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PRELIMINARY STUDIES ON SMOKE SPREADING PREVENTION AND THERMAL RADIATION BLOCKAGE BY A WATER CURTAIN

N.K. Fong, W.K. Chow and W.T. Chan
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

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ABSTRACT

Drencher sprinkler discharging water curtains is proposed to divide a building into different ‘compartments’ when it is under fire. Experiments were conducted in a chamber to investigate whether radiative heat flux can be blocked, and whether smoke spreading can be prevented. Performance of the proposed design under various discharge conditions was studied experimentally. The chamber was divided into two sides by discharging a water curtain, with a fire setting up on one side. The temperature distribution, heat flux, and optical density of the two sides were measured. Experimental results showed that the water curtain might not be so effective in stopping smoke spreading but effective in blocking thermal radiant heat.

1. INTRODUCTION

Buildings are required to be divided into compartments [e.g. 1] so that spreading of fire and smoke can be confined. However, it is difficult to install smoke control equipment in certain buildings, such as tunnels and corridors where space is limited. A proposal was made on dividing the building under fire into different parts by water curtains so that spreading of heat and smoke to other areas can be prevented. In fact, installing drencher systems in all refuge floors for covering external wall openings was specified in the local codes on fire services installations [2]. Whether this is good or not has to be further watched.

A drencher system is a sprinkler with a directional discharge that produces a water curtain [e.g. 3]. It can be controlled either manually or automatically and it works with a deluge system. A drencher system would not directly extinguish the fire, but would block radiant heat from entering into the protected areas. It is used for protecting windows, wall roofs and large openings of the building against smoke and fires [e.g. 4,5]. When the system is actuated, water discharged out of the drencher spray nozzles would be blocked by the metallic part, the direction of water flow is changed by 90°. Depending on the shape of the nozzle, a curtain-like spray pattern is discharged to the windows concerned for typical design with different guides appeared in the literature [e.g. 6-9].

The proposal of using the discharged water curtain for dividing a physical space into different parts is assessed. Whether spreading of heat and smoke to other areas can be prevented by the water curtain were studied experimentally.

2. EXPERIMENTAL SETUP

Drencher system can be used to prevent spreading of heat [e.g. 4,5,10]. The required water discharge pressure and flow rate of the system are based on the potential hazard of the protected area. In order to measure the performance of drencher system, experiments were carried out in a fire chamber at the laboratory of Department of Building Services Engineering, The Hong Kong Polytechnic University. Parameters including radiant heat flux, optical density and temperature distribution were studied.

The chamber is of length 4 m, width 2.9 m and height 2.6 m as shown in Fig. 1. Pipeworks were installed inside the chamber so that a drencher nozzle was placed at the ceiling centre of height 2.5 m (as typical protected area is of this height) above the floor level. A fire resistant board is mounted between the drencher and ceiling. The window sprinkler model as shown in Fig. 1a was used. Three nozzle sizes (labeled as A, B and C) were selected with orifice diameter of 10 mm (k-factor = 43), 13 mm (k-factor = 84) and 19 mm (k-factor = 111) under working pressure of 2, 3 and 4 bars as listed in Table 1. Physical properties of the water curtain discharged by these three nozzles were reported in another article [11].

By discharging a water curtain, the chamber is divided into two sides, fire side F and protected side P, as in Fig. 1. A wood crib fire with dimensions $0.3 \times 0.3 \times 0.3$ m^3 and mass 3.45 kg was put in side F to generate smoke and heat. It was placed 500 mm away from the center of the drencher as shown in the figure. Prevention of smoke spreading and blocking of thermal radiation were examined. The temperature, heat flux and optical density were recorded. As that chamber is located in downtown area next to the entrance of a cross-harbor tunnel, so only a small fire was used.

A thermocouple tree was placed on each side of the chamber to measure the temperature distribution. There are eight K-type 1/0.2 mm thermocouples (T9 at the top and T2 at the bottom) spaced 0.3 m apart, starting from 0.5 m above finished floor level as shown in Fig. 1b.

