# Analysis for Evaluating the Heat Transfer Performance of PCHE

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## 1. Introduction

Sodium cooled fast reactor or gas cooled reactor coupled with a S-$CO_2$ Brayton cycle can provide significantly improved cycle efficiency relative to that with a Rankine steam cycle at high temperature operating condition. Among the various components in the S-$CO_2$ Brayton cycle, primary/secondary coolant heat exchanger and recuperator are the essential components. Because those heat exchangers should be operated at very high pressure and temperature conditions, the heat exchanger with micro-channels can be a candidate. Thus, a Printed Circuit Heat Exchanger (PCHE) [1] in which micro-channel is made by using etching and diffusion bonding technologies is a viable option. In this study, a simple analytical model is presented for evaluating heat transfer performance of PCHE, and the applicability of the model is evaluated using the available data.

## 2. Analytical Model

The flow passages of PCHE are approximately semi-circular in cross-section, and have zig-zag shape along the flow direction. The hot and cold fluids flow in counter-flow direction at separated channels. In the model, PCHE is represented by a hot channel and a cold channel which are connected through solid wall as shown in Fig. 1.

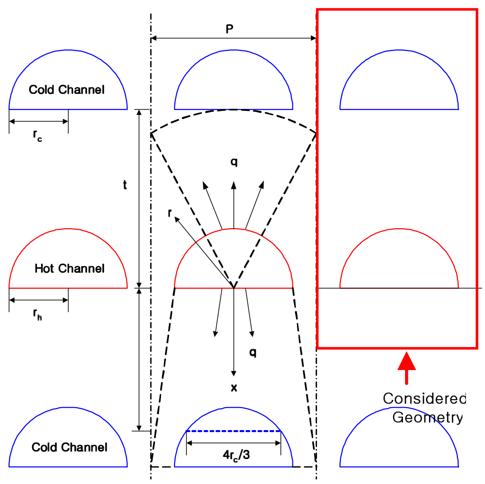


Fig.1 Considered geometry and conduction model

The flow is assumed to be steady and one dimensional. Also, the axial conduction along the flow direction is neglected. The governing equations which are composed of the balances for mass, momentum and energy are given as follows.

$$\frac{\partial(\rho u)}{\partial z} = 0 \tag{1}$$

$$\frac{\partial(\rho u^2)}{\partial z} + \frac{\partial P}{\partial z} + \frac{f}{2De}\rho u^2 = 0 \tag{2}$$

$$\frac{\partial}{\partial z}[\rho u\,(h + \frac{u^2}{2})] = Q \tag{3}$$

In Eqs. (1)~(3), ρ, u, z, P, f, $D_e$, h and Q are the density, the velocity, the axial coordinate, the pressure, the friction factor, the hydraulic diameter, the enthalpy and the heat transfer rate per unit fluid volume, respectively. The heat transfer rate (QV, V=fluid volume) can be represented by using the log-mean temperature difference ($\Delta T_{LMTD}$), the overall heat transfer coefficient (U) and the heat transfer area (A) as,

$$QV = UA\Delta T_{LMTD} \tag{4}$$

and the overall heat transfer coefficient (U) is defined using the hot channel heat transfer coefficient ($H_h$), the cold channel heat transfer coefficient ($H_c$) and the thermal resistance of wall ($R_w$) as follows.

$$U = \left[R_h + R_w + R_c\right]A \quad where\ R_h = \frac{1}{H_h A_h},\ R_c = \frac{1}{H_c A_c} \tag{5}$$

The thermal resistance of wall is calculated by considering only transverse conduction across the wall as shown in Fig. 1. Based on the assumption that the cold channel wall temperature in upper part is approximated by the temperature at r=t, and that in lower part is approximated by the temperature at $x = t - (4\sqrt{2}/3)r_c$ which corresponds to average chord length of semi-circle, the one-dimensional conduction analysis results in the following thermal resistance of wall.

$$R'_{w,upper} = \frac{t\ln(t/r_h)}{2r_c k_w}$$

$$R'_{w,lower} = \frac{A(x=x_1)\ln(\frac{A(x=x_1)}{C})}{\pi r_c k_w S} \tag{6}$$

*where*

$$S = \frac{P - 2r_h}{t}\Delta z \qquad P = 2r_h\Delta z$$

In Eq. (6), $R_w^{'}$ and $\Delta z$ indicate the thermal resistance of wall per unit length and the length increment along the flow direction, respectively.

## 3. Analysis Results

With the given geometry and the inlet flow conditions of cold and hot channels, Eqs. (1)~(6) are numerically solved using the finite difference method. In this study, using the existing experimental data, the applicability of the model is examined. The experimental data presented in Ref. [2] is selected as the reference data since the detailed internal structure of PCHE is described there and also the data was produced in a supercritical $CO_2$ loop. The geometrical data of PCHE and the experimental conditions used in the analysis are shown in Table 1 and Table 2, respectively.

