Evaluation of Heat Removal Performance of Passive Decay Heat Removal system for S-CO2 Cooled Micro Modular Reactor

Jangsik Moon, Jeong Ik Lee, Yong Hoon Jeong*
Dept. of Nuclear & Quantum Engineering, KAIST,
291 Daehak-ro, Yuseong-gu, Daejeon, 305-701, Republic of Korea
**Corresponding author: jeongyh@kaist.ac.kr*

1. Introduction

S-CO2 cooled Micro Modular Reactor (MMR) shows minimized on-site construction due to its modular system. The modular systems is able to be transported by large trailer. Moreover, dry cooling system is applied for waste heat removal. The characteristics of MMR takes wide range of construction area from coast to desert, isolated area and disaster area [1, 2].

In MMR, Passive decay heat removal system (PDHRS) is necessary for taking the advantage on selection of construction area where external support cannot be offered. The PDHRS guarantees to protect MMR without external support.

In this research, PDHRS of MMR is introduced and decay heat removal performance is analyzed.

2. Thermal analysis of PDHRS

2.1 Schematic of PDHRS in MMR

After shutdown, reactor coolant system is getting heat due to decay heat and pressurized. During normal shutdown external S-CO2 cycle removes the decay heat. However during DBAs, which are loss of flow accident (LOFA), loss of heat sink (LOHS), loss of coolant accident (LOCA), and station blackout (SBO), the decay heat cannot be removed by the external S-CO2 cycle.

To cope with the DBAs, PDHRS is equipped and Fig. 1 shows the schematic of PDHRS. PDHRS takes two loop heat transfer system. One loop is connected to reactor vessel and a heat exchanger is equipped which is shown in Fig. 2. The loop is independent to power conversion cycle for reducing common cause failure. Another loop has water as working fluid and two loops transfer heat in the heat exchanger. The water loop gets heat from the heat exchanger and release heat to containment wall. Finally, water heat sink removes heat at containment wall by evaporation of water.

Reactor coolant system of MMR has very low thermal inertia, therefore the PDHRS is designed to have large amount of removal performance. The decay heat is evaluated as 2 MW at early time after shutdown.

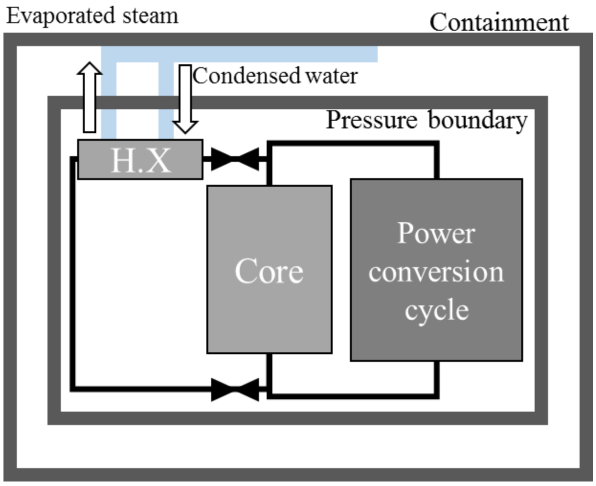

Fig. 1. Schematic of PDHRS in MMR

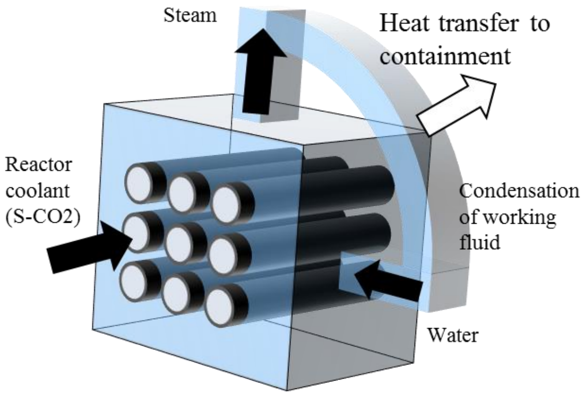

Fig. 2. Schematic of heat exchanger in PDHRS

2.2 Heat removal performance of PDHRS

In this chapter, coolant temperature in S-CO2 loop and cladding temperature is analyzed at specific decay heat generation, Q. Steady state is assumed.

Through heat transfer path from core to heat sink, convection of S-CO2 at heat exchanger and fuel pin is dominant. Heat transfer coefficient of evaporation and condensation in water loop is considered as typically used value.

