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Preliminary CFD Analysis and Experiment on Double-Etched Circular Channel Printed Circuit Heat Exchanger

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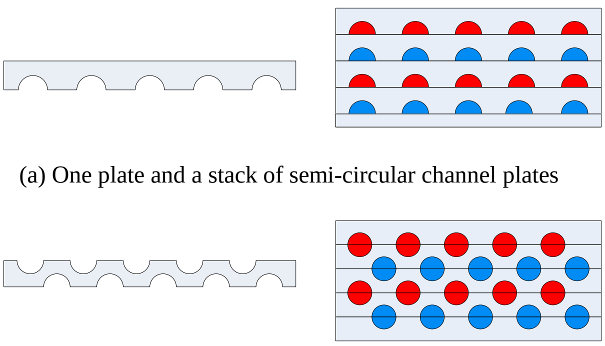
1. Introduction

A Very High Temperature Reactor (VHTR), one of Gen-IV reactor concepts, has been drawing attention as a promising solution for future energy problem since VHTR is inherently safety and high system efficiency is achieved due to its high temperature operation [1]. The heat exchange performance directly affects system efficiency because system efficiency is closely interrelated to the amount of heat transfer from primary side to secondary side. A Printed Circuit Heat Exchanger (PCHE) has been proved to be very efficient owing to its micro-scale channels which leads to extensive heat transfer area and suitable to be adopted in VHTR. In this paper, double-etched circular channel PCHE has been proposed which is unlike conventional semi-circle channel PCHE. Thermal-hydraulic performance analysis of PCHEs with two different channel cross-section shapes was carried out based on CFD and experiment.

2. Double Etched Circular Channel PCHE Concept

2.1 Double Etched Circular Channel PCHE

Almost every existing PCHEs has semi-circle shape cross-section [2]. Circular channel PCHE was built for performance comparison with conventional one. Fig. 1 represents two different types of PCHE studied in this paper. There are several advantages in circular channels in terms of thermal and hydraulic performance.



(a) One plate and a stack of semi-circular channel plates

(b) One plate and a stack of double-etched circular channel plates

Fig. 1. Cross-section of etched plates

2.2 Thermal Performance Improvement

The amount of heat transfer is as follows:

$$\dot{q} = UA\Delta T_{LM}$$

With the rest of conditions fixed, heat transfer can be enhanced if heat transfer area is widened. When channel length and diameter is fixed, circular channel has wider heat transfer area than semi-circular channel and therefore higher thermal performance.

2.3 Hydraulic Performance Improvement

The pressure drop in a channel is calculated:

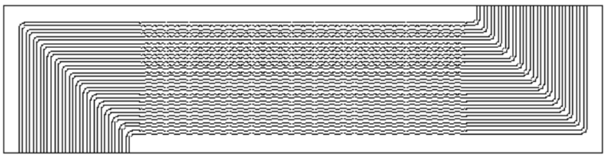
$$\Delta P = f \cdot \frac{1}{2}\rho v^2 \cdot \frac{L}{D_h}$$

Pressure drop is inversely proportional to hydraulic diameter. With the same diameter, hydraulic diameter of circular channel is bigger than that of semi-circular channel by 1.6 times. When the rest of conditions remain the same, pressure drop of circular channel is 60% of that of semi-circular channel resulting in improved hydraulic performance.

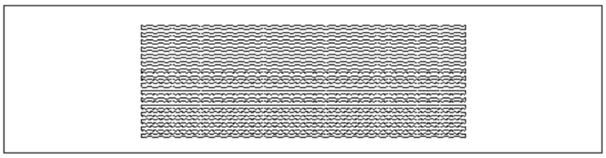
2.4 Fabrication of Double-Etched PCHE

A circular channel PCHE was fabricated and shown in Fig. 2. It is 51(mm) x 210(mm) x 35(mm) and has 2 inlets and 2 outlets on sides. Hot and cold helium flows in the opposite direction resulting in a countercurrent flow. Its flow channel configuration is shown in Fig. 3. We defined the wavy channel region as core region and the rest of straight channel region as branching region for convenience. If this is a case, circular shape is only maintained in the core region and the channel is semi-circular shape in branching region, because branching cannot be accomplished if circular shape is kept in the branching region.

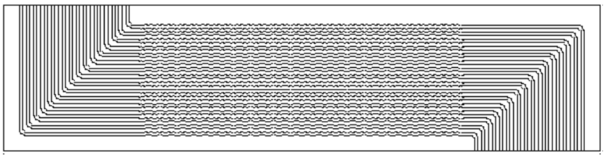
Fig. 2. Double-etched circular channel PCHE



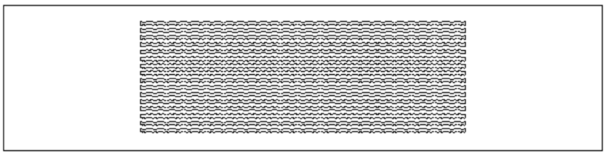
(a) The front (hot side)



(b) The back (hot side)



(c) The front (cold side)



(d) The back (cold side)

Fig. 3. The front and the back of etching plate of Double-etched circular channel PCHE

The detailed geometry information of two types of PCHE is summarized in Table I. There are 20 plates, 16 channels on each plate resulting a total of 320 channels. Diameters of both are equal to 1.2mm. Hydraulic diameters are not equal because of the channel cross-section shape difference. Total channel length and core channel length are the same but heat transfer area of circular PCHE is larger than that of conventional one.