A heat flux transducer (64 series, Schmidt-Boelter type) was used to measure the radiative heat flux with and without using the water curtain under different operating conditions. It was mounted on the thermocouple tree at 0.7 m above floor finished level and perpendicular to the fire, as shown in Fig. 1a. The signal from the heat flux transducer was then measured by a multimeter with the data recorded at intervals of 10 s.

A smoke generator was used to give larger quantity of smoke, in addition to the smoke emitted from burning wood. A smoke layer was kept at a clear height of 1 m above the floor. Optical smoke density was measured by a helium-neon laser with a photocell placed 600 mm apart. It was mounted at 1.8 m above floor level on an aluminium stand. Optical signals measured at the photocell were sent for recording by the computer. By comparing the light intensities I_o and I_x before and after passing through the smoke of path length x of 0.6 m, optical density OD (in dBm^{-1}) of the smoke can be determined:

$$OD = \frac{1}{x}\log_{10}\left(\frac{I_o}{I_x}\right) \quad (1)$$

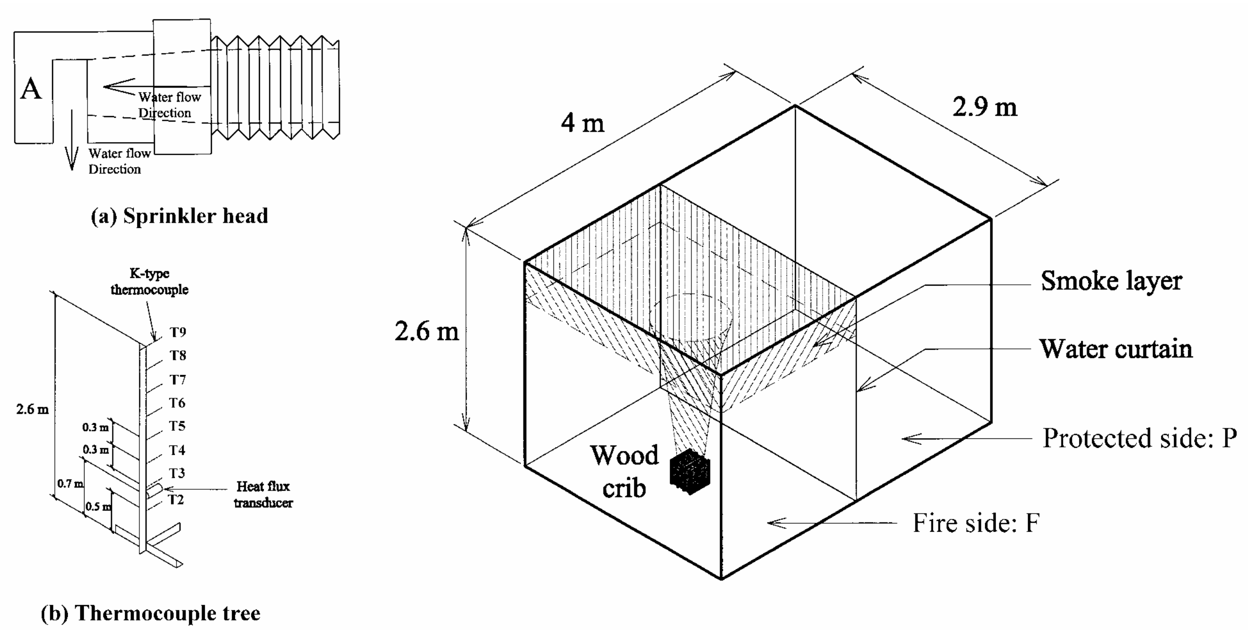

Fig. 1: Geometry of the experimental setup

Table 1: Summary of results

Orifice	Orifice size / mm	Tests	Water pressure / bar	Flow rate / m^3hr^{-1}	Max radiative heat flux / kWm^{-2}	Max temp in the chamber with a water curtain / °C
A	10	A1	2	3.15	0.44	50
		A2	3	3.53	0.33	45
		A3	4	3.98	0.33	42
B	13	B1	2	3.60	-	-
		B2	3	4.02	-	-
		B3	4	4.37	-	-
C	19	C1	2	3.76	-	-
		C2	3	4.35	-	-
		C3	4	5.07	-	-

It was found that the experimental error on the optical density was less than ± 0.01% if the smoke meter was calibrated properly.

