High-temperature Elastic Structural Analysis on a Small-Scale PHE prototype

a Keenam Song[a*], S-D Hong[a], and H-Y Park[b]
[a]*Korea Atomic Energy Research Institute, P.O.BOX 105 Yusong, Taejon, Rep. of KOREA*
[b]*AD solution*
[*]Corresponding author: knsong@kaeri.re.kr

1. Introduction

Hydrogen is considered a promising future energy solution because it is clean, abundant, and storable, and has high-energy density. One of the major challenges in establishing a hydrogen economy is how to produce massive quantities of hydrogen in a clean, safe, and economical way. Among the various hydrogen production methods, nuclear hydrogen production is garnering worldwide attention since it can produce hydrogen, a promising energy carrier, without an environmental burden.

The PHE (Process Heat Exchanger) is a component that utilizes the nuclear heat from the nuclear reactor to provide hydrogen. A PHE is used in several processes such as nuclear steam reforming, nuclear methanol, nuclear steel, nuclear oil refinery, and nuclear steam [1]. The PHE of the SO_3 decomposer, which generates the process gas such as H_2O, O_2, SO_2, and SO_3 at a very high-temperature, is a key component in the nuclear hydrogen program in Korea [2].

Recently, KAERI (Korea Atomic Energy Research Institute) established a small-scale gas loop for the performance test of VHTR components and manufactured a small-scale PHE prototype made of Hastelloy-X. A performance test on the PHE prototype is under way in the small-scale gas loop at KAERI. In this study, in an effort to evaluate the high-temperature structural integrity of the PHE prototype under the test condition of the gas loop, a high-temperature elastic structural analysis was performed.

2. FE modeling

A schematic view of the inside of the PHE prototype is illustrated in Fig.1. The PHE prototype is designed as a hybrid concept to meet the design pressure requirements between a nuclear system and hydrogen production system [3]. That is to say, the hot helium gas channel has a compact semicircular shape, similar to a printed circuit heat exchanger, and is designed to withstand the high pressure difference between loops, while the sulfuric acid gas channel has a plate fin shape with sufficient space to install and replace the catalysts for sulfur trioxide decomposition.

All parts of the PHE prototype are made from Hastelloy-X of a high-temperature alloy. Grooves of 1.0 mm in diameter are machined into the flow plate for the primary coolant (nitrogen or helium gas). Waved channels are bent into the flow plate for the secondary coolant (SO_3 gas). Twenty flow plates for the primary and secondary coolants are stacked in turn, and are bonded along the edge of the flow plate using a solid-state diffusion bonding method. After stacking and bonding the flow plates, the outside of the PHE is covered with the Hastelloy-X plate of 3.0 mm in thickness.

Figure 2 shows the overall dimensions, and each part of the PHE prototype from the 3-D CAD modeling. Based on Fig. 3, FE modeling using I-DEAS/TMG Ver. 6.1 [4] was carried out and analyses such as a thermal analysis and structural analysis are carried out using ABAQUS Ver. 6.8 [5].

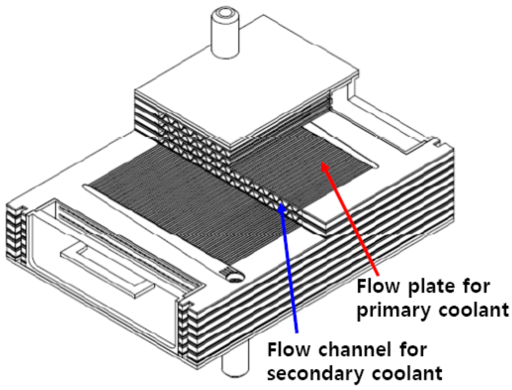

Fig. 1 Inside of PHE prototype

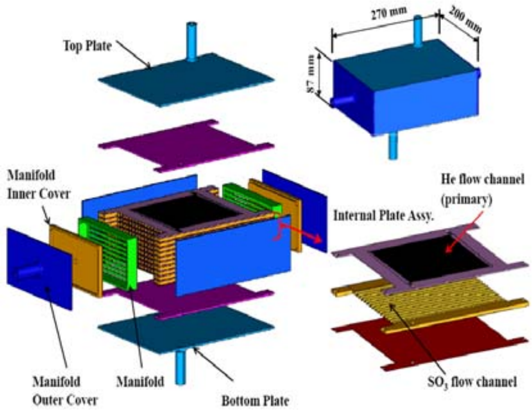

Fig. 2 Parts of PHE prototype

3. Analysis

A thermal analysis on the PHE prototype under the fixed test condition of the helium gas loop was performed. Based on the temperature distribution shown in Fig. 3, a high-temperature elastic structural analysis was performed by imposing a displacement constraint condition at each end of the primary/secondary flow pipelines as shown in Fig. 4, considering the pipeline stiffness of the small-scale gas loop [6].

