Conjugate Heat Transfer Analysis of the High Temperature Heater for Supplying Superheated Steam to a Lab-scale HTE Device

Churl Yoon*(cyoon@kaeri.re.kr), Sung-Deok Hong, Hong Sik Lim, and Chan Soo Kim

Korea Atomic Energy Research Institute

Purpose and Ultimate Goal

Purposes : To analyze conjugate heat transfer phenomena inside the HTH (High Temperature Heater) by using Computational Fluid Dynamics (CFD) methodology

Ultimate Goal : To validate and improve the proposed HTH design

HTH in HTE(High Temperature Electrolysis)

HTE for simulating VHTR (Very High Temperature gas-cooled Reactor):

- 30kW lab-scale Helium loop in KAERI consists of
  - · High Temperature Electrolysis (HTE) system
  - · Helium loop supplying high temperature He gas (3.0MPa, 1000°C)
- In Helium loop, preheater and main heater (HTH) heat up 3.0MPa He gas up to 500°C and 1000°C, respectively.

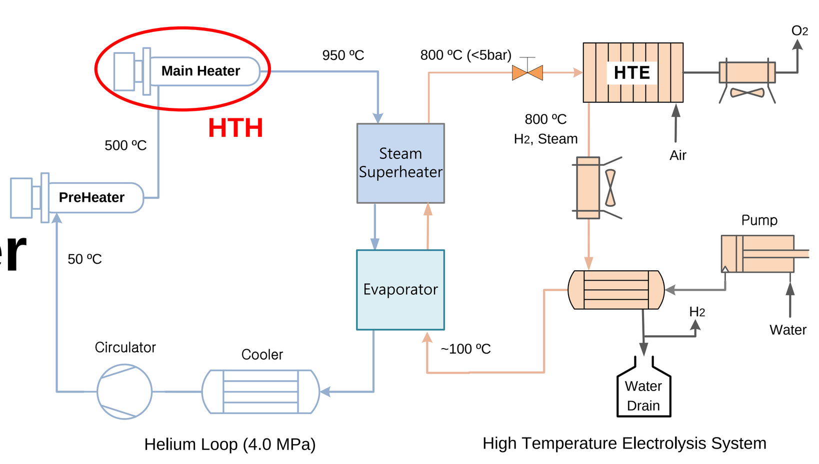


Fig. Lab-scale Helium Loop in KAERI

HTH (High Temperature Heater):

- 4 electric heater: Carbon Fiber Composite (CFC)
- Spacers: Boron-Nitride
- Liner: Corundum
- Insulator: Kaowool™ ceramic fiber
- Vessel: SUS316 steel

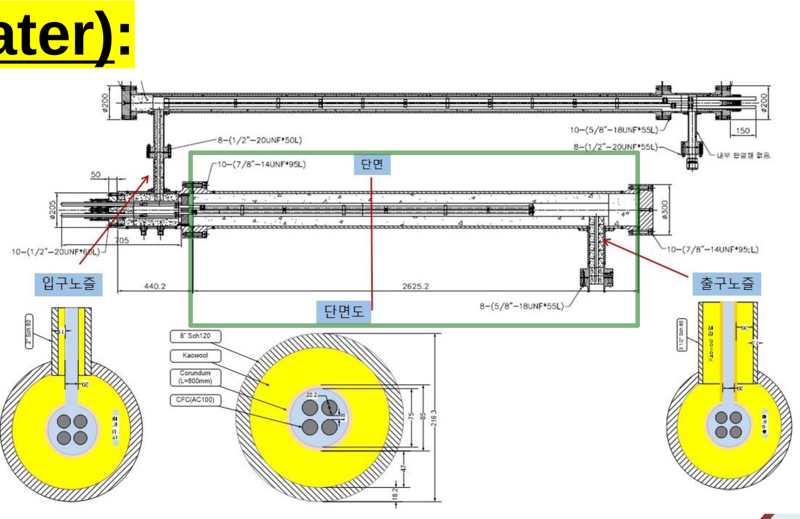


Fig. High Temperature Heater (HTH)

CFD Analysis Methodology

Computational Domain: Green lined section in the left lower figure

Part Geometries: All parts including spacers and end mount were generated by ANSYS 'Design Modeler'.

