International Journal on Engineering Performance-Based Fire Codes, Volume 6, Number 4, p.248-254, 2004

RADIATION BLOCKAGE EFFECTS BY WATER CURTAIN

C.L. Choi
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

ABSTRACT

Water curtain discharged from a drencher sprinkler system would be useful for isolating the fire source and areas nearby for property protection. Experiments will be conducted to investigate whether radiative heat flux can be blocked by water curtain under various operating conditions for measuring temperature distribution and heat flux in a chamber. Physical properties of the water curtain, including the water discharge pattern and mass flux distribution will also be studied for better understanding of its effectiveness.

1. INTRODUCTION

According to Australian Standard (AS 2118.2) [1], fire can spread from one building (source) to a nearby building (receiver) if the heat radiated by the source impinges on a window of the receiver at sufficient levels to cause breakage of the glazing or ignition of combustibles inside the receiver. Therefore, drenchers are required to protect the openings by spraying water onto a glass surface to reduce the radiant heat passing through that surface to safe levels. Therefore, the spacing of buildings should ensure adequate separation in the event of fire as stated in NFPA 80A [2] in order to mitigate the effects of radiant heat from nearby fires. In the local codes on fire services installations [3], it was specified to install drencher systems in all refuge floors for protection against internal and external "exposure" or large openings. Also, it is recommended for limited spaces such as corridors and tunnels due to its easy installation [4].

Drencher system is an arrangement of pipe and discharge heads so positioned that a curtain of water may be interposed between a fire and the property being protected. It is different from the water spray system that drencher system is not used to extinguish or control fires involving flammable liquids. It can be controlled either manually or automatically to let water flow to the drencher spray nozzle. The wall wetting sprinkler as shown in Fig. 2 is one commonly used drencher sprinkler, its design feature is different from general glass-bulb sprinklers that water discharged from its head is blocked by the metallic part so direction of the water is changed by 90^{o} and this directional discharge from the nozzle outlet produces a flat 180^{o} fan-shaped spray pattern. A paraboloid water distribution is hence given and directed towards the ground for a definite protection area.

The number of drencher heads can be determined from the area being protected that the maximum spacing between heads is 2.5 m to 3 m. And the operating conditions for the drencher system are not only changed with the potential hazard of the protected area but also the regulations and standards. Since different codes have different requirement of water discharge pressure and flow rate, a summary of three standards is given in Table 1. For example, Australian Standard (AS2118.1, AS2118.2) required the flow rate over the protected area to be not less than 5 L/m^2 per min. According to NFPA 13 [5], the flow rate in each sprinkler should not be less than 56.8 L/min. For Chinese Regulation [6], the flow rate is specified to be 0.66 L/s, or 39.6 L/min at 4 bar for 10 mm orifice size drencher head.

Thermal radiation is the transfer of heat in electromagnetic wave emitted by a hot body in the spectrum between 0.1 μm (ultraviolet) and 100 μm (mid-infrared). Temperature of the fires is of the order of 1300 K and the maximum emission wavelength of the black body is about 2 μm for these temperature levels. A model has been put forward by Ravigururajan and Beltran [7], and the optimum water droplet size for effective radiation attenuation was found to be close to the emission wavelength of fire. For 2 μm radius water droplet, optical characteristics are expressed by the complex index:

$n^* = n - ik$

where refractive index, n(2 μm) = 1.306 and

absorptive index:

$k(2\ \mu m) = 1.1 \times 10^{-3}$

This shows that scattering plays a very important role in radiation attenuation compared to absorption, so that the diffused and re-collected fluxes through water curtain should also be considered except the direct transmitted one.

