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Analysis of heat transfer performance and pressure drop for different zigzag channel bending angles of PCHEs

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1. Introduction

The Printed Circuit Heat Exchanger (PCHE) is generally fabricated by stacking metal plates with microchannels, which are produced using a chemical etching process, through the diffusion bonding method in high-temperature and high-pressure environments to form a single integrated unit. PCHE provides superior heat transfer performance due to its microchannels, offering a larger heat transfer area per unit volume compared to conventional heat exchangers. This enables the possibility of lightweight and compact designs. Also, because it is a single integrated unit owing to the diffusion bonding process, it has higher mechanical strength compared to heat exchangers joined together using welding.

Due to these characteristics, it is widely used in extreme environments such as ultra-high temperature and pressure. Recently, much research has been conducted on various shapes of microchannels to improve the heat transfer performance of PCHE[(1) - (2)]. In this study, we aim to derive the optimal configuration of PCHE by comparing and analyzing heat transfer performance and pressure drop based on variations in the zigzag channel bending angle using numerical analysis.

2. Numerical Methods and Results

This study was conducted using Ansys Fluent 18.1. Figure 1 illustrates the design parameters for the straight and zigzag channels. The analysis domain consisted of one plate each for the hot side and the cold side. The specifications of the heat exchanger have dimensions of 81.5(L) × 40(W) × 2(H)mm with a channel width of 1.5 mm, a channel height of 0.5 mm, and a uniform 1 mm spacing between channels. Figure 2 indicates that when the number of grids is greater than 14,359,120, the pressure drop remains basically unchanged. To validate the numerical results, a comparison with data from Kwon et al.[(3) - (4)]'s straight channel experiments was presented in Figure 3. The pressure drop and heat transfer rate comparisons between experimental and numerical data show errors of 18% and 10%, respectively, due to the heat exchanger's header not being considered. For the zigzag channels, five types were selected for comparison of heat transfer performance and pressure drop based on bending angle variations. Table I shows the design parameters for numerical models. These include model 1 with straight channels and models 2 to 5 with bending angles of 160°, 140°, 120°, and 100°, respectively. Depending on the angle variation of the zigzag channel, the number of channels per plate is 12 for models 1 to 3, 11 for model 4, and 10 for model 5. Both the straight and zigzag channels have a channel length of 81.5 mm. The heat transfer rate according to the bending angle for the zigzag channel is shown in Figure 4. Figure 5 shows the velocity pathlines (i.e. streamlines) in the middle of the channel for various bending angles at Re=700. It can be observed that turbulence is notably enhanced due to the occurrence of vortexes when the bending angle is less than 140 degrees, resulting in improved heat transfer performance.

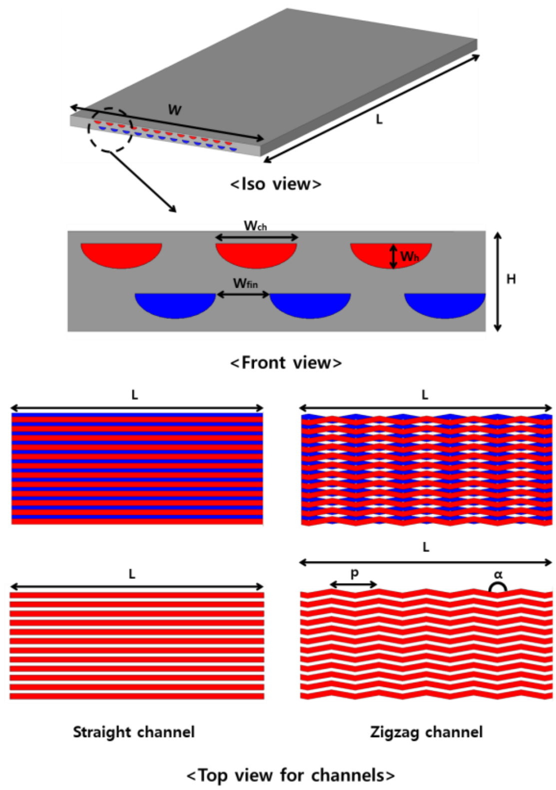

Fig. 1 Schematic diagram for the design parameters of the channels.

