Preliminary study on a reactor vault cooling system using the TRACE code

Sung Hoon Joung[a], Dong – Wook Jerng[a*]
a. Chung-Ang University, 84, Heukseok-ro, Dongjak-gu, Seoul, Republic of Korea

Introduction

- A prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR) which is under development by Korea Atomic Energy Research Institute (KAERI) uses liquid sodium as coolant. Therefore, the emergency injection strategies which is commonly used in PWRs cannot be adopted. Therefore, the safety systems which removes decay heat passively are essential. Therefore, the reactor vault cooling system (RVCS) which cools the external surface of containment vessel via natural convection of air is introduced. The purpose of this paper is to provide an insight for modeling the lower part of RVCS with the TRACE code, in particular, the natural convection and radiation heat transfer.

Model description

- In this model, 1-D pipes are used to simulate inlet and outlet. Containment vessel(CV) is modeled as a 3-D vessel component in cartesian geometry. The vessel has 9 levels in the axial direction and 12 cells in the horizontal direction.
- The curvature of the CV was simulated by adjusting the volume fraction of cells in a stair shape.

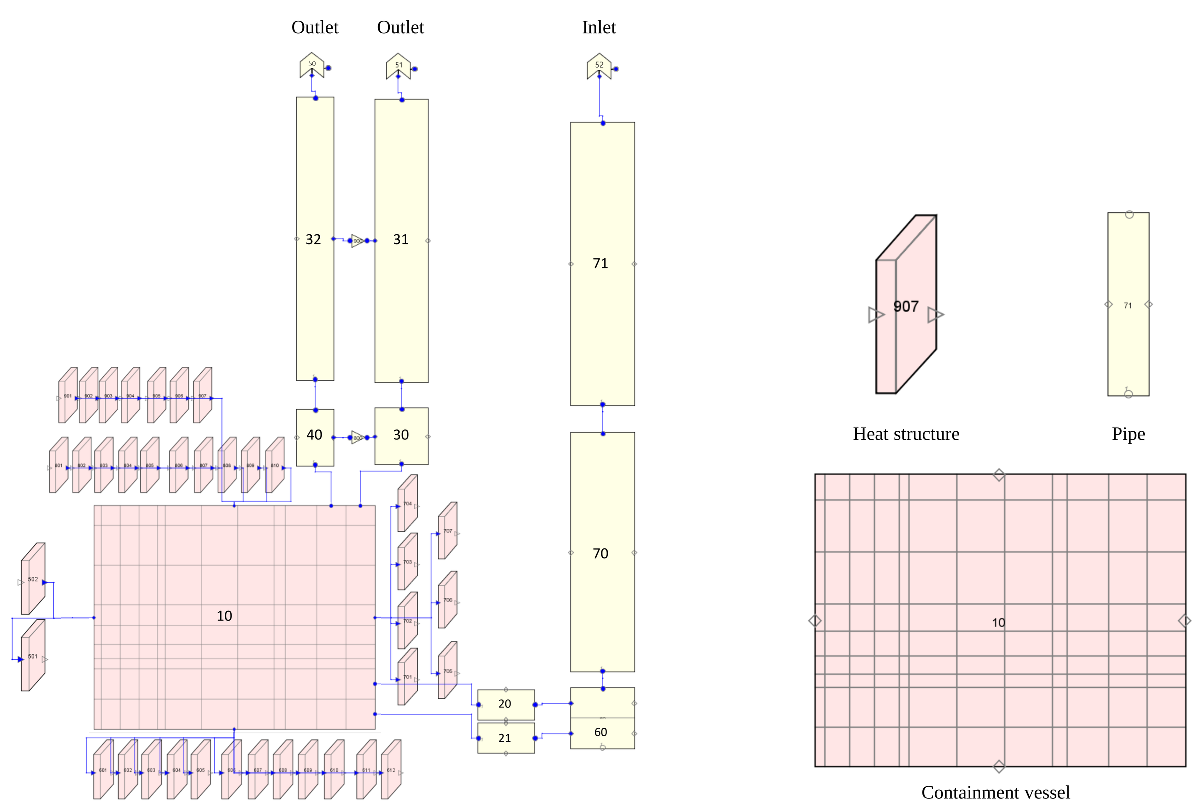

Fig. 1. TRACE nodalization for RVCS

Table 1. Input data for TRACE code simulation

	Experiment	TRACE-Code
Volume	0.25 $[m^3]$	0.25 $[m^3]$
Heat rate	3821.28 [W]	3821.28 [W]
Inlet air temperature	295.12 [K]	295.12 [K]
Outlet mass flow rate	0.047 [kg/s]	0.047 [kg/s]
Initial pressure	101.325 [KPa]	101.325 [KPa]

