Comparative Design Study on the Intermediate Heat Exchanger Assembly of VHTR System

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1. Introduction

A large helical tube type heat exchanger has been used for the intermediate heat exchanger of HTGR(High Temperature Gas-cooled Reactor) and VHTR(Very High Temperature Reactor). The PCHE(Printed Circuit type Heat Exchanger) is a promising candidate of the intermediate heat exchanger for advanced reactor system due to its compactness. However, the maximum size of PCHE is limited by the size of the diffusion bonding equipment and the capacity of the compression press. The VHTR intermediate heat exchanger requires a big heat transfer capacity generally. A number of PCHE modules are used to satisfy the large heat transfer capacity of the VHTR intermediate heat exchanger. Rules for design and fabrication of PCHE are specified in ASME Section VIII but not in ASME Section III of nuclear components [1].

In this study, PCHE module is designed according to ASME Section VIII and IHX assembly of VHTR is designed by stacking a number of PCHE modules. The effect of design pressure on the size of heat transfer region is investigated to minimize the size of intermediate heat exchanger. The secondary headers of each modules are connected to the secondary inlet pipes and outlet pipes. All of the modules including inlet pipes and outlet pipes are installed inside pressure vessel. The effective heat transfer region is surrounded by the insulator to reduce the design temperature of the pressure vessel.

2. Module Design

2.1 Module design based on primary pressure and differential pressure

The flow channel of PCHE is a semi-circular shape. Semi-circular flow channels are assumed to be a rectangular cross section as shown in Fig.1 in to determine key dimensions based on the ASME section VIII [2]. According to ASME section VIII, the membrane stress across the thickness S_m should be less than allowable stress of ASME Section II Part D [3]. Also, total stress S_T should be less than 150% of allowable stress. The joint efficiency of diffusion bonding is 0.7 along the diffusion bonded direction. The effective heat transfer region of PCHE is defined by several key dimensions such as flow channel radius R, edge width t_1, wall thickness t_2, and ridge width t_3. The radius of flow channel is mainly influenced by thermo-hydraulic performance and other parameters are dominated by the strength criteria and the manufacturability. When the design pressure is 1MPa, the effect of flow channel radius on the key dimensions are shown in Fig. 2. The effect of design pressure on the key dimensions when the flow channel radius is 0.5mm is shown in Fig.3 Key dimensions of the effective heat transfer region are determined to be larger than the minimum values of Fig.2 and 3.

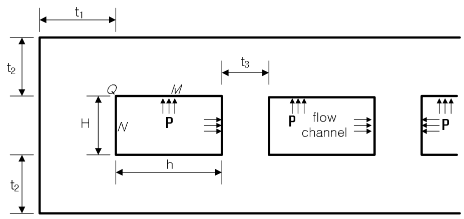

Fig. 1 Flow channel assumption and key parameters

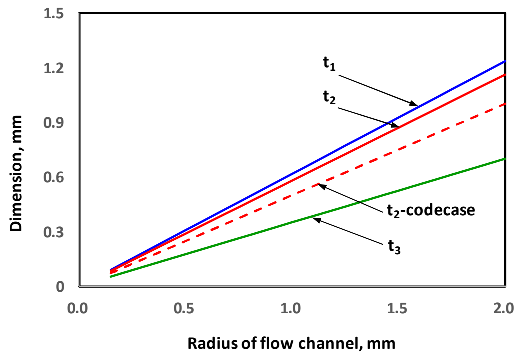

Fig. 2 Effect of flow channel size on key dimensions

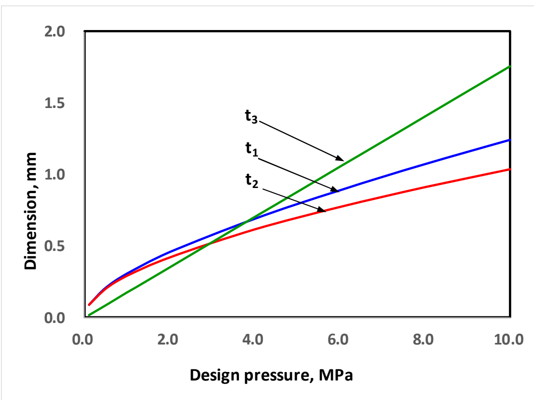

Fig. 3 Effect of design pressure on key dimensions.

