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RECENT EXPERIMENTAL STUDIES ON BLOCKING HEAT AND SMOKE BY A WATER CURTAIN

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ABSTRACT

Drencher water systems are commonly installed across openings for substituting fire resisting constructions in the Far East including Hong Kong. The objective is to protect some designated areas by blocking heat, smoke and toxic gases to there in a fire. However, such blocking effect was not clearly demonstrated by experimental studies in the literature. Full-scale experiments on assessing the blocking effect of heat, smoke and toxic gases in a building fire were carried out recently and summarized collectively in this paper.

A two-room structure was constructed with a fire room and a protected room. A water curtain with common design data on operating pressures and flow rates was discharged at the opening between the two rooms. A propanol pool fire of diameter 600 mm and heat release rate 165 kW was burnt in the fire room. Thermal radiative heat fluxes in the protected room before and after discharging the water curtain were studied. Smoke spreading through the water curtain from the fire room was also measured. Spreading of toxic gases through the water curtain was studied by taking carbon monoxide as an indicator to evaluate the blocking effect of the drencher system in a fire.

Results indicated that the water curtains discharged from the selected nozzles are not continuous water layers. There are many air voids in the water curtain and which can be quantified by using porosity. Only thermal radiation can be blocked, but not smoke and toxic gases. The protected room can be kept relatively cool against a small fire. Smoke and carbon monoxide would still spread through the water curtain. The carbon monoxide concentrations in the protected room were roughly the same for cases with or without discharging the water curtain.

1. INTRODUCTION

Drencher systems are commonly installed instead of providing fire resisting constructions for many projects in the Far East [1,2]. Examples are big buildings with large spaces such as public transport interchanges [3], bus depots, tunnels [4], and openings in refuge floors. Discharging a water curtain (or screen) from the nozzle in a drencher system is expected to carry out similar functions as a fire resisting construction [5]. The water curtain would reduce radiant heat transmission in a building fire, and wash away the smoke particles with scrubbing effect. Heat and smoke spread then appear to be blocked by the water curtain.

However, there are concerns [6-9] whether the water curtain is able to perform similar functions as the fire resisting constructions. Very few works on investigating water curtain appeared in the literature [6-16]. Whether those systems would work as expected should be watched and justified by full-scale burning tests with bigger fires. Preliminary experiments with small fires were reported separately. In this paper, the above works reported earlier would be grouped together and reviewed collectively. The report would then provide necessary information on whether the water curtain can work as expected.

The discharged water curtain from the nozzle of a drencher system was investigated experimentally in a two-room structure as in Fig. 1. Three drencher nozzles labeled A, B and C commonly used in the market as shown in Fig. 2 were selected. The three nozzles were operated under their normal working conditions [5,17-20] to discharge water curtains to cover the opening between the two rooms. Suitable optical arrangement was designed to catch the fluctuating shapes of the water curtains. Photographs on the instantaneous shapes of the water curtains discharged were taken to observe the air voids. Results suggested that the water curtain discharged from some nozzles cannot prevent the smoke spread [6-9,15]. The key point in affecting the blocking of smoke is whether the discharged pattern is a continuous water layer. Air voids inside the curtain would not be able to block smoke spread. The shape of the curtain and the air voids inside were examined.

