Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Flow Distributions of Printed Circuit Heat Exchanger for Supercritical CO_2 Precooler

Han Seo, Byung Ha Park, Yong-Wan Kim, Yoonhan Ahn, Heungjun Chung, Jae Eun Cha*
Korea Atomic Energy Research Institute (KAERI)
Daedeok-daero 989-111, Yuseong-gu, Daejon, Republic of Korea, 34057
**Corresponding author: jecha@kaeri.re.kr*

1. Introduction

Supercritical CO_2 (SCO_2) has been extensively considered as one of the next power generation system because the system can be operated in wide range of heat source temperature [1-3]. The SCO_2 cycle is operated above the critical state, thus the system components and overall size of the system can be decreased compared to the steam and gas Brayton cycles. For the compact size of heat exchanger, printed circuit heat exchanger (PCHE) has been widely studied as the heat exchangers for the SCO_2 Brayton cycle. The volume of the PCHE can be minimized up to 1/30 compared to conventional shell-and-tube heat exchangers with the same heat duty [4]. In a flat metal plate, chemical etching process is conducted to make flow channels, and the etched plates are joined together with diffusion bonding process. Then, inlet and outlet headers are welded to the core to make the PCHE product.

Numerous studies related performance analysis of the PCHE focused on the heat exchanger core, where the heat transfer between hot and cold fluids is occurred by assuming uniform flow distributions into the channels from the headers [5-6]. However, flow maldistributions are commonly appeared in the heat exchangers: these results in lower performance of the heat exchangers [7]. Therefore, flow distributions from the headers to the channels should be analyzed to secure the performance reliability of the PCHE. In the present study, the design of the precooler including core and headers was studied.

2. Performance Analysis of Precooler

The performance core analysis of the PCHE was performed based on the design condition of the precooler. The performance reliability of the precooler is important because it is connected with the compressor, which is the major component influencing on the cycle efficiency. Table I lists the operating condition of the PCHE. Water is used as the coolant to make the desired operating condition of the SCO_2. The amount of heat exchange from the SCO_2 to the water is about 2 MW. Mass flow rate of the SCO_2 is optimized as 12.55 kg/s, based on the cycle efficiency. The inlet and outlet temperature of the SCO_2 are 76.2 and 34.4 °C, respectively. The inlet and outlet pressure of the SCO2 are 82.17 and 79.87 bar, respectively. On the other hand, inlet and outlet temperature of the water are 25 and 50 °C, and the mass flow rate is determined by the heat exchange rate of the precooler.

Table I: Design condition of precooler

SCO_2	
Mass flow rate	12.55 kg/s
Inlet & outlet temp.	76.2 & 34.4 °C
Inlet & outlet pressure	82.17 & 79.87 bar
Water	
Mass flow rate	18.057 kg/s
Inlet & outlet temp.	25 & 50 °C
Inlet & outlet pressure	TBD

The simulation of the precooler was conducted using in-house code. Figure 1 shows a schematic structure of the precooler including core and headers. The core volume of the precooler is 640 x 240 x 960 mm^3. A number of hot and cold channels are same as 52,800. Table II lists a simulation results of the precooler. The temperature of the SCO_2 is similar to the design condition of precooler, but the pressure drop of the SCO_2 does not satisfy the design condition. Further pressure control device should be installed in front of the precooler.

Table II: Performance simulation of precooler

SCO_2	
Inlet & outlet temp.	76.2 & 34.6 °C
Pressure drop (kPa)	3.7
Water	
Inlet & outlet temp.	25 & 50 °C
Pressure drop (kPa)	8.6