Further, visibility V (in m) was deduced by an empirical formula reported in the literature [e.g. 12,13]. V can expressed in terms of an attenuation coefficient α and a constant K determined experimentally as:

$$V = \frac{K}{\alpha} \tag{2}$$

where

$$\alpha = 2.303 \text{ OD} \tag{3}$$

The value of K is 6 for illuminated signs and 2 for both reflecting signs. Taking K as 6 in this experiment gives:

$$V = \frac{-1.57}{\log_{10}\left(\frac{I_x}{I_o}\right)} \tag{4}$$

3. EXPERIMENTS

A total of twelve fire tests on assessing the performance of the drencher system in blocking thermal radiation and stopping smoke spreading were carried out. Each test lasted for about 30 minutes. About 3.45 kg of wood crib was burnt in each test so that the total heat given out was not higher than 66 MJ. The experiments were further divided into two groups:

- Group 1

  Nine tests on the nozzle with fire were carried out. The tests were labeled as A1 to C3 with the three nozzles A, B and C system settings listed in Table 1. Each test was repeated three times. The air temperature distribution, heat flux and optical density at side P were recorded.

- Group 2

  Only test A2 was carried out and repeated three times. Air temperature distribution, optical densities at both sides F and P were recorded in order to investigate whether smoke spreading can be prevented upon actuation of the drencher system.

Results of the experiments are summarized in Table 1 as well.

4. THERMAL ASPECTS

As shown in Fig. 2 on results for tests in A1, A2 and A3, the radiative heat flux was reduced in comparing to the case when there were no water curtains. Increasing the water pressure and flow rate would reduce the heat flux. Further, it was found that smaller droplets would increase the radiant heat blocking effect.

Temperatures measured by the thermocouples were averaged with 15 sets of data. Thermocouples were calibrated by immersing them in hot water at 100°C for 2 minutes. A maximum error of only ± 0.2°C was found by taking average of 15 data.

