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Evaluation on the High-temperature Structural Integrity of the small-scale PHE prototype

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1. Introduction

Recently, nuclear hydrogen production is garnering worldwide attention since it can produce hydrogen, a promising energy carrier, without an environmental burden. The nuclear hydrogen program in the Republic of Korea (ROK) is strongly considering producing hydrogen by employing a Sulfur-Iodine (SI) water-splitting hydrogen production processes. An intermediate loop that transports the nuclear heat to the hydrogen production process is necessitated for the nuclear hydrogen program as shown in Fig. 1. In the intermediate loop, whereas the HGD (Hot Gas Duct) provide a route of a high temperature gas from the nuclear reactor to the IHX (Intermediate Heat Exchanger), the PHE (Process Heat Exchanger) is a component that utilizes the nuclear heat from the nuclear reactor to provide hydrogen. PHE is used in several processes such as nuclear steam reforming, nuclear methanol, nuclear steel, nuclear oil refinery, and nuclear steam [1]. PHE of the SO3 decomposer which generates processed gas, such as H_2O, O_2, SO_2, and SO_3 at very high temperature is a key component in the nuclear hydrogen program in ROK [2, 3].

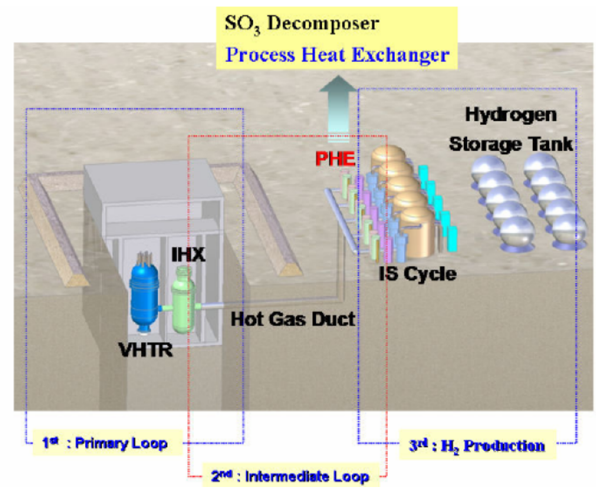

Fig. 1 Nuclear hydrogen system

A performance test on the small-scale PHE prototype made of Hastelloy-X is under way in the small-scale gas loop at KAERI as shown in Fig. 2. In this study, in order to evaluate the high-temperature structural integrity of the PHE prototype under the test condition of the gas loop, structural analysis on the PHE prototype is carried out, considering the stiffness of pipelines connected to the PHE prototype in the gas loop.

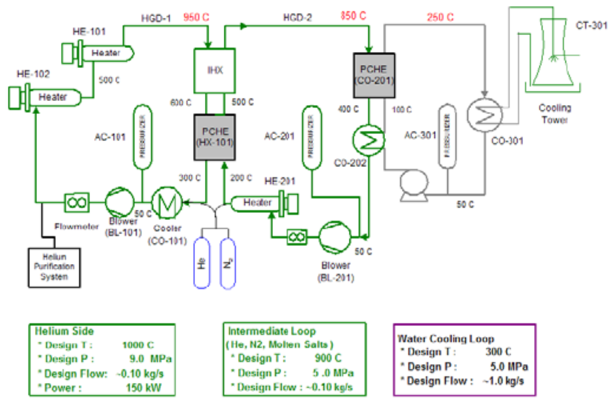

Fig. 2 KAERI's small-scale gas loop

2. FE modeling

Figure 3 shows 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 was carried out and analysis such as thermal analysis and structural analysis are carried out using ABAQUS Ver. 6.8 [4].

3. Analysis

Thermal analysis

Figure 4 shows the thermal analysis results of the PHE external prototype under fixed test condition of the gas loop. According to Fig. 4, the temperature distribution is nearly symmetrical along the vertical axis and maximum temperature of the outside represents about 837.15℃.

High temperature structural analysis

Figure 5 represents a set-up of the PHE prototype in the gas loop. High-temperature structural analysis is carried out, considering the stiffness of the pipeline connected to the PHE prototype [5].

