Preliminary Computational Study on Conduction Thermal Resistance for a Zigzag Printed Circuit Heat Exchanger with Monitoring Channels

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1. Introduction

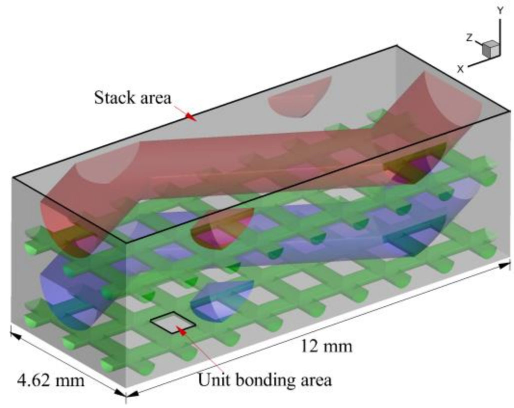
A printed circuit heat exchanger (PCHE) is a compact heat exchanger with high heat transfer performance. The PCHE has been studied for application to various industries [1]. In the nuclear industry, the PCHE was studied as an intermediate heat exchanger in high temperature gas-cooled reactors and sodium-cooled fast reactors [2-4]. Recently, the PCHE was studied as a promising candidate of steam generator (SG) for pressurized water reactors (PWRs) [5].

The U-tube and helical-tube SGs are conventional types of the SG, and the integrity of the SG tube shall be regularly inspected through the direct inspection. The inspection of flow channels of the PCHE, when the PCHE is used as the SG, is also required, but the direct inspection of them is almost impossible because the PCHE has a huge amount of micro-sized channels. Hence, the monitoring channels were introduced for real-time surveillance to diagnose the integrity of the channels as an alternative of the direct inspection [6]. The monitoring channels are placed between the main flow channels in a sandwich structure so that any leak from the main flow channels through the crack can be detected by the continuous monitoring of the condition in the monitoring channel.

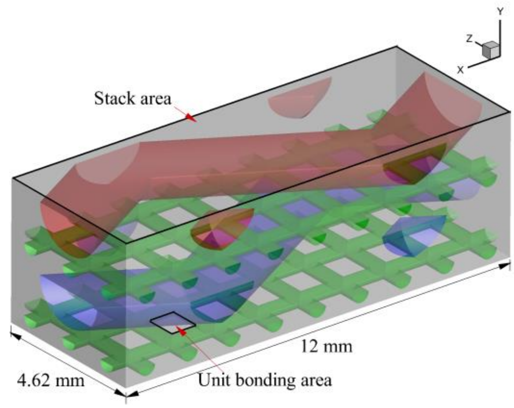
In the previous study [7], the effect of the monitoring channel on the thermal performance of the PCHE was studied, where the straight channels were considered as the main flow channels. The conduction thermal resistance was calculated and compared in consideration of the monitoring channels with various sizes and arrangements because the monitoring channels degraded the conduction heat transfer in the PCHE. The conduction thermal resistance increased with the increase of the monitoring channel size, but the effect of the arrangement of the monitoring channel was negligible for the monitoring channel of small size.

In this study, the zigzag channel is selected as the main flow channel because that is another conventional flow channel adopted in the PCHE. The effect of the monitoring channels on the thermal performance is investigated through the conduction analysis to exclude the effect of the convection heat transfer in the main flow channels, and the results are compared with those for the PCHE with straight channels as the main flow channel.

2. Methods and Results



(a) Aligned main flow channels



(b) Counter-aligned main flow channels

Fig. 1. Computational domains for the PCHE with monitoring channels.

