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DISCUSSION OF THERMAL ACTIVATION ON HEAT COLLECTION PLATE OF SPRINKLER HEADS

by

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Heat collection plates (HCP) are installed above sprinkler heads in some tall halls in the Asia-Oceania region to give faster thermal actuation. In this study, experiments were thus conducted in a fire chamber to determine thermal activation times of sprinkler heads with and without HCP. Three HCP with different diameters were selected and tested with pendent fast response liquid-in-bulb sprinkler heads. A total of 48 sprinklers heads were studied under different conditions of height and pool fire size. The HCP was found to reduce sprinkler activation time in a fire chamber test by up to 61%. Thermal activation time of sprinkler heads was also investigated by the common plunge test in a wind tunnel. Results indicate that activation was delayed by 5%, 18%, and 221% on average by the three HCP. An HCP of pie plate shape with small diameter would alter the physical scenario of heating up the heat sensing element of sprinkler heads assumed in the plunge test. Therefore, the effect of HCP cannot be appropriately assessed in a wind tunnel.

Key words*: sprinkler head, HCP, thermal response*

Introduction

The number of big fires in buildings appears to be increasing [1]. New challenges arise from storing too many combustibles in rooms of taller buildings, where both fire load density and occupant loading are high. There are new materials, fire retardants, clean refrigerants and environmental-friendly fire suppressants, which the older fire tests might not be effective to guarantee adequate fire safety. New scenarios of big fires and explosions due to battery and power supplies are not yet included in codes developed years ago. New living styles with more plastics furniture and glass partition areas give more fire hazards. Protection against flashover fires must be carefully considered. Traditional water suppression systems, particularly automatic sprinkler systems [2-5], are required by the fire authority to reduce the possibility of uncontrolled fires. However, they are installed to meet earlier fire codes, which might not be able to face the challenges. Sprinkler will discharge water upon activation to cool the burning objects, prewet walls and floors, cool the smoke layer to reduce the chance of flashover, and to

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displace oxygen away from the burning objects. It is necessary to study how to improve their performance with respect to the two key performances of sprinklers: appropriate thermal activation and adequate water delivery, particularly for tall and big halls.

Tall halls are common in public transport facilities including airports, high speed railway systems (HSRS) and subway stations [6, 7]. Automatic sprinkler systems are installed to reduce the possibility of uncontrolled fires [8]. Sprinkler heads are supposed to be located inside the smoke layer and be heated up to the activation temperature, fig. 1(a), for discharging water. However, it takes a long time for smoke to descend to lower levels under the ceiling in tall halls [4, 6, 7] to address the important problems of thermal activation of active water systems in tall halls [9].

