Effects of coefficients of algebraic heat flux model on turbulent natural convective flow simulation in BALI configuration

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1. Introduction

IVR-ERVC is one of the severe accident management strategies to prevent RPV from failure. The integrity of RPV is determined by comparing the internal heat flux with the external critical heat flux. For the realistic assessment, it is important to accurately predict the internal heat flux, i.e. thermal behavior of molten pool materials so called corium. It has been reported that the Rayleigh number of the molten pool can be reached up to 10^{17}, meaning strong turbulence. Therefore, turbulent natural convection (TNC) phenomena should be resolved to understand thermal behavior of the oxide layer.

Due to the size of the reactor and expected turbulence intensity in the pool, it is practical to use RANS method. An advanced RANS model, especially a turbulent heat flux model, is required to simulate the complex behavior in BALI configuration. Meanwhile, this research team is generating numerical database of BALI using high-fidelity method (large eddy simulation: LES), and suggesting the coefficients for advanced RANS heat flux model.

In this study, numerical simulation of BALI using preliminary proposed coefficients of advanced RANS model was performed, and thermal hydraulic characteristics varied depending on the coefficients were investigated.

2. Methods and Results

Currently, numerical simulation using high-fidelity method (LES) has been conducted to generate numerical database (DB) of BALI experiment. Based on the LES DB, the coefficient of algebraic heat flux model is currently being proposed, and in this study, the BALI case was simulated using the proposed coefficient at this phase. SST model are used to predict turbulent moment flux.

2.1 Algebraic heat flux model and its coefficients

The AFM model for turbulence heat flux is shown in Eq. (1). Each term is the production term in the exact transport equation of the turbulent heat flux which is simplified through appropriate assumption, and it is reported that it can reflect the basic physical phenomenon of complex flow including turbulent natural convection [1]. The model coefficients used in this study are listed in Table 1. Case 1 representes the coefficients proposed in the previous study. Cases 2 and case 3 represent the proposed coefficients based on LES DB analysis. Overall, AFM coefficients have been proposed to be smaller than previous one. R_h in the Table 1 represents a thermal to mechanical time-scale ratio of temperature variance (θ^2) equation. It determines the magnitude of the dissipation of the temperature variance equation. Generally, it assumed to be a constant value, and the currently suggested value is bigger than the previous one. The turbulence model in this paper is implemented in OpenFOAM.

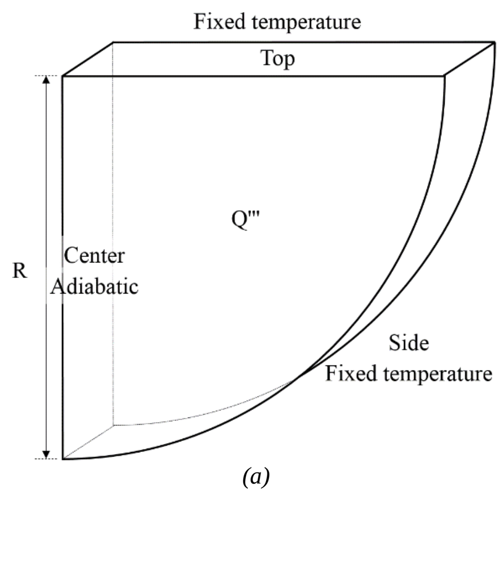
$$\overline{\theta u_i} = -C_0 \frac{k}{\varepsilon}\left(C_1 \overline{u_i u_j} \frac{\partial T}{\partial x_j} + C_2 \overline{\theta u_j} \frac{\partial U_j}{\partial x_j} + C_3 \beta g_i \overline{\theta^2} \right) \quad (1)$$

Table 1 Model coefficients for AFM [2].

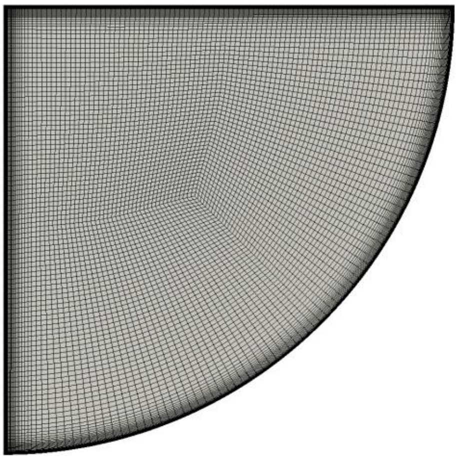
	C_0	C_1	C_2	C_3	R_h
Case 1	0.2	0.25	0.6	0.385	0.5
Case 2	0.2	0.125	0.075	0.11	0.5
Case 3	0.2	0.125	0.075	0.11	2.0

2.2 Numerical conditions and grid resolution

BALI facility is a 1/4 circular slice and the radius is 2 m, which is equal to the actual French PWR as shown in Fig. 1. The side and top wall temperature is the freezing temperature of water, 273.15 K, and the center wall is adiabatic. In the simulation, the wall-function is not used, therefore, the near wall grid is adjusted.