2.1 Computational Setup

Three-dimensional thermal conduction analyses were conducted. ANSYS was used, and the steady-state and constant properties were assumed. Fig. 1 shows the computational domain. Both the main flow channels and monitoring channels have the cross section of semi-circle. The inclination angle for zigzag channel was set as 30°. The red and blue walls indicate the primary and secondary side channel walls, respectively. The depth of the primary and secondary side channels is 1 mm. The vertical distance between the primary and secondary side channels is 1 mm, regardless of the existence of the monitoring channels, and the horizontal distance between neighboring channels in both primary and secondary sides is 2 mm. The green and gray walls indicate the monitoring channel walls and the other solid walls, respectively. The depth of the monitoring channels is 0.25 mm, and the arrangement of those was similar to that in the previous study [7]. The horizontal distance between neighboring monitoring channels is 0.83 mm and 1.04 mm in x- and z-direction, respectively. The convective boundary condition was imposed on the primary and secondary side walls, and the heat flux on the monitoring channel walls was assumed as zero. The periodic condition was adopted on the other solid walls. For the computation, the solid region was discretized with 20 million hexahedral cells.

The zigzag channels with different inclination angle and pitch can be adopted in the primary and secondary sides to satisfy the required performance on each side, which induces the misalignment of the main flow channels. In this study, to examine the effect of the misalignment of the main flow channels, aligned and counter-aligned main flow channels were considered as shown in Fig. 1.

Table I: Conduction thermal resistances for the PCHE without the monitoring channels

	Case 1 [7]	Case 2	Case 3
Normalized conduction thermal resistance (K·m²/W)	9.41×10^{-5}	9.46×10^{-5}	10.26×10^{-5}

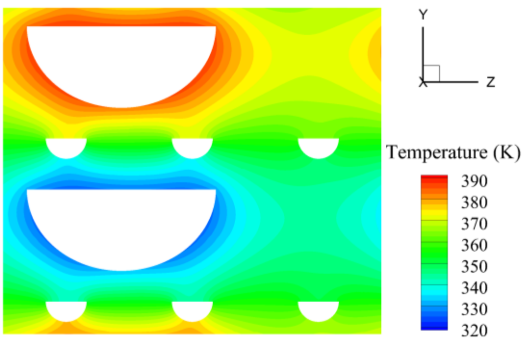


Fig. 2. Temperature distribution of the PCHE with the monitoring channels at x = 1.5 mm (Case 5).

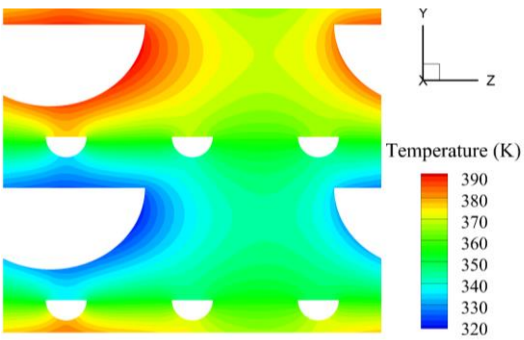


Fig. 3. Temperature distribution of the PCHE with the monitoring channels at x = 3 mm (Case 5).

2.2 PCHE without the monitoring channels

The conduction analyses for the PCHE without the monitoring channels were performed. The heat transfer coefficient and fluid temperature for the convective boundary condition were set, which were 50,000 W/m^2·K and 400 K, respectively for primary side channel and 25,000 W/m^2·K and 300 K, respectively for secondary side channel. To compare the heat transfer performance of the PCHE, the conduction thermal resistance was calculated by

$$R_c = \frac{\Delta T}{Q}, \tag{1}$$

where R_c, $\triangle T$, and Q are the conduction thermal resistance, temperature difference between the primary and secondary side channel walls, and heat transfer rate between the primary and secondary side channel walls, respectively.

The results were summarized in Table I, where the conduction thermal resistance was normalized by multiplying the stack area for a comparison. Cases 1, 2, and 3 indicate the analyses for the PCHE with straight, aligned zigzag, and counter-aligned zigzag channels, respectively. The conduction thermal resistance for Case 2 was similar to that for Case 1 because the main flow channels were aligned in every cross section for both cases. However, the conduction thermal resistance of Case 3 was 9.07 % larger than that of Case 1 because the path for conduction heat transfer increased by the misalignment of the main flow channels.