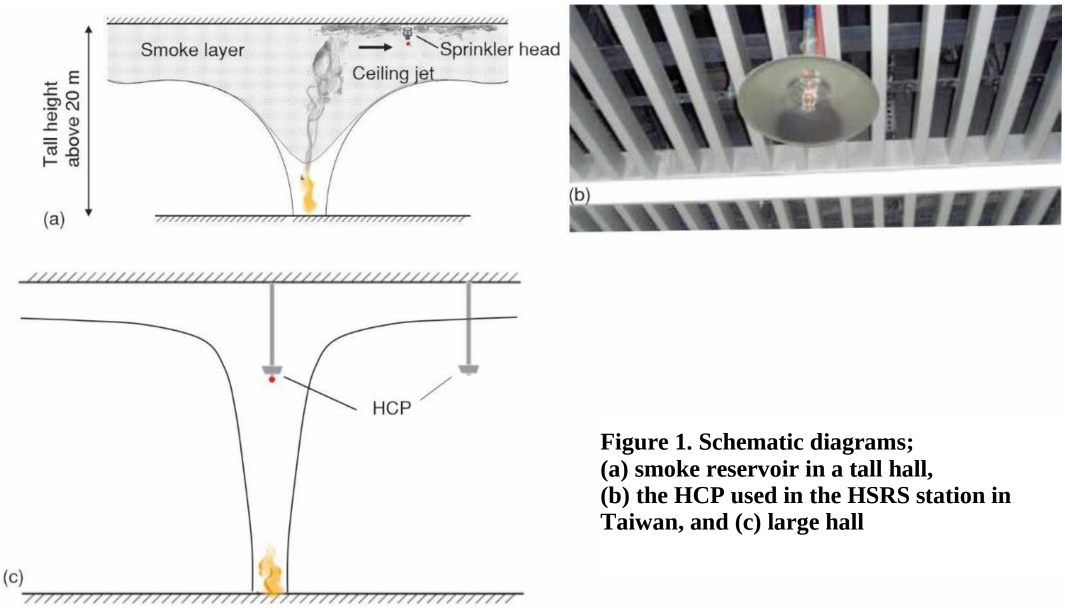

Figure 1. Schematic diagrams; (a) smoke reservoir in a tall hall, (b) the HCP used in the HSRS station in Taiwan, and (c) large hall

The HCP are then put above sprinkler heads in the Asia-Oceania (AO) region to attain faster thermal actuation [10-12]. An example is the HSRS stations in Taiwan [12], fig. 1(b). However, very few works on evaluating the thermal performance in heat collection of HCP are reported in the literature [10, 12, 13]. There are no clear experimental studies for supporting code requirements of the HCP by some jurisdictions [11, 12, 14]. The concept behind is not adequately explained in the literature.

The effect of HCP on thermal sensitivity of sprinkler heads will be studied in this paper. Real-scale burning tests for assessing HCP in a large hall require prohibitive resources. Firstly, there must be adequate selection points in the hall for burning tests with detailed statistical analysis. Secondly, a big fire is required to produce a thick smoke layer to immerse sprinkler heads away from the ceiling as shown in fig. 1(a). Thirdly, it is difficult to control physical conditions, namely temperature and air speed adjacent to the sprinkler head, in tall halls. An alternative approach is to expose the sprinkler head to hot air at appropriate temperature and velocity. Providing such a micro-climatic condition [15-22] is good enough for assessing the thermal performance of sprinkler heads. Such an experimental study can be carried out in a fire chamber [10, 13]. The activation times of sprinkler heads with and without HCP above a pool fire will be measured. The results can be used to justify whether it is necessary to install HCP above sprinkler heads in tall halls. Appropriate fire protection systems [9, 23-35] can then be designed.

Furthermore, the thermal performance is also evaluated by a standard sprinkler head wind tunnel [15-22]. The activation time of sprinkler heads with and without HCP will be tested [10, 13] under different air temperatures and speeds in the wind tunnel. Whether this test is appropriate for assessing thermal response of sprinkler heads with HCP will be discussed.

Heat collection plates

The HCP are designed to collect heat and accelerate sprinkler activation [11]. However, HCP is not recommended to be used in an updated American standard [23]. It is argued that objects above a sprinkler head cause delayed activation in case the fire is not directly below it [2]. However, fire protection professionals in the AO region have different views. On the contrary, a European standard [7] stipulates that if the heat sensing element of a sprinkler head installed at lower level may be wetted by those at higher level, water shield should be provided above these sprinkler heads. In Japan, Korea, Hong Kong and Taiwan, HCP are required in some projects such as tall halls with perforated ceiling. In Taiwan, HCP should be provided [12, 14] when the sprinkler head is more than 30 cm below the ceiling as specified in the building code. The HCP should be made of metal with a diameter of more than 30 cm. The sprinkler deflector plate should be less than 30 cm below the HCP. There are reports criticizing these requirements [12] and so it is worthwhile to have further analysis.

There are very few reports on evaluating the thermal performance of HCP [9-12] in the literature. Consequently, there are no reliable experimental results on supporting code requirements of the HCP [9, 11, 12]. To fill such a gap, the effects of HCP on the thermal sensitivity of sprinkler heads were studied in the present study. The activation times of sprinkler heads with and without HCP above a pool fire were measured. Results can be used to justify whether it is necessary to install HCP above sprinkler heads in tall halls. Appropriate fire protection systems [2, 3, 9] can then be designed.

The HCP [16-19] is usually in dome shape of metal baffles or *pie plate* to accelerate the response of sprinkler heads by collecting heat from a fire. Installing an HCP above a sprinkler head is believed to be capable of reducing the activation time of the thermal sensing element of the sprinkler head suspended at an extended distance below the ceiling of tall halls.

