# Thermal-Hydraulic Sensitivity Study of Intermediate Loop Parameters for Nuclear Hydrogen Production System

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## 1. Introduction

The Very High Temperature Gas-cooled Reactor (VHTR) is one of the advanced Generation IV reactor concepts especially for nuclear hydrogen production [1]. As shown in Fig. 1, the heat generated from the VHTR is transferred to the intermediate loop (IL, green line, middle side in Fig. 1) through Intermediate Heat Exchanger (IHX). It is further passed on to the Sulfur-Iodine (SI) hydrogen production system (HPS) through Process Heat Exchanger (PHX) (blue line, right side in Fig. 1). The IL provides the safety distance between the VHTR and HPS.

Since the IL performance affects the overall nuclear HPS efficiency, it is required to optimize its design and operation parameters. In this study, the thermal-hydraulic sensitivity of IL parameters with various coolant options has been examined by using MARS-GCR code [3], which was already applied for the case of steam generator [2].

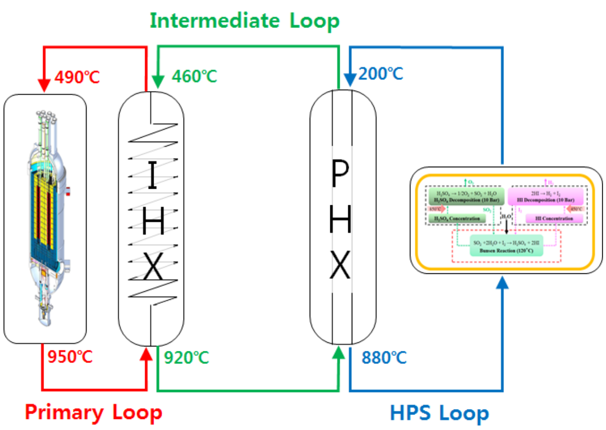



Fig. 1. Schematic diagram of nuclear hydrogen production system.

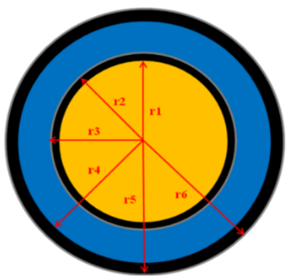
## 2. Methods and Results

As coolant options, the helium (He), carbon dioxide ($CO_2$), and He-$CO_2$ (2:8) gas mixtures are considered. The reference boundary conditions with the pressure of 70bar, safety distance of 100m, and pipe diameter of 1.7123m (See Fig 2.) represent operation and design parameters of the IL. Simulations were performed to examine the heat loss, pressure drop, subsequent circulator work and surface area for a given safety distance.

### *2.1 Operation Conditions of IL*

As shown in Fig. 1, the hot coolant with 950℃ from VHTR having the thermal power of 350 MWth returns to the reactor at 490℃ after transferring heat to the IL. Assuming the mean temperature difference of 30℃ across the IHX and HPS, the hot and cold side temperatures of the IL and HPS are considered to be 920/460℃ and 880/200℃, respectively.

Mass flow rates ($\dot{m}$) of IL are determined by coolant thermal properties of each He, $CO_2$ and gas mixtures by using the relationship, $Q = \dot{m} \cdot C_p \cdot \Delta T$. In Table 1 the operation conditions are summarized.




| Materials | Radius. (m) |
|---|---|
| Coolant (Hot gas) | 0.45120 (r1) |
| In617 | 0.52740 (r2) |
| Insulator (Kaowool) | 0.54010 (r3) |
| Coolant (Cold gas) | 0.70375 (r4) |
| SA508 | 0.84345 (r5) |
| Insulator (Kaowool) | 0.85615 (r6) |

Fig. 2. Reference Concentric IL Pipe - hot gas (yellow), cold gas (blue), insulator (black).

Table 1. Operation conditions of the IL and PHX

| | | |
|---|---|---|
| IL | | |
| Coolant | He, $CO_2$, He+$CO_2$ (2:8) | |
| Flow Rate | Variable | |
| Operation Pressure | 70 | bar |
| Pressure Drop | ~1 | bar |
| Temp. (Hot Stream) | 920 | °C |
| Temp. (Cold Stream) | 460 | °C |
| Safety Distance | 100 | m |
| Pipe Diameter | Variable | |
| PHX | | |
| Coolant | $H_2O$ | |
| Flow Rate | 130.7 | kg/s |
| Inlet Temp. (Water) | 200 | °C |
| Outlet Temp. (Steam) | 880 | °C |
| Surface Area | Variable | |

### *2.2 MARS-GCR Modeling of IL*

The nodalization of IL and HPS for MARS-GCR analysis is shown in Fig. 3. Concentric loop piping is modeled using PIPE component consisting of 20 hydrodynamic volumes. Hot coolant flows along the inner side of concentric pipe from IHX to PHX, while it returns back along the outer annulus after heat transfer in PHX. Since the thermal performance of heat exchangers is predetermined, inlets and outlets of the heat exchangers are modeled as source and sink boundary conditions.

The heat conduction and transfer across the inner and outer pipes are modeled to analyze environmental heat loss. Total loop pressure drop is calculated by summing up those in the loop pipes and heat exchangers. Pressure drop in heat exchangers is estimated using the relation equation, $\Delta P = K \cdot \rho \cdot v^2/2$ [4].

