Numerical analysis of the effect of the thickness of water-layer on fire resistive performance of curtain walls

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***Abstract*— As high-rise buildings globally increase, double-layered curtain walls are being preferred for the beauty and natural ventilations. However, when the external cladding of a building comprising glasses or metals is damaged, fire can rapidly propagate to upper levels and it makes loss of lives and property.**

In this study, when water directly flows on the surface of wall to be protected, numerical analysis is performed to investigate the effect of the thickness of water-layer on fire resistive of the curtain wall.

Consequently, the thickness of the water-layer decreases as temperature of the curtain wall increases, that is, the fire resistive performance decreases. Also, the rate of increases in temperature of the curtain wall is much larger than that of the rate of decreases in the thickness. This is important from the point of view of the design and safety standards for curtain wall systems.

Keywords*— *curtain wall: CFD; fire resistive performance; water-layer

I. INTRODUCTION

As high-rise buildings globally increase, double-layered curtain walls are being preferred for the beauty and natural ventilations. However, when the external cladding of a building comprising glasses or metals is damaged, fire can rapidly propagate to upper levels and it makes loss of lives and property. Thus, it is important to investigate and control distribution of temperature in the curtain wall when fire occurs.

Numerous researches have been conducted to advance the fire resistive performance of curtain walls for decades. Water spray curtain is a representative system to cut off heat. The curtain composed of water droplets is generally located in front of the wall to be protected. It behaves as a filter and can reduce radiative heat flux [1]. Water sprays can provide thermal shielding to maintain the integrity of neighboring structures in case of reservoir fire [2, 3]. However, the difficulty lies in the optimal nozzle design and high injection pressure is needed.

Our research team have tried to advance the water curtain system. The final system is that a flowing water-layer is directly laid on the surface of the curtain wall to cut off heat. The greatest advantage of this system is easy to control temperature of the curtain wall by adjusting a flow rate of the water-layer. However, there is a little researches and relational statue globally.

In this study, when water directly flows on the surface of wall to be protected, numerical analysis is performed to investigate the effect of the thickness of water-layer on fire resistive of the curtain wall.

II. NUMERICALDETAILS

A. Modeling and Grid generation

The numerical domain is 2-dimensional geometry as shown in Fig. 1. The domain is divided to four regions including hot

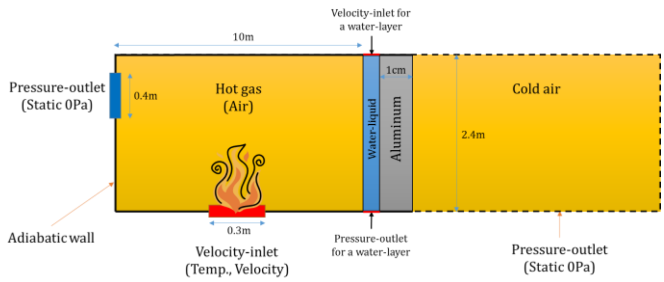

Fig. 1. Schmetic of the numerical domain.

gas (room), water-layer, curtain wall (aluminum) and ambient air (cold air). Three numerical cases are selected to investigate the influence of thickness of water-layer on fire resistive of the curtain wall as shown in Table 1.

The room size is 10 m x 2.4 m. Hot gas, which means a fire plume, is entertained from the region of 0.3m. Also, the hot gas and fresh air flow in/out through the window. The curtain wall is made up of aluminum and the thickness is 1 cm. Geometric conditions except the thickness of water-layer are equal in all numerical cases.

Grids are generated with ANSYS ICEM V14.5 and comprise square cells. The number of cells selected by grid independent test is shown in Table 1.

B. Governng Equations

The standard k-e turbulence model considering buoyancy effects is used for turbulent flows and the y+ value of first nodes from walls of the hot gas region remains within 100.

Radiation effect is considered with the P-1 radiation model. The reflection of incident radiation at the surface is isotropic with respect to the solid angle. Refractive index for hot gas and water is 1.0 and 1.33 regardless of variations in temperature and flow conditions, respectively. Conjugate heat transfer is calculated interfaces between two regions, e.g., hot-gas and water-layer, curtain wall and ambient air.

