Thermal-hydraulic Analysis of Chimney Effect Using OpenModelica

Minseok Choi[1]

[1] *Gyeonggi-do, Korea, cminlife22@gmail.com*

EXTENDED ABSTRACT

In the nuclear power plants, the chimney effect is considered to remove decay heat in the long-term accident scenario. At the external containment vessel of a nuclear power plant, 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, 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 OpenModelica [3]. OpenModelica is an open-source software to provide a modeling and simulation environment based on Modelica. Modelica is an acausal language to model multi-physics system. Chen's experiment [4] was referred for evaluation.

Jing used a pressure coefficient to include the reverse flow [2]. The pressure coefficient K_{out} can be obtained:

$$\epsilon = \frac{\Delta\rho}{\rho_{amb}} \approx \frac{\Delta T}{T_{amb}} = \frac{Q}{\dot{V}\rho C_p T_{amb}} \tag{1}$$

$$Fr = \frac{\dot{V}}{A\sqrt{2gD\epsilon}} \tag{2}$$

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

Δρ and ΔT refer to the differences in density and temperature at the inlet and outlet, respectively. Fr is Froude number, which is the ratio of the inertia force to uplift force, Q is the heat supplied by heater, $\dot{V}$ is the flow rate, ρ is the air density, C_p is isobaric specific heat, Tamb is the ambient temperature, A is the outlet area, and D is the length of the shortest side at the outlet.

Chen's chimney has a height of 1.5 m and a width of 0.615 m [4]. 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 varied.

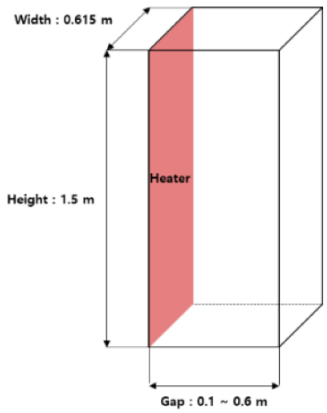

FIGURE 1. Illustration of the chimney

Fig. 2 shows the experiment configuration. Air flows from the atmosphere into the chimney. Before the chimney, a virtual pipe is introduced on the right side of the model to compensate the pressure difference caused by elevation. Pressure

coefficients were applied at the outlet and inlet of the chimney. The inlet K is 1.5. The outlet K is 1.0 under normal cases, but if reverse flow occurs, the outlet K can be increased.

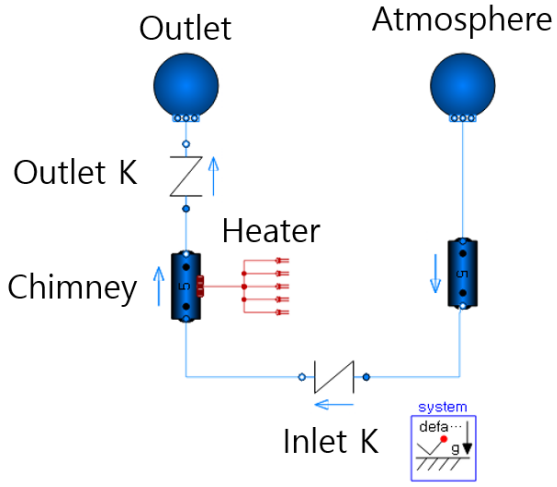

FIGURE 2. OpenModelica model configuration

Fig. 3 shows comparisons between the experimental and analytical results. Outlet K 1.0 means the results of OpenModelica when the outlet K is 1.0. In case of the modified K, the outlet K under consideration of reverse flow. It is shown that accuracy is higher when the reverse flow is considered.

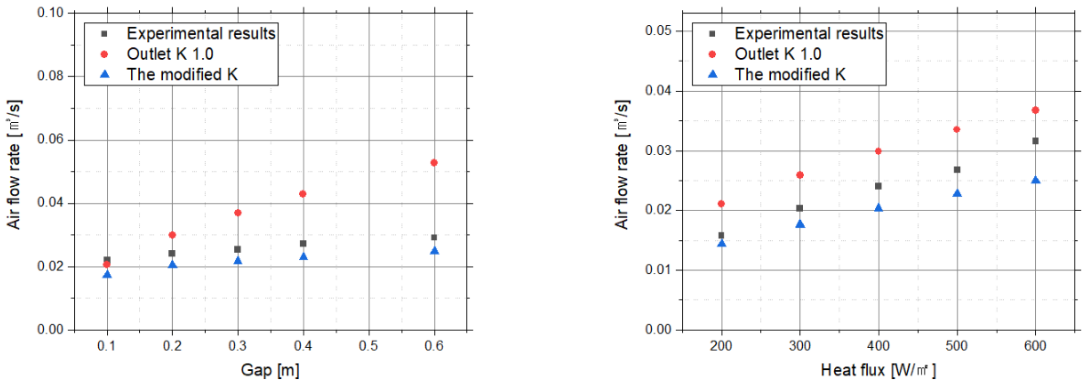

FIGURE 3. Comparison of air flow rate with varying gap size (left) and heat flux (right)

It has been confirmed that OpenModelica can predict the flow rate more accurately if the reverse flow is considered. However, to apply this study to long-term accident scenarios in nuclear power plants, it is necessary to generalize the conditions under which reverse flow occurs.

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