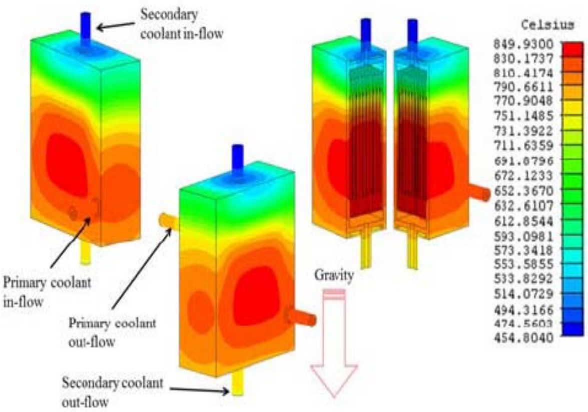

Fig. 3 Temperature contour

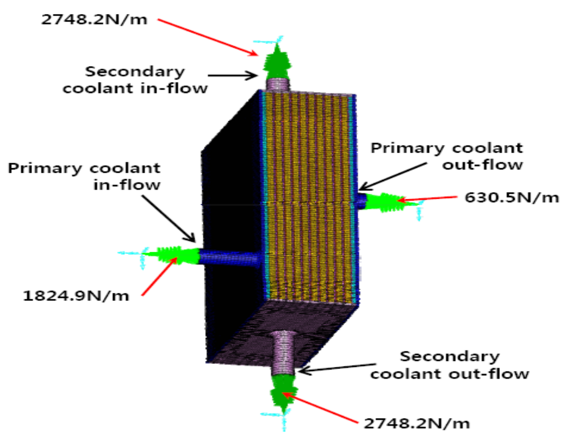

Fig. 4 BC for structural analysis

Figure 5 shows the elastic stress distribution at the pressure boundary of the PHE prototype. The maximum local stress of 272.33 MPa around the edge between the top plate and side plate exceeds the yield stress of Hastelloy-X (239.7 MPa at 746℃) [7] by 13.6%. Even though the maximum stresses exceed the yield stress for the small-scale PHE prototypes, the high-temperature structural integrities of the PHE prototype seem to be maintained under the normal test conditions of the gas loop, owing to the chamfering effect on each edge. That is to say, since the edges of the PHE prototype are chamfered realistically, the maximum stress will be decreased to some extent when considering the chamfered edges.

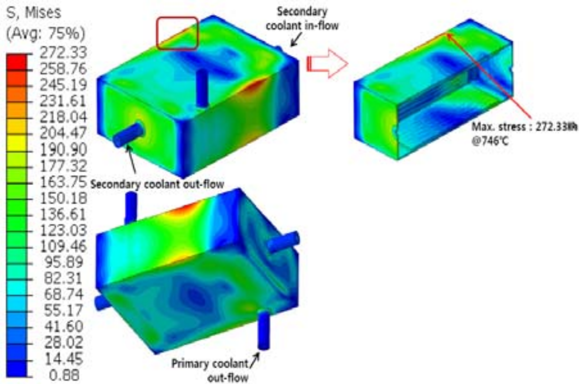

Fig. 5 Stress contour

4. Summary

A high-temperature elastic structural analysis on the small-scale PHE prototype under the gas loop test condition was performed. As a result of the analysis, high-temperature structural integrities of the PHE prototype seem to be maintained under the normal test condition of the gas loop, owing to the chamfering effect on each edge.

Acknowledgements

This project has been carried out under the nuclear R & D program by MEST (Ministry of Education, Science and Technology in Republic of Korea).

REFERENCES

[1] Lee, W. J. *et al.*, *NET*, **41**(4), 413-426, 2009.
[2] Chang, J. H, *et al.*, *NET*, **39**(2), 111-122, 2007.
[3] Kim, Y. W. *et al.*, "High Temperature and High Pressure Corrosion Resistant Process Heat Exchanger for a Nuclear Hydrogen Production System," R.O.K Patent # 10-0877574 (2008).
[4] I-DEAS/TMG Analysis User Manual Version 6.1 (2009).
[5] ABAQUS Analysis User's Manual, Version 6.8 (2009).
[6] Song, K. N. *et al.*, "High-Temperature Structural Analysis of a Small-Scale Prototype of a Process Heat Exchanger (III)," *Trans. A of KSME*, Vol. 35, No. 2, (2011) pp. 191-200.
[7] Hastelloy-X Alloy website, www.haynesintl.com.