Result

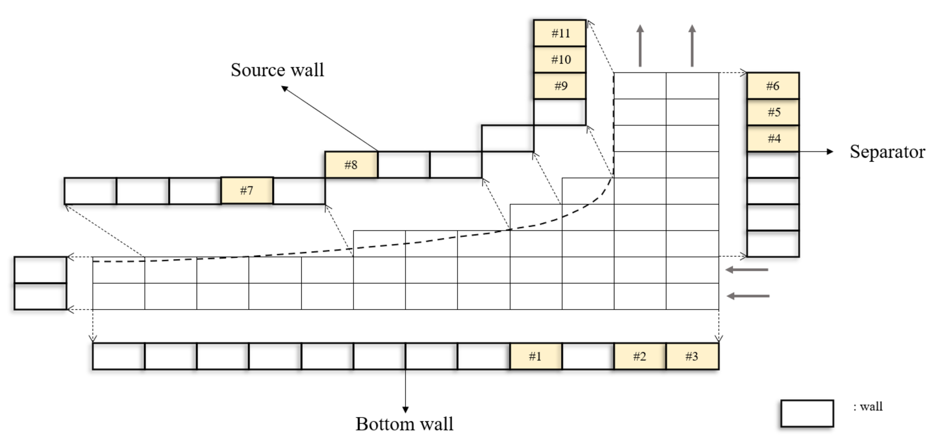

Fig. 2. Detailed diagram of 3-D vessel component

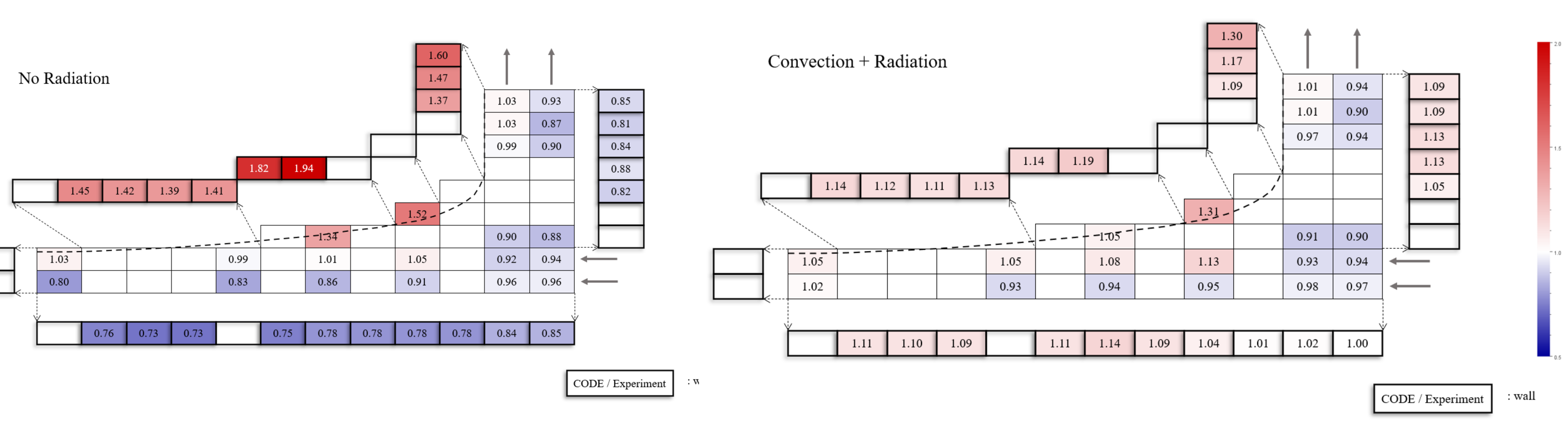

Fig. 3. Comparison between the model and experiment

Result

Table 2. Average temperature error at components

Component	Convection [%]	Convection + Radiation [%]
Heating section	54.1	14.5
Bottom wall	22.3	7.1
Separator	15.9	9.8
Air	9.7	6.9
Outlet	1.1	1.1
Average	22	8.7

