# Thermal-hydraulic experiments for the PCHE type steam generator

C.W.Shin [a], H.C.NO [a*]
[a]*Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-no, Yuseong-gu, Daejeon, Republic of Korea*
[*]*Corresponding author: hcno@kaist.ac.kr*

## 1. Introduction

Printed circuit heat exchanger (PCHE) manufactured by HEATRIC is a compact type of the mini-channel heat exchanger. The PCHE is manufactured by diffusion bonding of the chemically-etched plates, and has high heat transfer rate due to a large surface. Therefore, the size of heat exchanger can be reduced by 1/5~1/6[1] and PCHE can be operated under high pressure, high temperature and multi-phase flow. Under such merits, it is used as heat exchanger with various purposes of gas cycle and water cycle. Recently, it is newly suggested as an application of a steam generator. IRIS of MIT[2] and FASES of KAIST[3] conceptually adopted PCHE as a steam generator.

When using boiling condition of micro-channel, flow instability is one of the critical issues. Instability may cause unstable mass flow rate, sudden temperature change and system control failure. However instability tests of micro channels using water are very limited because the previous studies were focused on a single tube or other fluid instead of water. In KAIST, we construct the test facility to study the thermal hydraulics and fluid dynamics of the heat exchanger, especially occurrence of instability. Conclusively, this research is aimed at minimizing the issues for utilizing PCHE as the steam generator.

## 2. Methods and Results

### *2.1 test facility*

The objectives of our test facility are (1) to identify the occurrence of instability under two phase water cycle of steam generator, and (2) to examine whether it can normally operate using throttling effect

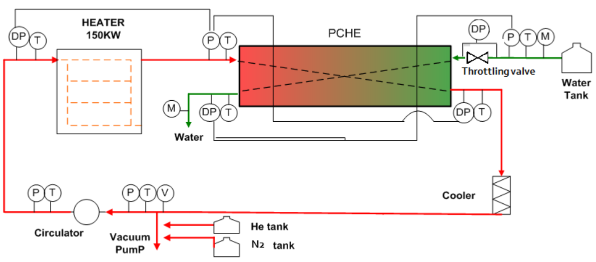


Fig. 1. Schematic diagram for PCHE test facility

Figure 1 is the schematic diagram of the PCHE test facility. Each of the two separated channel operates by helium cycle of hot channel and water cycle of cold channel. Differential pressure gauges, manometers and thermometers are installed at each position. Circulation is forced using circulator and pump for hot and cold channel, respectively. When the value of k increases, differential pressure at the entrance increases accordingly, thereby preventing the occurrence of instability [4-5]. Throttling valve is installed at the entrance of water channel to increase the k value there, and the differential pressure gauge is installed to measure the pressure at both ends. Table 1 shows detailed dimensions and test condition of PCHE. The PCHE is 300mm (W)* 144mm (H)* 600mm (L) and composed of 96 steel plates which have 88 semi-circular flow ways. Semicircular hot channels and circular cold channels are stacked alternately. There exists countercurrent flow in hot channel and cold channel. The inlet condition of the tests of helium is maximum 20bar, 550 C$^o$ and 60 m$^3$/h, whereas those of water is atmosphere, 20 C$^o$ and 0.5m$^3$/min to 30kg/min.

### *2.2 instability test*

According to the mass flow rate of water, the tests were performed the sub-cooled boiling test, the saturated boiling test and the super-heated steam test. As changing helium temperature of primary side, heat transfer could be controlled and the phase of water at the outlet is varied by changing the water flow rate. Under each condition, the oscillation of the entrance flow rate is observed by mass flow meter at the entrance. We first examined the occurrence of instability and the amplitude of oscillation.

Table 1 shows the test matrix and results of instability tests. The inlet conditions of primary side are 13bar, 256 C$^o$ or 380 C$^o$.

