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# CFD Analysis of a Very High Temperature Helium Heater in the VHTR Simulated Experimental Loop

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## 1. Introduction

Very High Temperature Gas Cooled Reactor (VHTR) has been selected as a high energy heat source for a nuclear hydrogen production. The VHTR heat is transferred to a thermo-chemical hydrogen production process through an intermediate loop [1]. Since the VHTR operates at high temperature and a high pressure ($950^oC$ & 7.0 MPa), the performance of the main system components are not fully validated. It is required to demonstrate the performance and integrity of the system component by experiments.

A medium scale Helium loop that can simulate a VHTR is now under constructing in Korea Atomic Energy Research Institute [2]. A “very high-temperature Helium heater” is a key component of this Helium loop. The heater is supplied electricity to heat up the helium coolant up to 950°C at the pressure of 9MPa. A design check of the heater is very critical to operate of the loop with safe. The purposes of this study are to determine whether operating of the “very high-temperature Helium heater” could make any fatal condition by using CFD technique and to find out the optimum design specifications.

## 2. Methods and Results

Target exit temperature of the main He heater, the second heater in the primary side, is ~$950^oC$, therefore the maximum temperature over the whole system appears at the heating rods in the main heater. The main heater is analyzed by CFD to check whether the maximum temperature exceeds the design limit, ~$1600^oC$, or not.

### *2.1 Computational Domain*

Figure 2 shows the cross-sectional view and mesh of the heater, which is identical over the whole axial distance. The heater is one-through type and the heated length of the heater is 2.5 m. The outer vessel of the heater is made by SUS304 steel, and a thick insulating layer of Ceramic Fiber is installed inside the vessel to prevent a thermal failure of the vessel from the high temperature Helium flows through the central passage, in which 24 electrically powered heaters(C/C Composite) are located in a staggered pattern. In the central fluid region, prismatic layers of fine grid are inserted near the solid boundaries to meet the requirement of the wall modeling. The total number of nodes is 4,056,918 with 251 axial nodes.

### *2.2 Heat Load and Boundary Conditions*

In normal operating conditions, the total heat load and the He mass flow rate are assumed to be 270kW and 0.1kg/s, respectively. The inlet temperature is $500^oC$ and the environmental temperature is $30^oC$. The operating pressure was set to be 10 ~ 90 atm. By preliminary calculation without radiation, the outer vessel surface temperature will reach a few hundreds degree Celsius. That means that radiation heat transfer plays an important role at the outer wall boundary as

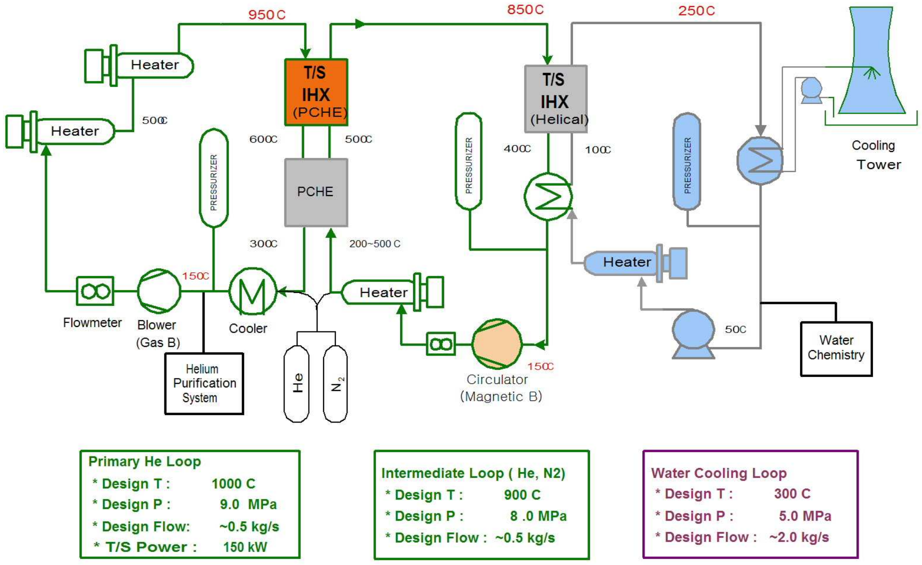


Fig. 1. Medium scale Helium loop.

