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Suppression Capability Investigation for a Water Mist System in a Basement Building Fire

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Summary

Protecting against basement fires in commercial buildings is of major concern in Taiwan. Basements typically fill with high-temperature dense smoke rapidly during a fire, frequently generating deadly conditions that hinder escape from a fire. The water-mist fire suppression system (WMFSS) is a highly efficient fire suppression device that enhances the safety of people during a basement fire. The tiny water droplets with various diameters can absorb large amount of heat and the water vapors can prevent the occurrence of flashover during a building fire. This study investigates fire-suppression characteristics using a WMFSS in a basement barbershop fire accident in Taiwan. This accident caused extremely severe casualties (22 dead / 7 injured) in 1993. The fire is simulated using Fire Dynamics Simulator (FDS) software for various scenarios. Computational results demonstrate that fire-suppression capability (including the influence of sprinkler spray in different positions, number of the sprinklers, flow fluxes, and mean droplet diameters) and cooling effects are improved significantly when using droplets with small mean diameters. Therefore, if such a WMFSS is implemented in the building basement, the severe consequences/casualties would be greatly reduced. Simulation data may be useful in future fire safety design and for use in WMFSS installation regulations.

Introduction

Smoke gases from a basement building fire might spread through corridors and ventilation systems to the entire building. Most fire deaths are due to the inhalation of smoke and toxic gases. Therefore, controlling/reducing the smoke extraction during a building fire can save lives, aid firefighting, and protect property [1].

Various water-mist fire suppression systems (WMFSSs) have been developed to mitigate the consequences of building fires. These systems have economic benefit and are highly efficient fire-suppression systems. These systems generate little or no pollution during fire control and are significantly more efficient than traditional fire sprinklers [2–5]. The WMFSS codes, developed by US National Fire Protection Association (NFPA750), indicate that mean droplet diameter should be $<1000\mu m$ [6]. These systems are operated under high jet pressure that pushes water through a special water nozzle to produce the water mist that cools the fire source and thermal plume. Fire-suppression water droplets generated by the system

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can remove oxygen and block radiant heat via evaporation of water droplets and, thus, extinguish a fire.

This study investigates the performance characteristics of WMFSSs quantitatively during a full-scale fire. A fire field model FDS is utilized to develop a computer simulation model of a barbershop fire in Taiwan. The fire accident caused severe casualties. A water mist system is assumed to be implemented near the fire source to determine the effects on fire suppression of different sprinkler positions, number of the sprinklers, flow fluxes, and mean droplet diameters.

Description of the fire and simulation

The FDS fire model developed by US National Institute of Standard and Technology (NIST) in 1997 [7] is employed to simulate the interaction of the fire plume and water mist in the basement floor. The Kardeng barbershop occupies the basement, first floor, and second floor of a 12-story commercial building. The arsonist set fire to himself in the basement hall and laid down in room 115. The fire was extinguished 100 minutes after ignition and caused 22 fatalities and injured 7 people [8,9]. Figure 1 presents the FDS computational geometry and direction of fire spread.

According to Taiwan's fire protection code, a commercial facility is allowed to implement the water-mist system with a water spray flux $>$20 L/min m^2 and spray pressure 2.7kg/cm^2 in all sprinklers. Five mean droplet diameters (1000, 800, 600, 400, and 200μm) in flux of 20 L/min m^2 are investigated to identify the interaction between water particle sizes and fire growth. Four water spray fluxes (25, 30, 35, and 40 L/min m^2), different sprinkler positions (Fig. 1), and number of sprinklers (2 and 5 sprinklers) are also analyzed. The total simulation time is set to be 60 seconds as the water-mist system suppresses fire. Table 1 shows the fire simulation and analytical parameters for the water-mist system.