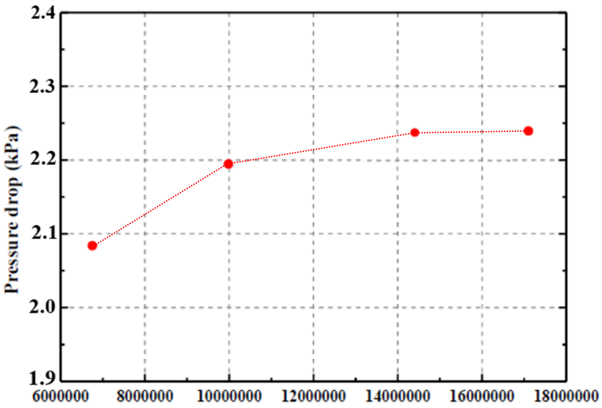

Fig. 2 Pressure drop with the number of grids.

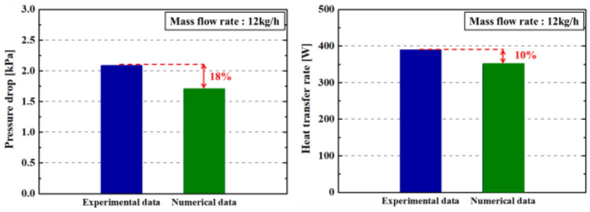

Fig. 3 Comparison of pressure drop and heat transfer rate for experimental and numerical results.

Table I: Design parameters for numerical models

Models No.	bending angle (°)	Pitch (mm)	the number of channels per plate (#)
1	180	-	12
2	160	12.93	12
3	140	12.09	12
4	120	10.95	11
5	100	9.53	10

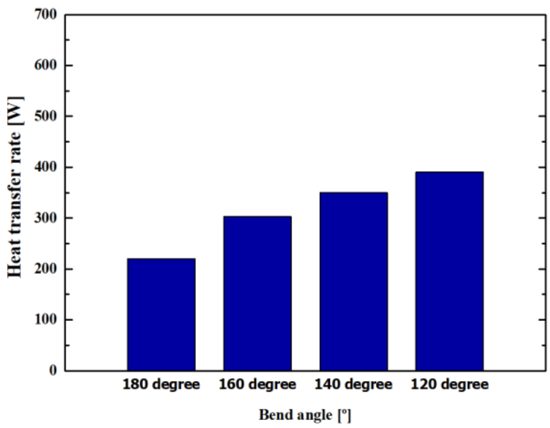

Fig. 4 The heat transfer rate according to the bending angle.

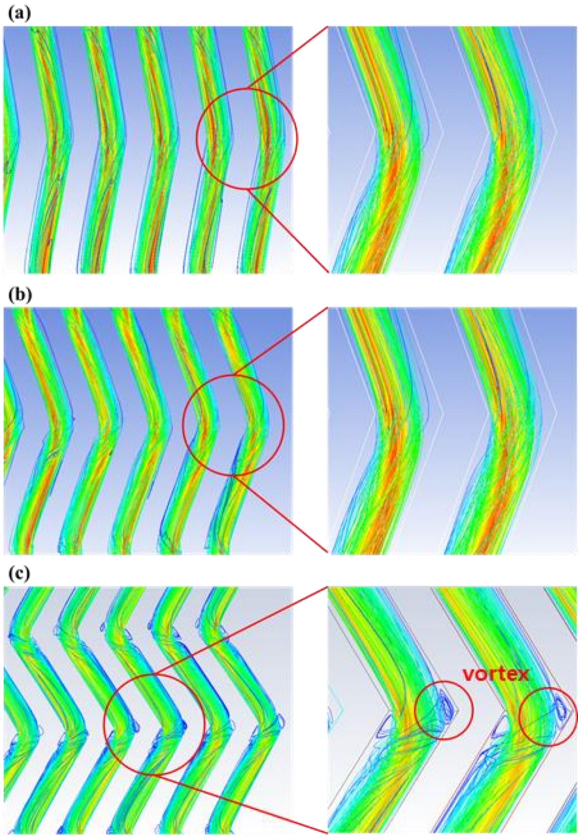

Fig. 5 Comparison of velocity pathlines for (a) 160 degree, (b) 140 degree, and (c) 120 degree.

3. Conclusions

In this study, numerical analysis was utilized to compare and analyze the heat transfer performance and pressure drop between straight channels and zigzag channels. Zigzag channels exhibited significant pressure drop compared to straight channels. However, the irregular flow within the channels resulted in an improvement in heat transfer performance. Also, as the bending angle decreased, there was an increase in pressure drop, yet heat transfer performance improved. We concluded that a zigzag channel with a 120-degree bending angle, which enhances turbulence through vortex formation, represents the optimal PCHE configuration due to its superior heat transfer performance in our test cases. For our future work, we are going to conduct optimal PCHE configuration design by considering the 100~180 degree cases using a comprehensive factor evaluation that compares pressure drop and heat transfer rate, simultaneously.

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