An experimental and numerical study on the air natural convection under high wall temperature conditions for the passive air cooling system

Koung Moon Kim[a], Sun Taek Lim[a], Seong Ho Kim [a], Dong-Wook Jerng[b], Ho Seon Ahn[a,*]

[a]Department of Mechanical Engineering, Incheon National University, Incheon, Republic of Korea
[b]School of Energy System Engineering, Chung-Ang University, Seoul, Republic of Korea
[*]*Corresponding author: hsahn@inu.ac.kr*

1. Introduction

Nowadays, passive air-cooling systems such as RVCS [1, 2], RCCS [3], for the decay heat removal system are received attention. However, there are few previous studies on the natural convection of air considered high wall temperature conditions corresponded the operating condition of SFR or VHTR. Cheng *et al.* [4] investigated the air natural convection for the passive air-cooling system targeted AP600 reactor. However, the maximum wall temperature was less than 200 ℃. Therefore, it was difficult to appropriately consider the thermal radiation effect, which has a large influence on the high wall temperature conditions.

In this study, to investigate the air natural convection with considering the thermal radiation effect, we conduct the air natural convection experiment in the range of the wall temperature up to 500 ℃. In addition, the numerical simulation is carried out using MARS code. The results of the experiment and numerical simulation are compared to each other based on both wall temperatures and the bulk air temperature.

2. Experiment

2.1 Experimental apparatus

The heated section consisted of two vertical walls. One side wall was heated directly by the nichrome wire heater (Directly heated wall, DHW). The opposite side wall (Indirectly heated wall, IHW) was heated indirectly by the thermal radiation heat transported from the DHW. The downcomer was vertically constructed to intake the ambient air. The horizontal connector was constructed to connect the heated section and the downcomer. The riser section was connected at the end of the heated section. Both wall temperatures and bulk temperatures at each height were measured using K-type thermocouples. Air flow rate driven by the natural convection was measured using a thermal-mass type flow meter in the downcomer with considering hydrodynamic entrance length. Both walls were made of stainless steel (316) material, and the other non-heating zones were made of galvanized steel ducts. Detailed information on the experimental apparatus were described in Ref. [].

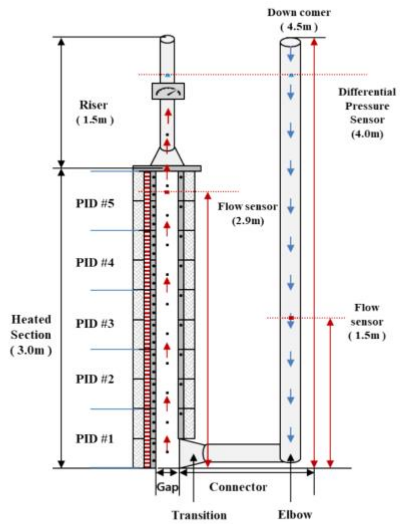

Fig. 1. Natural convection experimental apparatus [5]

2.2 Conducted experimental cases

Two experimental cases were conducted based on the different provide electric power. To evaluate the heat removal rate except for the heat loss the enthalpy rise in the channel was calculated based on the energy balance equation (Eq. 1). Table 1 shows the electric power and the heat removal rate in each case.

$$Q_{removal} = \dot{m} C_p \left(T_{Air,Out} - T_{\infty} \right) \quad (1)$$

Table 1. Problem Description

Case	Electric power (kW)	Heat removal rate (kW)
# 1	1.39	1.04
# 2	5.14	4.51

Although the experimental apparatus was well insulated using alumina-based insulation, the heat loss could not be ignored. This is due to the temperature of the experimental apparatus reached a maximum of 500 ℃, and thermal interaction with the ambient air by the radiation occurred.

3. Numerical simulation using MARS code

3.1 MARS code nodalization

Numerical simulation was conducted using MARS-KS code. For comparison between the experiment and the numerical analysis, the numerical model was nodalized with the same dimension as the experimental apparatus as show in Fig. 2.

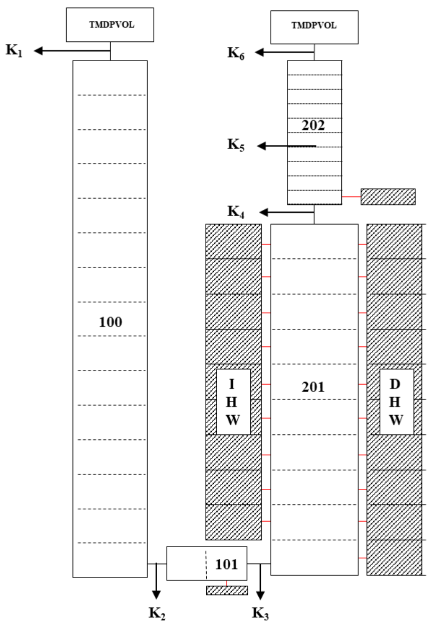

Fig. 2. Numerical model nodalization in MARS-KS [2]

3. Results and Conclusions

The presented results in this section are focused on both wall temperatures and bulk air temperature. Figure 3 shows the results of the experiment and numerical simulation. To appropriately consider the thermal radiation interaction in the numerical simulation, we considered an additional option that the radiation calculation could be performed in the wall temperature condition above 300 K.