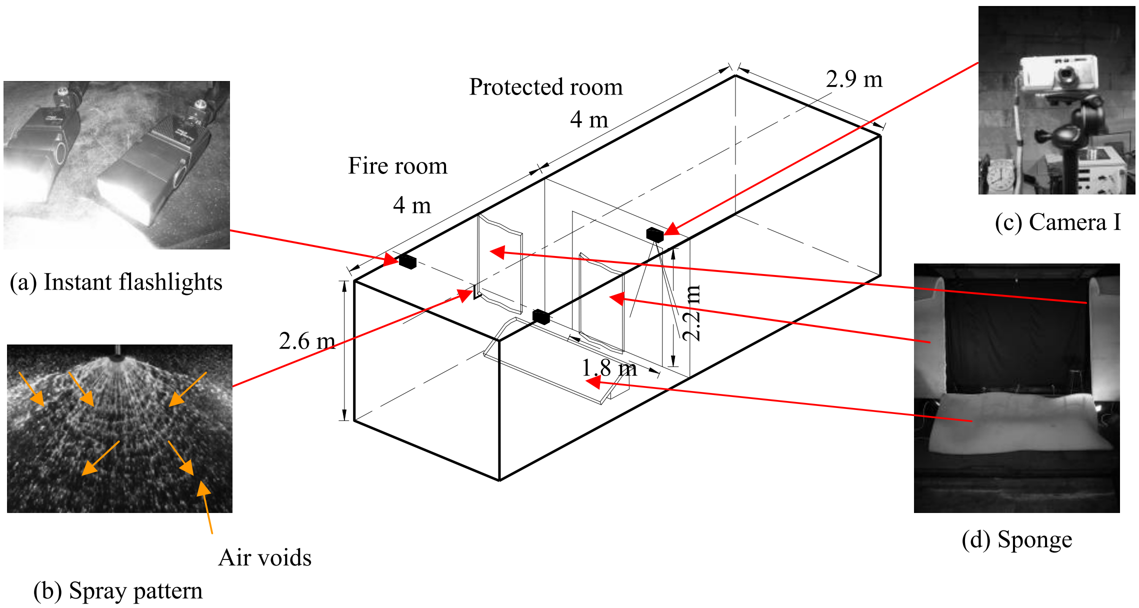


Fig. 1: Experimental setup for taking photographs

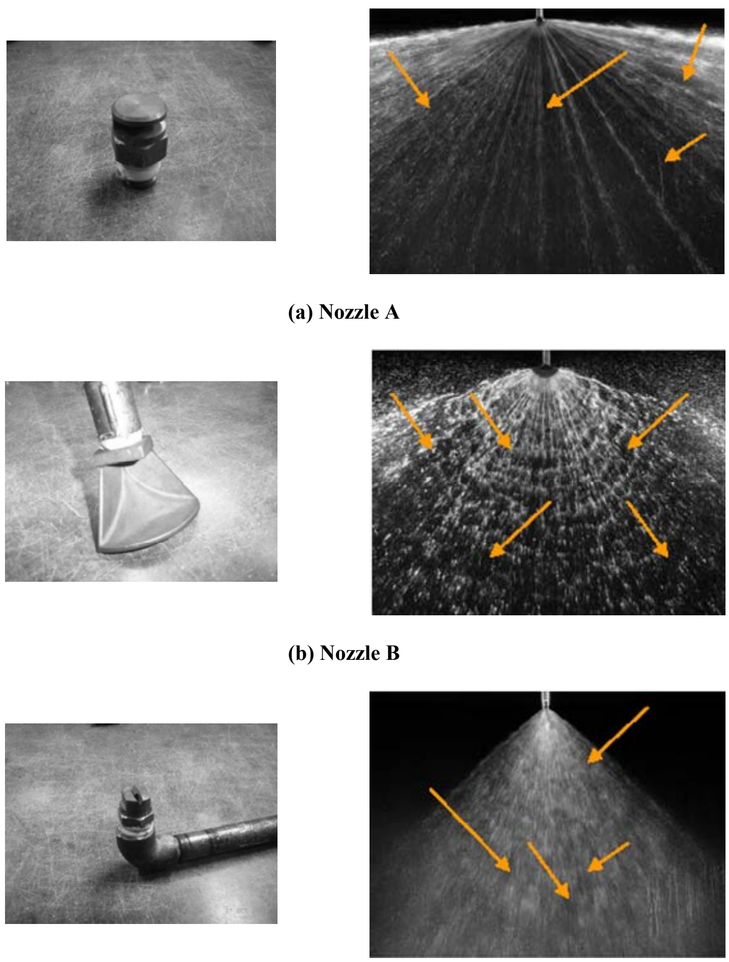


Fig. 2: The three tested nozzles

2. THE EXPERIMENTAL SETUP

Experiments were carried out for a two-room structure with a fire room and a protected room as shown in Fig. 1. A propanol pool fire was put in the fire room. The nozzle was installed at the centre top of the opening of width 1.83 m and height 2.2 m between the two rooms. A water curtain was discharged to cover this opening. Equipments include a digital camera, drencher nozzles, sponge, and instant flashlights. The optical instrument and camera were put in the protected room to take pictures of the water curtain. Instant flashlights provide fast intensive illumination for 'freezing' the moving object.

The operating characteristics of the three nozzles A, B and C are shown in Table 1. Except nozzle B, all other nozzles satisfied the flow requirement of 10 L/min/m^2 of protected area stated in the local code on fire service installations (FSI code) [5]. The value became 0.67 L/s for this opening area of 2.2 m by 1.83 m in the chamber. The minimum pressure requirement of 48 kPa (0.48 bar) [17] recommended by the National Fire Protection Association was also satisfied.

It is difficult to focus directly at the water curtain in taking photographs. Quality of photographs on the flickering curtain is affected by the dark background. To capture fast moving objects, an appropriate optical system was developed for taking photographs. Further, water mist was generated after the water curtain struck at the ground. Attempt was made to minimize the water mist generation at the side of the walls. To have a clearer picture, sponge was put in front of the lower floor as shown in Fig. 1d. Very clear pictures on the water curtain were then taken.

Two additional instantaneous flashlights were used to capture fast moving objects as explained before by Chow and Ma [7,8]. A stronger illumination source as in Fig. 1a was provided in a very short time to act as a stroboscope for 'freezing' the water pattern. These intensive flashlights would be actuated upon sensing an external flashlight to give simultaneous operation with two cameras I and II. Camera II was