Table 1: Summary of different standards for operating drencher system

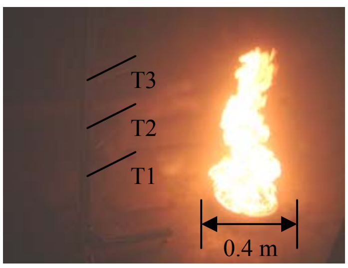
	Water pressure	Water Flow Rate
Australian Standard	**AS 2118.1 -- 12.12 Minimum discharge pressure** **Pressure at any sprinkler shall not be less than the following:** (a) Light Hazard system........................**70 kPa**. (b) Ordinary Hazard system ....**35 kPa**. (c) High Hazard system ....**50 kPa**. **AS 2118.2 -- 3.5 Pressure limitations** Pressure on any wall wetting sprinkler shall **not exceed 1 MPa**.	**AS 2118.2 -- 2.11 Open wall wetting sprinklers** Open sprinklers shall comply with the following requirements: (i) The average density of discharge over the protected area shall be **not less than 5.0 L/m^2 per min**. (ii) At not less than 25 percent of the inlets within the protected area, the density of discharge shall be not less than 3.5 L/m^2 per min. (iii) At no inlet within the protected area, shall the density of discharge be less than 2.5 L/m^2 per min.
NFPA	**NFPA 13 – 5-3.6 Exposure protection** 5-3.6.1 Piping shall be hydraulically calculated to furnish a **minimum of 48 kPa** at any sprinkler with all sprinklers facing the exposure operating.	**NFPA 13 – 5-3.7 Water curtains** Sprinklers in a water curtain shall be hydraulically designed to provide a **37 (L/min)/m** of water curtain, with **no** sprinklers discharging **less than 56.8 L/min**.

Chinese Regulation	**Water pressure (bar)**	**Water flow rate (L/s)**					
		Orifice diameter of drencher head (mm)					
		6	8	10	12.7	16	19
	3	0.21	0.36	0.57	0.93	1.47	2.06
	4	0.24	0.42	0.66	1.08	1.70	2.37
	5	0.27	0.47	0.74	1.20	1.90	2.66

2. METHODOLOGY

Experiments were conducted in a fire chamber at the laboratory of Department of Building Services Engineering, The Hong Kong Polytechnic University. Two symmetric chambers with 2.25 m (H) × 0.8 m (W) opening in between are of length 4 m, width 2.9 m and height 2.6 m as shown in Fig. 1. Pipeworks were installed for placing the drencher head above the opening center at 2.25 m from the finished floor level. The wall wetting sprinkler (Viking C-1 window sprinkler) with orifice diameter of 16 mm as shown in Fig. 2 was used.

By discharging the water curtain, two chambers are separated. Chamber with the pool fire located at the center is the fire side (F) and the other one is the protected side (P), as shown in Fig. 1. Also, a small fire – 2000 ml propanol pool fire with 0.4 m diameter was used.