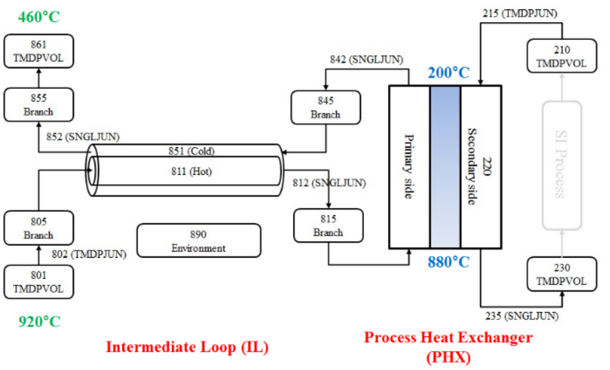



Fig. 3. The MARS-GCR modeling of IL

Finally, the circulator work is calculated by following equation [5];

$$W_{cir} = \frac{1}{\eta_{cir}} \dot{m} C_p T_{inlet} \left[ \left( \frac{P_{out}}{P_{in}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$W_{cir}$ : circulator work (MWth)
$\eta_{cir}$ : efficiency of the circulator (0.85)
$\dot{m}$ : mass flow rate (kg/s)
$C_p$ : specific heat at constant pressure (J/kg·K)
$T_{inlet}$ : inlet temperature to the IHX
$P_{out}$ and $P_{in}$ : outlet and inlet pressure of circulator
$\gamma$ : specific heat ratio ($C_p/C_v$)

### *2.3 Analysis Results*

Environmental heat loss, pressure drop and circulator work were analyzed for various operation conditions, pipe diameters and safety distances for each candidate coolants. Table 2 shows the results of different coolants in the reference condition.

Table 2. Evaluation results in the reference condition

| Coolant | $\gamma$ ($C_p/C_v$) | Pressure Drop* (bar) | Heat Loss (MWth) | $W_{cir}$ (MWth) | Q Transfer (MWth) |
|---|---|---|---|---|---|
| He | 1.663 | 1.748 | 0.362 | 6.485 | 406.65 |
| $CO_2$ | 1.225 | 3.083 | 0.422 | 5.212 | 384.38 |
| HE+$CO_2$ (2:8) | 1.250 | 3.289 | 0.415 | 6.062 | 387.65 |

* Pressure Drop (IL) = $\Delta P_{Hot} + \Delta P_{Cold} + \Delta P_{Pri}$

Environmental heat loss is proportional to the safety distance and pipe diameter, however, it is estimated as negligible. It was found that the circulator work is the major factor affecting on the overall efficiency. Circulator work decreases and Q transfer increases with the increase of surface area ($m^2$) of PHX. Fig. 4 shows the change of circulator work and Q transfer for the reference condition.

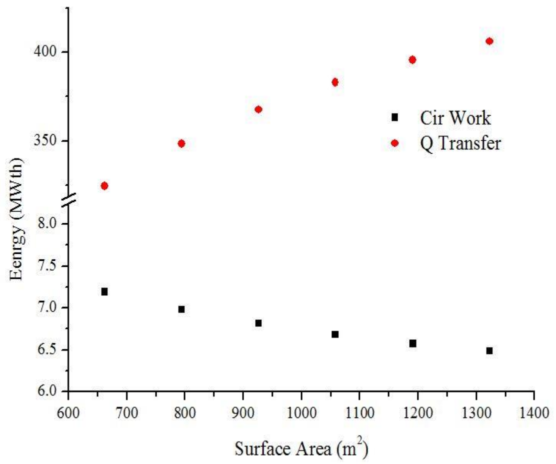



Fig.4. Circulator work and Q transfer in variable heat structure areas for He.

## 3. Conclusions

Sensitivity study of the IL and PHX parameters has been carried out based on their thermal-hydraulic performance. Several parameters for design and operation, such as the pipe diameter, safety distance and surface area, are considered for different coolant options, He, $CO_2$ and He-$CO_2$ (2:8).

It was found that the circulator work is the major factor affecting on the overall nuclear hydrogen production system efficiency. Circulator work increases with the safety distance, and decreases with the operation pressure and loop pipe diameter.

Sensitivity results obtained from this study will contribute to the optimization of the IL design and operation parameters and the optimal coolant selection.

## Acknowledgements

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## REFERENCES

[1] W.J. Lee, Y.W. Kim and J. Chang, "Perspectives of Nuclear Heat and Hydrogen", NET, Vol. 41, No. 4 (2009)
[2] N.V. Hoffer, P. Sabharwall and N.A. Anderson, "Modeling a Helical-Coil Steam Generator in RELAP5-3D for the Next Generation Nuclear Plant", INL/EXT-10-19621 (2011)
[3] W.J. Lee and H.N. Lee, "Implementation of the Pure and Mixture Gases Properties in MARS-GCR", KNS Autumn Meeting (2013)
[4] S. Kakaç and H. Liu, "Heat Exchangers Selection, Rating, and Thermal Design, $2^{nd}$ Ed.", CRC Press (2002).
[5] W.J. Lee, Preliminary Operating Parameters of Nuclear Hydrogen Demonstration System, NHDD_KA_07-RD-BT (2007).