High Temperature Helium Heater for 800℃ Steam Supply to a Lab-scale HTE Device

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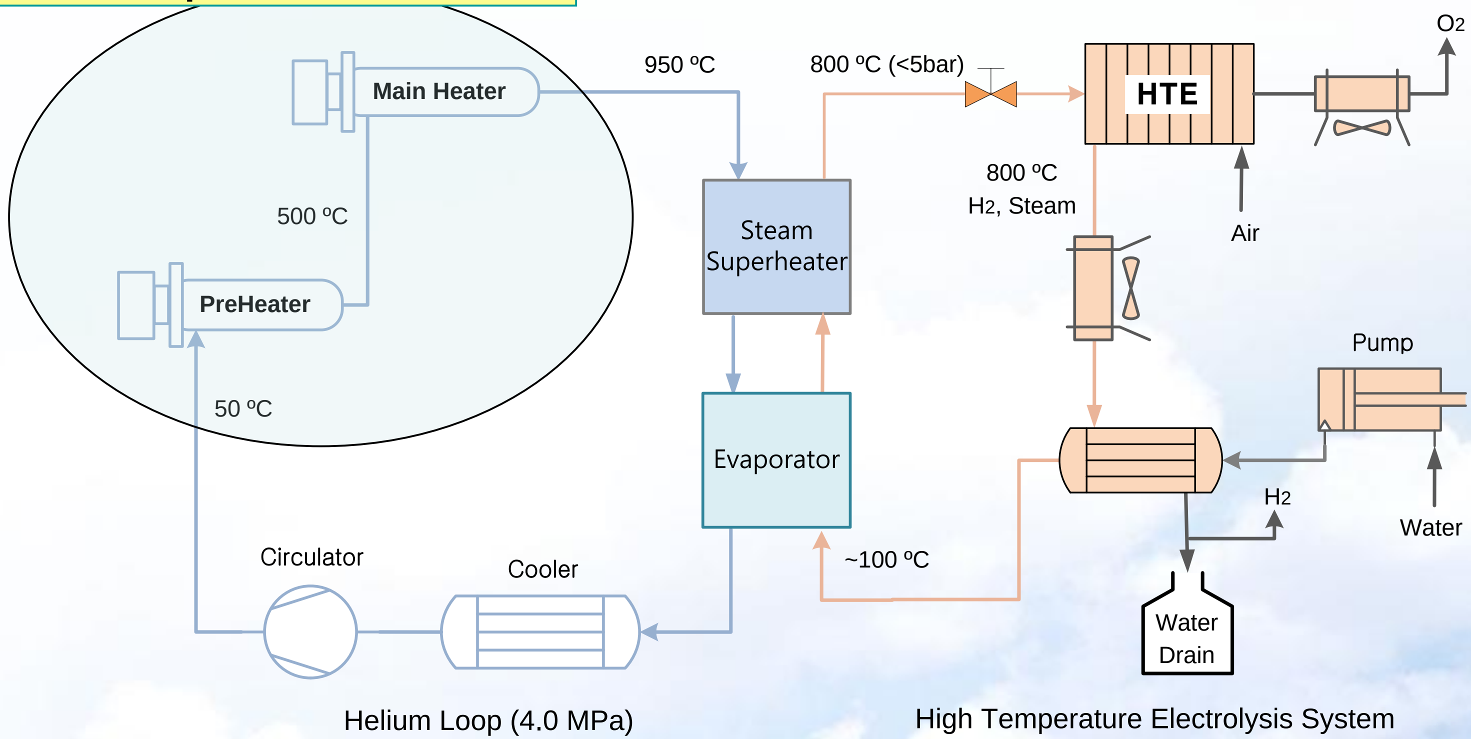
Introduction

- A Lab-scale helium loop for simulating a VHTR (Very High Temperature Gas Cooled Reactor) is now under constructing at the Korea Atomic Energy Research Institute. The Lab-scale helium loop will be connected to 30kW capacity “High Temperature Electrolysis (HTE) system” as a function of high-temperature steam supply to the HTE device. A *high-temperature heater* (HTH) heating the 4.0MPa helium up to 1000°C is one of key components in the Lab-scale helium loop

- In this study, we discuss the design methodology for a high-temperature heater. The HTH design output are validated by the thermal-hydraulic analyses using GAMMA+ code

