Development of Advanced Printed Circuit Heat Exchanger Analysis Code for Various Flow Paths

Seongmin Son[a], Youho Lee[a], Jeong Ik Lee[a]*

[a]*Dept. Nuclear & Quantum Eng., KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea*
**Corresponding author: jeongiklee@kaist.ac.kr*

1. Introduction

Heat exchangers of gas-cooled reactors need large surface area to achieve effective heat transfer. Among many options, Printed-Circuit Heat Exchanger (PCHE) is regarded as a potent candidate because it provides exceptionally large surface area with compactness.

Previously developed PCHE analysis codes models flow path configurations with either sole counter flow [1] or sole cross flow [2]. However, an actual PCHE usually consists of various hot and cold channel configurations, including regions of counter flow, cross flow, and parallel flow, depending on header locations. Figure1 shows various PCHE flow configurations with different header locations.

In this research, we (1) develop an advanced PCHE analysis code that gives PCHE performance by capturing flow configuration effects with respect to different header locations, and (2) discuss design implications of flow path dependent PCHE performance.

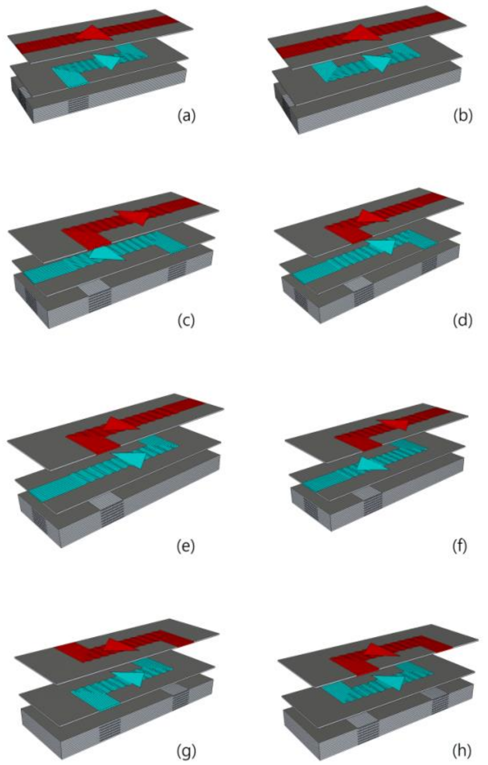

Figure **1**. Eight different PCHE flow configurations with different header locations

2. Development of PCHE analysis code

Numerical methods and algorithms were used to get temperature and pressure profile of PCHEs with the eight flow configurations shown in Figure1.

Generally, PCHE analysis methods for various flow configurations are mostly the same. Yet, we can categorize the eight flow configurations into two in order to leverage their similarities in numerical solution schemes. Case (a) ~ (f) and case (g) ~ (h) exhibit different characteristics because of flow structures. For Case (a) ~ (f), only 2 types of flow configurations are present; counter flow and cross flow. For case (g) ~ (h), parallel flow regions is included in addition to the cross and counter flow regions. This leads to the necessity of developing different meshing schemes for two categories, as illustrated in Figure2

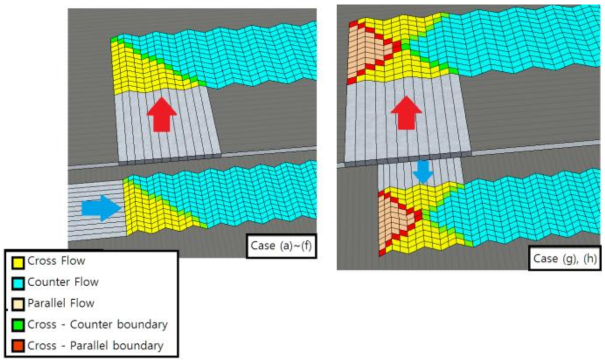

Figure 2. Meshing Scheme for PCHE analysis

3. PCHE Performance Results

3.1. Effectiveness analysis of PCHE with various flow paths

With the developed code, we analyzed effectiveness of PCHE with respect to different flow path configurations. Reference PCHE design and operating conditions are shown in Table 1.

Table 1. Reference Conditions

Parameter	Value
Hot Channel Diameter (mm)	1.8
Cold Channel Diameter (mm)	1.8
Hot channel fluid	CO_2
Cold channel fluid	CO_2
Hot channel inlet temperature (K)	700
Cold channel inlet temperature (K)	500
Hot channel inlet pressure (kPa)	20000
Cold channel inlet pressure (kPa)	20000

Hot channel flow rate (kg/s)	1
Cold channel flow rate (kg/s)	1
Plate material	AISI 316 (k=15W/m K)
Plate thickness (mm)	1.4
No. of Hot fluid channels	500
No. of Cold fluid channels	500
$\mathbf{L_x}$ (m)	0.065
$\mathbf{L_y}$ (m)	0.065
$\mathbf{L_z}$ (m)	0.042

PCHE effectiveness was obtained with different PCHE length (L_z) as shown in Figure3. It can be inferred that header location, and flow path configurations become less important with increasing effectiveness.