Pendent liquid-in-bulb fast response sprinkler head with operating temperature of 68 °C as in fig. 2(a) was selected for study in this paper. Three common HCP selected by fire engineers in many projects were used:

- The HCP-A is of flat shape and a diameter of 90 mm as in fig. 2(b). This HCP was used in Hong Kong in some projects.
- The HCP-B is commonly used in transport halls in Taiwan, with pie plate shape and a diameter of 110 mm, fig. 2(b).
- The HCP-C is another sample commonly used in Taiwan, with pie plate shape and a diameter of 165 mm, fig. 2(b).

A total of 48 sprinklers heads were tested under different heights and pool fire sizes for the fire chamber test. There were 12 tests labelled as C1 to C12. Each test was carried out with 4 sprinkler heads under no HCP, with HCP-A, HCP-B and HCP-C as in tab. 1. Another 40 sprinkler heads were tested in the common wind tunnel plunge test. Very little works were reported on HCP of sprinkler heads, but it is of wide application in construction.

Figure 2. Experimental devices; (a) sprinkler heads, (b) HCP: HCP-A: 90 mm diameter, HCP-B: 110 mm diameter, HCP-C: 165 mm diameter, and (c) fire chamber test

Table 1. Activation times of sprinkler heads

	Test number	Activation time [seconds]			
		No HCP	With HCP-A	With HCP-B	With HCP-C
Fire chamber test 48 (12 ×4) sprinkler heads	C1	81	69	38	35
	C2	77	75	35	33
	C3	85	68	43	39
	C4	89	73	45	40
	C5	92	78	39	40
	C6	83	69	34	38
	C7	76	72	42	30
	C8	90	70	40	42
	C9	79	68	44	39
	C10	92	69	38	36
	C11	84	70	39	38
	C12	88	73	36	34
	Average	84.7	71.2	39.4	37.0
	Standard deviation	6.1	3.4	3.7	3.7
Wind tunnel test 40 (10 ×4) sprinkler heads	W1	19	18	60	24
	W2	18	20	55	22
	W3	22	19	66	23
	W4	19	20	58	21
	W5	17	19	63	22
	W6	19	21	56	24
	W7	17	20	68	22
	W8	18	21	60	21
	W9	20	22	59	23
	W10	21	19	64	23
	Average	19.0	19.9	60.9	22.5
	Standard deviation	1.6	1.2	4.3	1.1

Fire chamber test

Sprinkler heads are supposed to be inside a smoke reservoir [23, 24] in real fire as in fig. 1(a) and exposed to certain air temperature and velocity. These micro-climatic conditions inside the smoke layer underneath the ceiling can be achieved by a fire chamber test 5 with smaller pool fires. A total of 48 sprinkler heads were tested in a 3.4 m tall chamber as shown in fig. 2(c). Sprinkler heads were installed 1.6 m below the ceiling and 1.8 m above the floor level along the central pool fire axis. Both the sprinkler heads and the pool fires were located at the centre of the fire chamber. Experiments with the three different HCP were carried out. The experimental conditions are shown in tab. 1.

An 800 ml propanol pool fire was put on floor along the vertical sprinkler axis. A thermocouple tree was set up above the pool fire source along the central axis for measuring gas temperature once every second. The temperature near the sprinkler head, measured by thermocouple T6, was used to record the micro-climatic conditions.

As reported in previous experimental studies, the temperature measured from the developed thermocouples has less than 1% uncertainties.

The activation times for sprinklers tests C1 to C12 under fire chamber are summarized in tab. 1. Sprinkler heads with HCP are observed to be activated much faster with 50% of activation time of those without an HCP.

Wind tunnel test

Wind tunnel test is commonly used to evaluate thermal response [11, 17] of sprinkler heads as in fig. 3 under constant air temperature, T_g, and speed *u*.