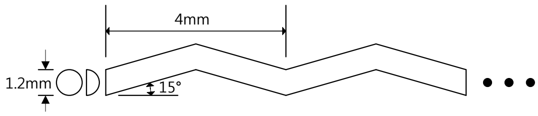
In this paper, thermal-hydraulic performance analysis has been conducted and performance improvement were investigated both numerically and experimentally.

Table I: PCHE geometry information.

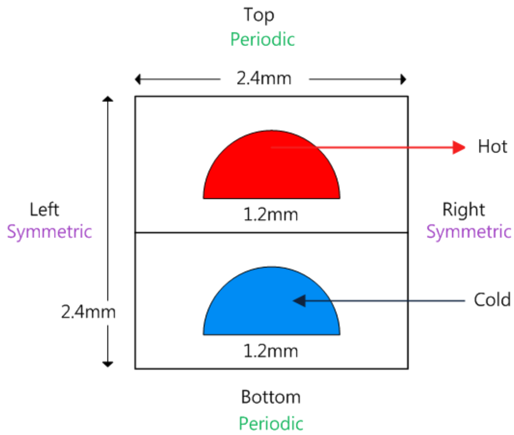
	semi-circle	circle
Number of hot channels	160	160
Number of cold channels	160	160
Diameter (mm)	1.2	1.2
Hydraulic diameter (mm)	0.733	1.2
Total heat transfer area (m^2)	0.1052	0.1180
Core heat transfer area (m^2)	0.05775	0.07057
Total channel length (mm)	213.1	213.1
Core channel length (mm)	117	117

3. Preliminary CFD Analysis

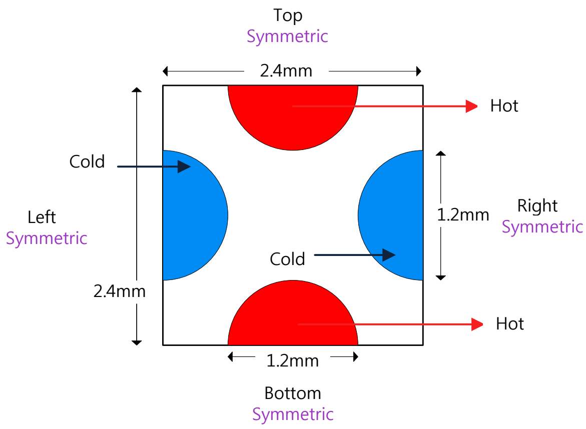
Fig. 4 shows the considered geometry of semi-circular and circular PCHE and their boundary conditions.



(a) Top view



(b) Front view (semi-circular PCHE)



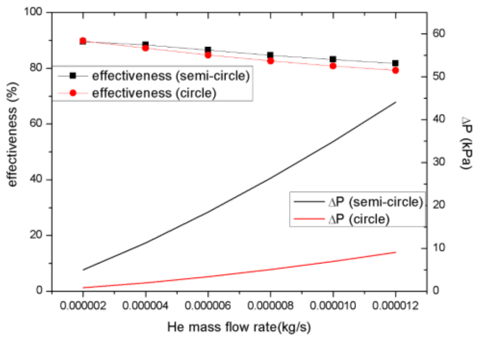
(c) Front view (circular PCHE)
Fig. 4. Considered geometry and boundary conditions.

The tested conditions are shown in Table II. In this study, inlet temperature and outlet pressure of both hot and cold side are set up as a constant, respectively. Mass flow rates of hot and cold side remain the same in all cases. The numerical simulation was performed using FLUENT.

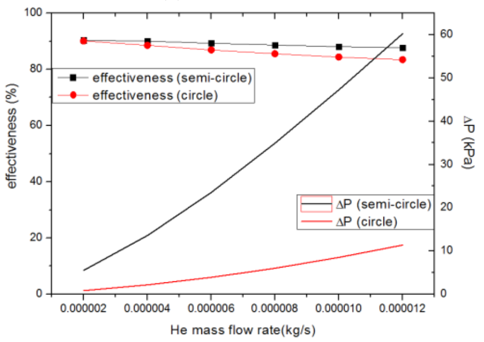
Table II: Tested conditions.