Propanol pool fire

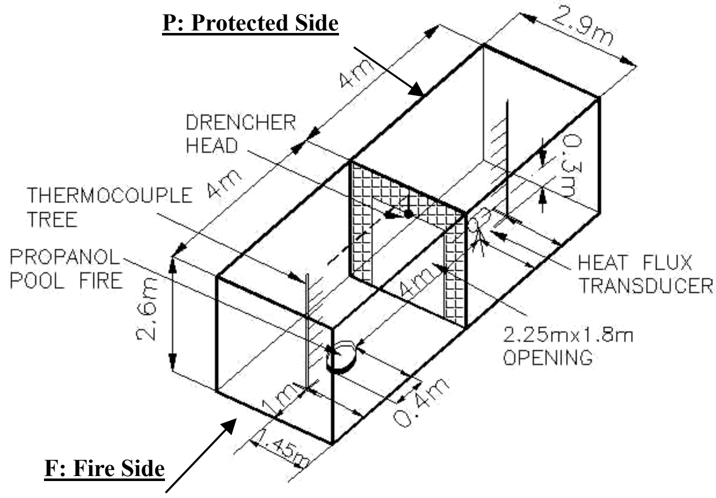


Fig. 1: Geometry of fire chamber

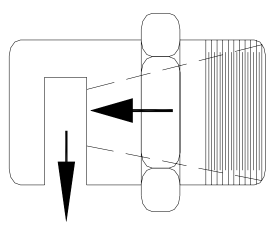


Fig. 2: Water flow direction of drencher head

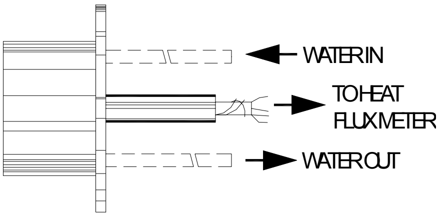


Fig. 3: Configuration of HTR - Smooth body with flange and water cooled

- Physical pattern

  The discharge pattern of water curtain was observed from the photographs taken after discharging water through the drencher nozzle.

  Water was collected by 27 measuring cylinders of 140 mm diameter placed 300 mm away from each other for 1.5 min. The mass flux density (in mm/min) can then be calculated by the collected water level (in mm) and duration of water collection (in min), the mass flux distribution was hence observed from the plotted graphs.

- Temperature measurement

  A thermocouple tree was placed on each side of the chamber in order to measure the temperature distribution. Thermocouples with seven K-type 1/0.2 mm thermocouples are spaced 0.3 m apart (T1 at the bottom and T7 at the top). Thermocouples were calibrated by immersing them in hot water at 100°C and ice water at 0 °C for 2 minutes respectively. By taking average of five data, the maximum error was found to be ± 0.2 °C.

- Heat flux measurement

  To measure the intensity of the thermal radiation field, a heat flux transducer (64 series, Schmidt-Boelter sensor type with sapphire window attachment) as shown in Fig. 3 was used. It consists of a multi-layered thermopile assembly. For fire test purposes, it is used in a configuration where the sensing element is mounted in water-cooled body. It is also configured as radiometer that its window is used to eliminate convective currents so that only the radiation is being measured and the spectrum transmitted by sapphire window is nominal from 0.15 to 5.0 μm which is suitable for measuring 2 μm wavelength emitted from the fire.

  Based on the ASTM Standard E603 Room Fire Experiment, the heat flux transducer is suggested to be located at the room center floor level in order to protect the cooling and data lines from fire and physical damage. Hence, it was placed at 0.3 m from the floor level at the center of protected side. Also, it has a calibration which is traceable to the National Institute of Standards and Technology. All data was read directly on a H-201 heat flux meter and recorded by a Fluke187 multimeter at intervals of 5 s.

  The results are shown in Figs. 4 to 11 with a summary in Table 2.

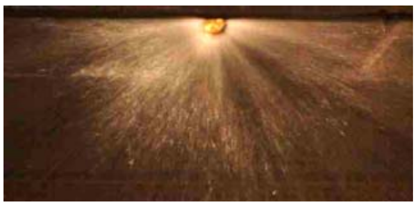


Fig. 4: Water discharge pattern

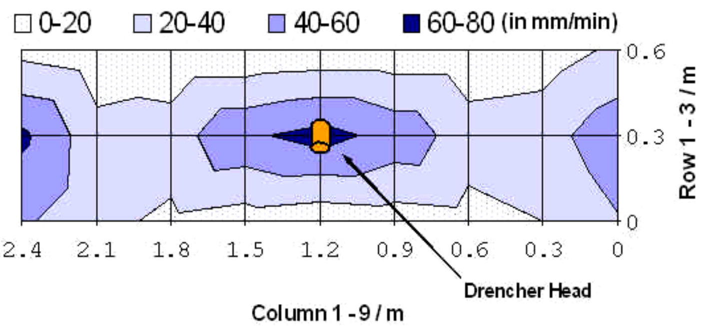


Fig. 5: Mass flux distribution of water spray at the floor level for Test 2

Table 2: Summary of physical properties

Test	Pressure (bar)	Flow rate (L/s)	Mean mass flux density (mm/min)	Max. mass flux density under drencher head center (mm/min)
1	2	0.389	20.5	30.0
2	3	0.445	24.2	49.3
3	4	0.493	25.1	66.7