Table 1: Fire simulation and analytical parameters for the water-mist system

Fire parameters \ Variations	Water spray flux (L/min m^2)	Droplet mean diameters (μm)	Numbers of sprinkler
Heat release rate (kW)	20,25,30,35,40	200,400,600,800,1000	1
Upper layer temperature (°)	30	400,1000	1,2,5
Carbon monoxide concentration (ppm)			
Soot volume fraction (ppm)			
Fire spread	30	400	1
Fire cross-section temperature (°)			
Fire smoke expansion		1000	5
Fire water vapor distribution			

Results and Discussion

To determine the effects of various water spray fluxes and mean droplet diameters on fire suppression, a water-mist sprinkler set above the fire source center was

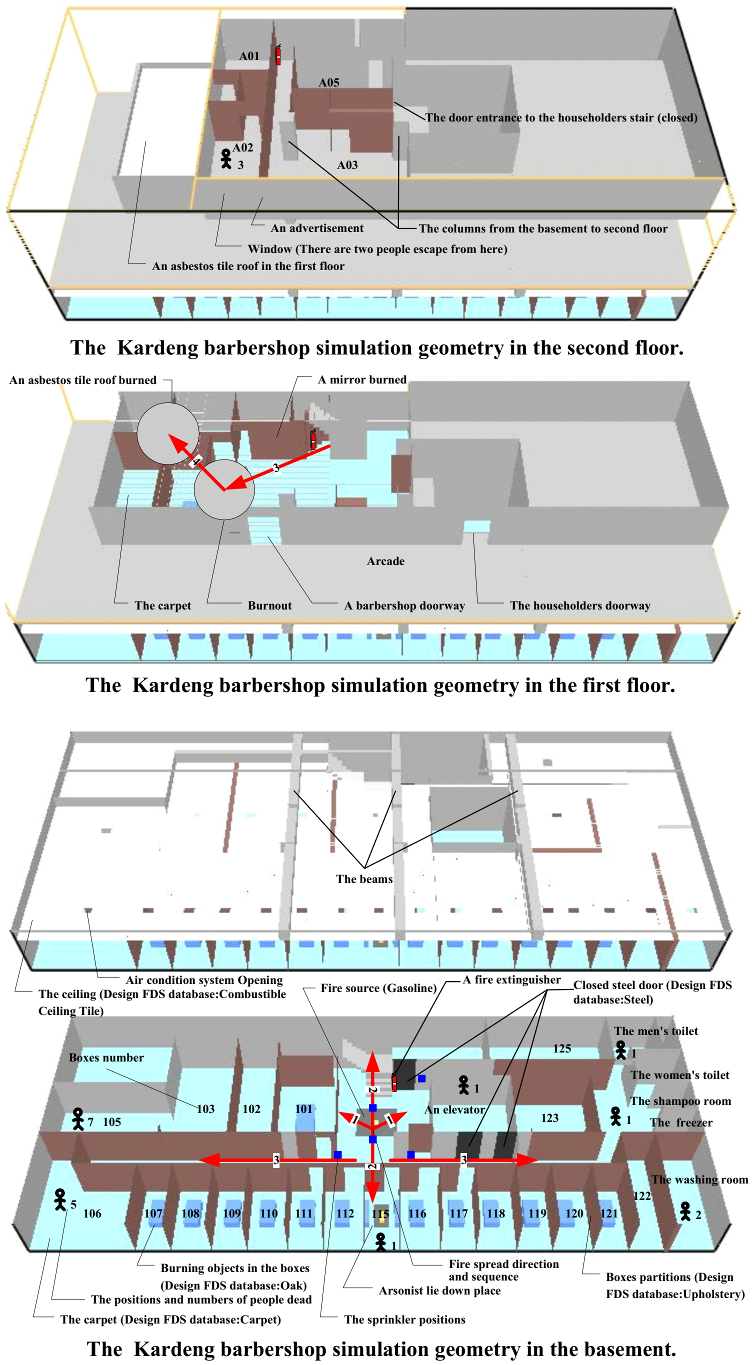

Figure 1: Three-dimension floor plans of the building

tested. The WMFSS simulation Response Time Index (RTI), operating pressure, spray radius, and activation temperature were set 50 $(m/s)^{1/2}$, 2.8bar, 2.1m, and 74˚C, respectively. The water spray flux $\dot{m} = K\sqrt{p}$ was controlled by K-Factor of 166, 207, 248, 290, 331 L/min $bar^{1/2}$. Figures 2∼6 show the heat release rate (HRR) variations over time. As can be seen from the results, the fire intensity under different water-spray fluxes has a similar variation/behavior with large mean droplet diameters of 600–1000μm and the maximum HRR was over 15MW during fire simulation. The fire suppression effect appeared to be small. At mean droplet diameter of 400μm and as water-spray flux increased, the maximum HRR greatly declined. Fire suppression and extinguishment were significant/notable at mean droplet diameter of 200μm, and the maximum HRR was approximately 5MW. The effect of various water spray fluxes on fire suppression is illustrated on Fig. 7. It can be seen that the larger fluxes tend to effectively reduce the HRR. However, when it reached over 30 L/min m^2, the cooling effect appeared to be limited/negligible.