In analysis of heat removal performance, mass flow rate in S-CO2 cycle is one of main parameter. The mass flow rate is determined by natural circulation. At steady state pressure loss in loop and driving pressure caused by density difference is same. Friction loss is dominant in pressure loss and it is calculated by following relation.

$$\Delta P_{loss} = f \frac{L}{D_e} \frac{\rho v^2}{2}$$

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{e}{3.7D_e} + \frac{2.51}{\mathrm{Re}\sqrt{f}} \right)$$

The driving pressure is calculated by following relation.

$$\Delta P_{driving} = (\bar{\rho}_{cold} - \bar{\rho}_{hot}) gH$$

$\bar{\rho}_{hot}$ and $\bar{\rho}_{cold}$ means average density at hot and cold side.

From the mass flow rate, convective heat transfer is calculated. The convection of S-CO2 is calculated by Gnielinski correlation [3].

$$Nu = \frac{hD_e}{k}$$

$$= \frac{(f/8)(\mathrm{Re}-1000)\,\mathrm{Pr}}{1+12.7\sqrt{(f/8)}\,(\mathrm{Pr}^{2/3}-1)} \left[1 + \left(\frac{D_e}{L_h} \right)^{2/3} \right] \left(\frac{T_{bulk}}{T_{wall}} \right)^{0.45}$$

$$f = \frac{1}{[1.82\log(\mathrm{Re}) - 1.64]^2}$$

Using above physical models and iteration process, coolant temperature and cladding temperature is calculated. Geometric condition of heat exchanger and core is shown in Table I, and calculation results is shown in Fig. 3, and Fig. 4. The results show that 2 MW of decay heat generated at early time after accident can be removed by PDHRS without damage in system.

Core	
Hydraulic diameter [m]	1.75e-2
Fuel pin length [m]	2.8
Fuel pin length (active) [m]	1.2
Fuel pin diameter [m]	1.5e-2
Number of pin	2286
Flow area [m^2]	0.23
Heat exchanger	
Tube diameter [m]	3e-2
Tube length [m]	0.7
Number of pin	320
Flow area [m^2]	0.23

3. Conclusions

The PDHRS guarantees integrity of reactor coolant system. The high level of decay heat (2 MW) can be removed by PDHRS without offsite power.

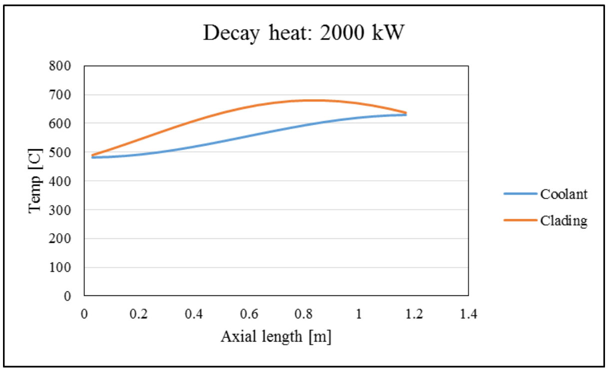

Fig. 3. Reactor coolant system temperature in decay heat generation of 2 MW

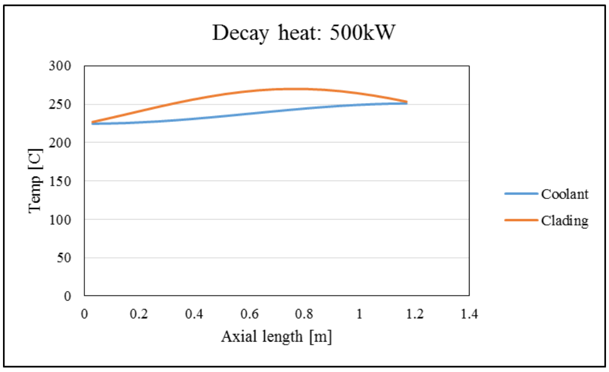

Fig. 4. Reactor coolant system temperature in decay heat generation of 500 kW

REFERENCES

[1] J. Moon, Y. H. Jeong, and J. I. Lee, Passive Decay Heat Removal System Options for S-CO2 Cooled Micro Modular Reactor, Transactions of the KNS Spring Meeting, May 29-30, Jeju, Korea, 2014.
[2] Seong Gu Kim, Min Gil Kim, Seong Jun Bae, and Jeong Ik Lee, Preliminary Design of S-CO2 Brayton Cycle for KAIST Micro Modular Reactor, Korean Nuclear Society Autumn Meeting, Oct. 24-25, 2013, Gyeongju, Korea.
[3] M. A. Pope, Thermal Hydraulic Design of a 2400 MWth Direct Supercritical CO2-Cooled Fast Reactor, Thesis (Ph. D.), MIT, 2006.