Table 3: Summary of measurements at 390 s (1 min after discharging water curtain)

Test	Pressure (bar)	Temp. at fire side (°C)	Temp. at protected side (°C)	Radiative heat flux at protected side (KWm^{-2})	Time for complete burning of fire (s)
Water curtain					
A	2	83	84	0.22	379
B	3	98	69	0.13	421
C	4	81	55	0.12	527
No Water curtain					
D	---	118	93	0.45	228

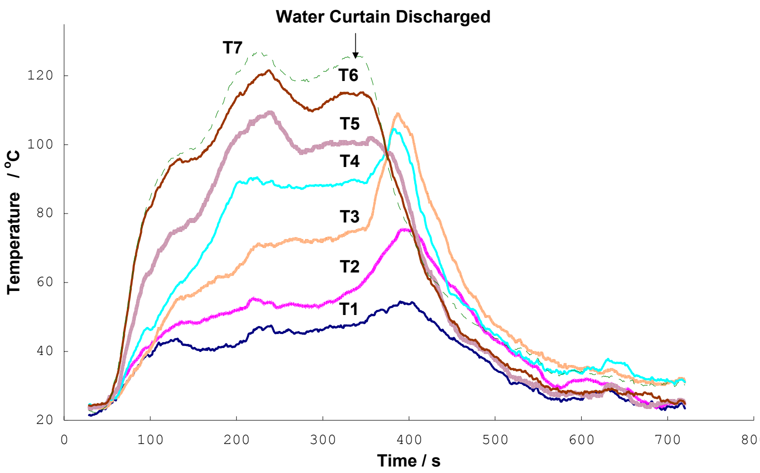


Fig. 6: Temperature distribution at fire side for Test C

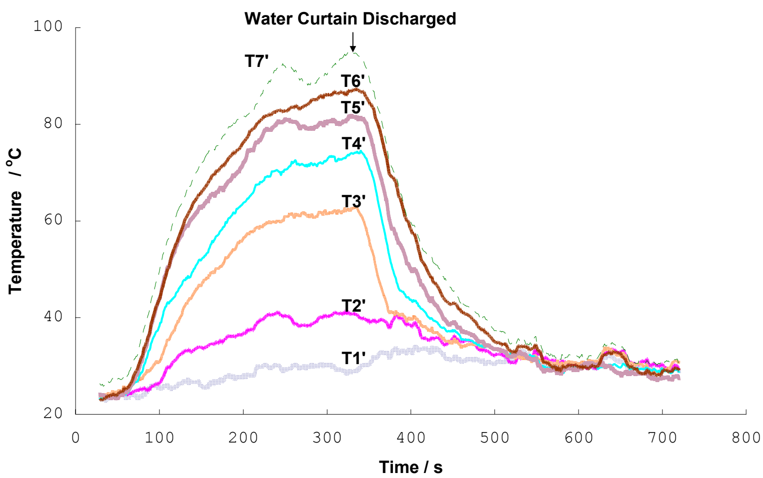


Fig. 7: Temperature distribution at protected side for Test C

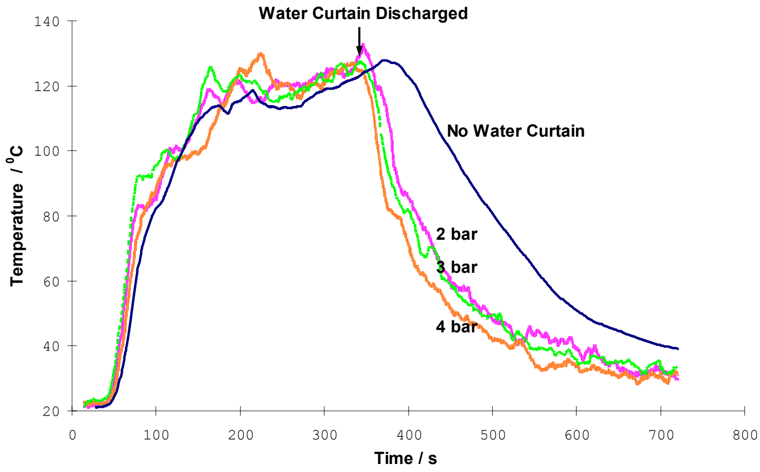


Fig. 8: Maximum temperature (T7) at fire side under different operating conditions