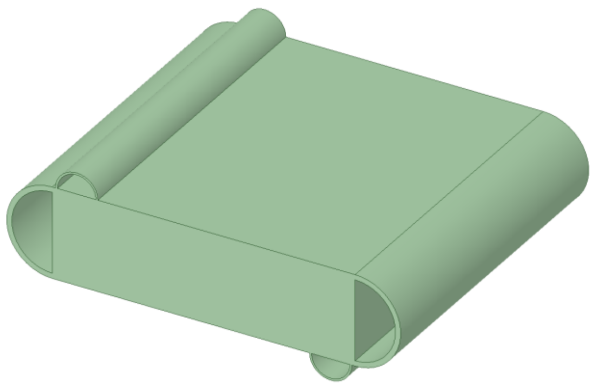

Fig. 1. 3D structure of the precooler

3. Flow Distributions of Precooler

Flow distributions in the PCHE channel is important because the coolability is depended on the flow rate in each hot and cold channel. Because the outlet condition of the SCO_2 is close to the critical state, two-phase could be formed if the mass flow rate of neighboring hot and cold channel is not uniformed: the efficiency and structural integrity of the compressor could not be guaranteed. This means that uniform flow distributions in each hot and cold channel should be provided by the PCHE header. Owing to the limited diffusion bonding technology, the PCHE has a rectangular shape: the flow uniformity (the mass flow rate of neighboring hot and cold channels) should be provided by the PCHE header. To analyze the flow distributions in the PCHE channels with various header designs, commercial CFD code was used.

The channel diameter of the cold and hot channels is millimeter-scale, it is difficult to use the same scale of the PCHE channel in the CFD analysis. Scaled channel diameter of the channel was considered with having the same frontal area and pitch per diameter ratio. Figure 2 shows a 3D structure used in the CFD analysis. The ratio of the width and height is 1:4. Total 297 flow channels were considered to analyze the flow distributions from the inlet header. Generally, the inlet and outlet nozzles are located at the center position of the header.

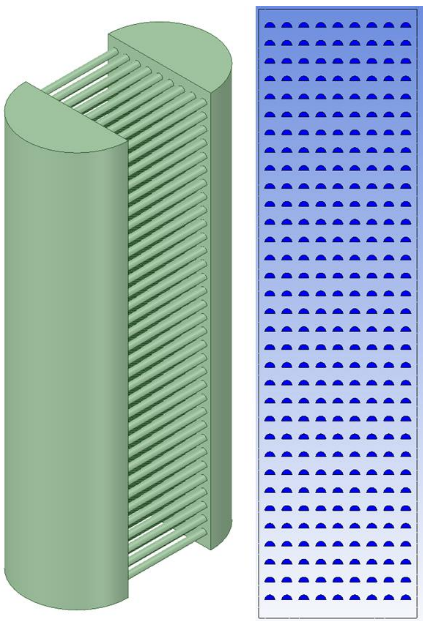

Fig. 2. Scaled precooler structure used in CFD analysis.

Figure 3 shows a normalized flow distributions of the channels: big difference of mass flow rate between the center and the end of channels was appeared. The cooling performance could be deteriorated due to the maldistribution of the SCO_2 and the water. The major parameter influencing on the flow uniformity is the pressure drop of each flow channel. Therefore, several types of inlet headers were selected to provide the uniform pressure drop from the inlet to outlet nozzles for entire flow channels.

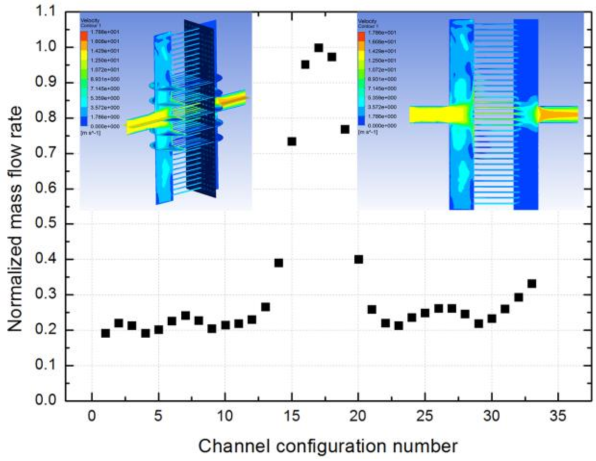

Fig. 3. Flow distributions in case of center position inlet and outlet nozzles.

