ON THE SPRINKLER TANK SIZE AND FAST RESPONSE SPRINKLER HEADS

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ABSTRACT

The time taken to use up water in a sprinkler tank was discussed. Reference was made to the thermal responses of sprinkler heads. A hazard scenario was considered with simulations on the activation time of sprinkler heads by FIREWIND.

1. INTRODUCTION

The maximum number of sprinklers that can be operated in a fire before using up all the water in the sprinkler tank is now of concern to the local industry. The question was not raised previously while following the factual codes or using standard design guides. However, in implementing 'engineering approach' [e.g. 1] with sprinkler installed to give better fire protection, the question was asked and design engineers have to defend their design by demonstrating that water will not be used up within a reasonable period of time.

In fact, when the water in a sprinkler tank will be used up depends on the number of sprinkler heads activated. The number of sprinkler heads that would be activated in a fire depends on the time it takes to be activated. A parameter, the response time index (RTI) of the sprinkler head, can be measured by the Factory Mutual plunge test [e.g. 2] to quantify how fast the sprinkler head can be activated. This is a parameter of the sprinkler head itself, without depending on the ambient fire environments or more specifically, the heat transfer coefficient which depends on the air speed.

In this short note, the number of sprinkler heads that would be activated and the time it takes to use up all the water in the sprinkler tank will be discussed.

2. NUMERICAL VALUES

Suppose the sprinkler tank is of volume V_s (in m^3), the flow rate of sprinkler is f_s (in m^3s^{-1}), the refilling rate of water to the tank is f_r (in m^3s^{-1}) and the number of sprinkler heads activated is N, mass balancing gives the time t_u (in s) for using up water in the tank:

$$V_s = (N\, f_s - f_r)\, t_u \qquad (1)$$

Putting in numerical figures for ordinary hazard 1 (OH1) under the Loss Prevention Council (LPC) rule [3] for common local design:

- $V_s = 55\ m^3$
- For low flow rate:

  $f_s = 375\ \ell min^{-1} = 6.25 \times 10^{-3}\ m^3s^{-1}$

  For high flow rate:

  $f_s = 540\ \ell min^{-1} = 9 \times 10^{-3}\ m^3s^{-1}$
- $f_r = 75\ \ell min^{-1} = 1.25 \times 10^{-3}\ m^3s^{-1}$

Solving equation (1), t_u is plotted against N in Fig. 1.

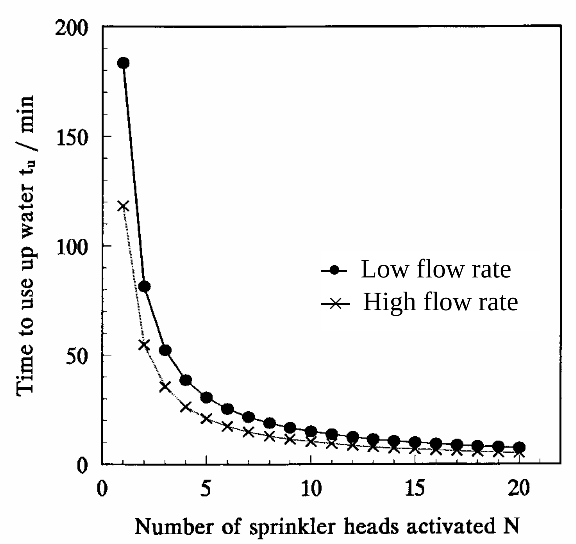

Fig. 1: Time to use up water in the tank

It is observed that for high flow rate sprinkler system, operating one sprinkler head would take a long time of 118 mins to use up all water in the sprinkler tank. However, operating 10 sprinkler heads will take only 10 mins! Therefore, the number of sprinkler heads to be activated is critical in ensuring sufficient delivery of water.

3. THERMAL ACTIVATION

The number of sprinkler heads activated can be calculated using empirical equations on fire plumes, ceiling jets etc. available in the literature [e.g. 4]. Suppose the sprinkler heads are installed with spacings of 3 m, a fire is located 3 m below a certain sprinkler head (labelled as position I) as shown in Fig. 2. There will be 4 sprinkler heads (labelled as position II) at 3 m away from the central fire axis, 4 sprinkler heads (labelled as position III) at 4.24 m away from the central fire axis, and 4 sprinkler heads (labelled as position IV) at 6 m away from the central fire axis.