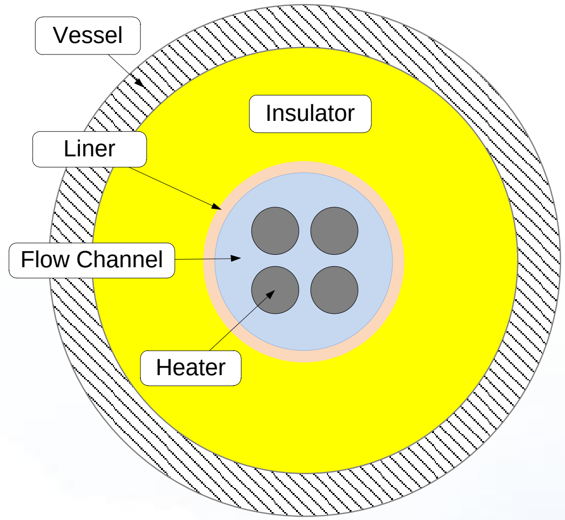
HTE Experimental Loop

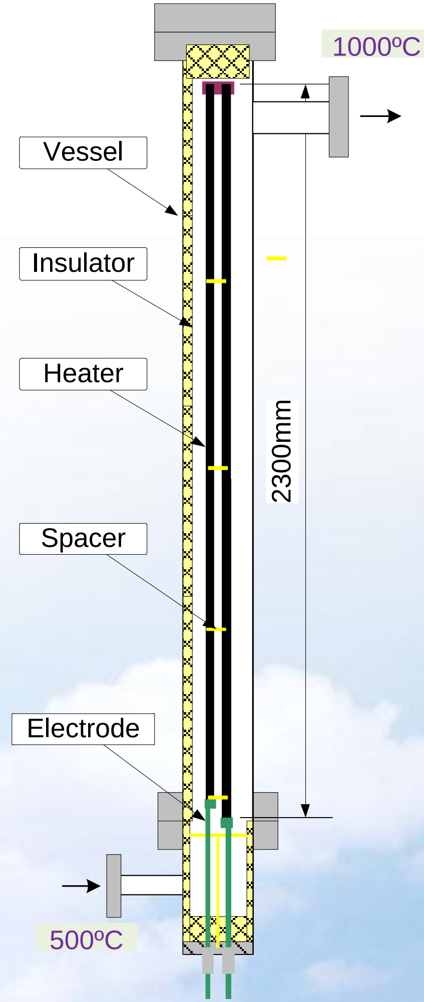
- **Specification of heater system**
  - **Power : 55.0 kW**
  - **Design pressure : 6.0 MPa**
  - **Flow rate: 1.0 kg/min**
  - **Inlet/outlet temp. : 50/1000 °C**

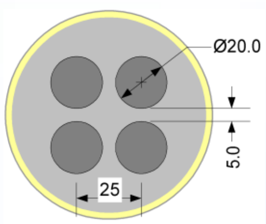


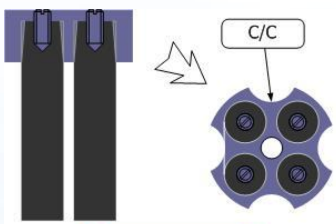
High-temp. Helium Heater

- Vessel
  - 114mm outer diameter (SS304)
- Internal insulator
  - Kaowool ceramic fiber (1600°C)
- Corundum liner
  - Prevention of dust ingress
  - Low conductivity (2.0 W/mK)
- Heater element
  - Carbon fiber composite (CFC)
  - 2x2 bundle, 2.3m heated length
- BNP-ceramic spacer
- Mo & Ni electric connectors

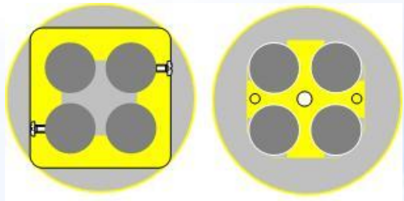


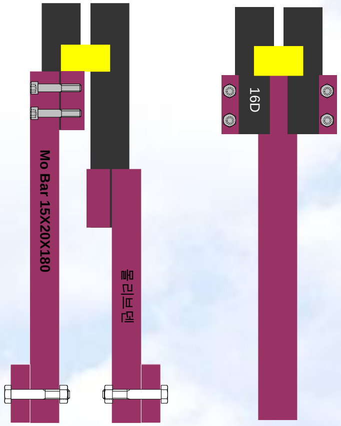






Upper Connection


External and Internal Spacer



Mo Connectors

Mechanical Design Requirements

❑ Flow induced vibration

- Reduced velocity

$$\frac{U_{Critical}}{fD} = K\sqrt{2\pi\zeta\frac{m}{\rho D^2}}$$

❑ Acoustic vibration

- Speed of sound in a gas

$$\upsilon_S = \sqrt{\frac{\gamma\Re T}{M}}$$

❑ Thermal stress

- Generated as components attempt to expand against restraints or non-uniform temperature distribution within the body
- Appropriate Internal insulations for keeping the steel boundaries

Item	Design Requirement
Helium outlet T	≤ 1000 °C
FIV	$U/(fD)$ < 22
AV	υ_S << 1739 m/s
Temperature limit (Material)	- Heater element < 1500 °C - Ceramic Liner < 1300 °C - Insulator < 1200 °C - Vessel (Alloy) < 450 °C - Vessel (304SS) < 360 °C

