The Design and Analytical Validation of a C/C Composite Helium Heater for a VHTR Simulated Experimental Loop

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1. Introduction

A medium scale He loop for simulating a VHTR (Very High Temperature Gas Cooled Reactor) is now under constructing at the Korea Atomic Energy Research Institute [1]. A *high-temperature heater* (HTH) heating the 9.0MPa Helium up to 950°C is one of key components in the medium scale He loop [Fig. 1]. The HTH normally uses a non-metal heating element which can withstand temperatures in excess of 2000°C in an oxygen and moisture free environment. In this study, we discuss the design methodology for a high-temperature heater that has the following operating conditions:

Power,	300 kW
Pressure,	9.0 MPa
Inlet/outlet temperature,	500/1000 °C
Flow rate,	0.1 kg/s

The HTH design output was validated by the thermal-hydraulic analyses using both GAMMA and CFD codes.

2. Design Requirements

Design requirements for the high temperature heater are derived from thermal-hydraulic, mechanical and electrical considerations.

2.1 T/H Requirements

The *maximum operating temperature* (MOT) of the heating element is the primary factor in the HTH design which depends on the MOT of an internal insulator, a reflector and a heating element that form the flow channel of HTH. For example, a super Kaowool (internal insulator material) has the MOT of 1650°C. Keeping the flow regime turbulent in the HTH flow channel has great benefit in reducing the size of HTH. The heat transfer coefficient in turbulence flow is generally one order larger than that in laminar flow. The requirement of the Reynolds number in the flow channel exceeds the value of 2300 which is a departure from laminar flow to turbulent flow. The heat loss of the HTH depends upon the thickness of the internal insulation, the thermal stress of the vessel (maximum allowable surface temperature of the vessel), electric power and additional cooling devices. If we fix the cross-sectional geometry of HTH, we can obtain the necessary amount of heat loss through the energy balance.

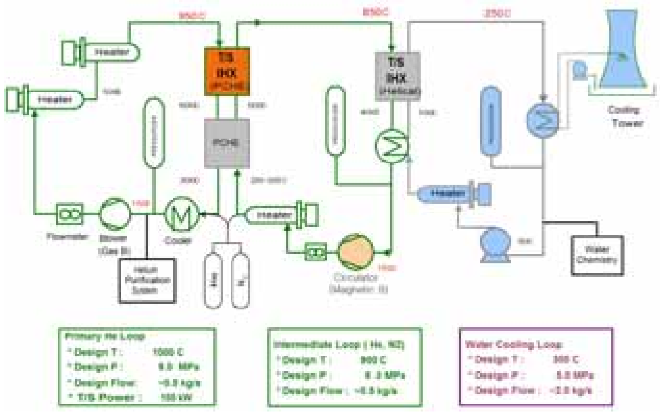


Fig. 1. Medium scale Helium loop

Heat transfer by conduction to outer wall of HTH
= Heat loss by convection & radiation to air

2.2 Electrical Requirements

The voltage limit of 380VAC depends on the power facility in our experimental building. There is no current limit, but 600amp is recommended because that is the maximum current limit of the available power lines (flexible power lines). For this reason, a 3-phase WYE connection is a good connection method for the electric power supply to HTH because it reduces the local current 73% less than that from the 3-phase delta connection.

2.2 Mechanical Requirements

Three aspects of the mechanical design of the HTH are considered to arrive at the following mechanical requirements: fluid-induced vibration, sound-induced vibration, and thermal stress analysis. The fluid induced vibration and the acoustic vibration were simply checked by the method proposed by Hong, et al. (2006). Thermal stresses are generated for all of the HTH components (liner, vessel, heater, spacers, connector) which expand against adjacent structural supports. Below 450°C, creep and creep rupture effects are usually negligible under high pressure conditions for steels and stainless steels [3].