Three types of header designs were selected for the flow uniformity of the precooler. Case 1 has two inlets located on the top and bottom of the heater with one outlet located at the center of the outlet header, case 2 has two inlets with larger inlet header compared to the case 1 and it has one outlet with the same position of the case 1, and case 3 has four inlets and four outlets in the inlet and outlet headers, respectively. Figure 4 shows the normalized flow distributions for various inlet and outlet header cases. As shown in Figure 4, considering pressure balance cases (case 1&2&3) flow uniformity, compared to the center positioned inlet and outlet nozzles. The case 3 is the most ideal case for the flow uniformity, but it is not appropriate for manufacturing inlet and outlet headers: case 2 and case 3 were selected as the candidate of inlet and outlet headers. The flow uniformity can be increased when the longer flow path and smaller flow channel diameter are used [8-9]. The present study has not the same size of the flow channel compared to the precooler. This means that the flow uniformity will be increased when the equivalent design of the precooler is used.

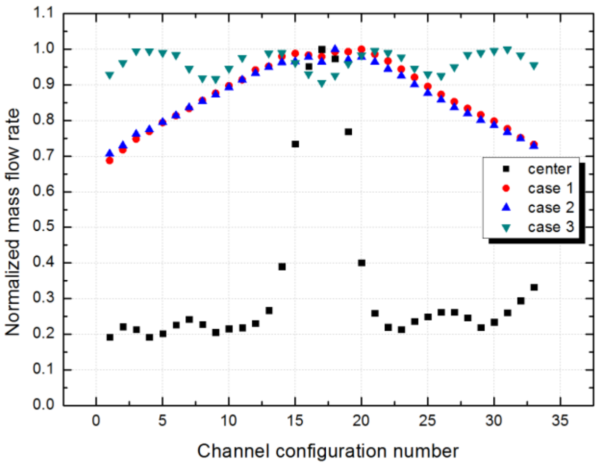

Fig. 4. Flow distributions in each channel for various cases.

4. Conclusions

The performance of the heat exchanger is depended on the flow uniformity of the heat exchanger channels. Several types of inlet and outlet header nozzles were considered to provide the flow uniformity of each flow channel: case 2 and 3 were considered as the precooler headers. Based on the simulation results and manufacturing possibility, the precooler manufacturing process will be performed

Acknowledgements

This work was supported by the Civil-Military Technology Cooperation Program of the Republic of Korea (No. 17-CM-EN-04).

REFERENCES

[1] V. Dostal, M. J. Driscoll, P. Hejzlar, A Supercritical Carbon Dioxide Cycle for Next Generation Nuclear Reactors, MIT-ANP-TR-100, 2004.
[2] J. E. Cha, Y. Ahn, J. Lee, J. I. Lee, H. L. Choi, Installation of the Supercritical CO_2 Compressor Performance Test Loop as a First Phase of the SCIEL facility, The 4th International Symposium-Supercritical CO_2 Power Cycle, 2014.
[3] Y. Ahn, S. J. Bae, M. Kim, S. K. Cho, S. Baik, J. I. Lee, J. E. Cha, Review of Supercritical CO_2 Power Cycle Technology and Current Status of Research and Development, Nuclear Engineering and Technology, Vol. 47, pp. 647-661, 2015.
[4] K. Natesan, A. Moisseytsev, and S. Majumdar, Preliminary Issues Associated with the Next Generation Nuclear Plant Intermediate Heat Exchanger Design, J. Nucl. Mater., Vol. 392, pp.307-315, 2009.
[5] U. Pasquier, W. X. Chu, M. Zeng, Y. T. Chen, Q. W. Wang, T. Ma, CFD simulation and optimization of fluid flow distribution inside printed circuit heat exchanger headers, Numerical Heat Transfer, Part A, Vol. 69, pp. 710-726, 2016.
[6] O. K. Siddiqui, S. M. Zubair, Efficient energy utilization through proper design, Renewable and Sustainable Energy Reviews, Vol. 74, pp. 969-1002, 2017.
[7] B. W. Lance, M. D. Carlson, Printed Circuit Heat Exchanger Flow Distribution Measurement, ASME Turbo Expo 2017, GT2017-64560, 2017.
[8] O. Tonomura, S. Tanaka, M. Noda, M. Kano, S. Hasebe, I. Hashimoto, CFD-based optimal design of manifold in plate-fin microdevices, Chem. Eng. J., Vol. 101, pp. 397-402, 2004.
[9] M. S. Gandhi, A. A. Ganguli, J. B. Joshi, P. K. Vijaya, CFD simulation for steam distribution in header and tube assmeblies, Chem. Eng. Res. Des., Vol. 90, pp. 487-506, 2012.