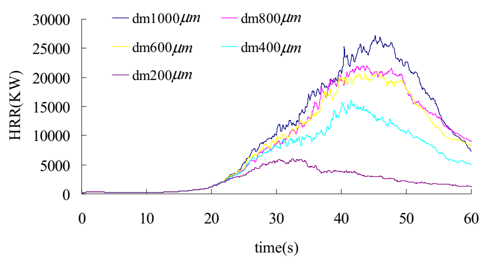

Figure 2: Fire HRR variations for mean droplet diameters in water spray flux of 20 L/min m^2

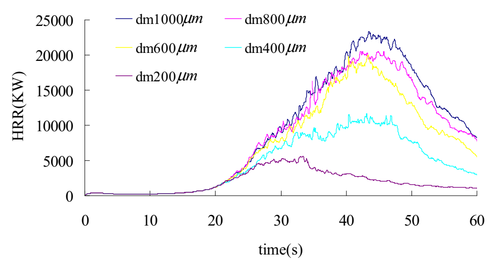

Figure 3: Fire HRR variations for mean droplet diameters in water spray flux of 25 L/min m^2

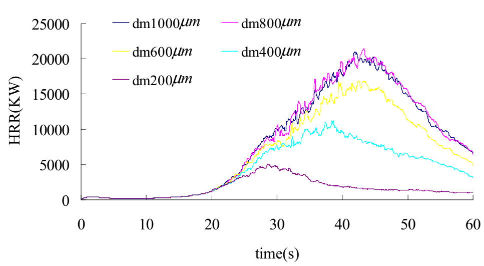

Figure 4: Fire HRR variations for mean droplet diameters in water spray flux of 30 L/min m^2

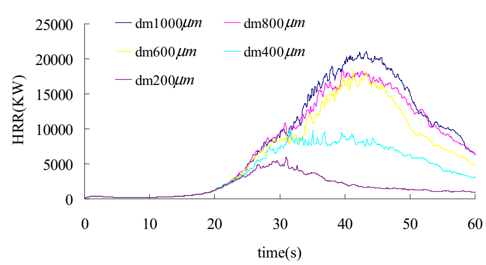

Figure 5: Fire HRR variations for mean droplet diameters in water spray flux of 35 L/min m^2

Next, the effects of various sprinkler numbers (1, 2 and 5) at different positions (Fig. 1) and mean droplet diameters (400 and 1000μm) with a fixed water

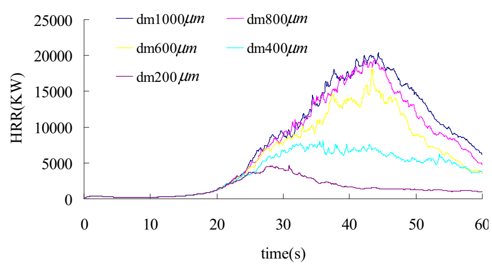

Figure 6: Fire HRR variations for mean droplet diameters in water spray flux of 40 L/min m^2

spray flux of 30 L/min m^2 on fire dynamics were analyzed. Figures 8∼10 show analytical results for fire hazard (upper layer temperature, carbon monoxide (CO) concentration, and soot volume fraction). After the sprinklers start operation, the temperature gradient with mean droplet diameter of 400μm was, in general, found to be much smaller than that with mean droplet diameter of 1000μm, and temperature was under 260˚C after fire simulation for 1 minute (Fig. 8). The cooling effect of only one single sprinkler with mean droplet diameter of 400μm appeared to be much better than that of five sprinklers with mean droplet diameter of 1000μm. For all sprinkler groups with mean droplet diameters of 400 and 1000μm, mean CO concentration variations reached roughly 1000ppm and 2000ppm after 32 and 40 seconds, respectively (Fig. 9). Soot accumulation during fire simulation (Fig. 10) increased consistently and slowly as the gasoline fire source was suppressed by the water-mist system.

