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Experimental and Numerical Study on Transient Behavior of Printed Circuit Heat Exchangers

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1. Introduction

A printed circuit heat exchanger (PCHE) is a candidate intermediate heat exchanger (IHX) for a PMR200, which is a demonstration plant of a high temperature gas-cooled reactor (HGTR). A PCHE is manufactured from diffusion bonding process with multiple metal plates, which have plenty of micro channels. Micro channels on the plates were produced by mechanical machining or chemical etching. A PCHE is a very compact type and it has fine operating efficiency and effectiveness, which saves capital cost.

PMR coolant is helium. The evaluation method for steady-state thermal hydraulic performance of a PCHE with helium was well developed [1-3]. Kim performed a transient test [2]. Cold inlet temperature was suddenly decreased after steady-state. Decreased temperature was about 20. It was too small to estimate the transient behavior. The transient behavior of a PCHE is very important issue for predicting anticipated as well as postulated accidents in a HTGR.

The studies of transient response for counter flow configuration using both analytical and numerical method were well reviewed by Bunce and Kandiakr [4]. Many authors considered conventional heat exchangers, such as shell and tube type. They considered interfacing wall between two fluids but outer shell of heat exchanger was not considered for transient behavior. However, heavy top cover plate and bottom cover plate are attached by diffusion bonding to endure high pressure from working fluid in PCHE. The mass of metal is very large. It is believed that a PCHE system has slow response time because of the heavy metal plates. It is needed to consider the effect of cover plate to evaluate transient behavior of PCHE.

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

2. Experiments

We installed two PCHEs, which are made of alloy 617 and alloy 800HT, in helium experimental facility. **Fig. 1** shows a schematic diagram of the helium experimental facility.

The working fluid was helium. Both primary and secondary loops were compressed to 15 bars. Gas blowers were used and the mass flow rate was 0.5 kg/min. The flow rates were almost the same in the primary and the secondary loops. Only gas heaters in primary loop were utilized to heat up the inlet of Alloy 617 PCHE. The inlet temperature was reached to 400°C after 7000 seconds of operation. On the other hand, The inlet temperature of Alloy 800HT PCHE was fixed to 30°C using a water cooler. The heated helium in primary and secondary loops was cooled by water coolers. All PCHEs were insulated with ceramic fiber.

All parameters, such as temperature, pressure, and flow rate, were obtained by data acquisition system. Data acquisition rate was 1 Hz.

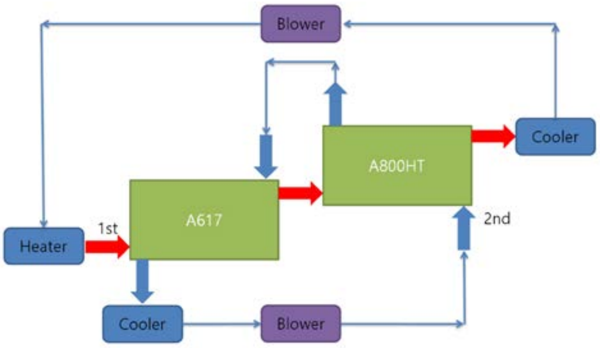

Fig. 1. Schematic diagram of helium experimental facility with two PCHEs

3. Analysis

The gas multicomponent mixture analysis (GAMMA+) code, which has capability to calculate thermal-hydraulic transient in multicomponent mixture system, was utilized for the numerical analysis.

Fig. 2 shows nodalization for helium experimental facility. One set of a hot channel plate, a cold channel plate and interfacing wall was simulated but flow area and heated area were matched to the real PCHE configurations. Top and bottom cover plate were simulated and total mass of metal was also matched to the real one.

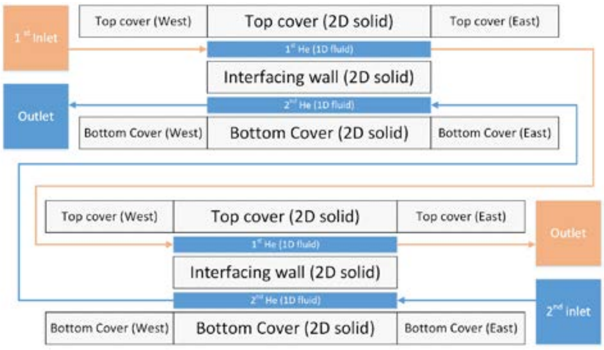

Fig. 2. GAMMA+ nodalization for helium experimental facility

4. Results and Discussion

Fig. **3** shows experimental and calculation results of Alloy 617 heat exchanger outlet temperature. Red line was from the calculation, which simulated only fluid and interfacing wall without top and bottom cover plates. It significantly overestimated results. Blue line was from the calculation, which simulated the whole of PCHE as shown in Fig. **2**. It showed good agreement with experimental results, blue line.

Several authors have presented modeling for the transient behavior of conventional counter flow heat exchangers, such as shell and tube type, with two fluids and interfacing wall [4]. However, it is not enough to model PCHE. Top and bottom cover plates should be modeled with considerations on total heat transfer area and total metal mass.

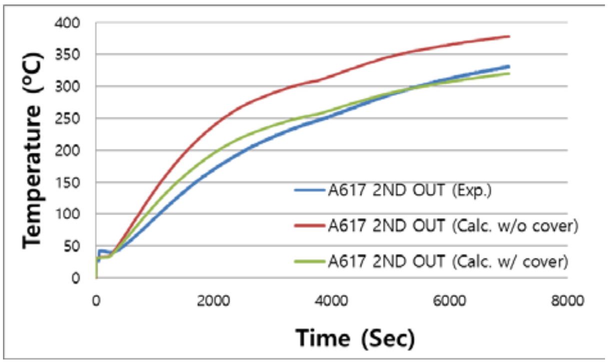

Fig. 3. Comparison of secondary loop outlet temperatures

Fig. **4** shows time dependent transient effectiveness graph from the experiments and the calculations. The calculation results with the modeling of the cover plates also showed good agreement with the experimental results.

Hot helium transfers heat through interfacing wall to cold helium and it heats up the PCHE metal at the same time. The transient behavior is largely affected by the mass of PCHE metal.

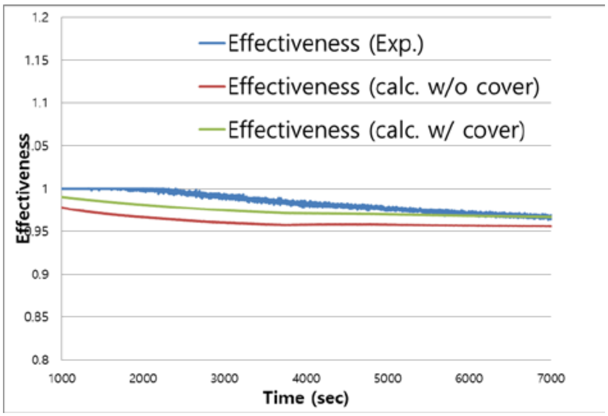

Fig. 4. Transient effectiveness

5. Conclusions

A PCHE modeling should be performed with considerations on total PCHE metal mass and total heat transfer area. A PCHE has relatively large volume of metal compared with fluid channel due to cover plates to endure high pressure condition. The transient behavior is very sensitive to the metal mass in PCHE.

The presented experimental results show start-up process for high temperature operation. As shown in the results, PCHE systems with helium fluid has very slow transient response due to low heat capacity of helium. Careful consideration is required to design a PCHE system with helium coolant.

Acknowledgement

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