# A Study on the Buoyancy and Radiation Effects of the Experimental Helium Loop for VHTR Simulation

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## 1. Introduction

A medium-scale Helium loop for simulating the VHTR(Very High Temperature Reactor) is now under construction in Korea Atomic Energy Research Institute. Two electric heaters of the test Helium loop heat the Helium fluid up to 950°C at the pressure of 1 ~ 9MPa. To optimize design specification of the experimental Helium loop, conjugate heat transfer in the high-temperature Helium heater was analyzed by CFD simulation. Main factors tested in this CFD analyses are the effects of turbulence, buoyancy forces, and geometrical configuration of the heater, etc. From the previous studies[7,8], the optimum design configuration was selected. In this study, the gravity and emissivity effects on the thermal-fluid characteristics will be investigated by sensitivity studies.

## 2. Analysis Methodology

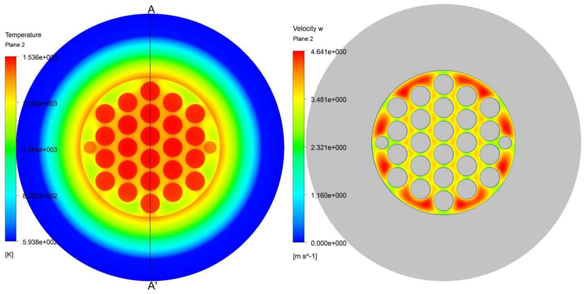
The selected design has 18 electric heaters inside a 2.5m-long pressurized steel vessel, inside of which is a 38mm-thick coaxial insulating pipe made of Ceramic Fiber. The Helium fluid heated up to 500°C in the first low-temperature heater flows in the second Helium heater, and is heated again up to 1000°C before exiting through the outlet at 9MPa pressure. During this heating process, part of the heat is transferred in lateral direction and lost to the atmosphere outside the pressure vessel. Due to the high-temperature characteristics, radiation heat transfer is also play an important role in this problem.

The continuity, momentum and energy equations associated with the equations of turbulent kinetic energy and turbulent dissipation transport equation were solved by a commercial CFD code, ANSYS CFX release 12.0. In this study the 'P-1' radiation heat transfer model was adapted, in which all the surfaces were assumed to be diffuse and grey. When we define incidence radiation as $G_v \equiv \int I_v d\Omega$, the transport equation of G becomes as follows with the diffuse-grey assumption.

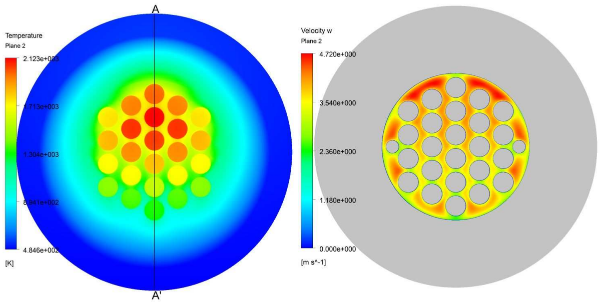
$$\nabla(\Gamma\nabla G) - K_a G + 4K_a \sigma T^4 = S, \quad \text{with } \Gamma = \frac{1}{3(K_a - K_s) - AK_s} \qquad (1)$$

Here, $K_a$ = absorption coefficient, $K_s$ = scattering coefficient, and $\sigma$ = Stephen-Boltzmann constant. And the source term due to the radiation heat transfer in the energy equation was obtained by

$$-\nabla q_r = K_a G - 4K_a \sigma T^4 \quad . \qquad (2)$$



(a) With radiation heat transfer in inner channel



(b) Without radiation heat transfer

Fig. 1. Results of Design II with gravitation in –Y direction: Horizontal Installation of the Heater

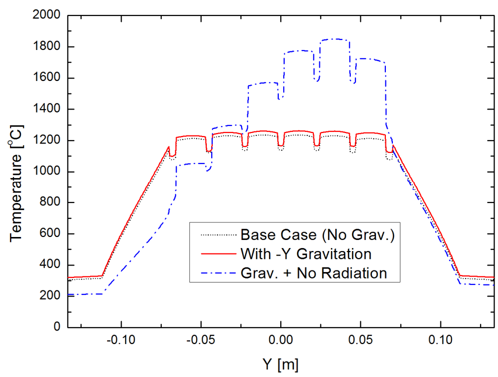



Fig. 2. Vertical temperature profiles at exit (Z = 2.49m): Gravity effect.