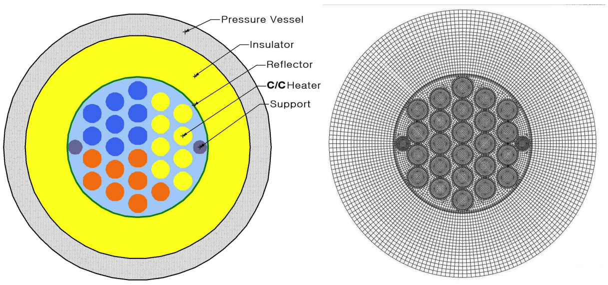


Fig. 2. Cross-sectional view of Helium heater and mesh.

well as the inner fluid region. Thus, the heat flux at outer vessel surface can be expressed as,

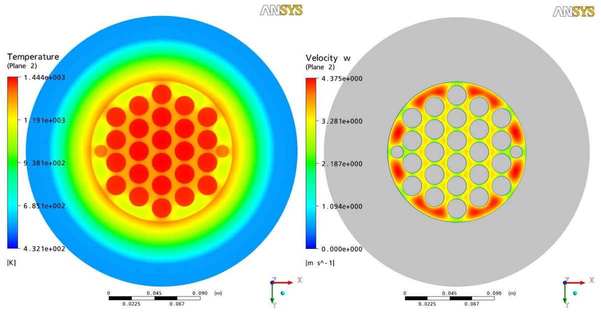
$$q''_w = h\left(T_w - T_\infty\right) + F\varepsilon\sigma\left(T_w^4 - T_\infty^4\right) \qquad (1)$$

where, *h* is convective heat transfer coefficient, *F* is a view factor, ε is emissivity, and σ is Stefan-Boltzmann constant.

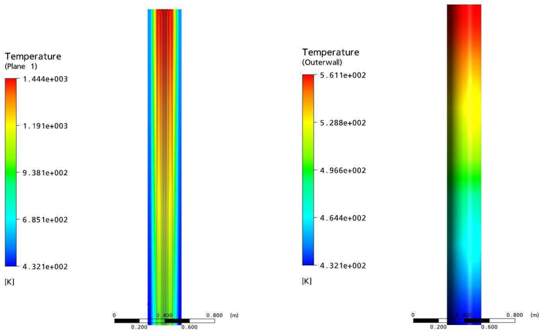
### 2.3 Fluid Model

A commercial CFD code, ANSYS CFX release 11, is used for the analysis. Because the *Re* number of the He flow is in the range of transition region, either laminar or turbulent flow models are applied. The radiation heat transfer from the heaters to the inner surface of the insulator is account for by P1 radiation model [3]. Thermal boundary condition at the vessel outer wall is expressed as a function of local surface temperature with constant convective heat transfer coefficient of 10W/m$^2$K. The effective thermal conductivity of the vertically mounted insulator is set as a function of temperature as follows [4]:

$$\lambda_{eff}[W/mK] = 0.0201 + 6.04\times10^{-4}\cdot T(K) \qquad (2)$$



(a) temp. at exit (b) axial velocity at exit



(c) cross-sectional temp. (d) vessel surface temp.

Fig. 3. Results of turbulent fluid flows with a heat load of 270kW and a mass flow rate of 0.1kg/s at 90 atm.

Table I: Average exit Helium temperatures and maximum heater temperatures.

| | | Laminar | Turbulent |
|---|---|---|---|
| Avg. Exit He Temp. | 90 atm | 963.9 °C | 962.9 °C |
| | 10 atm | 959.9 °C | 958.8 °C |
| Max. Heater Temp. | 90 atm | 1,317 °C | 1,171 °C |
| | 10 atm | 1,315 °C | 1,168 °C |

### 2.4 Results

Figure 3 shows the analysis results for the turbulent fluid flow at 90 atm. As expected, the heater temperatures are the maximum over the domain and reach up to 1,171°C. Due to the direct heating by radiation, inner surface temperature of the insulator is higher than that of the He flows. Stream-wise velocities are high at the near-boundary regions where most spacious flow passages are located. The outer vessel surface temperatures are in the range of 150 ~ 300°C, which are lower than the case without radiation heat loss from the outer surface. Table I summarizes average exit He temperatures and maximum heater temperatures for all test runs.

## 3. Conclusions

To optimize design specification of the experimental Helium loop, conjugate heat transfer in the high-temperature Helium heater was analyzed by CFD simulation. From the analysis results, the maximum temperature does not exceed the allowable limit. It is confirmed that flow characteristics of the given geometry well meet the design requirements.

## Acknowledgement

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