linked to camera I for manual focus and exposure control. Once the button was pressed, camera II would provide flashlight to trigger the intensive flashlights. Camera I would take the photograph at the same time. Using such strong illumination instead of the camera flashlight can give a longer distance between the camera and the water curtain in taking pictures. This arrangement would also prevent water striking at the camera. Appropriate shutter speed, aperture setting and flash exposure of the camera were adjusted.

Table 1: The three tested nozzles

Parameters \ Nozzle	A	B	C
Orifice Size /mm	8	13	5.2
K-Factor	40	115	16
Pump Pressure / bar	12.30	10.50	11.80
Flow Rate / L/s	1.49	1.70	0.83
Outlet Pressure / bar	5.0	0.8	9.7
Porosity β / %	28.6	41.3	23.2
Fire duration / s	846	947	722
Average radiation attenuation / %	72.7	68.1	75.6
Temperature dropped in protected room / ^{o}C	58	43	65
Time required for temperature to reduce 50 ^{o}C / s	56	230	12
Maximum CO concentration without water curtain / ppm	25	25	25
Maximum CO concentration at protected room / ppm	70	74	79

3. THE DISCHARGED WATER CURTAINS

High water pressure above 10 bars was provided by the pump to give sufficient working pressure for each nozzle. Large pressure drop across the nozzle due to design limitation of the drencher head gave smaller pressure at the outlet. The outlet pressure of the nozzle is affected by the K-factor. The larger the K-factor, the greater the pressure drop at the nozzle. Therefore, nozzles with lower K-factors are preferred. Typical discharged spray patterns from the three drencher nozzles are shown in Fig. 2. The spray angle of the patterns discharged from nozzle A was about 180^o. Smaller spray angles were found for nozzle C. However, spray angle is not a concern. Installing more nozzles along the same row with smaller spacing would give full coverage of the opening.

The discharged water curtains were observed to be not continuous layers. Many air voids were formed inside the water curtains with locations varying. Operating the system under high pressures and flow rates would not give continuous water layers. Having so many air voids in the water curtain at different locations would not prevent smoke and toxic gases from spreading through.