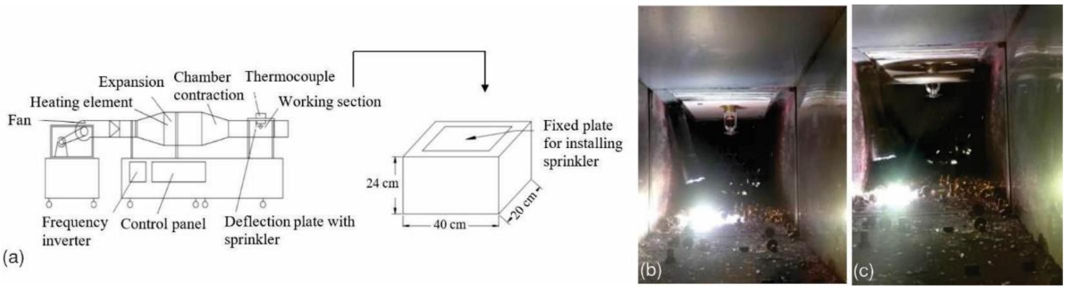

Figure 3. Wind tunnel test; (a) construction of wind tunnel, (b) sprinkler heads without HCP, and (c) sprinkler heads with HCP

A wind tunnel of 3 m long, 1.6 m high, and 0.7 m wide made of 1.2 mm thick mild steel sheet at constant air speed was used. Detailed operations were reported elsewhere [13, 18, 19].

The sprinkler heads were installed along the air flow direction in the tunnel as in fig. 3. A total of 40 sprinkler heads were tested in the tunnel in 10 tests. As sprinklers in tall halls like those in HSRS stations are provided to protect life and to minimize service disruption, they are required to operate early in a fire. Low air velocity of 1 m/s and temperature 90 °C were used in the wind tunnel test [7, 16-22]. The activation times of sprinkler heads were measured in the 10 tests, labelled as W1 to W10 in tab. 1.

In the wind tunnel test, the activation times of sprinkler head without HCP were even shorter than those with an HCP installed above. The activation time for sprinkler heads with HCP-B (60 seconds for test W1) was almost tripled compared with that for a bare sprinkler head (19 seconds in test W1). This is because adding an HCP above the sprinkler head in the wind tunnel as fig. 3 would change the physical scenario. Heat would be lost to the HCP but the temperature is not high enough to emit strong radiative heat flux, thus giving a longer activation time compared with a bare sprinkler head. Therefore, this would delay the activation of the sensing element.

Experiments on fire scenarios with HCP right above the fire and HCP outside the fire plume region were reported [12]. The HCP would not be effective for the latter. Wind tunnel with air acting horizontally at the sprinkler head is similar to the latter scenario. The experimental study reported [12] and the wind tunnel test in this paper share similar results. Wind tunnel test is not appropriate for evaluating thermal response of sprinkler heads with HCP because sprinkler heads are heated in a scenario different from that in real applications.

Experimental observation

The activation times of the sprinkler heads with or without HCP are very different as shown in fig. 4. A line slope of 1 is also drawn in the figure to show the comparison.

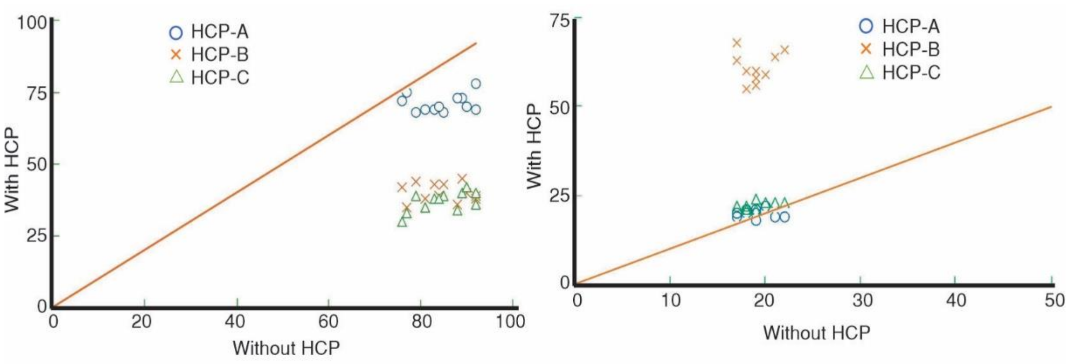

Figure 4. Sprinkler activation time and temperature profile; (a) Fire chamber test and (b) Wind tunnel test

An HCP above the sprinkler head in the fire chamber test gives a much shorter time than those without it. As shown in fig. 4(a), the activation time of sprinkler heads with HCP-A is 3% to 25% shorter than bare sprinkler heads. The HCP-B, which is larger in size than HCP-A even has a much shorter activation time, at 44% to 59% shorter than bare sprinkler heads. The HCP-C, being the largest in size amongst the three, has the shortest activation time, ranging from 51% to 61% shorter than bare sprinkler head. With a larger size of the HCP, more heat is received from the pool fire, which is subsequently reflected to heat sensing element of sprinkler heads.