In case #1, the DHW (W1) temperature estimated by numerical results is very similar to the experimental result. However, it was confirmed that the IHW (W2) temperature predicted by numerical analysis cannot adequately predict the experimental results. As increased wall temperature (# 2), both wall temperatures estimated by the numerical simulation cannot be predicted by the experimentally measured temperatures as shown in Fig. 3.

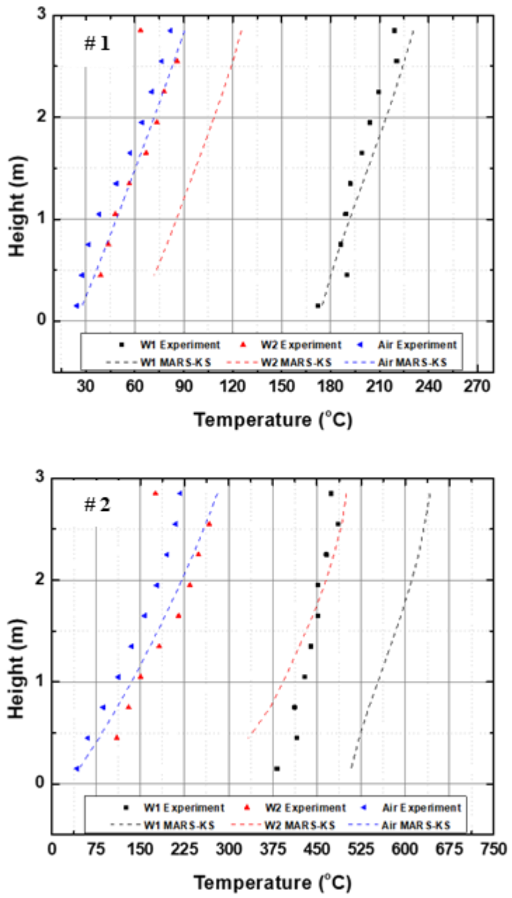

Fig. 3. Comparison between the experimental results and numerical simulation results (# 1- top, # 2- bottom)

From these results, we can suggest two conjectures. Firstly, the IHW temperature cannot be well predicted by MARS code simulation regardless of the wall temperature condition. Second, in the low thermal boundary condition (# 1), the DHW temperature can be sufficiently predicted using MARS-KS code. However, in the high thermal boundary condition corresponding to about 500 degrees (#2), the DHW temperature cannot be estimated appropriately using MARS-KS code.

These results imply that the heat transfer correlation associated with the air natural convection used in MARS code is not appropriate under high-temperature conditions.

ACKNOWLEDGEMENTS

This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (Ministry of Science and ICT) (NRF-2017M2A8A4018582)

NOMENCLATURE

C_P : Specific heat
T_∞ : Ambient temperature
$T_{Air,Out}$: Air temperature at the outlet
$\dot{m}$: Mass flow rate
$Q_{removal}$: Heat removal rate

REFERENCES

[1] Choi, C., Jeong, T., & An, S. (2018). Thermal-hydraulic analyses of passive reactor vault cooling system (RVCS) in PGSFR using MARS-LMR. Annals of Nuclear Energy, 117, 333-342.

[2] Kim, K. M., Hwang, J. H., Wongwises, S., Jerng, D. W., & Ahn, H. S. (2020). Design of A scale-down experimental model for SFR reactor vault cooling system performance analyses. Nuclear Engineering and Technology, 52(8), 1611-1625.

[3] Shin, D. H., Kim, C. S., Park, G. C., & Cho, H. K. (2017). Experimental analysis on mixed convection in reactor cavity cooling system of HTGR for hydrogen production. International Journal of hydrogen energy, 42(34), 22046-22053.

[4] Cheng, X., and U. Müller. "Turbulent natural convection coupled with thermal radiation in large vertical channels with asymmetric heating." International journal of heat and mass transfer 41.12 (1998): 1681-1692.

[5] Kim, K. M., Lim, S. T., Jerng, D. W, & Ahn, H. S. Natural convection phenomena of the air in the vertical parallel plates under high wall temperature conditions, Transactions of the Korean Nuclear Society Spring Meeting, Korea, 2021.