The SIMPLE algorithm is used for pressure-velocity coupling of 2-dimensional steady flow.

C. Boundary Conditions

Water flows from top to bottom in the water-layer on the surface of the curtain wall. Thus, the velocity-inlet condition with 0.1 m/s and the pressure-outlet with static pressure 0 Pa are applied to the top and the bottom of the water-layer, respectively. And temperature of water is fixed to 300K. The inlet velocity and the temperature is equivalent in all numerical cases.

In order to assume a fire plume, the temperature of hot gas is 1000K and the flow rate per unit depth is 0.15 m2/s. Also, the pressure-outlet condition is applied to the window. Outer walls around the room and the curtain wall are no-slip condition and adiabatic condition for flow and heat transfer calculations, respectively. Conjugate heat transfer including conduction and convection is calculated interfaces between two regions, e.g., hot-gas and water-layer, curtain wall and ambient air.

The pressure-outlet condition is applied to all boundaries of the ambient air region except the interface with the curtain wall. In addition. When backflows occur at boundaries applied with pressure-outlet such as the window and the ambient air region, temperature of backflows is 300K as the ambient temperature.

TABLE I. NUMERICAL CASES AND NUMBER OF GRID CELLS

Case No.	Thickness of water-layer	Number of grid cells
1	2mm	11,280
2	5mm	10,920
3	10mm	9,820

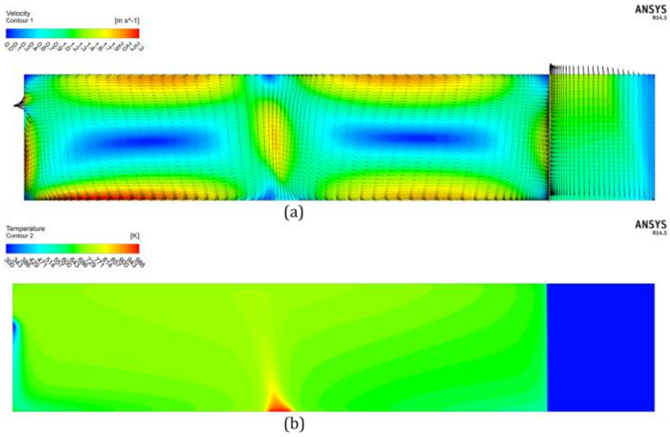

Fig. 2. (a) Velocity contour and vector, (b) Temprature conour

III. RESULTS AND DISCUSSION

Hot gas, i.e., fire plume, causes two large vortex around the room due to a ceiling jet. Also, an ascending air current occurs along the right side of the curtain wall because hot wall surface causes buoyant flows as shown in Fig. 2 (a). And Fig. 2 (b) shows the distribution of temperature in domain.

Fig. 3, Fig. 4 and Fig. 5 show temperature profiles along the horizontal line near curtail wall. In terms of global trend, hot gas is rapidly cooled near the water-layer. This is because flowing water continuously takes away heat from the hot gas. There is no temperature gradient inside the curtain wall along the axis x-direction, and then temperature steeply decreases at the outer surface of the curtain wall. On the contrary, along A-A' line as shown in Fig. 3, temperature of the ambient air region is higher than that inside the curtain wall due to the buoyant flows. The reason is that the air heated up by the curtain wall rises due to the buoyancy effect. Overall, the thickness of the water-layer decreases as temperature of the curtain wall increases, that is, the fire resistive performance decreases. This is because the thickness of the water-layer is directly related with the rate of heat taken away by the flowing water. Also, the rate of increases in temperature of the curtain wall is much larger than that of the rate of decreases in the thickness.

Fig. 6 shows temperature profiles inside the curtain wall along the vertical line. When the thickness of the water-layer is 2 mm, temperature suddenly increases in all points. The water-

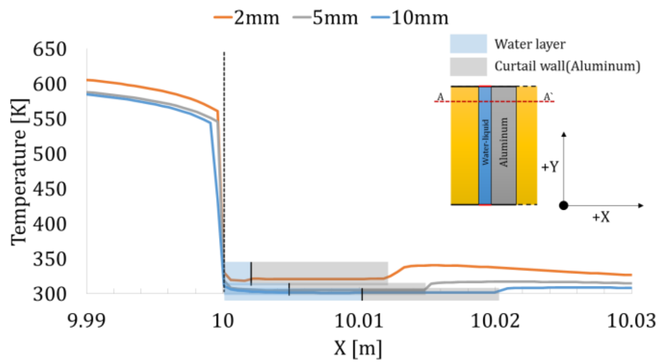

Fig. 3. Temperautre profile along the A-A' line at y = 2.3 m.

