Steady-state and Transient Analysis of a Printed Circuit Heat Exchanger

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1. Introduction

A printed circuit heat exchanger (PCHE) is a very compact type heat exchanger and it has good operating efficiency and effectiveness, which saves capital cost. It is a candidate intermediate heat exchanger (IHX) for a high temperature gas-cooled reactor (HGTR)

It is hard to design thermo-fluidic performance of a PCHE because a PCHE core consists of multiple metal plates, which have plenty of micro channels. It is essential to predicting steady-state performance and transient behavior of a PCHE for nuclear application.

The evaluation method for steady-state thermal hydraulic performance of a PCHE was well developed [1-3]. Transient test was also performed [2]. Cold inlet temperature was suddenly decreased after steady-state. However, the degree of transient behavior in Kim et al.'s test was not enough to predict anticipated as well as postulated accidents in a HTGR. It is believed that a PCHE system has slow response time because of the heavy metal plates surrounding the core [4].

The steady state and transient behavior of PCHE was experimentally and numerically analyzed in the present study.

2. Methods and Results

Experiments were performed utilizing nitrogen loop test facility. The experimental results were compared with GAMMA+, the gas multicomponent mixture analysis code, calculation results.

2.1 Experiments

We installed an alloy 800HT PCHE in a loop experimental facility. The diameter of a semi-circle channel in the PCHE is 1.5 mm. It has wavy channels. The angle is 30°. The number of channel on a plate is 80. The effective length of a channel is about 0.503 m.

Fig. 1 shows a schematic diagram of the experimental facility. The working fluid was nitrogen. Pressure varied from 9 to 16 bar during the test. Gas heaters in primary loop were utilized. Inlet temperature in primary side was controlled from room temperature to 460℃. Inlet temperature in secondary side was fixed to room temperature. Mas flow rate in both sides was in the range of 9 to 10 kg/min. Table II summarizes experimental conditions. Transient test starts after steady state case 3 in Table 1. The operation of a gas heater in primary side stopped. The inlet temperature decreased from 460.4 to 103℃ during 5227 seconds.

Table I: Steady state test conditions

	Primary	Secondary
	Case 1	
Temperature (℃) Inlet – Outlet	342.4 – 56.0	20.6 – 288.1
Average pressure (bar)	12.5	9.6
Average flow rate (kg/s)	0.16	0.16
	Case 2	
Temperature (℃) Inlet – Outlet	460.4 - 78.0	20.6 – 396.5
Average pressure (bar)	11.1	9.6
Average flow rate (kg/s)	0.17	0.17

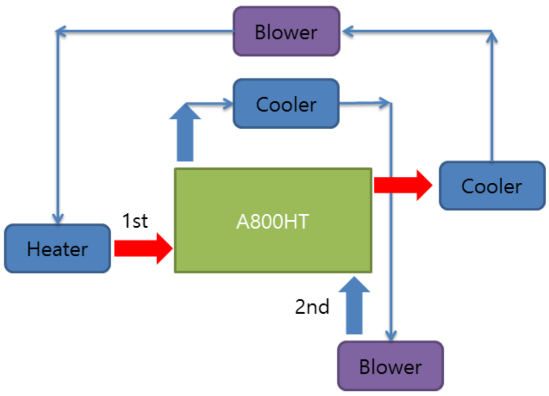

Fig. 1. Schematic diagram of experimental facility

2.2 GAMMA+ calculation

GAMMA+ has capability to calculate thermal-hydraulic transient in multicomponent mixture system. It was utilized for numerical analysis.

Fig. 2 shows the simplified model of PCHE core. Thermo-fluidic parameters such as flow area, volume, hydraulic diameter were matched with experimental conditions. Kim et al. developed successful modeling for PCHE with GAMMA code [1]. The same method was utilized for steady-state analysis in the present study. Bottom and top metal plates, which surround the core, were additionally modeled for the transient analysis. Inlet temperature, pressure and mass flow rate were fixed for steady state calculations. Those parameters varied with time for transient calculation.

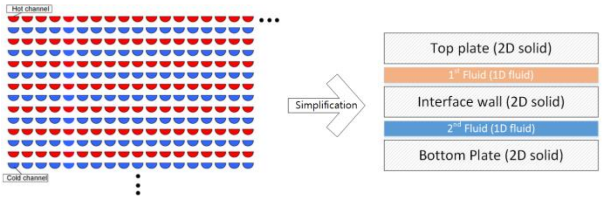

Fig. 2. Simplified PCHE core model

3. Results and discussion

Table II summarizes experimental results and calculation results. Calculations results show acceptable deviations. In case 1, the deviation of primary outlet temperature is 23.8% but the temperature difference is about 13.3℃. It seems that Kim et al.'s modeling method shows good agreement for steady-state analysis even though the shapes of PCHEs are different.

Table II comparisons between experimental results and calculation results

	Experiments	Calculation
	Case 1	
Inlet temperature $1^{st} – 2^{nd}$ (℃)	342.4 – 20.6	342.4 – 20.6
Outlet temperature $1^{st} – 2^{nd}$ (℃)	56.0 – 288.1	69.3 – 295.6
Deviation $1^{st} – 2^{nd}$ (%)	-	23.8 – 2.6
	Case 2	
Inlet temperature $1^{st} – 2^{nd}$ (℃)	460.4 – 20.6	460.4 – 20.6
Outlet temperature $1^{st} – 2^{nd}$ (℃)	78.0 – 396.5	80.6 – 394.6
Deviation $1^{st} – 2^{nd}$ (%)	-	3.3 – -0.5

Figure 3 shows transient behavior of PCHE. We stopped operation of a gas heater in primary side. It simulated sudden temperature decrease of primary inlet temperature. A notable point is the behavior of secondary outlet temperature. It decreased as the primary inlet temperature decreases but the slope of secondary temperature decrease is lower than that of primary temperature decrease. Secondary outlet temperature is higher than primary inlet temperature after 1500 seconds. We thought that the temperature of the PHCE body is higher than that of primary inlet. Heat transferred from the PCHE body to gas through secondary loop.

Calculation results showed different result with experimental results in transient analysis. It seems that the time constant of conductive and convective heat transfer calculation is lower than that of experimental condition. We experienced this kind of a late response in previous experiments with PCHE, repeatedly [4].

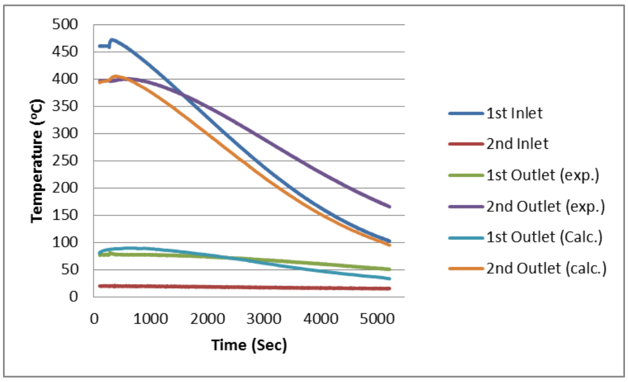

Fig. 3. Transient behaviors

4. Conclusions

We performed experimental and numerical analysis for steady-state and transient behavior of PCHE. Kim et al.'s modeling method for GAMMA+ showed good agreement with experimental results. The present calculation did not show good agreement with experimental results. Improvement for transient calculation is required in terms of modeling method or code. Further study is needed for transient analysis of PCHEs.

REFERENCES

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