## 3. Sensitivity of the Separate Effects

### *3.1 Buoyancy Effects*

Helium is an ideal gas, so that the fluid is basically Buoyant under heating processes. To examine the Buoyancy effects, analyses were performed accounting for the gravitational forces assuming horizontal or vertical installations of the heater. The base case for the comparison was the results of a turbulent analysis with 300kW heat load at 9MPa.

In a horizontal installation of the heater, the gravitational force of 9.80665 m/s$^2$ works in –Y direction of the applied coordinate system. Figure 1(a) shows the analysis results accounting for the gravitational force, which have no significant changes from the base case. However, the anticipated Buoyancy effects appear clearly in Fig. 1(b) when we remove radiation heat transfer from the analysis model. The temperature profiles in the A-A' line are compared in Fig. 2. The temperature profiles of the base case and the current results are similar except that the current result shows the higher maximum temperature by about 4$^o$C. Besides, local temperatures in the upper region (+Y region) increase when we apply gravitation in –Y direction without radiation heat transfer inside the Helium channel. As a result, we concluded that there would not be any severe local temperature increases in a horizontal Helium heater because the radiation-heated inner surfaces of the channel suppressed the Buoyancy forces.

In vertical installation of the heater, there was no significant disturbance in fluid temperature and velocity. The slight increases in velocities were thought to be caused by the density changes according to the temperature increases.

### *2.2 Emissivity of the Reflector*

A Molybdenum reflector will be attached at the inside surface of the insulating pipe for controlling the radiation heat transfer in the fluid channel. While the thickness of the reflector was neglected in the conduction heat transfer due to its relatively high conductivity, the emissivity of the reflector was not ignorable and so considered in the radiation heat transfer. The emissivity of the electric heaters was assumed to be 0.8, and that of the reflector was set in the range of 0.1 ~ 0.9. Figures 3 & 4 compare the temperature profiles at the A-A' line near the outlet for various emissivity without or with gravity. Without gravity, the maximum temperature increases and the reflector temperature decreases as the emissivity of the reflector becomes lower. With gravity, the vertical temperature profiles tilt more for the lower reflector emissivity, but local temperature changes are bearable.

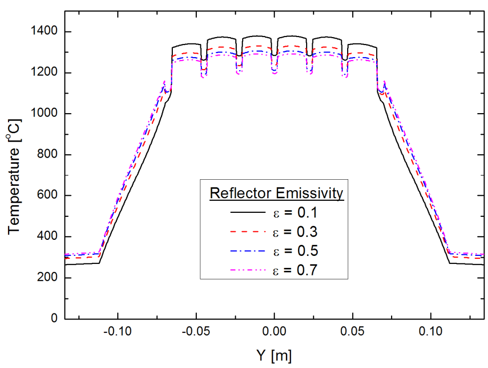



Fig. 3. Vertical temperature profiles at exit (Z = 2.49m): Sensitivity of reflector emissivity without gravity.

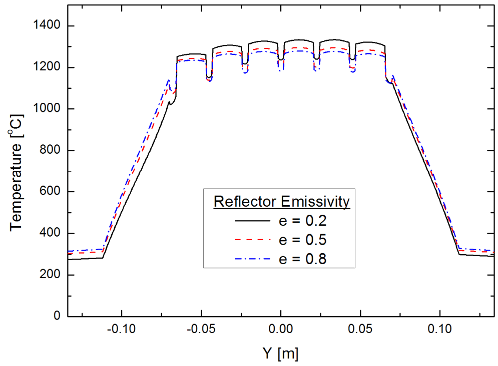



Fig. 4. Vertical temperature profiles at exit (Z = 2.49m): Sensitivity of reflector emissivity with gravity.

## 4. Conclusions

It is concluded that the Buoyancy effects on the Helium flows of the heater would be suppressed by radiation heat transfer in the channel. For the lower reflector emissivity, gravity affects more on the temperature distribution but the temperature variation is within a few ten degrees. For the future studies, the spacer effects on the fluid will be also tested.

## ACKNOWLEDGMENTS

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