Table I: test matrix of instability identification experiment

| Transferred power[kW] | Water flow rate oscillation[kg/min] | Outlet quality |
|---|---|---|
| 34.3(256 C$^o$) | 10-13 | -0.07 |
| 50(380 C$^o$) | 14-15 | -0.07 |
| 31.7(256 C$^o$) | 3-5 | 0.015 |
| 35(380 C$^o$) | 0-3.5 | 0.25 |
| 47.8(380 C$^o$) | 1-1.6 | 0.78 |
| 49(380 C$^o$) | 4.5-6 | 0.05 |
| 44(380 C$^o$) | 0.5-0.6 | 1.05 |

Except for the last superheated case, water flow shows the oscillation with amplitude of 1 to 3.5kg/min. For the fourth case in particular, the flow rate falls to zero as current stops flowing momentarily or even flows backward. It affects the heat transfer as well, as the heat transfer is reduced by 25% than in the boiling case, under same conditions. Also, figure 2 represents the temperature change under the superheated test. In case of superheated test, water could not sufficiently removed heat from the helium side, and the heat transfer is decreased accordingly, thus showing transient state where the exit temperature of vapor and helium keeps increasing.

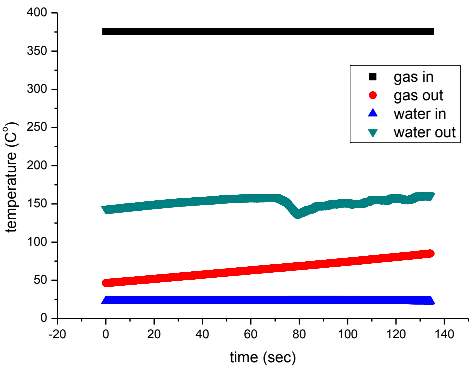


**Fig. 2 inlet and outlet temperature of helium and water during the superheated test**

*2.3 throttling effect test*

As mentioned above, instability not only causes unstable flow rate but also hinders heat transfer. One of the solution for preventing occurrence of flow instability is installation of an orifice or a valve at the entrance of water flow [4-5].

Several experiments were performed to confirm the effect of a throttling valve under the condition where the actual heat exchanger is installed, and to confirm the stability of flow as the value of K changes. Following results used water of 20C° and 1bar and helium of 320 C° and 16 bar. Figure 3 displays varying water flow with various K value.


**Fig. 3. Inlet mass flow rate instability of the boiling cases with different K-value**

When the valve is fully opened as in case 1 and 4, the flow oscillated between its lowest at 3kg/min and its highest at 5kg/min. But as K value is increased, the amplitude of the graphs obviously decreases. Especially, at K value of 1670 and pressure drop of 0.22 bar, the oscillation would be lowered by 90% and heat transfer increases by 20%.

## 3. Conclusions

We confirmed that the flow instability occurs during PCHE boiling tests of 1 bar and that the unstable flow affects heat transfer efficiency. And even reverse flow was observed and influenced the whole system. In order to stabilize the flow, the throttling valve at the entrance was installed. By inducing the pressure drop of inlet water, amplitude of oscillation declined by 90%. Finally, the throttling effect was experimentally confirmed that PCHE could be utilized as a steam generator.

## REFERENCES

[1] HEATRICTM, 2008. <www.heatric.com>
[2] Koroush Shirvan, Pavel Hejzlar, Mujid S. Kazimi, The design of a compact integral medium size PWR, Nuclear Engineering and Design, Vol.243, p.393-403, 2012.
[3] Ho Ski, Kim, H.C. NO, Conceptual design and reasibility study for fail-safe simple economical SMR(FASES) system, the ASME 2014 SMR symposium, Washington, 2014.
[4] JU Huaiming., et al., Two phase flow stability in the HTR-10 steam generator, Thinghua science and technology, Vol. 6 number 1, p.75-79, 2001
[5] G. Guido, J. Converti and A. Clausse, Density-wave oscillations in parallel channels-an analytical approach, Nuclear Engineering and Design 125 p.121-136, 1991.