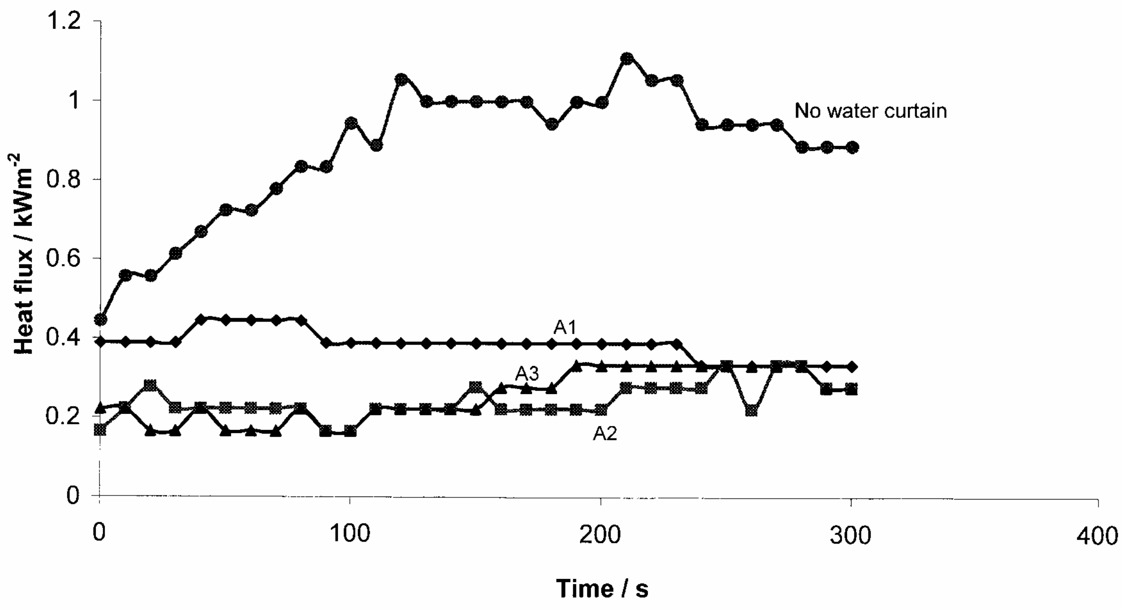

Fig. 2: Heat flux under different conditions for orifice A

From the experimental results, it was found that the temperature at the protected side P started to decrease when the drencher system was actuated. An example of the temperature profiles for thermocouples T2 to T9 for test A2 is shown in Fig. 3. It can be seen that the temperature at the highest position T9 reduced from 65°C to about 40°C. However, the temperature at the lowest level T2 was slightly raised due to the circulation of air flow induced by actuating the drencher system. As shown in Fig. 4, temperature on the fire side F decreased to below 70°C when there was a water curtain. Since the water curtain was not supposed to suppress the fire, temperature in the fire side would not drop as far as the wood crib kept burning.