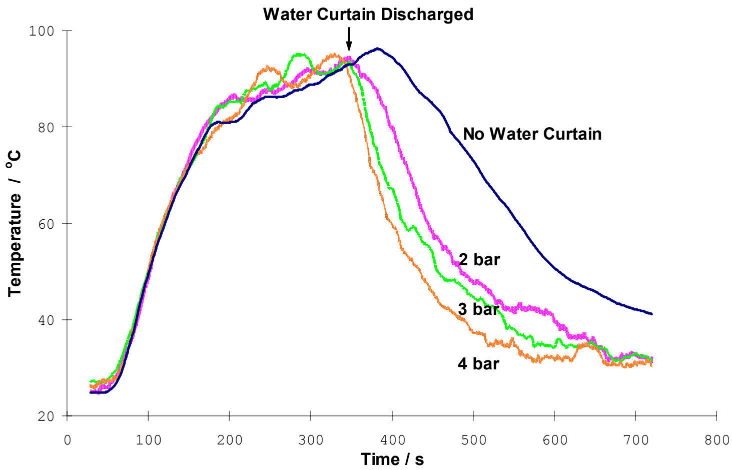


Fig. 9: Maximum temperature (T7') at protected side under different operating conditions

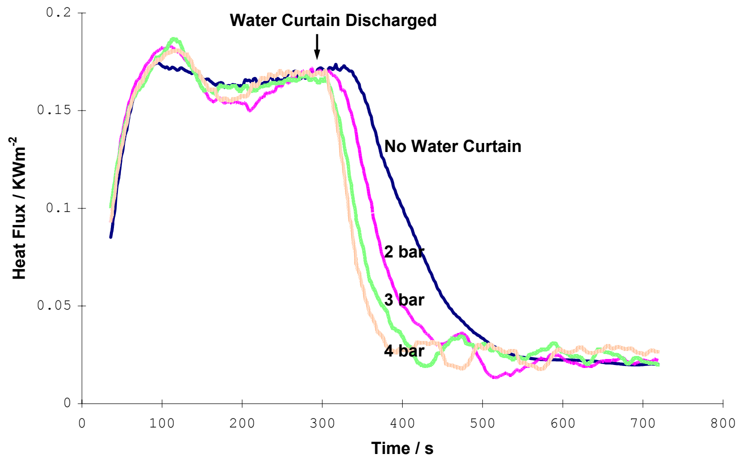


Fig. 10: Heat flux at protected side under different operating conditions

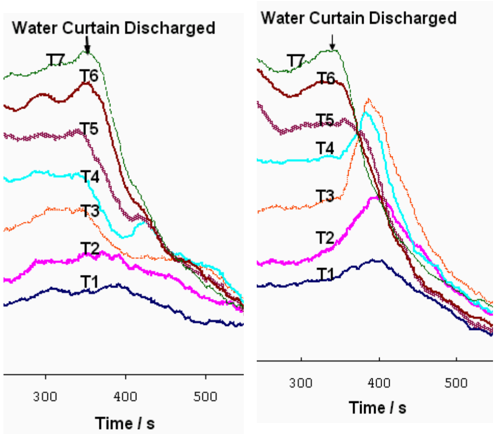


Fig. 11: Comparison between 300 s and 500 s at fire side for Test A (left) and C (right)

3. DISCUSSION

- Observation of curtain properties

As shown in Fig. 4, the photograph taken indicated that the curtain-like water spray discharged from the drencher head is non-uniformly distributed. For tests 1 to 3, the mean mass flux density increased with drencher discharge pressure and flow rate that it was ranged from 20.5 mm/min at 2 bar up to 25.1 mm/min at 4 bar and the mass flux density at the floor level was highest directly under the drencher head. An example shown in Fig. 5 for Test 2 indicated that the mass flux density increased along its centerline of distribution. As there was a deflection of water by the limit-size chamber, higher mass flux density was observed at two sides of the boundary.