As shown in Table 1, nozzles A and C gave acceptable pressures above 5 bars. For nozzle B, water pressure was only 0.8 bar at the outlet due to its large K-factor. Low outlet pressure would discharge a spray pattern with many air voids as in Fig. 2. Therefore, more air voids were found in the water curtain discharged from nozzle B. This might be due to the high K-factor of 115. Increasing the water flow rate did not reduce the amount of air voids.

Nozzles A and C were operating at higher pressure, water could be discharged with higher momentum to give a more continuous layer. Although nozzle C provided a greater outlet pressure than nozzle A, their areas of air voids appeared to be similar. This suggests that the amount of air voids depends not only on the pressure but also on the flow rate and the orifice design.

Spray angle of around 180^o was produced from nozzle A. The other 2 nozzles have smaller spray angles, particularly obvious for C. However, spray angle is not a concern. Installing more nozzles along a row with smaller spacing would give full coverage. Continuous water distribution within the spray pattern is the key.

Air voids of the discharged water curtain from the three selected nozzles were investigated. Pictures of the water curtain were taken first with grids assigned as shown in Fig. 2. Computer graphics package was used to measure the area without water.

The term porosity β is taken as the parameter [7,8] to quantify the amount of air voids. It is the percentage of area calculated as a ratio of area without water within curtain A_0 to the total area covered by the curtain A_w:

$$\beta = \frac{A_o}{A_w} \times 100\% \quad (1)$$

Measured results on β are also shown in Table 1.

4. THERMAL RADIATION ATTENUATION

Attenuation of thermal radiation was studied by the measured radiation heat fluxes in the protected room side as presented in Fig. 3. Assuming that the same thermal radiation was emitted from the 165 kW pool fire, radiation attenuation α (in %) is calculated [7,8] by the radiative heat fluxes at the protected room before discharging water curtain, I_0 (in kW/m^2) and the radiative heat flux after discharging water curtain I (in kW/m^2) as:

$$\alpha = (I_0 - I) / I_0 \times 100 \quad (2)$$

Values of radiation attenuation are zero or even negative from 0 s to 150 s for the three nozzles, suggesting that I is near to or higher than I_0 initially. This is because firstly, heat emitted from the pool fire at different time would not be exactly the same. Secondly, the thermal radiation heat flux emitted from the pool fire is fluctuating.

In tests without discharging water, the fire burnt for 587 s. The average burning duration for the three nozzles is also shown in Table 1. Significant reduction in radiative heat flux was observed 170 s after discharging water.

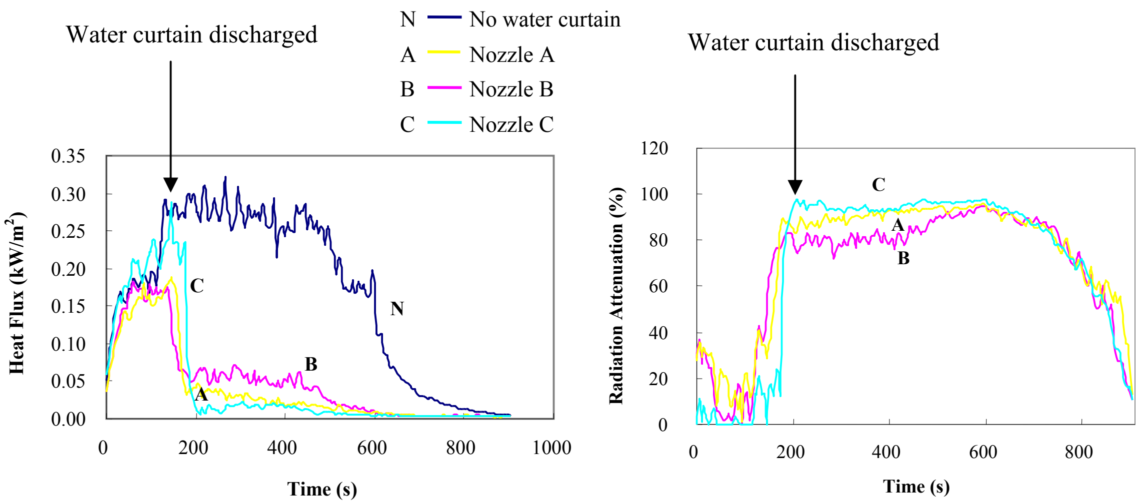
Unattenuated radiative heat flux was received at the protected room before discharging water curtain as shown in Fig. 3. After discharging water, heat fluxes reduced at the protected side. In view of Fig. 3 and Table 1, nozzle B gave the least radiation attenuation of 68.1%. Nozzle C has the highest value of 75.6%. Comparing with β as shown in Table 1, it is found that a smaller β would give higher radiation attenuation. The water curtain discharged from nozzle C with the smallest β would block more thermal radiation.