Figure 6 represents the stress distribution at the pressure boundary of the PHE prototype. The maximum local stress of 266.8 MPa on the edge of top plate, and maximum stress along the thickness through stress linearization is about 265.6MPa, based on Von Mises stress. This stress level is below the yield stress of the material (291 MPa at 500 ℃) [6], therefore high-temperature structural integrity of the PHE prototype seems to be maintained in the gas loop test condition.

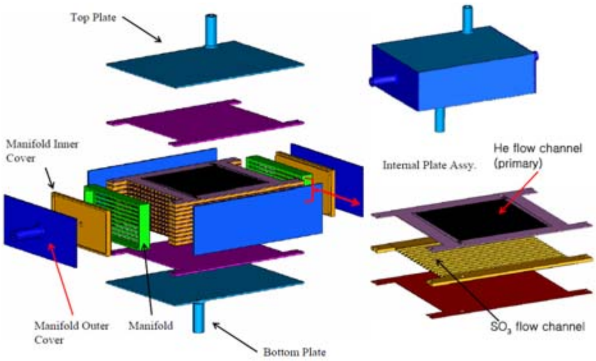

Fig. 3 Parts of a PHE prototype

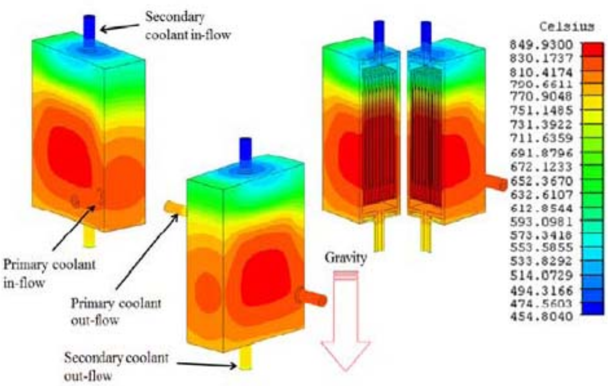

Fig. 4 Temperature distribution of PHE outside

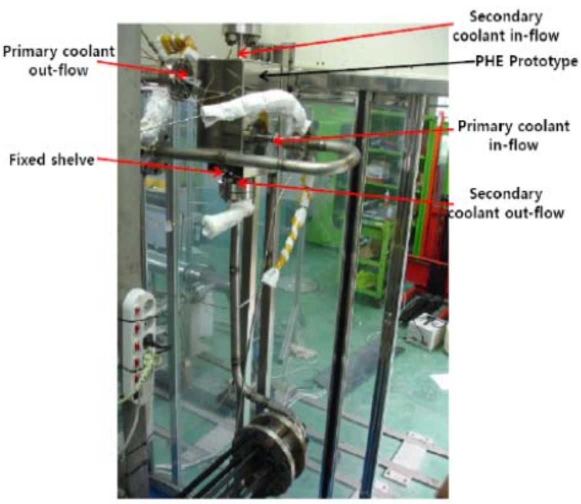

Fig. 5 Set-up of a PHE prototype in the gas loop

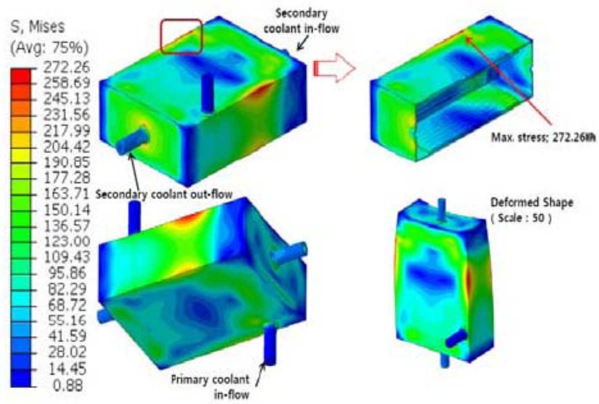

Fig. 6 Structural analysis results

4. Conclusion

In the effort to evaluate the high-temperature structural integrity of the PHE prototype, high-temperature structural analysis is carried out, considering the stiffness of the pipeline connected to the PHE prototype in the small-scale gas loop.

Under the test condition of the gas loop, the maximum stress at the pressure boundary of the PHE prototype is below the yield stress of Hastelloy-X. As a result, the high-temperature structural integrity of the PHE prototype seems to be maintained in the gas loop test condition.

Acknowledgements

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[6] Hastelloy-X Alloy website, www.haynesintl.com.