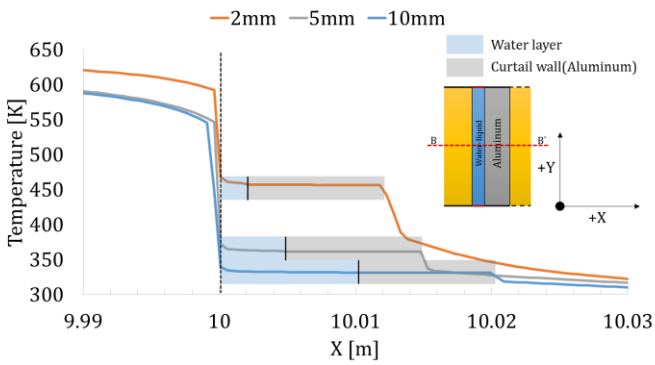

Fig. 4. Temperature profie along the B-B' line at y = 1.2 m.

layer can be assumed to an insulator because water flows with the constant velocity of 0.1 m/s. At the bottom of the curtain wall, Reynolds number is about 239,000 and the boundary layer thickness is about 2.5 cm. Thus, the effect of turbulent flows on the heat transfer can be neglected. Also, radiation effect can be neglected because water temperature is small. Consequently, conduction is dominant for the heat transfer between hot gas and the curtain wall.

$$\dot{Q}_{conduction} \sim \frac{1}{(\Delta t)^2} \tag{1}$$

The thickness of the water-layer, Δt, is related with heat conduction, $\dot{Q}_{conduction}$, as shown in (1). Therefore, temperature of the curtain wall suddenly increases as the thickness of the water-layer decreases.

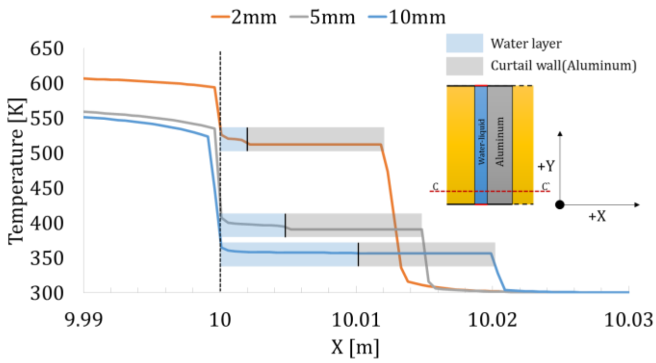

Fig. 5. Temperature profile along the C-C' line at y = 0.1 m.

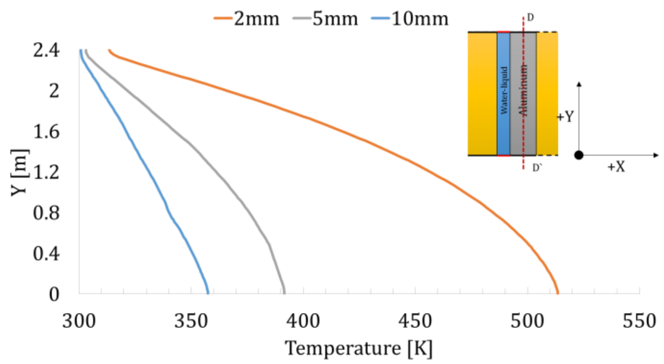

Fig. 6. Temperature profile along the C-C' line inside the curtain wall.

IV. Conclusion

This study is focused on the effect of the thickness of water-layer on fire resistive of the curtain wall.

Consequently, the thickness of the water-layer decreases as temperature of the curtain wall increases, that is, the fire resistive performance decreases. This is because the thickness of the water-layer is directly related with the rate of heat taken away by the flowing water. Also, the rate of increases in temperature of the curtain wall is much larger than that of the rate of decreases in the thickness.

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