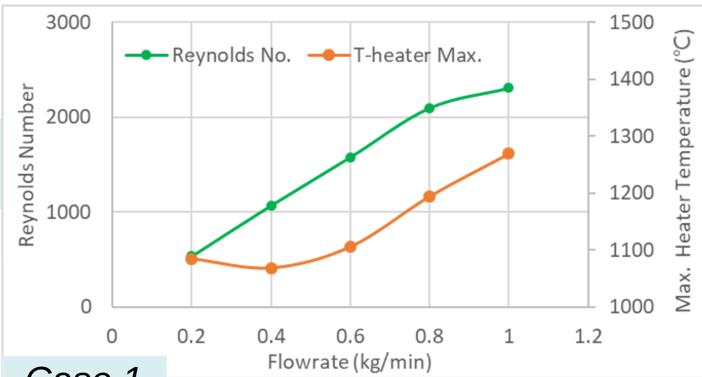
GAMMA+ Analysis

- GAMMA+ model
  - Four heater is lumped to one heater
  - Nodes
    - Axial 22 cells
    - Radial 17 cells
  - Radiation : View factor model (two zones)
- Main results
  - Vessel temperature is the main constraint of high-temperature heater operation
  - Helium flow is under laminar and mixed flow condition at Case 1
  - Helium flow is under mixed and week turbulent flow condition at Case 2

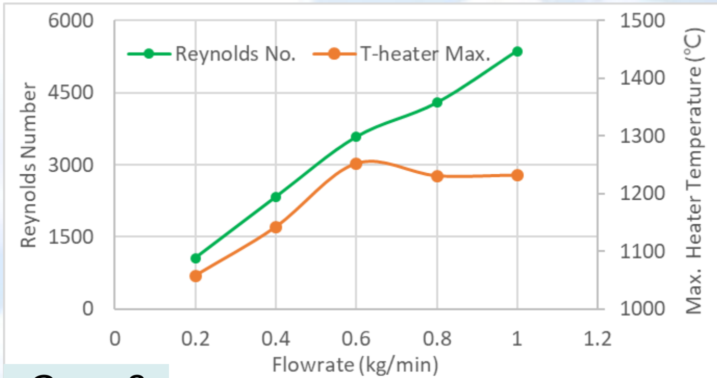
*Temperature limit: Vessel 360℃, Heater 1500℃

Flowrate (kg/min)	Reynolds No.(outlet)	Power (kW)	T-heater Max. (℃)	T-vessel Max. (℃)	Heat loss (kW)
Case 1 (flow area = 0.003161 m²)					
0.2	533	12.4	1084.9	338.5	3.76
0.4	1070	21.0	1068.7	335.3	3.59
0.6	1580	29.6	1105.9	340.9	3.68
0.8	2100	38.5	1194.5	360.0	3.94
1.0	2310	47.2	1269.4	372.9	4.23
Case 2 (flow area = 0.001571 m²)					
0.2	1060.0	12.4	1057.2	333.8	3.54
0.4	2330.0	21.3	1142.0	348.5	3.84
0.6	3580.0	30.2	1252.4	368.2	4.32
0.8	4290.0	38.8	1231.1	358.2	4.18
1.0	5370.0	47.3	1232.2	354.8	4.12

Pressure: 3.0MPa
Inlet/outlet temp.: 500/1000℃



Case 1



Case 2

GAMMA+ Analysis

- Comparison between helium and nitrogen
  - Temperature of the nitrogen gas heater increases by about 60℃ to produce the same amount of power(29.6 kW) as helium gas heater. In the case of the vessel, it decreased by 39℃. This is because helium gas is a mixed flow whereas nitrogen gas is a sufficiently developed turbulence flow
  - Helium gas does not easily generate turbulence compared to nitrogen gas

Parameter	Unit	Case 1		Case 2	
		He	N2	He	N2
T-heater Max.	℃	1106	1166	1252	1246
T-vessel Max.	℃	341	302	368	317
Heat loss	kW	3.68	2.83	4.32	3.16
Flowrate	kg/min	0.6	2.8	0.6	2.8
Reynolds No.	-	1580	8360	3580	16600
Power	kW	29.6	29.6	30.2	30.2

Pressure: 3.0MPa, Inlet/outlet temp.: 500/1000℃

Conclusion

- A high-temperature heater (HTH) heating the 4.0MPa helium up to 1000°C is one of key components in the Lab-scale helium loop that will be connected to 30kW capacity HTE system as a function of high-temperature steam supply to the HTE device. Thermal performance of the main heater is validated by a GAMMA+ analyses.

- As a result of the GAMMA+ analysis, it is found that helium gas does not easily generate turbulence compared to nitrogen gas. That is, in order to form a turbulent flow, helium gas requires a relatively small flow area compared to nitrogen gas. The normal operation of the 30kW HTE helium heater was 3.0MPa and 0.4kg/min, which was interpreted as satisfying all design requirements in case 2.

- From the GAMMA+ analyses, it is found that the vessel temperature is the main constraint of HTH operation.