Note that the values of α would not go up to 100% after discharging water due to the porosity inside the transient pattern. Thermal radiation can pass through the voids to the protected room. Low β value implies fewer air voids and hence higher radiation attenuation. Nozzles A and C gave better radiation attenuation due to their lower β values.

It was observed that smoke spread from the fire room to the protected room. This can also be justified by comparing the temperature profiles in both the fire and protected sides at the highest point as shown in Fig. 4. Temperatures at the protected room after discharging water curtain reduced due to the blocking of thermal radiation by the water curtain. Values of the temperature dropped are shown in Table 1. Air temperature at the protected side for nozzle B reduced by only 40 ^{o}C. Higher reductions in air temperatures of over 60 ^{o}C were recorded for nozzles A and C.

Although smoke was observed to spread from the fire room to the protected room, air temperature at the protected room reduced. Therefore, discharging water curtain is quite effective in keeping the protected space cool.

The three nozzles selected were operated under different flow rates and pressures. The discharged curtains from nozzles A and C were observed to be similar with porosity β shown in Table 1. Their effects on temperature reduction at the protected room were also similar, reduced by over 60 ^{o}C. For the discharging pattern of nozzle B, an average of lower temperature reduction of about 40 ^{o}C and a higher β value of about 40% were obtained. This suggests that the higher the β value, the more air space found in the water curtain. More heat would then be transferred to the protected side, giving higher air temperature at the protected side.



