Thermo-hydraulic Analysis of a Water-cooled Printed Circuit Heat Exchanger in a Small-scale Nitrogen Loop

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1. Introduction

Korea Atomic Energy Research has developed compact heat exchangers for nuclear hydrogen production and operated high temperature and high pressure gas loops for their verification tests. The development of high-temperature heat exchangers is very important because of its higher operation temperature and pressure than those of common light water reactors and industrial process plants. In particular, the intermediate heat exchanger is a key-challenged high temperature component in a Very High Temperature gas-cooled Reactor (VHTR). A printed circuit heat exchanger is one of the candidates for an intermediate heat exchanger in a VHTR. The printed circuit heat exchanger (PCHE) was developed and commercialized by HEATRIC [1]. The compactness is better than any other heat exchanger types, because its core matrices are fabricated by diffusion bonding with photo-chemically etched micro-channels. Various tests and analysis have been performed to verify the performance of PCHE. The thermal stress analysis of the high temperature PCHE is necessary to endure the extremely operation condition of IHX.

In this study, the thermo-hydraulic analysis for the laboratory-scale PCHE is performed to provide the input data for the boundary conditions of a structural analysis [2]. The results from the first-principal calculation are compared with those from computational fluid dynamics code analysis.

2. PCHE & Analysis Model

A water-cooled printed circuit heat exchanger (PCHE) was installed to cool the hot gas from the hybrid heat exchanger to room temperature. So, one stack of hot gas had two stacks of water to obtain enough coolability at the high temperature of inlet condition. The core dimension is 130 mm (W) x 220 mm (L) x 145 mm (H). As shown in Fig. 1, the channel lengths of the effective heated region of the water side and the hot gas side are 0.185 m and 0.187 m, respectively. The material of the heat exchanger body is stainless steel 316 because the plate temperature is very low for the heat transfer coefficient of water to be much higher than that of nitrogen.

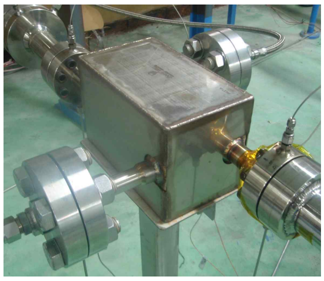
Figure 1 Water-Cooled PCHE

For the thermal stress analysis, the temperature and convective heat transfer coefficient distribution in the channels are required as the input data. Local heat transfer coefficients are obtained from Nusselt number at the heat exchanger design table provided by its manufacturer [3]. The printed circuit heat exchanger is not a simple counter-current heat exchanger but a combination with a rectangular counter-current heat exchanger (B) and two triangular cross-flow heat exchangers (A&C) at the inlet and outlet of the rectangular heat exchanger (B) as shown in Figure 2. Figure 2 shows the simplified nodding to calculate the temperature distribution in the channels. It was assumed that the uniform mass flow distribution is uniform in the channels. The axial conduction in the heat exchanger is negligible to calculate the temperature distribution.

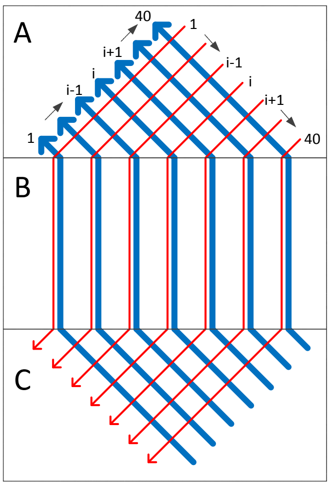

Figure 2 Nodding to Calculate Temperature Distribution for First-Principal Calculation

Figure 3 shows the mesh to calculate the temperature and mass flow rate distribution by COMSOL 4.3a [4] multi-physics code. The number of element is about 3,340,000. The flow regime is laminar flow due to the small diameter of the channel. To evaluate the mass flow distribution of the channels, the inlet and outlet boundary conditions are the uniform pressure drops between the inlets and outlets at each side. The pressure drop values were determined to obtain the same total mass velocity at the first-principal calculation. The inlet and temperatures of COMSOL 4.3a are equal to those of the first principal calculation.

