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Considering the Effects of Reverse Flow in Evaluating Chimney Effects in External Containment Vessel Using MARS-KS and CAP Codes

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1. Introduction

In the innovative Small Modular Reactor (i-SMR), the chimney effect considered to to remove decay heat in the long-term accident scenario. At the external containment vessel of i-SMR, air absorbs heat from the high-temperature containment vessel walls, and natural convection is formed due to the chimney effect. When the pressure difference is low, such as wide chimney area, the flow is driven by the chimney effect, and reverse flow occur at the outlet[1]. Therefore, when analyzing a system of chimney effect with a thermal-hydraulic analysis code, it was suggested to use a high minor loss coefficient considering reverse flow. Jing[2] had predicted flow rate in chimney effect experiments more accurately by considering reverse flow at the chimney outlet.

In this study, the chimney effect experiment was simulated by using the containment building thermal-hydraulic analysis code CAP and the system thermal-hydraulic analysis code MARS-KS, and the impact of reverse flow was evaluated. Chen's experiment was referred to evaluation[3].

2. Analysis of Chen's Experiment

2.1. Experimental description

Chen's chimney has a height of 1.5 m and a width of 0.615 m[3]. A heater is installed on one side of the chimney wall, as shown in Fig. 1. The gap between the chimney and the opposite wall is between 0.1 m and 0.6 m. The heat flux of the heater ranges from 200 to 600 W/m². The experiment was conducted in two cases: one where the heat flux was fixed at 400 W/m² and the gap was varied, and the other where the gap was fixed at 0.2 m and the heat flux was changed.

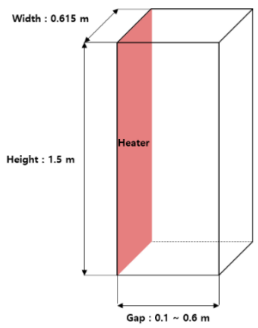

Fig. 1. Illustration of the chimney.

2.2. Modeling the Chen's Experiment

Fig. 2 shows the nodalization used in MARS-KS and CAP, respectively. In the heat structure, a constant heat flux is generated, same as the experimental conditions. The area of the chimney changes depending on the gap size and is identical to the experimental conditions. The minor loss coefficients, K, at the inlet and outlet are 1.5 and 1.0, respectively, which are the same as Chen's theoretical solution.

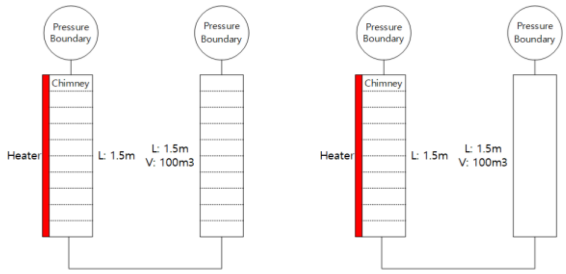

Fig. 2. Nodalization of MARS-KS(Left) and CAP(Right).

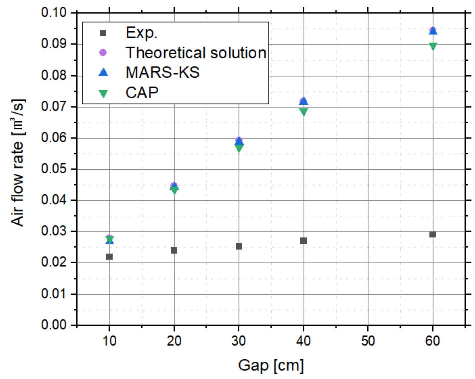

Fig. 3. Comparison of air flow rate with various gap.

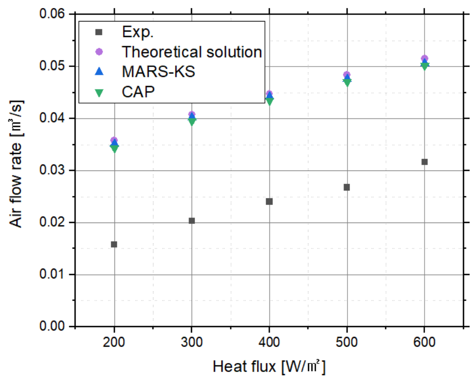

Fig. 4. Comparison of air flow rate with various heat flux.

2.3. Analytic results

Figs. 3 and 4 show the analytic results of CAP and MARS-KS, as well as the experimental results and the theoretical solution presented by Chen[3]. Regardless of the experimental conditions, both CAP and MARS-KS show higher flow rates than the experimental results.

3. Consideration of Reverse Flow

According to Cooper[1], when the pressure difference (ΔP) at the vent is lower than the critical pressure difference (ΔP_{Rev}), buoyancy forms the flow, which is a bidirectional flow that includes reverse flow. Therefore, the net flow is the value obtained by subtracting the reverse flow from the forward flow, and in such vents, a minor loss coefficient that considers the effects of buoyancy should be used.

