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Influence of fire source locations on the actuation of wet-type sprinklers in an office fire

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ABSTRACT

An experiment is conducted on a full-scale model office and an actual sprinkler system to explore the influence of fire source locations on sprinkler actuation. The office space is a brick structure that measures 5.7 m in interior length, 4.7 m in width and 2.4 m in ceiling height, and equipped with a sprinkler system. The investigated fire source (100 kW LPG burner) locations include the room center, wall centers, room corner, and other locations at different distances from sprinklers. The results show that actuation of the sprinklers is affected by the fire source locations and the heat conduction properties of the glass temperature-sensing bulb. Average actuation time of all the tests is 102 s, around 40 s faster than if the fire source is located in the room center. For fire sources in corners, sprinklers are quickly activated at the experimental time 75 s, showing concentrated hot gas flow.

1. Introduction

At a fire scene, the phase change of water from liquid to steam effectively removes heat directly from flames, slows high temperature combustion, and cools the fuel surface directly via the latent heat of evaporation. Large amounts of steam can also reduce the oxygen concentration (particularly effective in enclosed spaces) to extinguish fire [1]. Such characteristics make water a preferred extinguishing agent. Inside buildings, automatic sprinklers deliver water drops in the fire protection area to restrain, control, and extinguish fires. When heat initiates the detection component of the sprinkler system, the system discharges water into the activated sprinklers to extinguish the fire. Sprinkler systems are classified as wet pipe, dry pipe, pre-action and the deluge. Which type of system is utilized depends on climate conditions, ambient temperature, protection objectives, burning style and local regulations. Wet pipe sprinkler systems are highly recommended since they have a simple structure, low maintenance cost, high reliability, and fast response.

With regard to the mutual influence of fire scene characteristics and sprinkler actuation, Cooper [2] analyzed a two-layer-type model to explore different interactions, including upper-layer entrainment into the sprinkler spray, momentum and mass exchange between drops and entrained gas, gas cooling by evaporation, buoyancy effects, and others. Ingason [3] used a heated wind tunnel to observe the thermal response of the glass temperature-sensing bulb used in the sprinklers. Different combinations of the parameters, including the response time index (RTI), the conduction parameter (C), and the change of phase parameter (CHP), were used to predict the response times of various test conditions, including different fire growth rates. Hua et al. [4] developed a numerical simulation method to investigate the interaction between the fire plume and the water spray. Ruffino and diMarzo [5] investigated the evaporative cooling and actuation delay of the sprinkler adjacent to the one activated by releasing water droplets into the fire plume of hot gases. Schwille and Lueptow [6] conducted experiments where 5, 15, and 50 kW gas burner fires were exposed to a spray from one of three spray sources with 6–106 L/min water flow rates.

Regarding the effect of fire location on the actuation of sprinklers, Wade et al. [7] conducted a set of 22 fire/sprinkler experiments to investigate the sprinkler response times and to predictive capability of the BRANZFIRE fire model. The results showed that, when using the BRANZFIRE model for predicting sprinkler response times, incorporating the NIST/JET ceiling jet algorithm, gave a closer prediction of the sprinkler response time in a small room than

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Alpert's correlation. It was also found that the position of the sprinkler head beneath the ceiling is an important parameter and has a strong influence on the response time of the sprinkler; values for the RTI and C-factor were found to be not so critical. Bennetts et al. [8] indicated data relating to the performance of sprinklers, including the times for activation of various types of sprinkler heads (normal and fast response), and the efficacy of the systems as far as extinguishment is concerned, in real office fire situations. It has been observed that for a 4 m × 4 m office, a fire size of 300 kW (midway between the sprinkler head and the wall) was required to actuate the sprinkler head, located at the room center. Tests also showed that Quick Response sprinklers were generally activated before the Standard Response sprinklers. The former were in most cases activated when the adjacent air temperature was between 90 and 130 °C while the latter were activated at air temperatures between 180 and 210 °C.

In this study, an experiment is conducted on a full-scale model office space and an actual sprinkler system to explore the influence of fire source locations, include the room center, wall centers, room corner, and other locations at different distances from sprinklers, on sprinkler actuation.

2. Research method

2.1. 10 MW fire test facility

A full-scale fire experiment was done using the 10 MW fire test facility and a combustion gas continuous online analysis system. The device is in the Fire Experiment Center, Architecture & Building Research Institute, Ministry of Interior, located on the Gueiren Campus of National Cheng-Kung University.