2.2 Module header shape design

Secondary module header is welded to the stacked diffusion bonded effective heat transfer plates. The module header is subjected to high temperature and pressure. The stress distribution for a half cylindrical header and a circular ended module headers are investigated to determine header design shape. The circular shaped header has lower stress values than that of cylindrical shaped header. Stress distribution is calculated by using of commercial finite element code ABAQUS[4]. Longitudinal stress and transverse stress distributions are shown in Fig. 4.

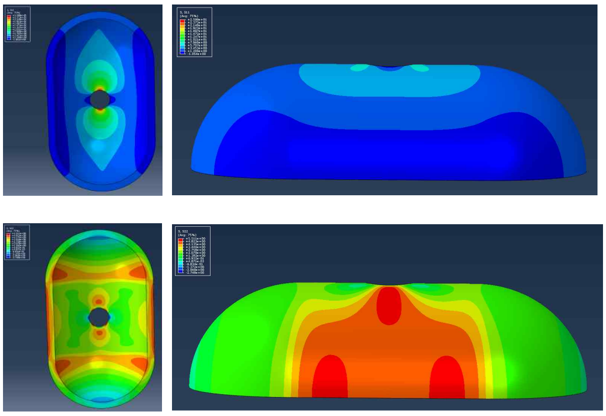

Fig. 4 PCHE modules arrangement inside pressure vesssel

In order to compare stress values with allowable stress value of ASME, linearized stress components are separated from the stress distribution along the thickness as shown in Fig.5

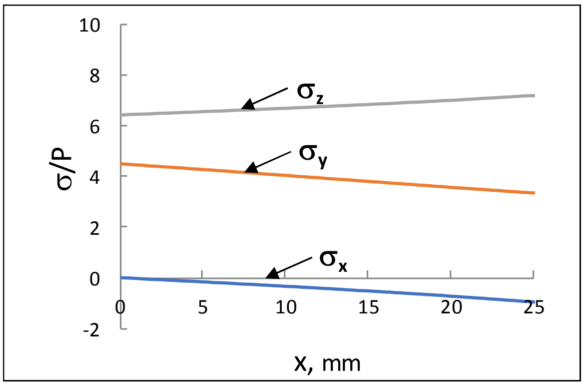

Fig. 5 Stress variation along the thickness.

When the effective heat transfer region is designed by 8MPa, maximum primary membrane stress is higher than alloy 617 $S_{mt}(10^5hr)$ at 950°C specified in ASME Section VIII. If the effective heat transfer region is designed by differential pressure between primary and secondary pressure, maximum primary membrane stress is 22% of alloy 617 $S_{mt}(10^5hr)$ at 950°C.

3. IHX Assembly Design

Intermediate heat exchanger of VHTR is designed to 350MWt heat transfer capacity. If the effective heat transfer modules are designed by the primary flow channel design pressure, it is composed of 200 PCHE modules since a module has 1.75MWt heat transfer capacity. However the effective heat transfer modules are designed by the differential pressure between primary flow channel and secondary flow channel, , it is composed of 56 PCHE modules. Arrangement of PCHE modules inside the pressure vessel is shown in Fig. 6. Whole modules are divided into 8 sections and each section has several modules. Alloy 617 is used to design heat transfer modules, internal pipes to distribute and collect secondary helium. The pressure vessel is designed by the conventional PWR material SA508. Thermal insulator designed by alloy 800H is installed between effective heat transfer region and pressure vessel to reduce the design temperature of the pressure vessel. A single heat transfer plate with flow path, a module by diffusion bonded plates, and whole intermediate heat exchanger are shown in Fig. 7.