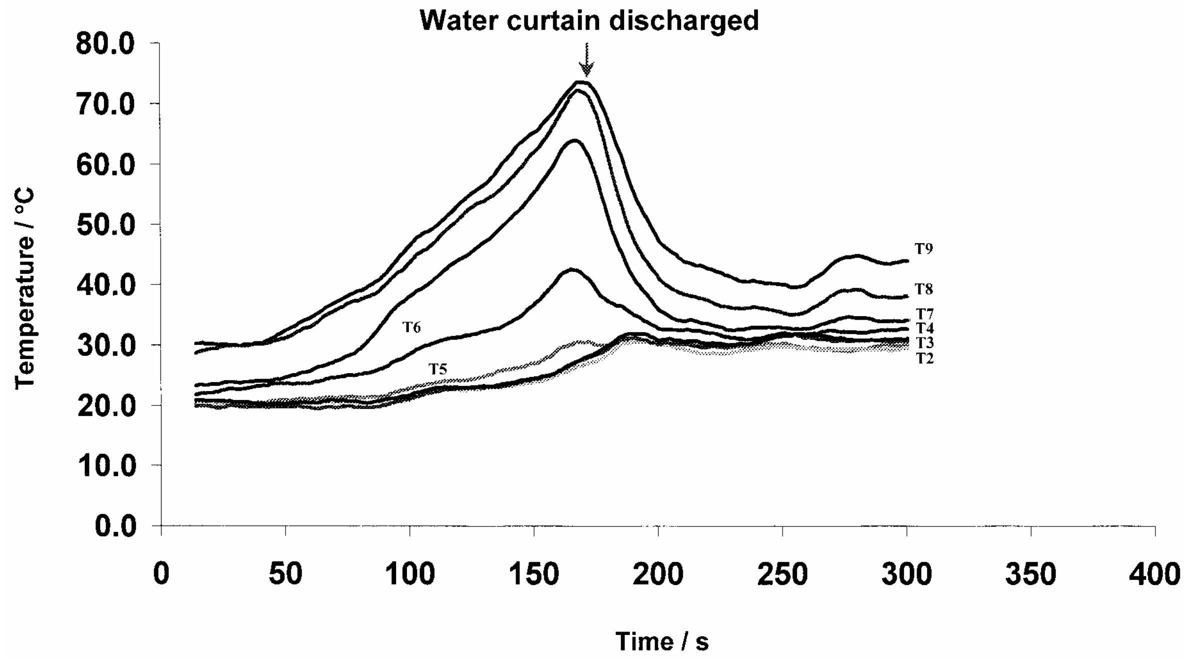

Fig. 3: Air temperature at protected side P for test A2

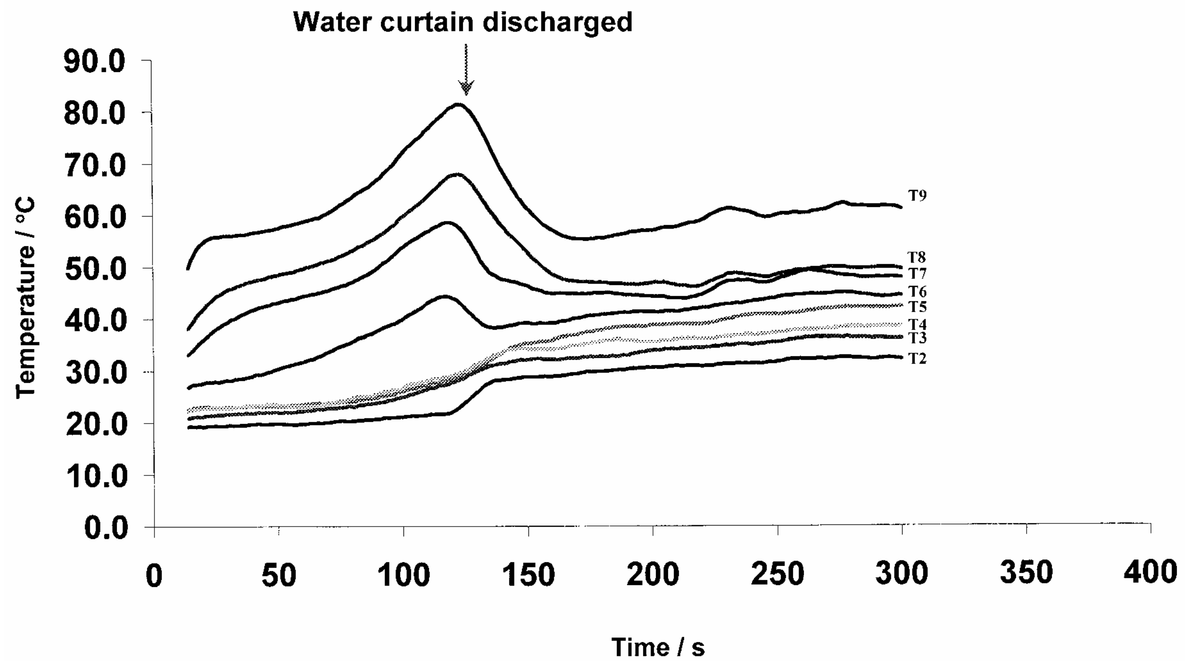

Fig. 4: Air temperature at fire side F for test A2

5. SMOKE SPREADING

Optical density of smoke in the two sides of the fire chamber was studied. Smoke was observed to be circulating in the space after discharging the water curtain. Effect of different water pressures and flow rates of the sprinkler system on smoke density was investigated. Average results over 25 data are shown in Fig. 5.

It is observed that increasing the water flow rate and pressure would have greater reduction in smoke density. As a result, visibility should be better. Values of visibility for tests A3, A2 and A1 were 35 m, 25 m and 17 m respectively, at 1000 s after starting the fire. Note that the visibility in the chamber with wood cribs burning without discharging a water curtain was below 10 m.

Upon discharging a water curtain, the visibility changed on both the fire side F and the protected side P. As the smoke was not extracted, the visibility was very low on side F.

6. CONCLUSION

Experimental studies on the performance of water curtain in preventing smoke spreading and blocking radiative heat under three types of operating conditions are reported. A water curtain was formed after discharging water from a drencher system. There were water droplets inside the curtain with non-uniform distribution [10]. The following can be concluded:

- Air temperature at the protected side P decreased after actuating the drencher system. The air temperature was further decreased with an increase in water supply pressure and flow rate. This might be a good demonstration of preventing heat spreading [e.g. 4].
- The radiative heat flux at the fire side F decreased significantly upon discharging a water curtain. Higher reduction in heat flux was found with an increase in water pressure and flow rate. Smaller water droplets would be better in blocking radiant heat.
- Smoke circulated in the fire side because of the airflow induced by the water curtain. The optical smoke density at side F was higher than at side P. Visibility [12,13] in the protected side P increased when there was a water curtain. The visibility in side P was further increased with increasing water pressure and flow rate of the system. Smoke could pass through the water curtain to the protected area. However, the amount of smoke was much smaller.

From this preliminary study, it is difficult to conclude whether operating a drencher system would be good in preventing smoke spreading. Further studies must be carried out to assess the performance of the system.