3. Results and discussions

Figure 2 shows the vertical and cross-sectional views of a HTH. The stainless-steel vessel of the HTH heater is internally insulated by Kaowool ceramic fiber which

Table 1. Main results of HTH design

Item	Design Results	
Power	300kW (3p wye, V=300V, I=600amp)	
Geometry	Fig. 2	
Insulator	Thickness (Kaowool)	41 mm
Heater Internal	- Heater outlet T - Heater maximum T - Reynolds number	1000 °C 1360 °C > 2300
Vessel	- Outer surface T (Max.)	370 °C

Table 2. Results of the T/H design validation

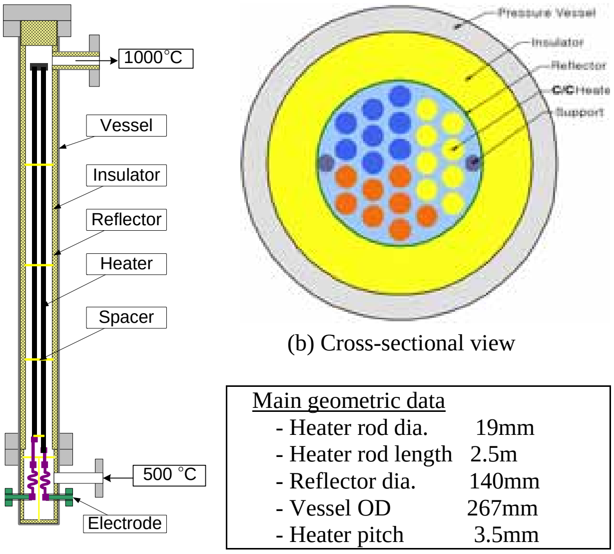
Variable	GAMMA	CFX
Pressure / Flow rate	9.0 MPa / 0.1 kg/s	
Power.	270 kW	
Exit He Temp.	1,000 °C	964 °C
Max. Heater Temp.	1,293 °C	1,317 °C
Outer Surface Temp. (Pressure Vessel)	295 °C	335 °C

protects the vessel from the 1000°C Helium. The molybdenum liner provides a robust separation between the insulation and the flow channel. It also functions as a reflector against the thermal radiation emitted by the 24 electrically heated C/C composite rod array. The 24 C/C composite rods withstand over 2000°C in the oxygen and moisture free environment. They are electrically connected by the 3-phase (R[yellow], S[blue], T[red] phase) WYE connection method as shown in Fig. 3. Each phase has 8 rods and current passes up and down with a common pair of 2 rods (parallel combinations of 2 rods with serial combinations of 4 rods). The rods in the 24 rod array are insulated from each other by BN-P ceramic spacers, equally spaced vertically 500mm between rods.

The main design results of HTH design are listed in Table 1 which satisfies the design requirements discussed in section 2. Thermal performance for the internal heater is validated with sophisticated design tools, GAMMA code and a commercial CFD code (ANSYS CFX release 11), and the results are in Table 2 and Figure 3, respectively.

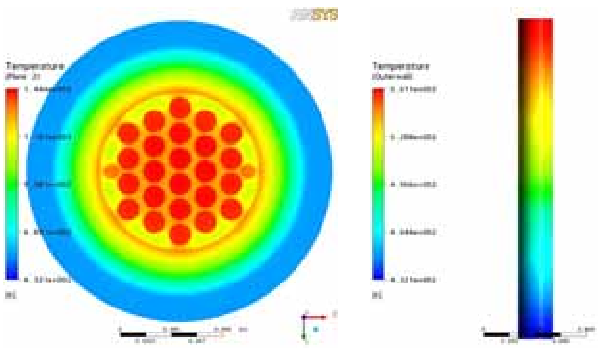
4. Conclusions

We designed a C/C composite Helium Temperature Heater for VHTR simulated experimental loop. The 3-phase WYE electrical connection method is the optimal arrangement of the 24 C/C composite heating elements for producing 300kW power. Thermal performance of the main heater is successfully validated by both the GAMMA and the CFD analyses. Radiation heat transfer contributes well to the restraint of abnormal temperature rising phenomenon in the heater.



(a) Vertical view (b) Cross-sectional view

Fig. 2. Vertical and cross-sectional views of a HTH



(a) T distribution at exit (b) Vessel surface T

Fig. 3. Validation results (ANSYS CFX release 11)

ACKNOWLEDGEMENTS

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