The 10 MW fire test facility consists of a smoke collection hood, smoke collection bend, mixture tube, measurement section, exhaust bend, and exhaust pipe, as in Figs. 1 and 2. Large objects or structures can be placed on the platform under the hood ❶ for testing. Hot gas, smoke, and combustion products are collected with the smoke collection hood, flow vertically through the smoke collection bend❷, are transferred horizontally into the mixture tube❸, go through the measurement section, and exit through the exhaust bend❹ and exhaust pipe❺ . The end of the exhaust pipe is finally connected to a waste gas treatment system❻. A large exhaust fan in the waste gas treatment system offers a maximum 30 m^3/s fire gas flow.

The combustion gas continuous online analysis system consists of (1) the gas analysis system (including O_2, CO, CO_2, NO_x, and HC analyzers, as well as a gas sampling/calibration system), (2) an optical density analyzer, (3) a flow rate/temperature monitor, and (4) a data processing system.

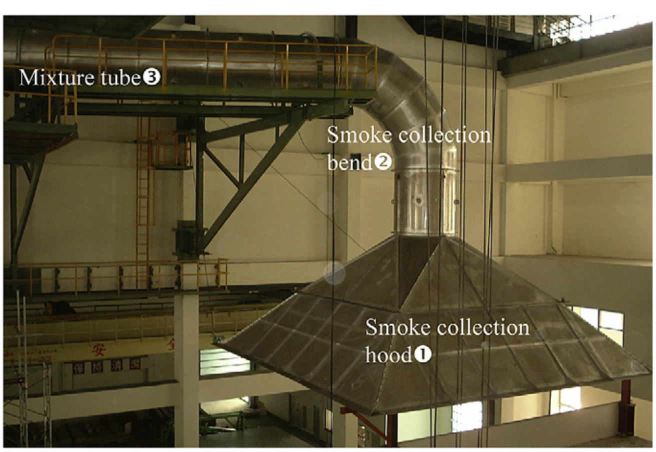

Fig. 1. 10 MW fire test facility.

Fig. 2. Waste gas treatment system.

2.2. Investigated model office

The investigated model office, as shown in Fig. 3, is located below the smoke collection hood (❶ in Fig. 1) of the 10 MW fire test facility. The interior plan dimension is 5.7 m × 4.7 m and the net ceiling height is 2.4 m. The walls are brick-laid in 0.26 m thickness with U = 2.59 W/m^2 K (two aligned 0.12 m bricks ($\rho = 1650$ kg/m^3, k = 0.8 W/m K, Cp = 0.84 kJ/kg K) and outside 0.001 m mortar layers ($\rho = 2000$ kg/m^3, k = 1.5 W/m K, Cp = 0.8 kJ/kg K, $\varepsilon = 0.5$; where ε is emissivity)). The floor is made of a 3 mm steel deck ($\rho = 7860$ kg/m^3, k = 45 W/m K, Cp = 0.48 kJ/kg K) and a 0.2 m concrete ($\rho = 2400$ kg/m^3, k = 1.5 W/m K, Cp = 0.8 kJ/kg K, $\varepsilon = 0.5$). Both northeast and southeast wings have a 2.1 m × 0.9 m single door to be opened. The ceiling is made of a light rigid frame and gypsum board ($\rho = 910$ kg/m^3, k = 0.17 W/m K, Cp = 1.19 kJ/kg K, $\varepsilon = 0.88$). To better directly observe behavior of the fire via sprinkler actuation and water droplets, two 2.4 m × 1.2 m fireproof windows are placed at the north wing of the western wall and the east wing of the southern wall. The distance between the window and ground is 0.6 m. See elevation of west and south in Fig. 3(b) and (c); the overall 3D view is in Fig. 3(d).

2.3. Sprinkler system

Four sprinkler heads, spaced uniformly in the model room and compliant with the Taiwanese regulation "Standards for Installation of Fire Safety Equipments Based on Use and Occupancy", were installed 0.15 m below the ceiling for each experiment, as shown in Fig. 4 (S_1–S_4). A pressure gauge and a pipe valve was installed sequentially upstream of each sprinkler head. The pressure gauge, placed between the valve and the sprinkler head, was used to observe sprinkler activation. The valve was closed when the pipe has contained water, in order to make the activated sprinkler head discharge a small amount of water. The sprinkler's K-factor is 80 LPM/$(bar)^{1/2}$, its temperature rating is 68 °C, its response time index (RTI) is 132 $(m\ s)^{1/2}$, and its C-factor is 0.6 $(m/s)^{1/2}$. All the