Mesh: Unstructured tetra meshes by 'ANSYS Mesher'
- Total cell number = ~ 25,000,000

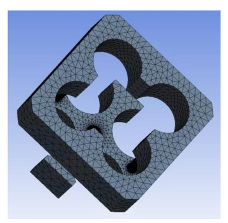


Fig. Spacer

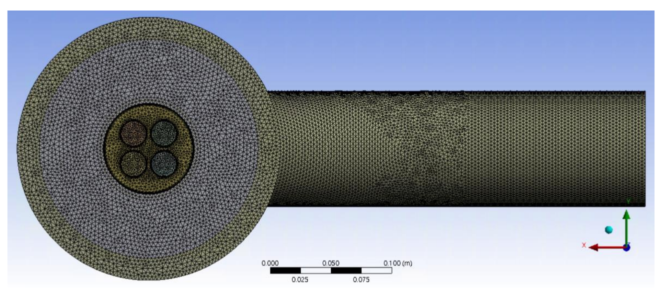


Fig. Inlet

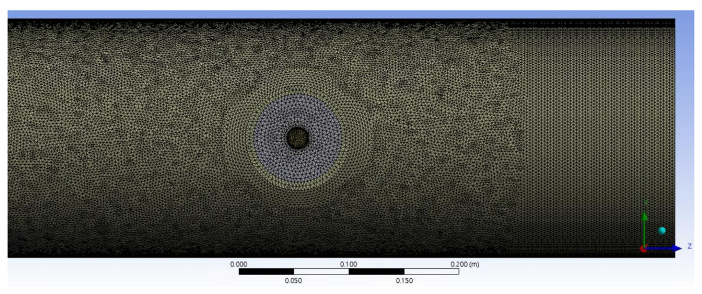


Fig. Outlet

Physics Models: All three conductive, convective and radiative heat transfer phenomena of the Helium gas, as well as conduction in the solid structures, were analyzed by using ANSYS CFX CFD software.

- · Turbulence: Shear Stress Transport (SST) Model
- · Radiative Heat Transfer: P-1 Model
- · Boundary Conditions:
  - Inlet: mass flow rates = 0.2 ~ 1.0 kg/min @500°C
  - Outer vessel surface: $q''_w = h(T_w - T_\infty) + F\varepsilon\sigma(T_w^4 - T_\infty^4)$

Streamlines and Pressure

Simulation Cases:

Case	A	B	C	D	E
MFR* [kg/min]	0.2	0.4	0.6	0.8	1.0
Power [kW]	12.4	21.0	29.6	38.5	47.2

* MFR = Mass Flow Rate

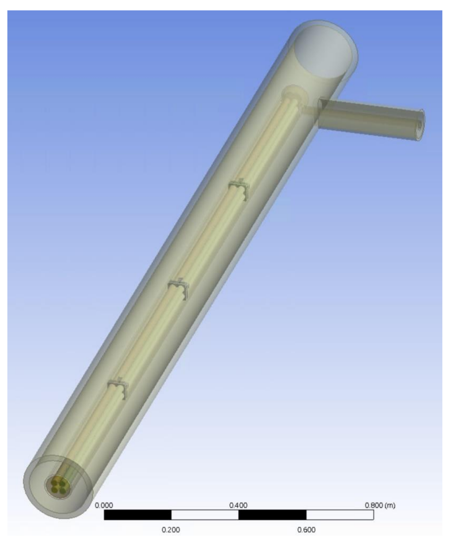


Fig. Computational Domain

Streamlines:

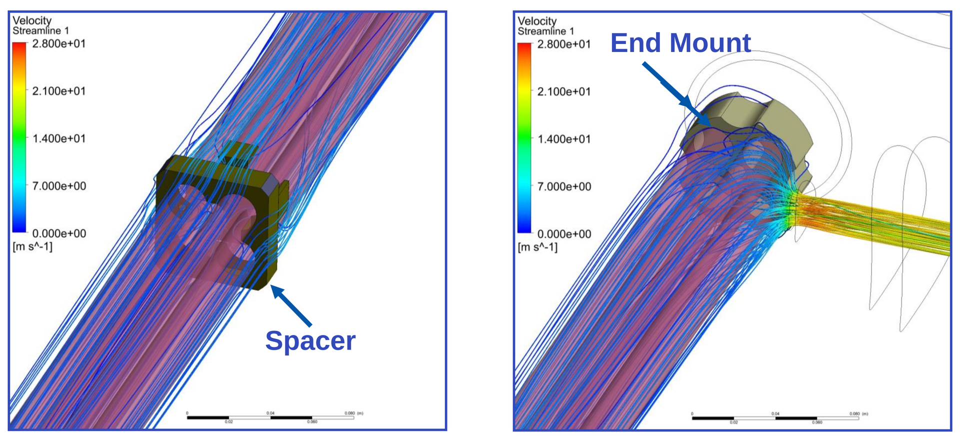
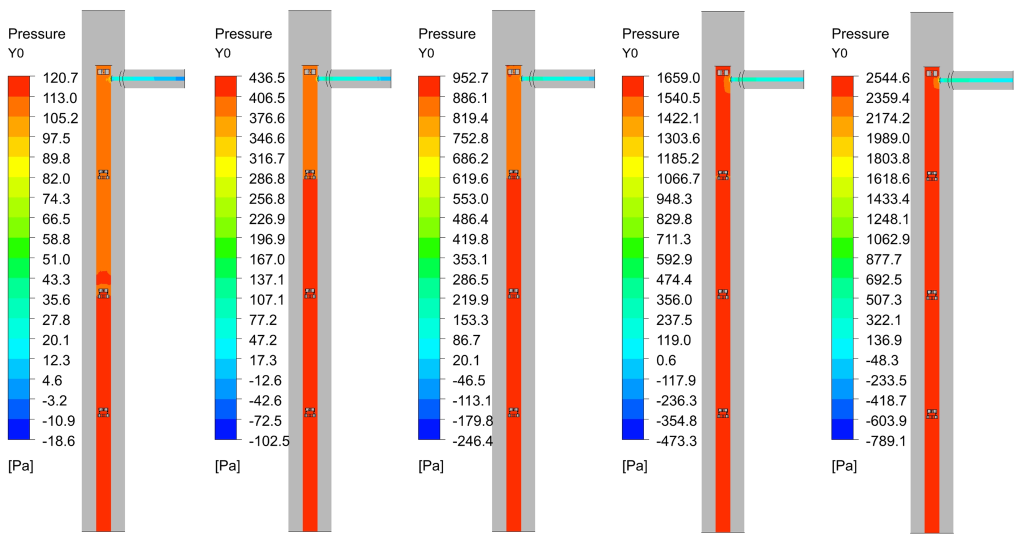


Fig. Streamlines of Case B

Pressure Fields:



Case A Case B Case C Case D Case E

Temperature Distribution

Selected Cross-sections:

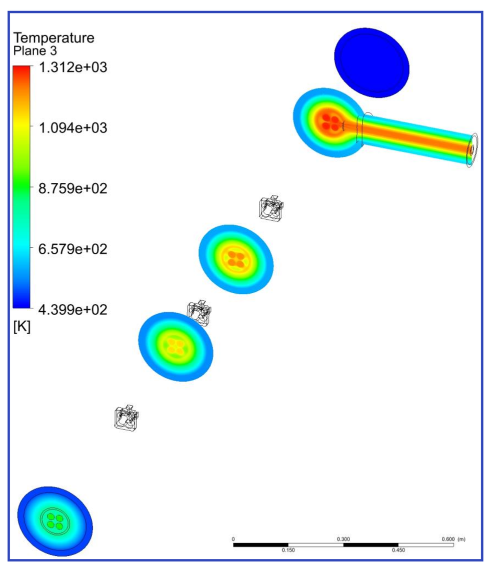


Fig. Temp. Contours for Case B

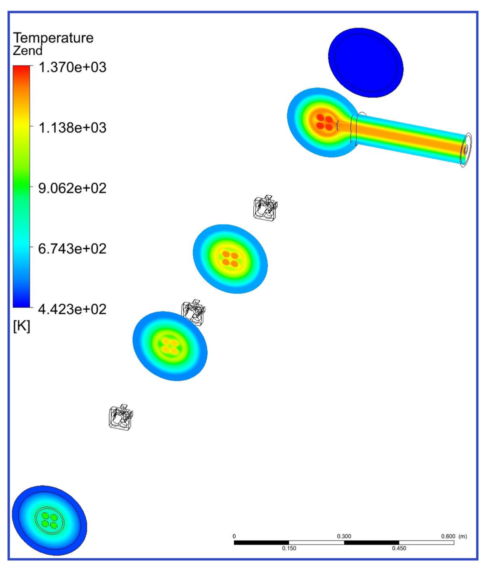
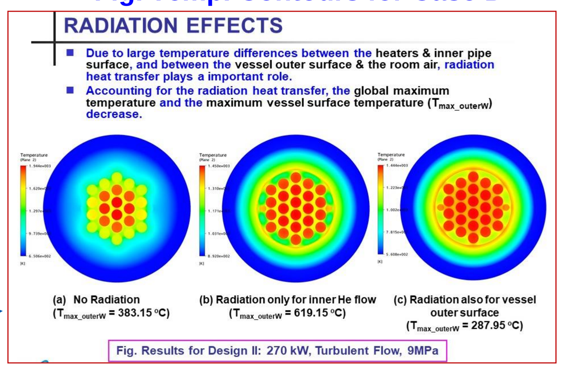


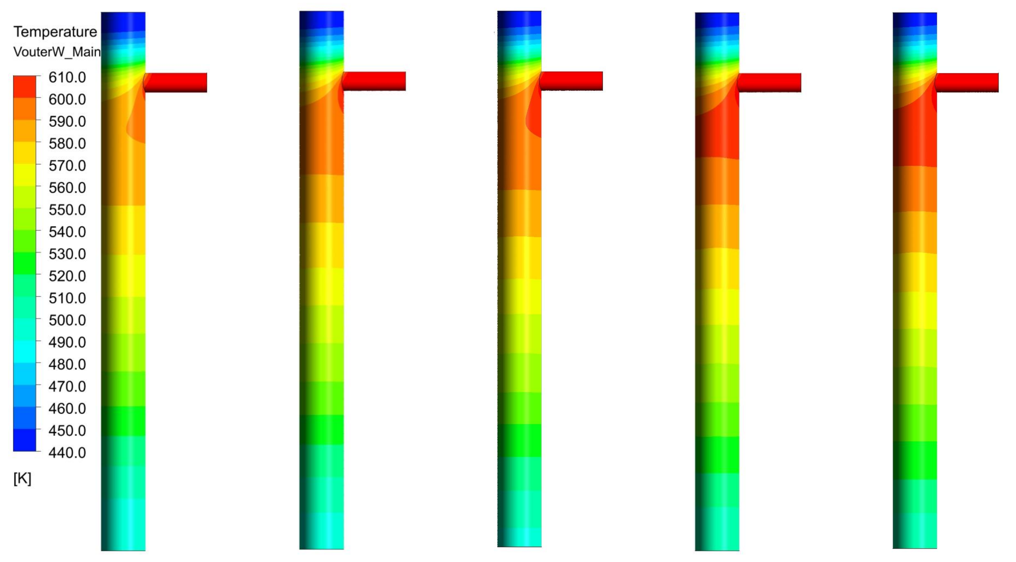
Fig. Temp. Contours for Case D

Due to the direct heating by radiation, the inner surface temperature of the inner liner is higher than neighboring He gas.



From Previous Study (Yoon et al., 2009)

Vessel Outer Surfaces:



Case A Case B Case C Case D Case E

Comparison with GAMMA+ Results

BC at the vessel outer surface:
- convective H/T coefficient h = 0
- emissivity ε = 0.5

MFR [kg/m]	Re (outlet)	Power [kW]	T_{max} (heater) [°C]	T_{max} (vessel) [°C]	Heat Loss [kW]
ANSYS CFX					
0.2	533	12.4	995.2	348.5	4.03
0.4	1070	21.0	1038.7	356.6	4.16
0.6	1580	29.6	1068.1	360.9	4.27
0.8	2100	38.5	1097.0	364.9	4.36
1.0	2310	47.2	1119.4	367.1	4.42
GAMMA+					
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

Conclusions:
- High velocity near obstacles and entrance to the outlet pipe
- High inlet pressure for high MFR
- Radiative direct heating heats up the inner liner surface.
- Relatively low Buoyancy force effect
- Good agreement with GAMMA+ results