	Hot side	Cold side
Mass flow rate (10^{-6} kg/s)	2~12	
Heat transfer rate (W)	1~2	
Inlet temperature (K)	500	300
Outlet pressure (bar)	1	

Fig. 5 represents CFD results for both types of PCHE. For turbulent case, standard k-ε model and standard wall functions were used. Symbol lines and solid lines indicate effectiveness and pressure drop, respectively. When mass flow rate per channel is equal, there is little difference between semi-circle and circle PCHE effectiveness. The difference gets bigger as mass flow rate increases and the maximum difference is smaller than 3% and 5% for laminar case and turbulent case, respectively. On the other hand, a huge difference exists in pressure drop. Pressure drop grows bigger as mass flow rate increases and the value of semi-circular PCHE is 5~6 times higher than that of circular PCHE. It is found that for the same conditions, turbulent case has higher pressure drop as well as higher effectiveness compared to laminar case. The gap between two cases grows bigger as mass flow rate increases.



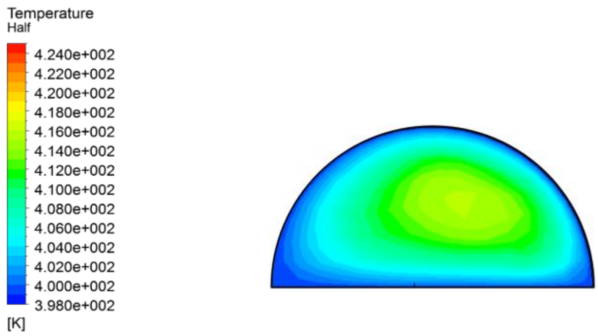
(a) Laminar case



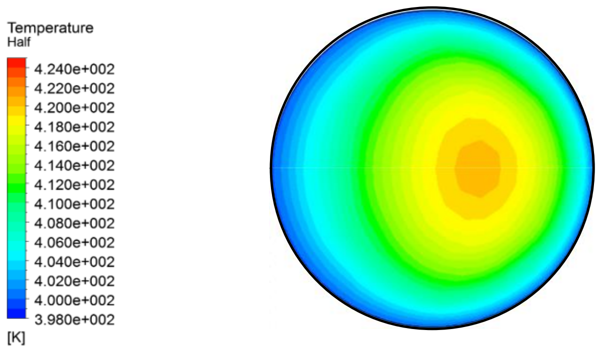
(b) Turbulent (k-ε) case

Fig. 5. Effectiveness and pressure drop

There is a certain difference between effectiveness of semi-circle and circle PCHE. It is caused by channel shape. The temperature profiles at the middle of the channels are shown in Fig. 6. In a semi-circular channel, the distance between the center of channel and channel wall is a half of channel radius. But the distance is twice longer in a circular channel. Hence, heat flux from the center to wall, which is proportional to temperature gradient, is larger in semi-circle channel resulting a little higher effectiveness.



(a) Semi-circle PCHE



(b) Circle PCHE

Fig. 6. Temperature profile at the middle of PCHE (Laminar, $\dot{m}$ =0.000006kg/s)

4. Preliminary Experiments

Fig. 6 shows the real size and configuration of the PCHE experimental rig. It consists of hot and cold side open loop, respectively.

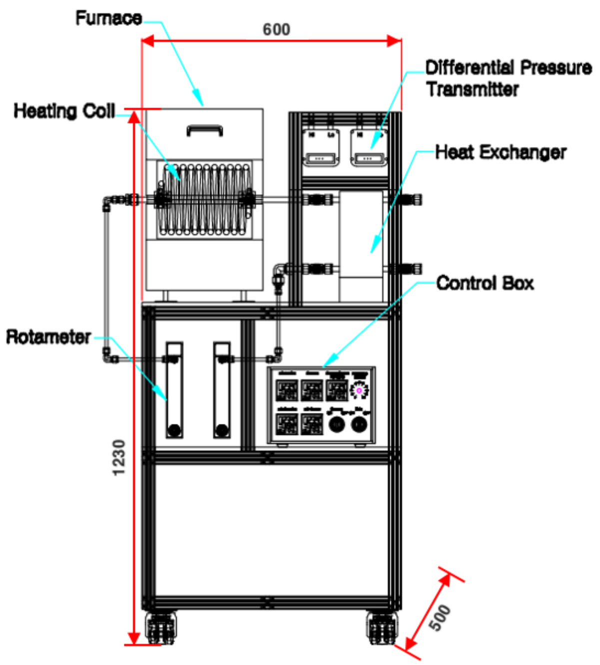


Fig. 6. Experimental rig.

Rotameters are used to measure volume flow rate of hot and cold helium. Hot side helium is heated to 500K passing through heater (2kW). Temperature at the inlet and outlet is measured by K-type thermocouples. Differential pressure gauge is used to measure pressure drop in PCHE. Helium which has passed through PCHE is than exhausted in the atmosphere.

5. Comparison of CFD and Experimental results

As soon as the experimental rig set up is finished, experiments will be carried out under the same condition as that of CFD analysis. The results will be compared and further discussions will be made.

6. Summary

This study has proposed channel cross-section shape modification for thermal-hydraulic performance improvement. With the rest of conditions remain the same, circular channel has wider heat transfer area and smaller hydraulic diameter than semi-circular channel. Numerical simulation shows that effectiveness doesn't change much while pressure drop significantly falls by 80%. Experiments will be conducted as soon as experimental system is set.

ACKWLEDGEMENT

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