Figures 11∼14 present a comparison of variation between the original fire scenario and that with different water-mist systems in terms of fire spread, temperature field, smoke transport/propagation, and water vapor distribution at 40 seconds of simulation. The base fire model V shape spread in the basement floor and rooms, and moved to the first floor hall in about 40 seconds (Fig. 11-A). The escape route through basement corridors and stairways was filled with high-temperature smoke (Figs. 12-A and 13-A). Figure 11-B shows the portion of fire that spread to basement floor corridors and first floor hall under 5 sprinklers with mean droplet diameters 1000μm; high fire temperature (Fig. 12-B) and smoke expansion (Fig. 13-B) were less severe than those of the original fire. The fire spread only to the region near the fire source with 1 sprinkler mean droplet diameter of 400μm (Fig. 11-C); the fire temperatures at most area/space appeared to be much lower (Fig. 12-C) and the smoke expansion was much less severe which the 2nd floor had no smoke present (Fig. 13-C). The mitigation effect can be obviously seen from Figs. 11-C∼13-C when employing one sprinkler with mean droplet diameter of 400μm. Figure 14 presents the water-vapor distribution at simulation for 40 seconds under 5 sprinklers and 1 sprinkler with mean droplet diameters 1000μm and 400μm, respectively. Water-vapor distribution zones in the fire building are for both systems were similar as the large droplets vapor slower than small droplet. Simulation results indicate that fire suppression with small spray droplets is better than that with large droplets, and potential damage of indoor decor and electrical and mechanical equipment can be reduced by less excessive water sprayed in the building.

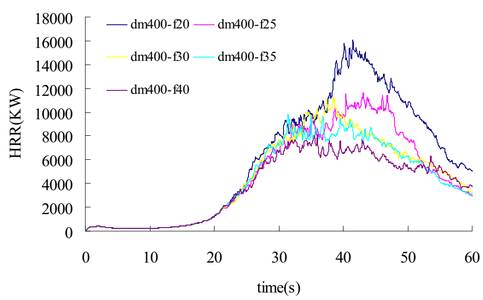

Figure 7: Fire HRR variations for different water spray fluxes in mean droplet diameters 400μm

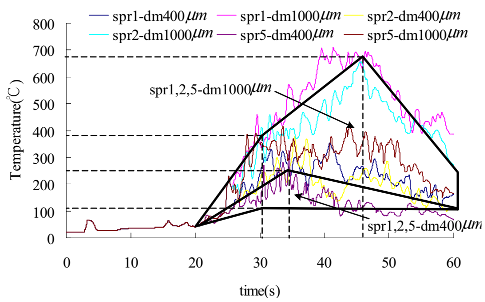

Figure 8: Upper layer temperature variations for mean droplet diameters of 400 and 1000$\mu m$and 1, 2, and 5 sprinklers with a water-spra y flux of 30 L/min m^2

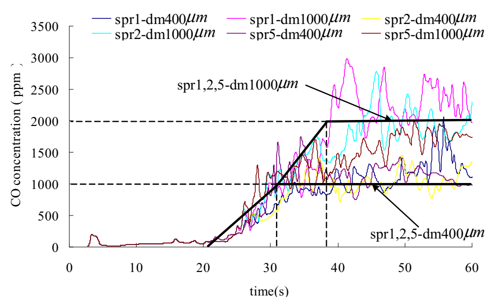

Figure 9: The CO concentration variations for mean droplet diameters of 400 and 1000$\mu m$and 1, 2, and 5 sprinklers with a water-spray flux of 30 L/min m^2

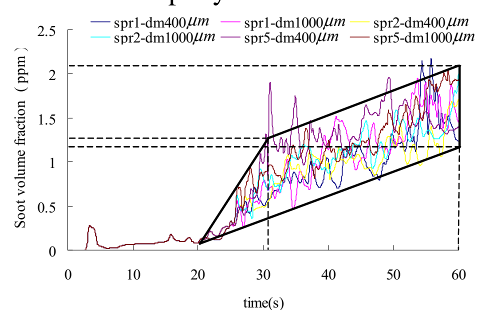

Figure 10: The soot volume fraction variations for mean droplet diameters of 400 and 1000μm and 1, 2, and 5 sprinklers with a water-spray flux of 30 L/min m^2