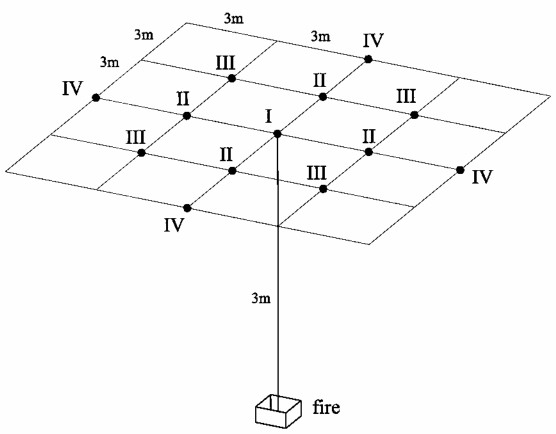

Fig. 2: Geometry of layout of sprinklers

These 13 sprinkler heads are likely to be activated by a fire of heat release rate Q. The fire engineers' calculator FIREWIND [5] is applied to study the thermal activation time t_a.

The NFPA t^2-fire [6] is used for the calculation, with Q (in kW) given in terms of t (in s) by:

$$Q = 1000\left(\frac{t}{t_g}\right)^2 \qquad (2)$$

In the above equation, t_g is 600 s, 300 s, 150 s, and 75 s for slow, medium, fast and ultra-fast t^2-fires respectively. A cut-off value of 5 MW was assumed.

Two values of thermal response index (RTI) of sprinkler heads with 68°C rating were considered in the assessment:

- 42 $(ms)^{1/2}$ for fast response sprinkler head,
- 350 $(ms)^{1/2}$ for normal sprinkler head.

Results of t_a together with the minimum heat release rate Q_{min} (in kW) required to activate each type of sprinkler head are shown in Table 1.

4. DISCUSSION

From Table 1, the minimum heat release rate required to activate the sprinkler head is very low, only 708 kW for sprinkler heads at position IV at 6 m away from the fire axis.

For a slow t^2-fire, it takes quite a long time to activate all 13 sprinkler heads at the four positions. Even at position I above the fire, it would require 224 s for a fast response sprinkler head, and 310 s for a normal sprinkler head to be activated. Therefore, the number of sprinkler heads that would be activated within 10 mins is only 5 (1 at position I and 4 at position II). The time to use up all the water in the sprinkler tank is very long, say over 20 mins as seen from Fig. 1.

Table 1: Activation time

Sprinkler head position	Minimum heat release rate Q_{min}/kW	Activation time t_a/s							
		RTI = 42 $(ms)^{1/2}$				RTI = 350 $(ms)^{1/2}$			
		Ultra-fast t^2-fire	Fast t^2-fire	Medium t^2-fire	Slow t^2-fire	Ultra-fast t^2-fire	Fast t^2-fire	Medium t^2-fire	Slow t^2-fire
I	64	38	66	119	224	73	116	187	310
II	354	88	160	304	590	150	241	404	704
III	501	102	186	353	686	177	282	469	816
IV	708	120	219	417	812	221	334	553	963

However, for a rapidly growing fire such as one similar to an ultra-fast t^2-fire, the longest time required to activate a normal sprinkler head at position IV is only 221 s. In such case, 1 sprinkler head would be activated in 73 s, 4 in 150 s, 4 more in 177 s, and a total of 13 sprinkler heads will be activated in 221 s, i.e. within 4 mins. The sprinkler tank will become empty 10 mins later as indicated in Fig. 1. For using fast response sprinkler heads, all 13 sprinkler heads will be activated within 2 mins. The sprinkler tank will then be empty within 12 mins after a fire starts! Care must be taken on sizing the sprinkler tank.

5. CONCLUSION

The sprinkler tank size should be selected by estimating the number of sprinkler heads designed to be activated. The number of activated sprinkler heads depends on the thermal sensitivity or the RTI of the sprinkler head itself. A bigger tank might have to be used for sprinkler heads with faster responses.

As normal sprinkler heads might operate at different times, so equation (1) should be derived from simulations on time-dependant variables. Further, the following conclusion can be drawn for those fast response sprinkler heads.

- Hazard assessment should be carried out to check the likelihood of having a rapidly growing fire. For example, if an ultra-fast t^2-fire is likely to occur, the sprinkler tank size should be increased.

- Volume of the sprinkler tank V_s should be a function of f_s, f_r, N and t_u. However, V_s should be bigger for higher values of f_s, larger N and longer t_u. A smaller value for V_s is expected if f_r is higher.

- N itself decreases for slower response sprinkler heads with higher RTI and slower growth of fire with higher t_g.

An empirical formulae for V_s can be fitted as:

$$V_s = a_1 f_s^{n_1} + a_2 f_r^{-n_2} + a_3 RTI^{-n_{3a}} \cdot t_g^{-n_{3b}} + a_4 t_u^{n_4} \qquad (3)$$

where a_1, a_2, a_3 and a_4 are constants; n_1, n_2, n_{3a}, n_{3b} and n_4 are positive numbers.

It is noted that incoming water pipe connected to a sprinkler tank through a ball valve would supply water to the tank. However, the inflow rate has to be determined carefully, and related to the number of sprinkler heads operated. Local water supplies are quite reliable, if the sprinkler tank is sized properly, water can fill up the tank. But still, the number of sprinkler heads activated is a key feature.

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