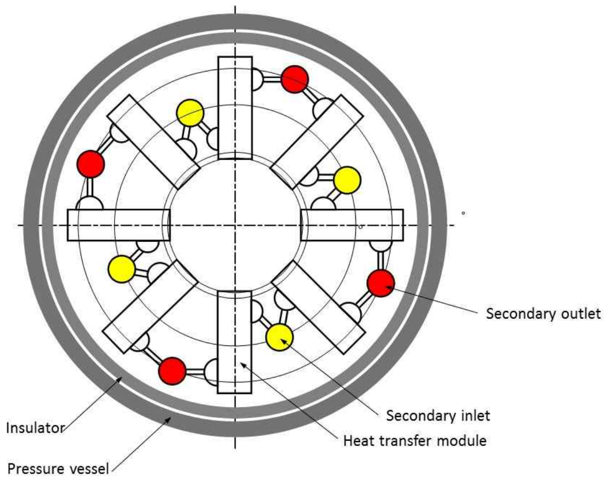

Fig. 6 PCHE modules arrangement inside pressure vesssel

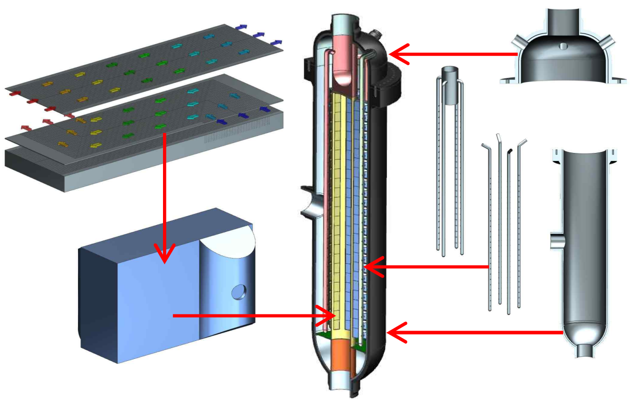

Fig. 7 Structure of intermediate heat exchanger assembly

As for the flow path, the primary helium is supplied to the bottom of the pressure vessel and then is distributed to each modules in radial direction. Secondary cold helium is supplied through four nozzles attached at the head of the pressure vessel. The secondary helium heated at the effective heat transfer modules is collected to the header located at the top of the pressure vessel. The primary and secondary flow path are shown in Fig. 8.

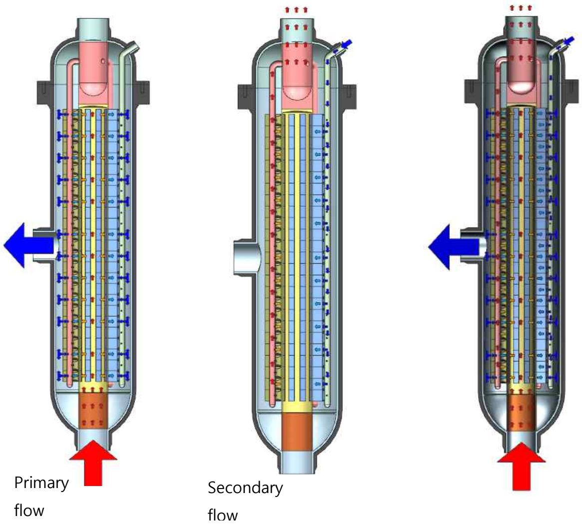

Fig. 8 Flow path of VHTR IHX assembly

When the effective heat transfer module is designed by differential pressure, the volume of intermediate heat exchanger becomes 25% of that designed by primary pressure.

4. Conclusions

Intermediate heat exchanger assembly by stacking a number of PCHE modules is designed according to ASME Section VIII. The effect of design pressure on the size of heat transfer region is investigated to minimize the size of intermediate heat exchanger. Circular shaped header is recommended to reduce stress values of secondary header than cylindrical shaped header. In order to maximize the compactness of PCHE type intermediate heat exchanger, it is recommended that the effective heat transfer modules designed by differential pressure of primary channel and secondary channel are installed inside the insulated pressure vessel designed by primary pressure.

Acknowledgement

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[4] ABAQUS/CAE 6.13-4