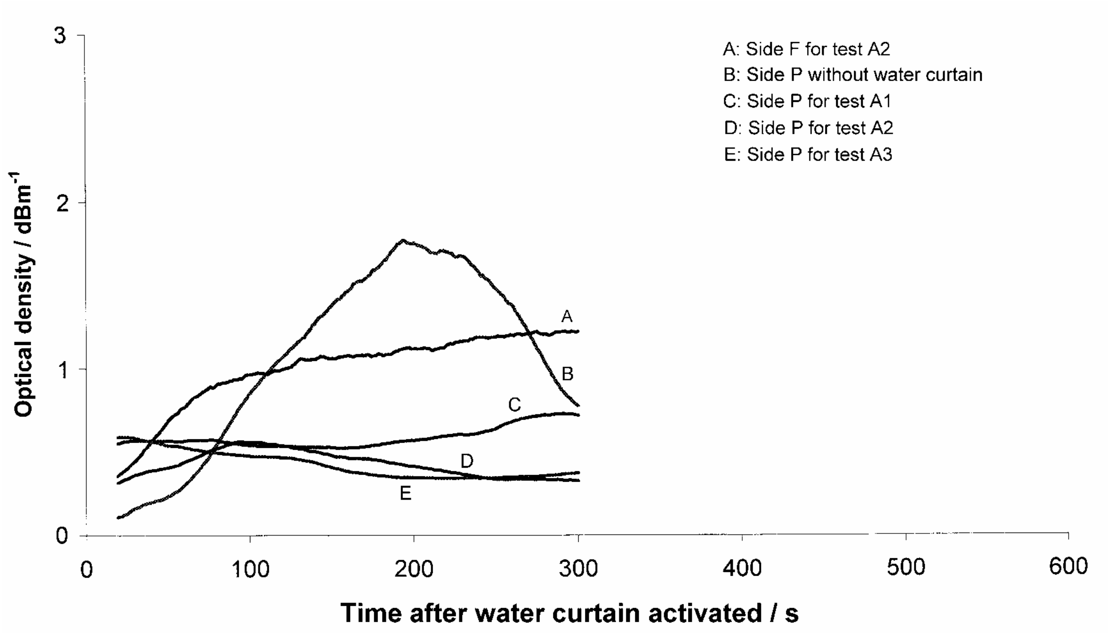

Fig. 5: Optical density at different conditions

REFERENCES

1. Code of Practice for Fire Resisting Construction, Buildings Department, Hong Kong (1996).
2. Code of Practice for Minimum Fire Service Installation and Equipment, Fire Services Department, Hong Kong (1998).
3. A. Coppalle, D. Nedelka and B. Bauer, "Fire protection: Water curtains", Fire Safety Journal, Vol. 20, No. 3, pp. 241-255 (1993).
4. T.S. Ravigururajan and M.R. Beltran, "A model for attenuation of fire radiation through water droplets", Fire Safety Journal, Vol. 15, pp. 171-181 (1989).
5. A.K. Kim, B.C. Taber and Lougheed, "Sprinkler protection of exterior glazing", Fire Technology Journal, Vol. 34, No. 2, pp. 116-138 (1998).
6. NFPA 13, Installation of sprinkler system, National Fire Protection Association, Ma, USA (1982).
7. NFPA 80A, Recommended practice for protection of buildings from exterior fire exposures, National Fire Protection Association, Ma, USA (1993).
8. Australia Standard, Automatic fire sprinkler systems, Part I: Standard (AS2118.1) and Part 2: Wall wetting sprinklers (Drenchers) (AS2118.2), Australia (1995).
9. Handbook of fire prevention and inspection, Shang-hai, Shang-hai Ke Xue Ji Shu Chu Ban She, China (1982).
10. C.L. Tien, K.Y. Lee and A.J. Stretton, Section 1, Chapter 5, Radiation heat transfer, Fire protection handbook, 18th ed., Quincy, Mass., NFPA, pp. 1-92 to 1-106 (1997).
11. N.K. Fong and W.T. Chan, "On the properties of a water curtain discharged from a drencher system", International Journal on Engineering Performance-Based Fire Codes, Vol. 3, No. 2, pp. 87-91 (2001).
12. E.G. Butcher, Smoke control in fire safety design, London, England, Spon (1979).
13. J.H. Klote and J.A. Milke, Design of smoke management systems, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, pp. 9-11 (1992).