m}{N_{cp} b L_w}, N_{cp} = \frac{N_t - 1}{2N_p}, D_h = \frac{2b}{\emptyset}$$

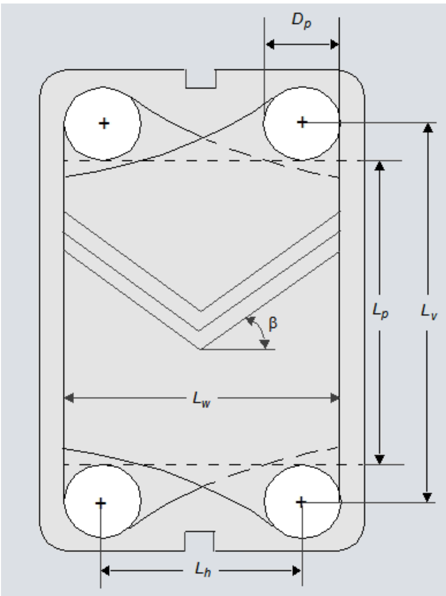

Fig. 3. Geometry of PHE.

2.3 Pump Modeling

Fig. 4 shows the pump performance curve which are used for both PCS and SCS pump and the rated flow rate and head of the two pumps are 200 kg/s and 20 m, respectively.

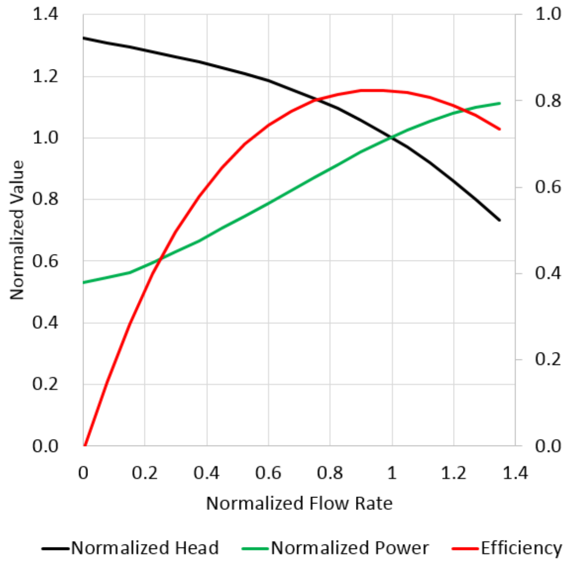

Fig. 4. Pump performance curve

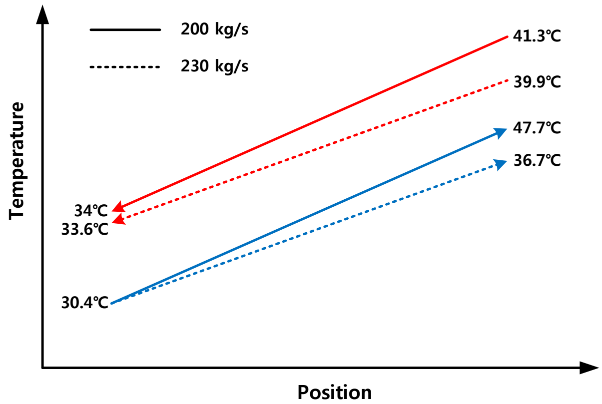

Fig. 5 Results

3. Conclusions

Fig. 5 shows the inlet and outlet temperatures of PCS and SCS in PHE at two flow rates (lower limit of flow band; 200 kg/s, upper limit of flow band; 230 kg/s). At 200 kg/s of PCS and SCS flow rates, the inlet and outlet temperatures are 41.3℃and 34℃, respectively. With increase of the flow rate, both of PCS inlet and outlet temperatures decrease to 33.6℃ and 39.9℃.

This result means the low limit of the allowable flow band should be used for the conservative design of primary heat exchanger. If the upper limit of the allowable flow band is used, the PCS outlet temperature which is the safety parameter used for the reactor shutdown increases with decrease of the flow rate. The increase of PCS outlet temperature allows us high possibility of the reactor shutdown.