Numerical Study on Longitudinal Heat Conduction in Printed Circuit Heat Exchanger

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1. Introduction

A printed circuit heat exchanger (PCHE) is classed as a plate machined heat exchanger. A flow plate is manufactured by etching process, typically. A bundle of flow plates is bonded by diffusion bonding. A main advantage of a PCHE is a compact size compared with conventional shell and tube heat exchanger. PCHEs are widely used for industry recently

A PCHE is a candidate intermediate heat exchanger type for a high temperature gas cooled reactor (HTGR). The use of PCHEs saves capital cost with good operating efficiency and effectiveness. The longitudinal heat conduction affects the performance of PCHE in HTGR operating condition, high temperature and high pressure. Thickness of flow plate and pitch between channels is large for enduring pressure in high temperate environment. The porosity of a PCHE for HTGR is about 0.1. That means metal walls easy to conduct a heat bypass and it reduces the effectiveness [1]. It also makes hard to develop accurate experimental heat transfer correlation for PCHE. The overall performance of a heat exchanger is degraded by the longitudinal conduction for a HTGR application.

The effect of longitudinal conduction for a PCHE in HTGR operating condition is studied with numerical calculation.

2. Methods and Results

In this section the shape of the PCHE for HTGR is described and some calculation method and conditions are described

2.1 dimension of PCHE

The material for the PCHE is Alloy 617. The dimension of a PCHE channel is design by referencing ASME Section VIII. Following Table I summarize the dimension of a PCHE channel for present study.

Table I: Dimension of a PCHE channel

	Value	Unit
Channel diameter	1.5	mm
Plate thickness	2.5	mm
Channel Pitch	3.8	mm
Channel length	600	mm
Allowable design pressure	10	MPa
Allowable design stress ASME Section II Part D	9.65	MPa

2.2 Numerical Model

Governing equations are derived for a counter-flow heat exchanger (Fig. 1) with longitudinal heat conduction.

Hot fluid: $\dot{m}\frac{dh}{dx} = hA\left(T_{f,h,i} - T_{w,h,i}\right)$

Cold fluid: $\dot{m}\frac{dh}{dx} = hA\left(T_{w,c,i} - T_{f,c,i}\right)$

Wall (hot): $k_w A_x \Delta x \frac{\partial T_w^2}{\partial x^2} + k_w A_y \frac{dT_w}{dy} + hA\left(T_{f,h,i} - T_{w,h,i}\right) = 0$

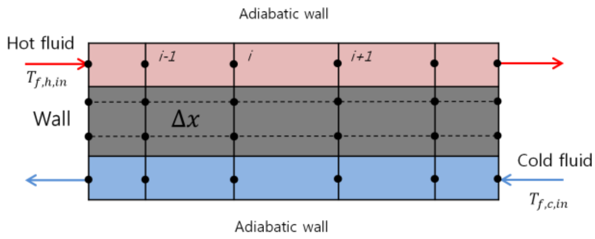

Fig. 1 counter-flow heat exchanger modeling

2.3 Calculation methods

Longitudinal heat conduction parameter is defined by

$$\lambda = \frac{k_w A_w / L}{\dot{m} c_p}$$

Following are assumptions for evaluating wall heat condition only. All physical properties such as fluid thermal conductivity, isobaric-specific heat, viscosity, density and solid thermal conductivity were fixed as constant value, helium properties at 650 °C. Flow regime was laminar and Nusselt number was also constant value, 4.089. The ratio of fluid heat capacity was 1.0 for balance flow condition.

Mass flow rate, the denominator of the parameter, was controlled to evaluate the effect of longitudinal conduction.

The mean temperature difference is defined by

$$\Delta T_{lm} (= LMTD) = \frac{\Delta\vartheta_1 - \Delta\vartheta_2}{\ln((\Delta\vartheta_1)/(\Delta\vartheta_2))}$$

ϑ is terminal temperature difference. The heat load is defined by

$$\dot{Q} = FF_{\lambda}(UA)\Delta T_{lm}$$

A correction factor F is 1 for pure-counter flow configuration. Another parameter F_λ is a correction factor for compensate longitudinal conduction. The performance degradation was evaluated in terms of F_λ.

4. Results

Calculation results are showed in **Table II** and Fig. 2. The performance degradation is negligible when longitudinal heat conduction parameter is less than 0.0001.

PCHE is typically designed with Reynolds number in the range of 500 to 2000. The overall performance degradation of heat exchanger is degraded about 10% in this range.

Table II Summary of calculation results

λ	F_λ	Re
0.000086	0.998237	16135
0.000863	0.965156	1614
0.001511	0.939924	922
0.003022	0.887663	461
0.008633	0.748017	161.4
0.015109	0.646234	92.2
0.030218	0.507599	46.1
0.060435	0.37176	23.1
0.086333	0.307065	16.1

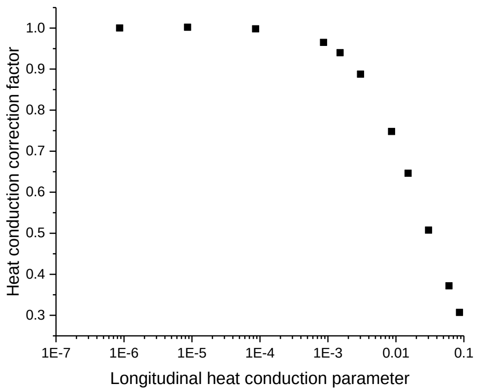

Fig. 2 Degradation of the overall heat exchanger performance due to longitudinal heat conduction

4. Conclusions

The effect of longitudinal heat conduction for a PCHE was briefly reviewed in a HTGR application. The PCHE is subjected to endure high temperature and high pressure. The PCHE plate thickness and channel pitch is relatively large compared with conventional PCHEs. It was showed that the performance is degraded as longitudinal parameter increases.

In thermal sizing stage, a heat bypass effect may be considered using the modified effectiveness method with well-known channel such as straight semi-circular channel [1]. Studies on heat transfer correlation for some innovative channels such as zig-zag, s-shaped and air-foil is in progress. The consideration on longitudinal heat conduction is required to enhance accuracy of heat transfer correlations. It is also required for PCHE thermal sizing with a lumped method.

REFERENCES

[1] JE. Hesselgreaves et al., Compact Heat Exchnagers: selection, Design and Operation, Elsevier (2017)