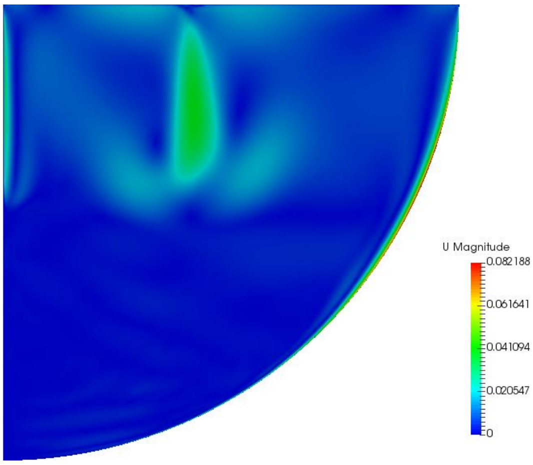


(a)



(b)
Fig. 1. Boundary condition and numerical grid of BALI simulation

2.3 Preliminary results



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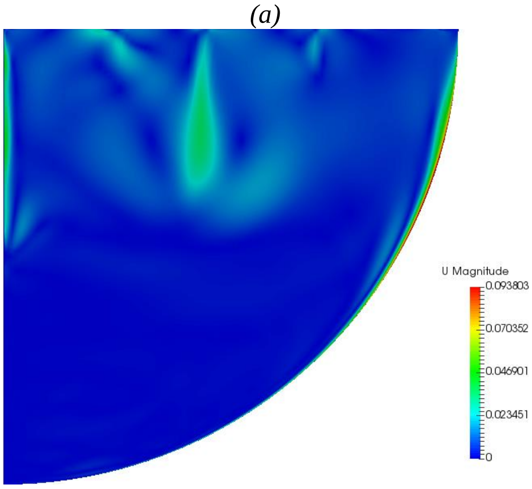

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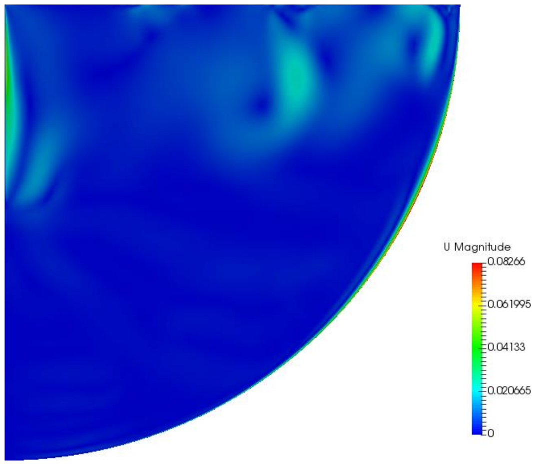

(c)
Fig. 2. Plots of velocity vector field: (a) case 1, (b) case 2, (c) case 3

Fig. 2 represents the velocity field in the BALI configuration. As the coefficients decrease, the overall flow structure is similar; however, the descending flow in the center domain has become weak slightly. The flow structure changes significantly depending on the R_h value: i.e., the structure of the conventional cell of the unstable layer changes.

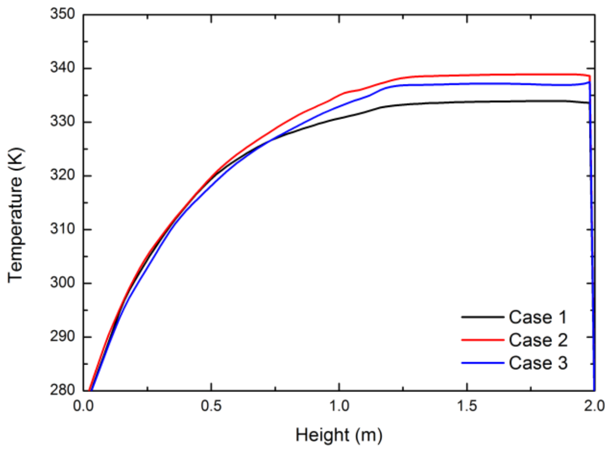

Fig. 2. Temperature distribution along the center wall

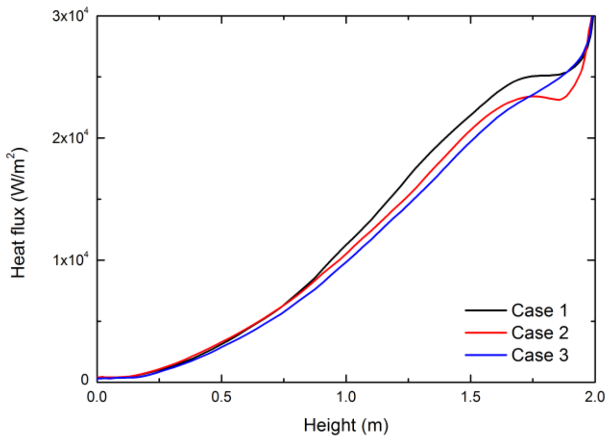

Fig. 3. Heat flux distribution along the side wall

Figure 2 and 3 show the temperature and heat flux, respectively. Temperature was measured 0.1 m away from the center wall from the bottom to the top. As the AFM coefficient decreased, the overall pool temperature increased (approximately 5K increase based on maximum temperature). This is because overall turbulent heat flux in the computational domain is underestimated. Comparing case 2 and 3, temperature distribution decreases slightly as R_h value increases.

The heat flux was calculated from bottom to top along the side wall. Case 1 and 2 show similar tendencies: that is, the heat flux distribution increase along the wall and then showing constant behavior, and increase again near the top surface. As the AFM coefficient decreased, the magnitude of heat flux also decreased. From the result of case 3, it can be seen the R_h value affect the overall behavior of heat flux.

3. Conclusions

In this study, the AFM coefficients and R_h currently proposed by this research team are applied to BALI simulation and the overall effect of coefficient is investigated. It was confirmed that the pool temperature was sensitive to AFM coefficients and R_h value, and that the different pool behavior could be predicted, especially depending on the R_h value. Future works include investigating the flow characteristics that vary depending on the coefficients in detail and tuning the coefficients so that RANS results can be validated with high-fidelity DB.

REFERENCES

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