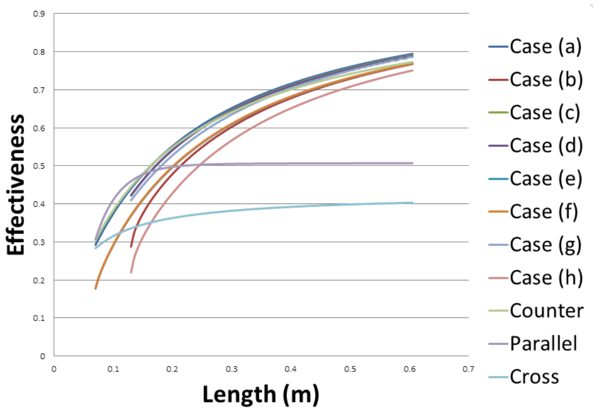

Figure 3. Effectiveness changes to belong the length of PCHE change

4.2. Pressure drop analysis of PCHE by flow path type

Another important factor to PCHE performance is pressure drop. Figure4 presents relationship between pressure drops of each PCHE types shown in Figure1 with respect to different PCHE length (L_z).

Pressure drops mainly depends on their flow path shapes. In hot channels, ranking for pressure drop are Case (a) ≅ Case (b) ≅ Case (c) ≅ Case (d) ≅ Case (g) ≅ Case (e) > Case (f) > Case (h). For cold channels, Case (a) ≅ Case (c) ≅ Case (d) ≅ Case (g) ≅ Case (e) > Case (f) > Case (b) ≅ Case (h).

4. Summary

We developed an advanced PCHE analysis code that captures various flow path effects with respect to different header locations.

In summary of this research, three important factors of the design HX - effectiveness, hot channel pressure drop, cold channel pressure drop are ranked descending order as follows.

Effectiveness:
Case (a) > Case (c) ≅ Case (d) > Case (g) > Case (e) ≅ Case (f) > Case (b) ≫ Case (h)

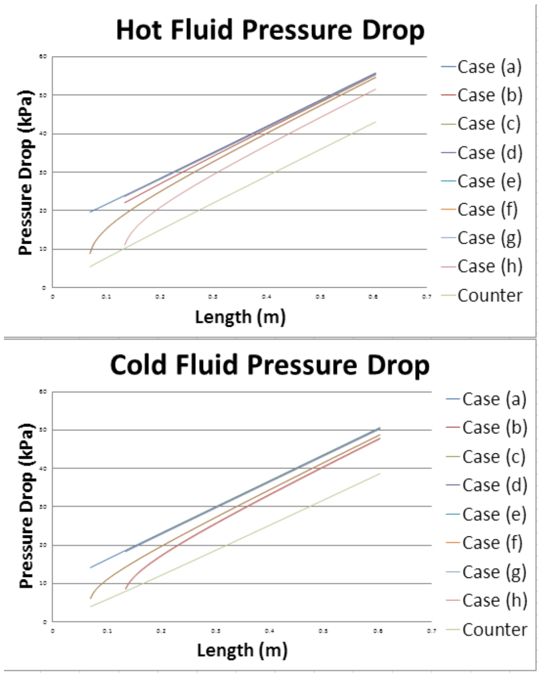

Figure 4. Hot and cold channel pressure drop profiles

Hot Fluid Pressure Drop:
Case (a) ≅ Case (b) ≅ Case (c) ≅ Case (d) ≅ Case (g) ≅ Case (e) > Case (f) > Case (h)

Cold Fluid Pressure Drop:
Case (a) ≅ Case (c) ≅ Case (d) ≅ Case (g) ≅ Case (e) > Case (f) > Case (b) ≅ Case (h)

From the view point of effectiveness maximization, flow path of case (a) in Figure 1 is best choice while case (h) is worst case. The opposite is true from view point of pressure drop minimization.

For PCHEs of low effectiveness operation, header locations and its flow path configuration bear important design implications in terms of achieving desirable effectiveness. Yet, for PHCEs of high effectiveness operation, design priority should be given to pressure-drop minimization with diminished importance in effectiveness sensitivity on header locations.

REFERENCES

[1] Frank P. Incropera, David P. Dewitt, Theodore L. Bergman, Adrienne S. Lavine., 2013. Foundations of Heat Transfer, john Wiley & Sons, Inc., Hoboken, New Jersey, pp. 494-495.
[2] Su-jong Yoon, Piyush Sabharwall, and Eung-Soo Kim, Numerical study on crossflow printed circuit heat exchanger for advanced small modular reactor,