- Fig.3 shows the ratio ($\boldsymbol{T_{CODE}}$ / $\boldsymbol{T_{EXP}}$)of the code value to the experimental value. The model with radiation heat transfer results in reduced errors in overall. The wall temperature of the heating section becomes lower and the bottom wall and air separator temperature becomes higher due to the radiation heat transfer. By accounting the radiation heat transfer, the wall temperature increases, which enhances convection heat transfer, reducing the error of the air temperature. As shown in Table 2, in the model that only considers convective heat transfer, the average error is 22% while the model with both convection and radiation heat transfer have an average error of 8.7%. As shown in Fig.3, Fig.4 regardless of the consideration of radiation heat transfer, the air temperature at point A showed the largest error. The temperature difference between points B and A is greater in the experiment compared to that of code. The code to experiment air temperature difference at point B shows relatively smaller difference than that of point A, which insists that the heat exchange in wall to air is calculated with moderate error.

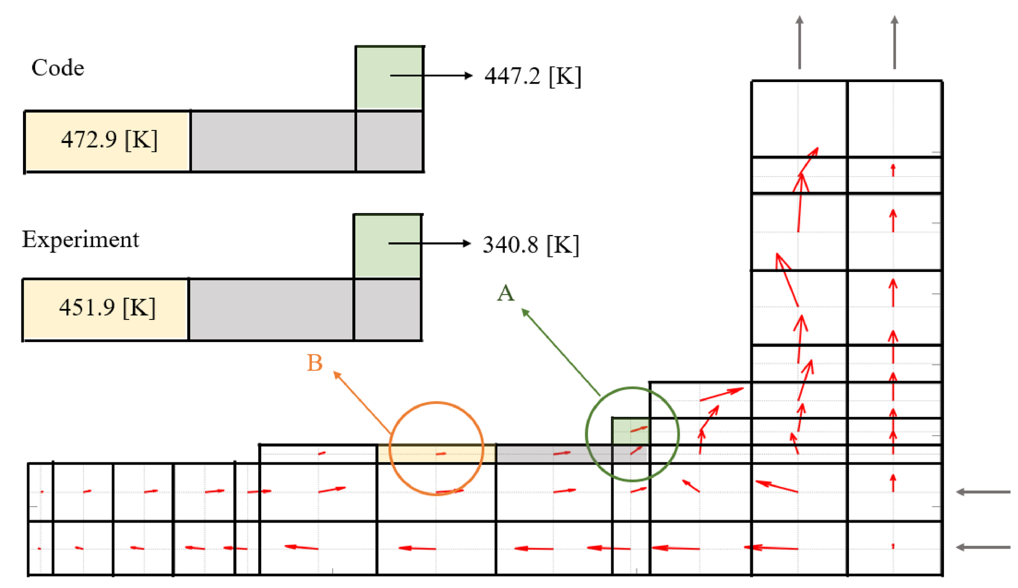

Fig. 4. Vector field indicating mass flowrate

- The larger error at point A is thought to be attributed to the estimation of mixing rate in TRACE code. It can be recognized in the vector field in Fig. 4 that, the air coming from the inlet rises to point A due to buoyancy force. Thus, the mixing of cold air from the inlet and hot air supplied along the heated surface results in lower air temperature in experiment at point A. However, the underestimation of mixing rate in TRACE code results in higher air temperature at point A.

Conclusions

The radiation heat transfer must be considered, as the surface temperature of CV is high enough to produce radiation heat transfer. When the radiation heat transfer is taken into the account, the average error of CV wall temperature is reduced to 14.5 %, which is huge reduction compared to convection-only case (average error of 54.1 %).

Reference

[1] J. Yoo, J. Chang, J.-Y. Lim, J.-S. Cheon, T.-H. Lee, S.K. Kim, K.L. Lee, H.-K. Joo, Overall system description and safety characteristics of prototype Gen IV sodium cooled fast reactor in Korea, Nuclear Engineering and Technology 48 (2016) 1059-1070.
2] Koung Moon Kim, et al., Design of A scale-down experimental model for SFR reactor vault cooling system performance analyses, department of Mechanical Engineering, Nuclear Engineering and Technology 52 (2020) 1611-1625
[3] D.-W. Jerng, Y-G Lee, B-J. Yun, et al., A study on heat transfer model and performance of Passive systems for nuclear power plant containment cooling, National Research Foundation of Korea, 2015
[4] W.H. McAdams, Heat Transmission, 3rd ed., McGraw-Hill, New York, 1954, Chap.7
[5] Frank P. Incropera, Fundamentals of heat and mass transfer, 7th ed., John Wiley & Sons, Chap.12