Table 1. Geometrical data for analysis

| | hot channel | cold channel |
|---|---|---|
| Plate material | SS316L | SS316L |
| Plate thickness, mm | 1.63 | 1.63 |
| Number of plates | 12 | 6 |
| Number of channels | 144 | 66 |
| Flow channel bending angle, degree | 115 | 100 |
| Horizontal pitch, mm | 4.50 | 3.62 |
| Pitch of right angle to flow direction, mm | 2.97 | 3.25 |
| Flow channel configuration | semi-circle | semi-circle |
| Wall width, mm | 0.60 | 0.70 |
| Channel width, mm | 1.90 | 1.80 |
| Channel depth, mm | 0.90 | 0.90 |
| Hydraulic diameter of channel, mm | 1.15 | 1.15 |
| Heat transfer area, $m^2$ | 0.697 | 0.356 |
| Cross sectional area of channel, $m^2$ | 0.00020 | 0.000092 |
| Channel active length, mm | 1000 | 1100 |
| Inlet and outlet part length, mm | 49.0 | 46.5 |
| Channel length, mm | 896 | 896 |

Table 2. Experimental conditions used in the analysis

| Test No. | $T_{h\_in}$ [°C] | $T_{h\_out}$ [°C] | $T_{c\_in}$ [°C] | $T_{c\_out}$ [°C] | $DP_h$ [kPa] | $DP_c$ [kPa] | $m_{h\_in}$ [kg/hr] | $m_{c\_in}$ [kg/hr] |
|---|---|---|---|---|---|---|---|---|
| 609-1 | 280.1 | 111.8 | 107.8 | 260.7 | 9.96 | 34.93 | 42.8 | 42.8 |
| 611-1 | 279.9 | 111.6 | 107.9 | 259.9 | 26.66 | 93.07 | 79.6 | 79.6 |
| 614-1 | 279.9 | 110.3 | 107.9 | 256.0 | 24.18 | 73.22 | 74.9 | 74.9 |
| 616-1 | 280.0 | 110.0 | 108.1 | 254.9 | 25.63 | 79.17 | 83.3 | 83.3 |
| 617-1 | 280.1 | 109.9 | 108.2 | 252.8 | 25.91 | 80.35 | 87.0 | 87.0 |

In Table 2, DP is the pressure drop, and the subscripts like h, c, in and out indicate the hot channel, the cold channel, the inlet and the outlet, respectively.

As for the heat transfer coefficient and friction factor, the empirical correlations developed in the experiment [2] were adopted. The comparisons between the calculation results and the measured data are presented in Fig. 2. The prediction accuracies are within ±3.0 % for temperatures and within ±3.2 % for pressure drops (the prediction accuracy for cold channel pressure drop is ±3.1 %). Although it can be considered that the good accuracies were obtained by using the correlation developed in the experiment, the developed methodology can be utilized in the evaluation of heat transfer performance analysis of PCHE and the development of thermal sizing method.

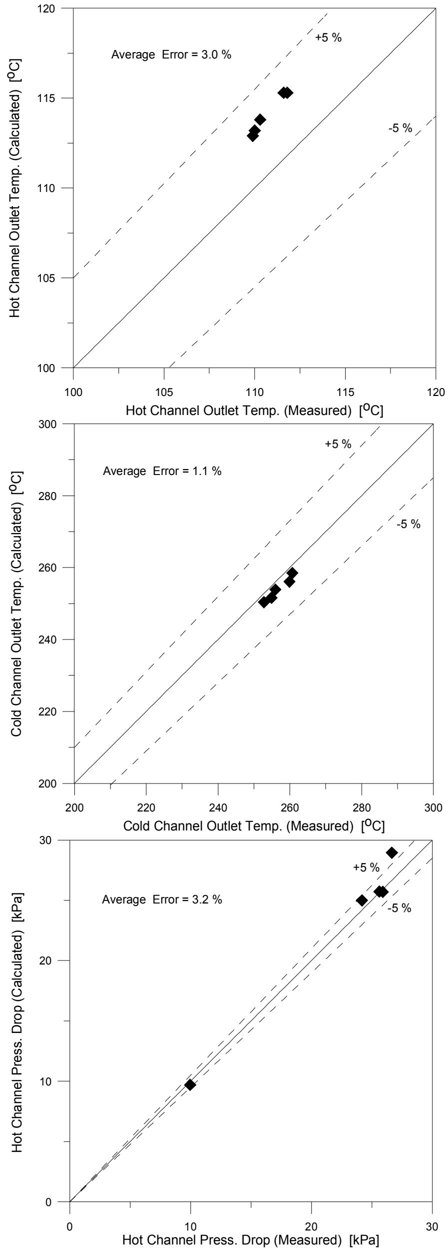


Fig.2 Comparison between calculation and data

## 4. Conclusion

To evaluate heat transfer performance of PCHE, a simple analytical model was developed, and its applicability was evaluated with the available experimental data. The results show that the calculation results by the developed model showed good agreement with the experimental data.

## REFERENCES

[1] Heatric™, hppt://www.heatric.com/.
[2] T. Ishizuka et al., Thermal-Hydraulic Characteristics of a Printed Circuit Heat Exchanger in a Supercritical $CO_2$ Loop, Proceedings of 11th Int. Topical Conf. on Nuclear Reactor Thermal-Hydraulics, Avignon, France, Oct. 2-6, 2005.