Conclusion

Fire suppression capability for a WMFSS in the basement of a commercial building was quantitatively analyzed. The FDS software was utilized to develop a computer model simulating Kardeng barbershop fire occurred in Taiwan (1993). Simulation results demonstrate that both small mean droplet diameters ($\leq 400\mu m$) and large water spray fluxes can significantly improve the suppression and cooling effect during a fire. However, fire suppression efficiency declined when water spray

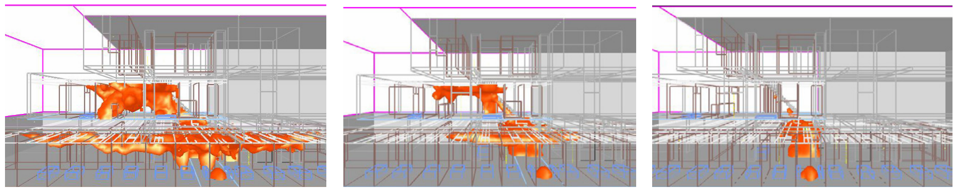

Fig. A. Without sprinkler Fig. B. 5 sprinklers (1000 μm) Fig. C. 1 sprinkler (400 μm)

Figure 11: Fire spread distribution at 40 seconds of simulation with different water-mist systems

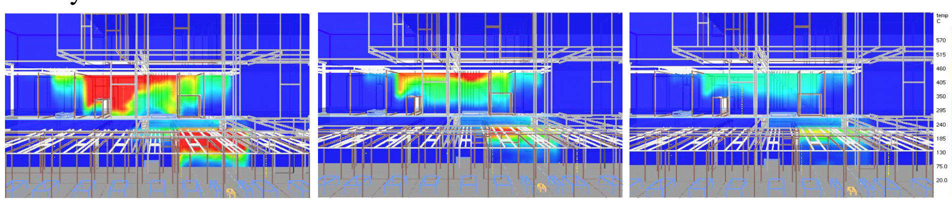

Fig. A. Without sprinkler Fig. B. 5 sprinklers (1000 μm) Fig. C. 1 sprinkler (400 μm)

Figure 12: Fire temperature distribution at 40 seconds of simulation with different water-mist systems

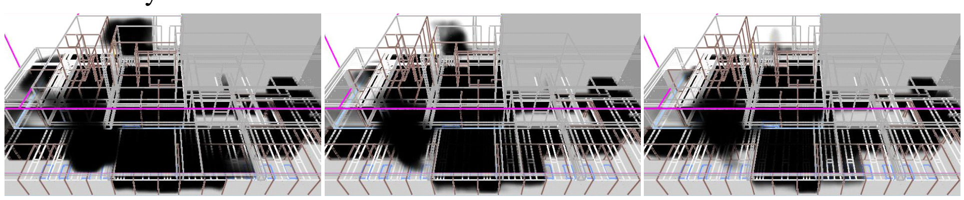

Fig. A. Without sprinkler Fig. B. 5 sprinklers (1000 μm) Fig. C. 1 sprinkler (400 μm)

Figure 13: Fire smoke distribution at 40 seconds of simulation with different water-mist systems

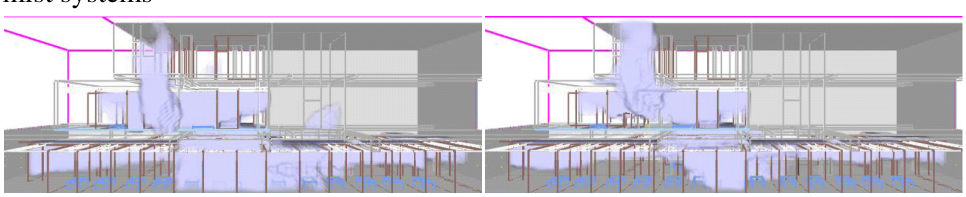

Fig. A. 5 sprinklers (1000 μm) Fig. B. 1 sprinkler (400 μm)

Figure 14: Fire water vapor distribution at 40 seconds of simulation with different water-mist systems

flux reached 30 L/min m^2 and excessive water could potentially damage the valuable mechanical/electrical equipment in the facility. The fire temperature greatly decreased with a WMFSS, However, suppression of toxic gases and smoke is little. Therefore, basement buildings must have a mechanism for exhausting smoke to reduce damage caused by heavy smoke and toxic gases.

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