3.1. The modified minor loss coefficient, K

The Fr_{rev} is the critical value at which reverse flow occurs in the vent. When the Fr is lower than Fr_{rev}, reverse flow occurs in the vent. When minor loss coefficient is calculated as follows[2].

$$(1)\quad \epsilon = \frac{\Delta\rho}{\rho_{amb}} \approx \frac{\Delta T}{T_{amb}} = \frac{Q}{\dot{V}\rho C_P T_{amb}}$$

$$(2)\quad Fr = \frac{\dot{V}}{A\sqrt{2gD\epsilon}}$$

$$(3)\quad K_{out} = 1 + \left[0.61 * \left(0.1 + 0.19 * \frac{Fr}{Fr_{rev}}\right)\right]^{-2}$$

Q is the heat supplied by heater, $\dot{V}$ is the flow rate, ρ is the air density, C_p is isobaric specific heat, A is the outlet area, and D is the length of the shortest side at the outlet.

3.2. Analytic results

Figs. 5 and 6 show the results calculated using the modified minor loss coefficient. Compared to the previous results, the analysis results are more similar to the experimental data.

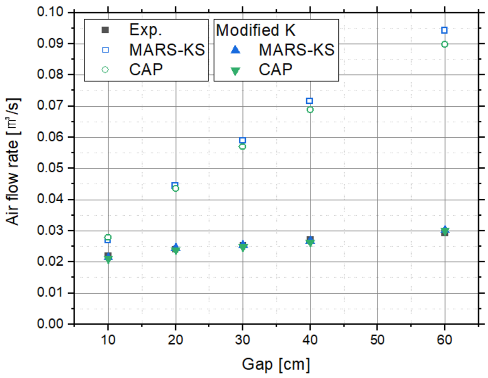

Fig. 5. Comparison of air flow rate with various gap using the modified K.

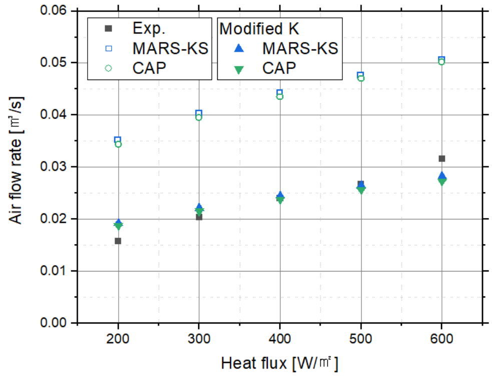

Fig. 6. Comparison of air flow rate with various heat flux using the modified K.

3.3. Comparison of wall temperature

Figs. 7 and 8 show a comparison between the experimental and analytical results. The comparison focuses on the temperature difference between the ambient and wall temperatures. Due to the air flow rate, the analytic results using the modified K show higher temperature difference.

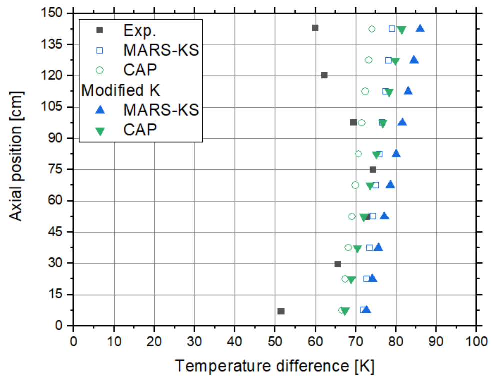

Fig. 7. Comparison of temperature difference at a gap size 20 cm and a heat flux 400W/m^2

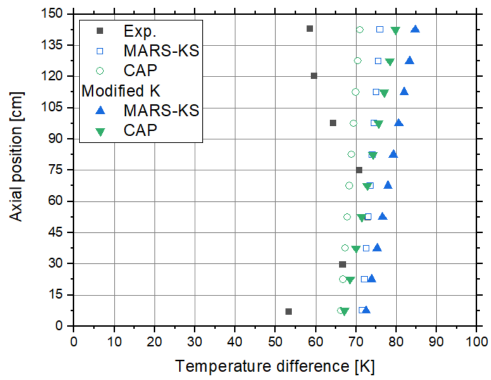

Fig. 8. Comparison of temperature difference at a gap size 40 cm and a heat flux 400W/m^2

4. Conclusion

If the pressure difference at the chimney outlet is not sufficiently large, reverse flow occur at the chimney outlet. When analyzing the chimney using a thermal-hydraulic code, the flow rate may be overestimated unless reverse flow is considered.

It has been confirmed that the thermal-hydraulic analysis codes MARS-KS and CAP can accurately predict the flow rate if the reverse flow is considered. However, to apply this study to the long-term accident scenario of the i-SMR, there is a need to generalize the conditions for the occurrence reverse flow.

ACKNOWLEGDEMENT

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