The results of wind tunnel tests are plotted in fig. 4(b). Only the HCP-A and HCP-C results are close to the line of slope equal to 1. The HCP-B is of a pie plate shape with a small diameter of only 110 mm. The edge of HCP-B shielded the heat sensing element of the sprinkler head from direct impingement of the prevailing air flow inside the wind tunnel, thus causing a much longer activation time, being 221% more than that with bare sprinkler heads. The HCP-C, although also of a pie plate shape, has a larger diameter of 165 mm. Thus, convective heat could still be transferred to heat sensing element of sprinkler heads after passing beyond the edge of HCP-C. The HCP-A is of a flat shape and has insignificant effect on the air flow pattern inside the wind tunnel. As such, the activation time of sprinkler heads with HCP-A is the closest to that of bare sprinkler heads.

Discussion

The HCP can collect convective heat to activate the heat sensing element faster. The temperature near the liquid-in-glass bulb would rise rapidly and the sprinkler heads operate in a shorter time. Sprinkler heads with HCP were observed to be activated much faster in the present study. The activation time of sprinkler heads with HCP could be even halved from those without an HCP. Very little works were reported on HCP of sprinkler heads. This is just a preliminary study in a small fire chamber. More systematic full-scale burning tests should be carried out to justify whether HCP can be used in tall halls with big space volume.

Safety aspects should be watched more carefully by top management of the organizations. Fire safety has to be provided according to regulations. However, the penalty on non-compliance with safety in many places was very low before. For example, penalty for a tower crane accident with casualty in 2007 in Hong Kong was only HK$36000 (US$4500) [36, 37]. Consequently, nobody would care to invest properly to ensure safety, particularly safety management in having sufficient number of guards.

As observed in many industrial building fires [1, 38, 39], fire detection and alarm systems were not working when fire broke out. Industrial building fires could be very hazardous as there might be lots of plastics materials burning to give toxic smoke and a hazardous environment. It is urgent to implement appropriate fire safety management with promotion of safety culture [1] and raising the penalty too, to alert various parties concerned to invest more on fire safety. In addition, the penalty should be significantly raised to alert different parties to be more responsible on safety. Such safety culture is changing recently.

The recent incidents of tower crane collapse [40] and the falling down of a huge LED screen in a concert in 2022 [41] are more serious cases, and the latter involved a criminal case. Higher penalty [42] up to HK$10 million (about US$1.25 million) is now implemented. Demand on recruiting more safety experts with practical experience is expected to be higher. This might create a bigger market for fire safety personnel to avoid having big fires [43, 44].

Conclusions

Traditional water suppression systems such as automatic sprinkler systems are believed to be reliable in limiting fire size and are required by the fire authority in many places. However, the current design guides and fire codes were not developed for new challenges such as fires in tall buildings. Active fire suppression system in tall atria is a good example. It is necessary to study how to improve their performance through updating associated research activities for recommending new approaches. Thermal activation is an aspect to scrutinize as pointed out above. For example, the main argument against applying HPC is their activation conditions. Experimental study of thermal activation on HCP of sprinkler heads is important.

As sprinkler with HCP was not examined enough, the issue of thermal activation on HCP of sprinkler heads was studied experimentally with some value added. The problem is important because it concerns directly the safety and property losses in a fire. The main concern against HPC is their activation conditions. At least, it is confirmed that a sprinkler with an HCP placed in a hot smoke plume as in fig. 1(a) would be activated earlier than one without an HCP. The HCP would hinder the smoke flow and would hold hot gases in the vicinity of the sprinkler head. Water can be discharged at the burning object quickly. Meanwhile a sprinkler with an HCP placed outside the smoke plume will not be activated so quickly, thus avoiding discharging water without anything burning below.

Based on the aforementioned experimental studies, the following two points are reached:

- In fire chamber experiments, sprinkler heads with HCP were activated faster than those without HCP, suggesting the appropriate use of HCP for tall halls.

- The common sprinkler wind tunnel test appears inappropriate for studying thermal sensitivity of sprinkler heads with an HCP.

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