Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Study on the Size of Printed Circuit Heat Exchangers for a Pool-type Research Reactor

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1. Introduction

A heat exchanger is one of the most important components widely used for both heating and cooling processes in many engineering industries. A printed circuit heat exchanger (PCHE), fabricated by diffusion-bonding or diffusion welding, is a promising type of heat exchanger in terms of its high efficiency, mechanical strength, operating conditions, small size, and so on. Generally, a PCHE includes semicircle flow channels in the hot and code sides assembled layer-by-layer with a variety of their size, channel number, and pattern. The performance of the PCHE depends on the PCHE designs, especially for the heat transfer coefficient and pressure drop of the fluid.

Research reactor utilizes heat exchangers to transfer the heat generated from the reactor core to the secondary side, in which it is not necessary to produce electricity. Therefore, the main difference between the heat exchanger used in the commercial nuclear power plant the log means temperature difference (LMTD) of the heat exchanger in which the LMTD in research reactor is significantly lower than that of the commercial nuclear power plant due to the low operating temperature and high mass flow rate. This study estimated the possible PCHE size for the research reactor under the low LMTD and high mass flow rate conditions.

2. Methods and Results

A plate-type PCHE was investigated with a number of the flow channel, size, structure width for the straight channel, which is easily maintained during the operation period compared to zigzag channels or more complex channels because of relatively low manufacturing uncertainty. Considering the long-term operation period of a research reactor and the simple geometry of the heat exchanger. Fig. 1 shows the cross-sectional view of the PCHE with key design parameters. In the figure, D denotes the channel diameter, H is the height of PCHE increasing proportional to the column of the flow channel, L is the channel length, $P1$ and $P2$ is the pitch of the channels. Note that the $P1$ and $P2$ is considered to be 1.2 times the channel diameter D. The subscript i indicates the channel number of each flow side. Then, the total volume of the PCHE is simply expressed as $H \times W \times L$.

The total mass flow rate and log mean temperature difference is 400 kg/s and 2.5 ℃, respectively. Two PCHEs are available during the reactor operation and they transfer half of the heat generated from the reactor core, which is 10 MWth. The inlet/outlet temperature on the primary side is 40/34 ℃, and inlet/outlet temperature on the secondary side is 31.5/37.5℃. With these given boundary conditions, the rest of the design parameters of the PCHE is studied.

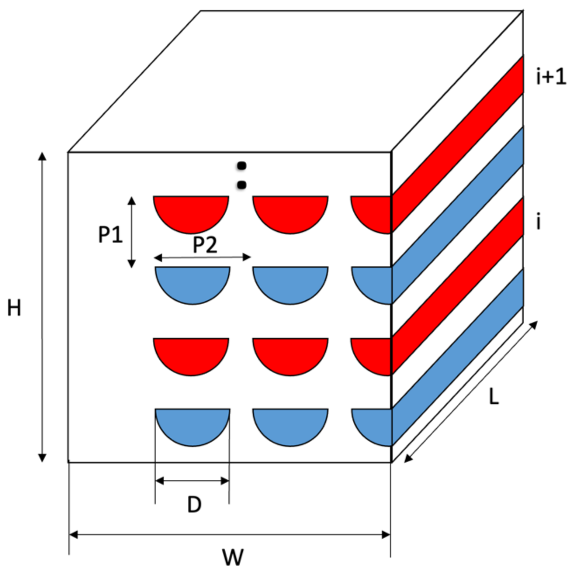

Fig 1. Cross-sectional view of a straight-channel PCHE with main design parameters

2.1 Heat Transfer Model

The heat transfer rate in the PCHEs is governed by Eq. (1).

$$Q = UA\Delta T_{lm} \tag{1}$$

where U is the overall heat transfer coefficient and A is the effective heat transfer area, and ΔT_{lm} is the log mean temperature.

$$\frac{1}{U} = \frac{1}{h_h} + \frac{1}{h_c} \tag{2}$$

where subscript h and c is the hot and cold side, respectively. Since the fluid channels are semicircular in cross-section, it is difficult to define exact wall thickness in one-dimensionally. The thermal resistance of the wall can be neglected depending on the wall thickness [1].

The heat transfer coefficient is obtained by Eq (3) for the turbulent regime of the water [2].

$$Nu = 0.122 Re^{0.56} Pr^{0.14} \quad (3)$$

The friction coefficient is obtained by Eq (4) for circular pipes as follows:

$$f = \frac{1}{4}\left(\frac{1}{1.82\log(Re) - 1.64}\right)^2 \quad (4)$$

Since this study focused on the size estimation for the research reactor, which does not produce electricity, further work should evaluate the efficiency of the PCHE with the consideration of the pressure drop and heat transfer rate.

2.2 Size Estimation Method

The PCHE size is determined by design parameters such as channel diameter, length, number of the channel, pitch. Once the volume of PCHE is determined, it can be manufactured according to its environment to be installed, by adjusting the height and width. The PCHE volume can be estimated as follows:

$$V = H \times W \times L = (1.2D)^2 \times 2N \times L \quad (5)$$

where N is the number of the flow channel on the primary or secondary side. It should be noted that the PCHE volume is significantly dependent on the pitch size (*1.2D*). First, the number of channels (*N*) and tube size (*D*) are given as initial conditions. And the required channel length is obtained by Eqs (1) ~ (3), enabling estimation of the volume of the PCHE and pressure loss by Eq. (4). In addition, the cross-sectional area of the flow channel and channel number are controlled to maintain the same mass flux.