(a) Radiative heat flux (b) Radiation attenuation

Fig. 3: Radiation blockage

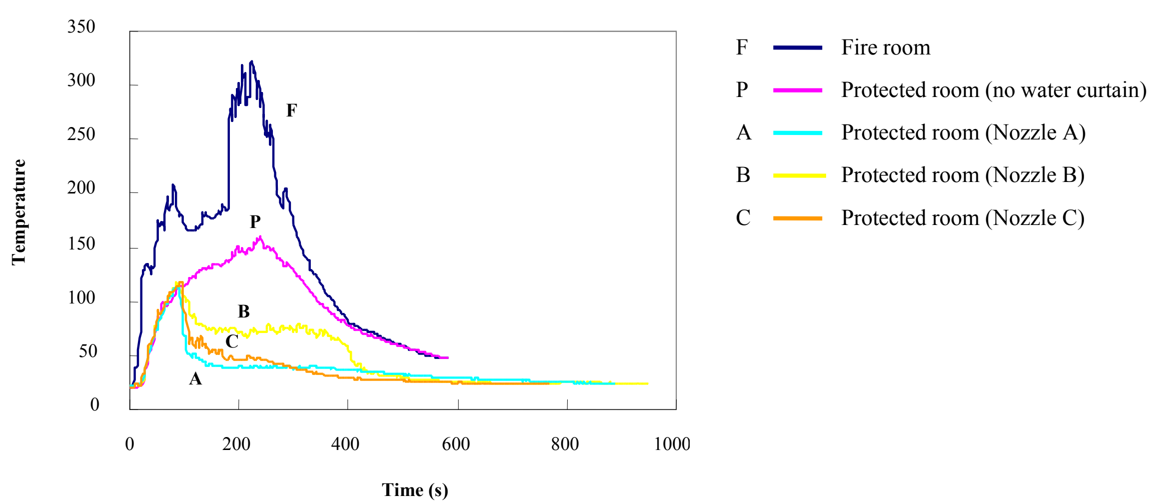


Fig. 4: Temperature profile in the two chambers

5. CARBON MONOXIDE

Profiles of CO concentrations during the fire for the cases with and without the nozzle were measured [9] and shown in Fig. 5. It is observed that the maximum CO concentration is 75 ppm for the case without discharging water curtain. This value is similar to the gas collected through the curtain discharged by any type of the three selected nozzles A, B and C as in Table 1. During the experiments, the CO concentration at the protected side increased gradually to about 70 ppm for all three nozzles. Therefore, carbon monoxide generated from the fire cannot be blocked by the water curtain.

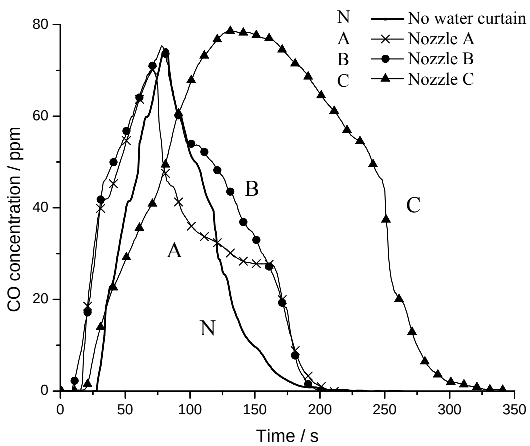


Fig. 5: CO concentration during fire with and without discharging water curtain

It was shown from this demonstration test that water curtain is not able to block toxic gases from spreading through the opening. Scientific proof of a generalizable hypothesis is not yet presented. Solubility of partial pressures of gases, solubility as a function of temperature, Henry's Law, or the physics that governs what mass of gas might be removed by passing through the water curtain should be added. Oxygen, carbon monoxide and carbon dioxide have different solubilities that are temperature dependent. Significant removal of carbon monoxide is not expected after casual mixing of a warm gas with a spray. Water curtain cannot effectively remove non-soluble or low-solubility toxic gases, which is partially demonstrated in the experiment. Further study will be carried out on comparing the reduction in carbon monoxide with reduction in hydrogen chloride in burning polymer such as polyvinyl chloride. The temperature and velocity of gases crossing the boundary should be reviewed. Porosity of the spray was taken as a nominal parameter. Information on drop size distribution and volumetric concentration might give better indication. Nominal spray characteristics might not be helpful. Actual characteristics are needed to indicate this point. The nozzle sprays used produce a non-uniform spray density. Information will be provided on the depth of the mixing zone, the efficiency of entrainment, or the dwell time for absorption of gases. The demonstration that carbon monoxide is not removed is mostly attributable to the result of the relatively low solubility of carbon monoxide. Soot collected on the downwind side of the spray screen suggested that scrubbing of soot was also incomplete. All these will be studied in the future [21,22].

6. CONCLUSION

Experimental studies on the water curtains discharged from three selected drencher nozzles A, B and C were reported. It is observed from the photographs that the water curtains were not continuous layers. The nozzle design, water pressure and flow rate are key factors in affecting the amount of air voids. Thermal radiation can be blocked by the water curtain. But with so many air voids in the water curtain, smoke and toxic gases can move through it and spread from the fire room to the protected area. Experiments on the three nozzles showed that the discharged water curtain was not able to block the transfer of smoke and carbon monoxide. The measured concentration at the protected side was still high. It is difficult to conclude that installing the system across an opening with the three tested nozzles is equivalent to providing a fire resisting wall across the opening.

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