- Measurements of thermal aspect

From the experimental results, it was found that the temperature at the protected side started to decrease when the drencher system was actuated, but that at the fire side did not drop as far as the pool fire kept burning. The temperature profiles for thermocouples T1 to T7 and T1' to T7' for Test C are shown in Fig. 6 and Fig. 7 respectively. It can also be seen that the highest temperature was measured at T7 due to the buoyancy of heat from the pool fire, and heat was transferred to adjacent chamber by the plume traveling along the ceiling jet which caused higher temperature at T7'.

Temperature at the lower level T1 to T4 was observed to rise slightly because there is circulation of air flow induced at the fire side when discharging water curtain that sustains the fire burning for longer time as shown in Table 3. This circumstance was not significant with lower discharge pressure for Test A shown in Fig. 11 that only T1 and T2 were affected.

Comparison shown in Fig. 8, Fig. 9 and Fig. 10 indicated that both temperature and heat flux decreased significantly when actuating the drencher system under increasing water pressure, so that radiant heat seems to be blocked by water curtain effectively under higher pressure and flow rate.

4. CONCLUSION

Experimental studies on the physical properties of water curtain and its performance in blocking radiative heat under different operating conditions of drencher system are reported. The following can be concluded:

- The fan-shaped water discharge pattern was observed to be non-uniform distribution but its droplets along centerline in the direction parallel to the liner drencher head entirely covered the opening between chambers. It might act as a good barrier for compartmentation in order to block the radiant heat transfer.

- Both air temperature and radiative heat flux at the protected side decreased significantly with increasing drencher operating pressure, flow rate and amount injected. This might be a good demonstration of preventing heat spreading.

This paper on preliminary study of water curtain is only the first of a series of reports, it is difficult to conclude which parameter plays the most significant role in radiation blockage. Further studies with different experimental setup must be carried out to assess the effectiveness of water curtain in radiation attenuation.

ACKNOWLEDGEMENT

The author wishes to acknowledge the guidance provided by her supervisor Dr. N.K. Fong and the laboratory staff of Department of Building Services Engineering, especially Mr. Angus Cheng, who has given valuable suggestions and guideline in this research project.

REFERENCES

1. Australian Standard, Automatic fire sprinkler systems, Part 1: Standard (AS2118.1) and Part 2: Wall wetting sprinklers (Drenchers) (AS2118.2), Australia (1996).
2. NFPA 80A, Recommended practice for protection of buildings from exterior fire exposures, National Fire Protection Association, Ma, USA (1982).
3. Code of Practice for Minimum Fire Service Installation and Equipment, Fire Services Department, Hong Kong (1998).
4. N.K. Fong, W.K. Chow and W.T. Chan, "Preliminary studies on smoke spreading prevention and thermal radiation blockage by a water curtain", International Journal on Engineering Performance-Based Fire Codes, Vol. 3, No. 3, pp. 98-103 (2001).
5. NFPA 13, Installation of sprinkler systems, National Fire Protection Association, Ma, USA (1982).
6. Chinese Regulation - Handbook of Fire Prevention and Inspection, Shanghai: Shanghai Ke Xue Ji Shu Chu Ban She, pp.703 (1982).
7. T.S. Ravigururajan and M.R. Beltran, "A model for attenuation of fire radiation through water droplets", Fire Safety Journal, Vol. 15, pp. 171-81 (1989).

Q & A

Q1: If the pressure is low for your water curtain system, what will happen?

Choi: The water drop size will be larger, and water cylinder may be formed, which will affect the radiation blockage significantly.