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Evaluation of Thermo-Fluid Performance of Compact Heat Exchanger with Corrugated Wall Channels

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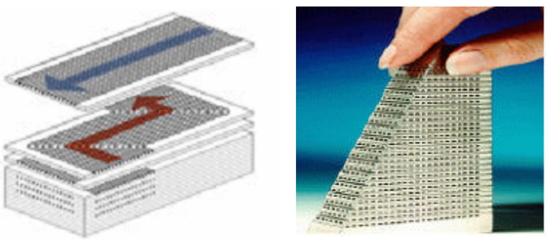
1. Introduction

One of the key components of an indirect nuclear hydrogen production system is an intermediate heat exchanger (IHX). For the IHX, a printed circuit heat exchanger (PCHE) is known as one of the promising types due to its compactness and ability to operate at high temperatures and under high pressures. The PCHE is a relatively new heat exchanger. It has been commercially manufactured only since 1985 and solely by one British vendor – Heatric^{TM} [1]. Due to its short history and limited production, sufficient information about the PCHE is not available for the design of the IHX in open literatures. The predominant shape of flow channels of the PCHE is laterally corrugated [2]. The flow in a corrugated wall channel is very interesting since a variety of flow phenomena can be considered by changing the amplitude-to-wavelength ratio. In the present paper, thermo-fluid performance of a heat exchanger with a typical PCHE geometry has been evaluated. Computational fluid dynamics (CFD) analysis was performed to analyze a gas flow behavior in a corrugated wall channel.

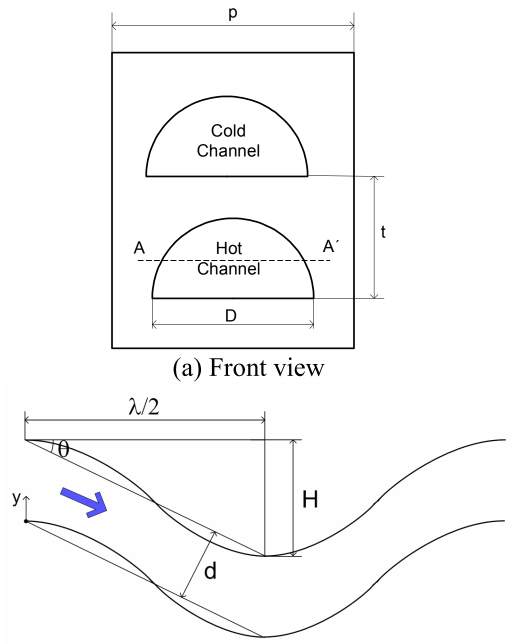
2. Physical Model

PCHEs are constructed from flat metal plates into which fluid flow channel are chemically made. As shown in Fig. 1(a), the etched plates are stacked and diffusion bonded together to form strong and compact heat exchange cores. A typical cross section of a plate stack is shown in Fig. 1(b). The flow passages are approximately semi-circular in cross-section, being typically 1~2 mm wide.



(a) Fabrication of PCHE (b) Section of PCHE
Fig. 1. Concept of PCHE [1].

Fig. 2 shows the considered geometry representing a unit cell of a typical PCHE. The hot and cold fluids flow in counterflow at the separated channels.



(a) Front view

(b) Top view

Fig. 2. Considered geometry.

Typical geometric data of a PCHE are selected for the present analysis. Table 1 summarizes the geometric data adopted. The tested conditions are shown in Table 2. Two cases, i.e., laminar and turbulent flow conditions, are considered in this work. Periodic boundaries are assigned for the four outside surfaces (left, right, top, bottom sides in Fig. 2(a)) of the unit cell. The CFD analysis was performed using a commercial code CFX 5.7.1 [3].

Table 1. Geometric data for CFD analysis

Channel diameter (D)	1.7976 mm
Channel pitch (p)	2.44 mm
Plate thickness (t)	1.6 mm
Wavelength (λ)	9.3333 mm
Slope angle (θ)	26^o
Total length	831 mm

Table 2. Tested conditions

		Hot channel	Cold channel
Fluid		Helium	Helium
Solid structure material		Alloy 617	Alloy 617
Inlet fluid temperature		950℃	450℃
Ave. Re number	Case1: Laminar	944	936
	Case2: Turbulent	3540	3820

3. Numerical Results

Fig. 3 shows the velocity profile and its development in the hot channel of the laminar case. It shows a fast flow development. Only after passing 1~2 wavelengths, the flows are close to the developed ones. In the case of the turbulent flow, the flow development is found to be faster.

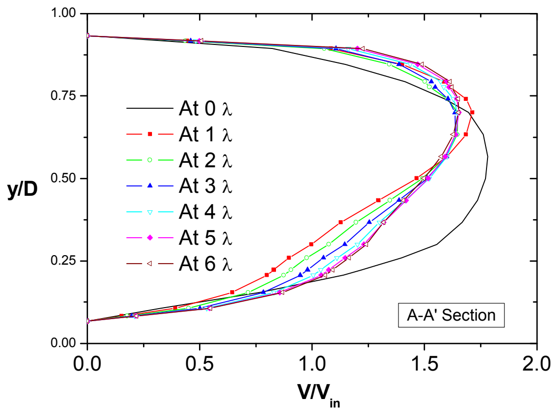


Fig. 3. Flow development (hot channel of laminar case).

Fig. 4 shows a typical temperature contour in the channel. It shows that the conductive resistance is much smaller than the convective one. This indicates that an effort to increase the conductive heat transfer is not effective for a better heat exchange.

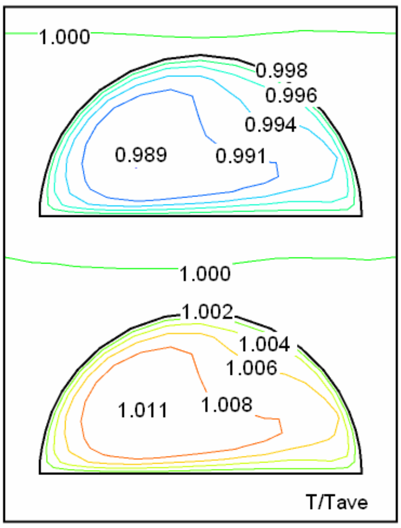


Fig. 4. Temperature contour (mid section of laminar case).

The calculated overall thermo-fluid performances in the tested cases are summarized in Table 3. For comparison, a typical heat exchanger model used in the MARS-GCR analysis [4] is also added. It should be noted here that the heat exchangers in Table 3 are not optimized ones and their comparisons are not completed. However, the table clearly shows the heat transfer enhancement by the PCHE geometry. It also shows the tremendous increase of the pressure drop in the case of the turbulent flow.

Table 3. Summary of predicted performance

Source	CFX Results		MARS-GCR
Heat exchanger	PCHE-Laminar	PCHE-Turbulent	Shell & Tube
Re (hot fluid)	944	3540	7554
Overall heat transfer coeffi. (W/m^{2}K)	1493	1991	539
Heat transfer area for 600 MWth (m^2)	21,565	5,931	28,510
LMTD (K)	18.6	50.8	38.8
Effectiveness (%)	95	91	94
Pressure drop (hot fluid, bar)	0.43	2.6	0.53

4. Conclusions

A numerical analysis was performed for a unit cell of a heat exchanger with a typical PCHE geometry using the CFX 5 code. The CFX 5 results show the heat transfer enhancement by the PCHE geometry. However, a large pressure drop was found in the case of the turbulent flow. Therefore, an optimization study is found to important for the design of the IHX.

ACKNOWLEDGMENTS

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