GAMMA+ Analysis on High Temperature Helium Heater for Its Optimized Operation Procedure

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1. Introduction

KAERI is constructing a middle-sized Helium Experimental LooP (HELP) to simulate Very High Temperature gas-cooled Reactor (VHTR) for the main component tests such as intermediate heat exchanger, hot gas duct and others [1]. A high temperature helium heater is one of key components in HELP, because it raises the helium temperature from 500℃ to 950℃, VHTR outlet temperature. The heater is designed based on the design [2] and operation experiences [3] of the high temperature heater in the small-scale gas loop. Hong et al. [4] discussed the design methodology of a high temperature heater and showed that its design was validated by thermal hydraulic analyses using the system analysis with GAMMA+ and the computational fluid dynamics analysis with CFX. The heater has the following design specification;

Power:	300 kW
Pressure:	9.0 MPa
Inlet/Outlet Temperature:	500/1000℃
Flow Rate:	0.1 kg/s

In this study, the high temperature heater was systematically analyzed with GAMMA+ to optimize the operation procedure. The heated material can't stand the thermal shock due to the sudden temperature change. The power-rising step of the heater is found to decrease the temperature rising time without the reduction of the heated element life time. In addition, the operation condition was analyzed for the removal procedure of oxygen and humidity in the helium system.

2. High Temperature Heater

Figure 1 shows the schematic diagram of the high temperature heater. The design inlet and outlet temperatures of the heater are 500℃ and 1000℃, respectively. The heater had 24 C/C composite heated rods made of C/C composite, which withstands a temperature up to 2000℃ at the oxygen and moisture free environment. The rods were electrically connected by the 3-phase wye connection method. Each phase has 8 rods with the parallel combination of 2 rods and serial combination of 4 rods. The BN-P spacers were installed to maintain the constant gap between the heated rods as shown in Figure 1.

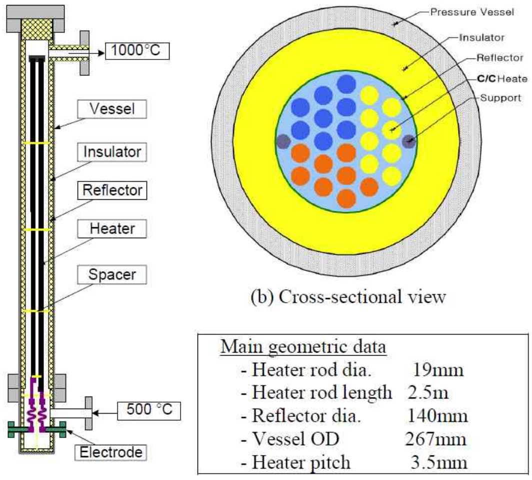

Figure 1. High Temperature Helium Heater

The turbulent flow regime in the heater must always be maintained to obtain the large heat transfer coefficient and the compact size of the heater. In addition, the heater has three mechanical requirements including flow induced vibration, acoustic vibration, and the thermal stress.

The pressure vessels were internally insulated to protect the direct contact with the high temperature gas. The liner between the heated element and the insulator was installed to reflect the thermal radiation from the heated element, maintain the flow channel in the heater, and prevent the large dust ingress from the insulator to the gas flow. The insulator material was Kaowool, and the liner was made of Molybdenum. The liner and the pressure vessel had the sliding joints to buff the thermal expansion by the high temperature operation. The insulator thickness was large enough to maintain the vessel temperature under 350℃ at the full power condition.

3. GAMMA+ Analysis

Figure 2 shows the GAMMA+ analysis model of the fluid and solid for the high temperature helium heater. The solid models include the heated element, the Kaowool(fiber), and the pressure vessel. In the model, the flow channel is single at the cross section based on the computational fluid dynamics analysis [5]. The inlet mass velocity, temperature, and pressure are 0.1 kg/s, 500℃, and 9.0 MPa, respectively. The heat generation distribution is uniform in the heated element. The boron nitride spacers were neglected to simplify the analysis. The vessel is cooled in the ambient air with room temperature.

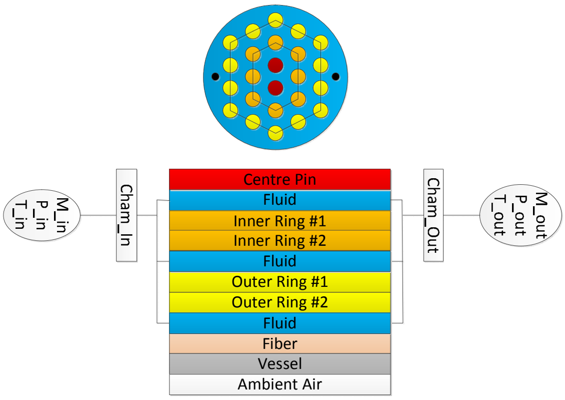

Figure 2 GAMMA+ Model for High Temperature Helium Heater

Table 1 shows the analytical results on the maximum heated element temperature and the outlet temperature of the high temperature heater. Temperature difference between the outlet temperature and the maximum heated surface temperature in the helium loop is relatively smaller than that of the nitrogen loop [2], because the heat transfer coefficient of helium flow is higher than that of nitrogen flow. Therefore, the large power step (~10 kW) will not result in the sudden increase of the heated element temperature as the heated element in the nitrogen loop. Since the temperature rising rate of the heated element is larger than that of the outlet gas temperature due to the increased radiation effect, the power increase rate must be gradually reduced in the high temperature region.

Table 1. Outlet Temperature and Maximum Heater Temperature during Normal Operation

Mass Velocity	Heated Power	Outlet Temperature	Max. Heater Temperature
0.1 kg/s	25 kW	541.15℃	565.76℃
	50 kW	588.00℃	637.16℃
	75 kW	634.88℃	703.44℃
	100 kW	681.89℃	767.58℃
	125 kW	728.03℃	829.70℃
	150 kW	774.78℃	890.20℃
	175 kW	820.32℃	949.85℃
	200 kW	865.20℃	1006.93℃
	225 kW	913.24℃	1066.54℃
	250 kW	959.42℃	1123.74℃
	270 kW	997.84℃	1169.75℃

Additionally, the oxygen and humidity removal operation in the helium system requires that the maximum heated element temperature must be under 480℃ at the atmosphere. The GAMMA+ analysis at the low mass velocity condition provided the following conservative operation condition.

Pressure:	3 MPa
Mass Velocity:	0.05 kg/s
Inlet Temperature:	300℃
Outlet Temperature:	402.1℃
Heated Power:	25 kW
Maximum Heated Element Temperature:	414.7℃

4. Conclusion

GAMMA+ analysis on the high temperature helium heater with various power conditions provides the basic information for the operation procedure. The large conductivity of the helium permits the larger fraction of the power change rate than that in the nitrogen loop. The analytical result also provides the operation condition for the oxygen and moisture removal procedure.

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