Table II: Conduction thermal resistances for the PCHE with the monitoring channels

	Case 4 [7]	Case 5	Case 6
Normalized onduction thermal resistance (K·m²/W)	13.01×10^{-5}	13.10×10^{-5}	13.75×10^{-5}

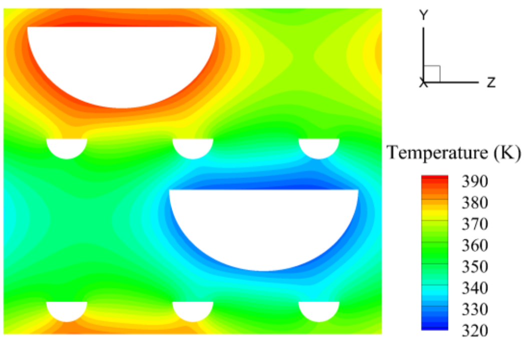


Fig. 4. Temperature distribution of the PCHE with the monitoring channels at x = 1.5 mm (Case 6).

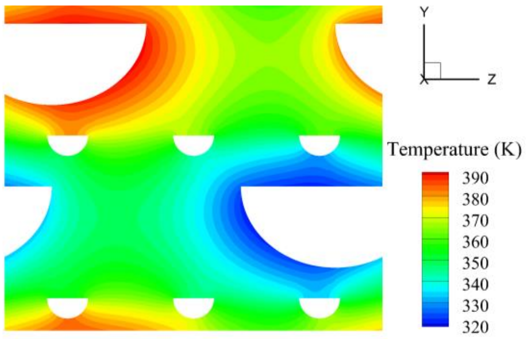


Fig. 5. Temperature distribution of the PCHE with the monitoring channels at x = 3 mm (Case 6).

2.3 PCHE with the monitoring channels

The conduction analyses for the PCHE with the monitoring channel were performed. The results were summarized in Table II. Cases 4, 5, and 6 indicate the analyses for the PCHE with straight, aligned zigzag, and counter-aligned zigzag channels with the monitoring channels, respectively. When the results of Table II were compared with those of Table I, it shows that the conduction thermal resistance increased by the addition of the monitoring channels. The conduction thermal resistances for Cases 4 and 5 were similar each other because the main flow channels were vertically aligned and only the alignment of the monitoring channel for Case 5 was varied along the axial position as shown in Figs. 2 and 3. The previous study [7] for the PCHE with straight channel showed that the alignment of the monitoring channel with the main flow channels was not important for the aspect of the performance of the PCHE.

The conduction thermal resistance of Case 6 was 5.72 % larger than that of Case 4, which shows that the difference of the conduction thermal resistance between the aligned and counter-aligned cases decreased by the introduction of the monitoring channels. As mentioned above, the effect of the monitoring channel on the conduction thermal resistance along the axial position was similar for Cases 4 and 5. However, since the main flow channels were misaligned in Case 6, the effect of the monitoring channel on the conduction thermal resistance can be different along the axial position and the overall effect can be reduced. Figures 4 and 5 show the temperature distributions on *yz*-plane at different axial positions for Case 6.

3. Conclusions

The thermal conduction analyses were performed to examine the effect of the monitoring channels on the thermal performance of the PCHE with zigzag channels. The PCHEs with aligned and counter-aligned main flow channels were considered. The results show that the difference in the conduction thermal resistance of the PCHEs with the straight and zigzag channels is so small when the main flow channels are vertically aligned, regardless of the existence of the monitoring channels. The misalignment of the main flow induced the increase of the conduction thermal resistance. The difference in the conduction thermal resistance of the PCHEs with the aligned and counter-aligned zigzag channels was decreased when the monitoring channels are present.

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