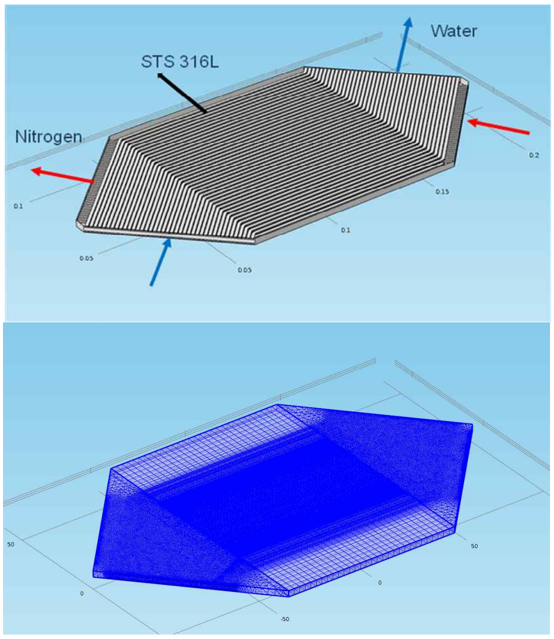

Fig. 3. Geometrical Model and Mesh of COMSOL 4.3a

3. Results and Discussion

Table 1 summarizes the comparison with the first-principal calculation results and the COMSOL 4.3a analysis results. The differences between two analysis results are negligible except in the case of the maximum outlet temperature in the water side. The mass flow distribution in the channels is uniform as the first-principal calculation.

Table 1. Comparison with Two Analysis Results

	First-principal Calculation	COMSOL 4.3a Analysis
Inlet T of Nitrogen	830℃	830℃
Outlet T of Nitrogen	20.29℃	20℃
Inlet T of Water	20℃	20℃
Max. Outlet T of Water	91.24℃	95.06℃
Avg. Outlet T of Water	30.42℃	29.47℃
Mass Velocity of Nitrogen	0.0167 kg/s	0.0165 kg/s
Mass Velocity of Water	0.3332 kg/s	0.3336 kg/s

The difference of the maximum outlet water temperature results from the axial conduction in the heat exchanger. Three-dimensional conduction heat transfer increases the exchanged-heat energy in the closest water channel to the hot nitrogen inlet. In the nitrogen side, the uniform mass velocity distribution is due to the very high effectiveness. In particular, the temperature-reduced region is cornered into the inlet of the nitrogen as shown in Figure 4. In the case of water side, the temperature-dependency of water material properties is too small to cause the mass velocity distribution by the uniform pressure drop.

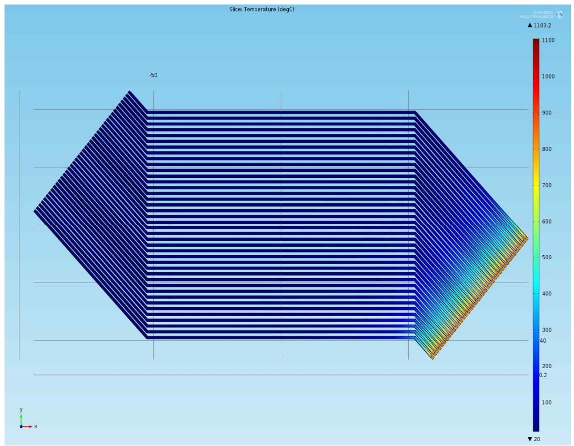

Fig. 4. Temperature Distribution in Nitrogen Channels

4. Conclusion

COMSOL 4.3a analysis is successfully performed at the uniform pressure drop condition in a set of flow channel stacks. The heat-exchanged region concentrated to the nitrogen inlet cause the uniform mass velocity distribution in the channels, therefore there is little difference between two analytical results. In the future, the computational fluid dynamics analysis will be performed in a He-He printed circuit heat exchanger. These analysis experiences expect to minimize the trial and error of the future analysis.

ACKNOWLEDGEMENT

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