2.3 Results

Fig. 2 shows the general trend of the PCHE size increasing with the number of the flow channel. It is obvious that the volume of the PCHE is proportional to the flow channel when the channel diameter is fixed.

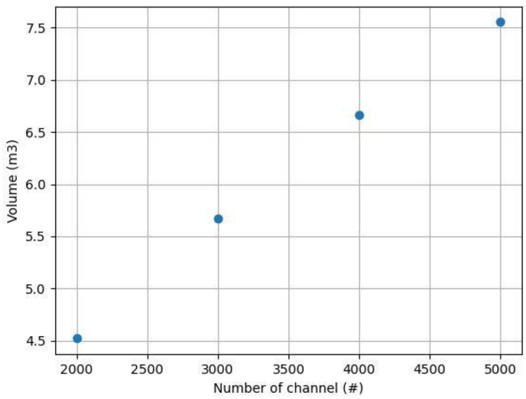

Fig 2. PCHE volume relative to the number of flow channels with 0.5 cm of channel diameter

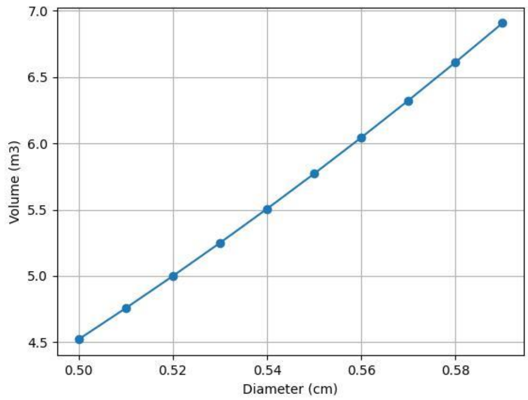

Fig 3. PCHE volume relative to the channel diameter when the number of the flow channels on the primary side is 1,000 (mass flux = 10,185 $kg/m^2 \cdot s$)

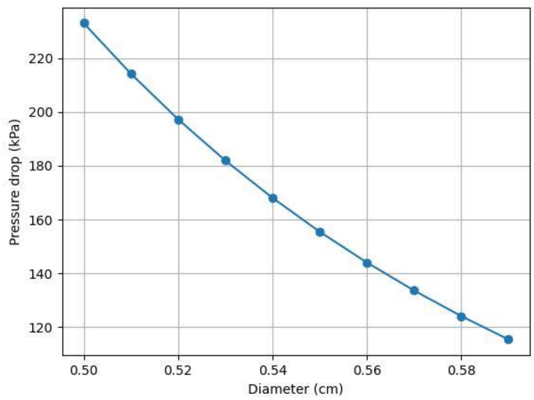

Fig 4. Pressure drop in the primary side relative to the channel diameter when the number of flow channel on the primary side is 1,000 (mass flux = 10,185 $kg/m^2 \cdot s$)

Figs. 3 and 4 show the PCHE volume and pressure drop relative to the channel diameter. The volume of the PCHE is linearly increased with the channel diameter, while pressure drop is significantly reduced. Based on these results, the PCHE size should be appropriately determined, considering pressure drop to improve the system efficiency.

Table 1. Overall heat transfer coefficient and pressure drop with the same mass flux (10,185 kg/m^2-s)

Variable	Value			
D (cm)	0.71	0.22	0.11	0.08
N (#)	1,000	10,000	40,000	80,000
L (m)	51.7	9.9	3.6	2.2
V (m^3)	7.4	1.4	0.52	0.32
U (W/m^2-K)	3,481	5,777	7,838	9,129
dP (kPa)	256.2	194.3	165.0	153.5

The overall heat transfer coefficient and pressure drop are calculated under the same mass flux, which means the increasing channel diameter decreases the flow channel number. The small size results in a higher heat transfer coefficient so that the required channel length can be reduced. The pressure loss is sensitively changed depending on the channel length for 50 m ~ 9.9 m. When the PCHE volume decreases from 7.4 m^3 to 0.32 m^3, the pressure loss converges to 153.5 kPa, which is similar to the core pressure drop in research reactor [3]. These PCHE size estimations should be validated with experimental studies or simulations in the future work.

3. Conclusions

The PCHE size for a research reactor is studied by changing channel diameter and the number of the flow channels. The pressure drop in the PCHE is significantly sensitive when channel diameter varies from 0.5 cm to 0.59 cm while the number of the flow channel is fixed. The required channel length (L) practically determines the applicability of the PCHE. For example, it is hard to use the PCHE, which requires 51.7 m of channel length. On the other hand, the PCHE with 0.08 channel diameter maintains reasonable pressure loss and channel size. The manufacturing cost should be evaluated in future work considering the PCHE size and maintenance aspect.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2020M2D5A1078131).

REFERENCES

[1] D. Kwon, L. Jin, W. S. Jung, and S. Jeong, Experimental investigation of heat transfer coefficient of mini-channel PCHE (printed circuit heat exchanger), Cryogenics, vol. 92, pp. 41–49, Jun. 2018, doi: 10.1016/j.cryogenics.2018.03.011.

[2] L. Chai and S. A. Tassou, A review of printed circuit heat exchangers for helium and supercritical CO2 Brayton cycles, Thermal Science and Engineering Progress, vol. 18. Elsevier Ltd, Aug. 01, 2020. doi: 10.1016/j.tsep.2020.100543.

[3] H. M. Son, K. Song, and J. Park, Core Thermal Hydraulic Characteristics of Open Pool Type Research Reactors, Transactions of the Korean Nuclear Society Virtual spring Meeting, 2021.