RESPONSE TIME INDEX OF SPRINKLERS

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ABSTRACT

The Plunge test would be carried out for measuring the activation time of two different types of sprinklers (Standard and Quick response bulb) under different gas velocity and temperature in a heated wind tunnel with and without radiation effect in the BSE laboratory. A total number of 90 sprinkler heads were tested by a wind tunnel following the Plunge test. Temperatures of the sensing element of sprinklers were measured by a computer. Experimental results were then recorded for the later analysis. After obtaining the result, the time constant and response time index would be calculated for interpretation. The above approaches would give a good analysis for the response time index of different types of sprinklers.

(This is a final year student research project for BEng(Hons) in Building Services Engineering.)

1. INTRODUCTION

Automatic sprinkler systems [1] are widely used as the fire detection and fire suppression system. Their rapid means of controlling fire are particular valuable in buildings because the system greatly reduces the possibility of having an uncontrolled fire. The system reliability is of vital importance to life safety and property protection. Its operation is governed by the temperature of the sensing element – frangible glass bulb. The glass bulb type sprinkler contains a liquid with high coefficient of expansion is contained with a small air bubble entrapped in it. When the liquid is heated, the liquid expands and the bubble inside will be compressed. As a result, it will be absorbed by the liquid and the pressure inside increases. Finally, the bulb shatters release the valve cap and the sprinkler operates until its operating temperature is reached.

As the sprinkler cannot operate too fast or too slow when there is fire. Therefore, the thermal sensitivity of sprinkler is very important in order to extinguish the fire. So, it is very interesting to investigate the thermal response of the standard and quick response glass bulb sprinklers.

In the actual situation, radiation contributes a large portion for the heat transfer to the sprinkler head in order to actuate the sprinkler. If considering the radiation from the fire or surrounding to the sprinkler head, the activation time of sprinkler would be more accurate to modify the actual performance of the sprinkler response. Accordingly, it is stimulated to inspect the thermal sensitivity of the sprinkler heads under the radiation effect. In the BSE wind tunnel, only the convective and conduction heat transfer is considered. Consequently, inserting a radiation panel into the wind tunnel is one of the methods to study the radiation effect on the sprinkler response.

2. OBJECTIVES

- To compare the differences between two different types of sprinklers on the RTI from the experiment, time constant and activation time of sprinklers.
- To investigate the relationship between RTI, time constant and gas velocity by using the BSE wind tunnel.
- To investigate the differences of RTI with and without radiation effect by different approaches.

3. EXPERIMENTAL SETUP

3.1 Wind Tunnel

The wind tunnel [1] will be used to simulate the ceiling jet of smoke. The BSE wind tunnel is shown in Fig. 1. It made from 1.2 mm mild steel sheet with the dimensions 3 m long, 1.6 m high and 0.7 m wide. It enables the tunnel air temperature to respond rapidly to any programmed change with its relatively low thermal mass. Firstly, the air is blown by the centrifugal fan with a specific frequency, and then the inlet air will pass through the heating section which consists of finned air heater. The heated air will pass through the contraction section and finally to the working section and then outlet.

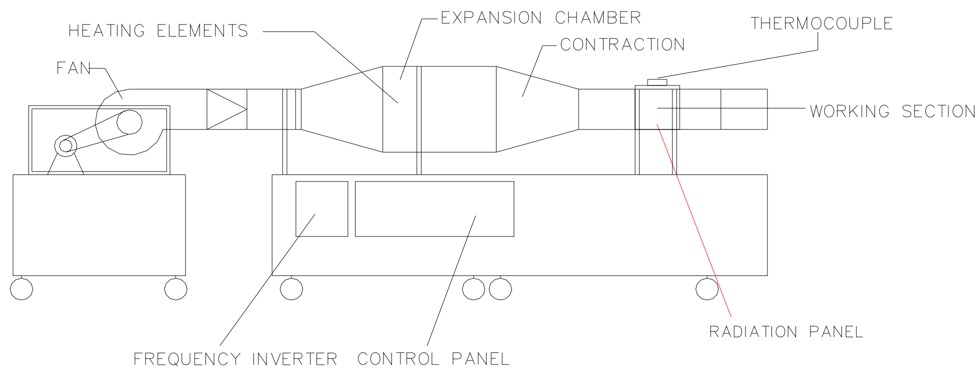


Fig. 1: BSE wind tunnel

One of the characteristics of the wind tunnel is that the working section of the wind tunnel is made of an aluminum case with water circulating inside. This water circulation ensures that the heat transfer to the sprinkler is predominantly by convection rather than radiation. Therefore, a radiation panel is needed to add inside the wind tunnel to modify the actual situation when there is a fire. The location of the radiation panel is shown in Fig. 1. Besides, the orientation of plunging the sprinkler in the working section is reversed. The detailed layout is shown in Fig. 2. The above arrangements can modify the actual situation of a fire including the radiation from the surrounding and the ceiling.

Experiments for air velocity of 1 ms^{-1}, 2 ms^{-1} and 3 ms^{-1} with three different air temperature of 90 ^{o}C, 100 ^{o}C and 110 ^{o}C were carried out. Those experiments will be tested with or without the radiation panel. K-type thermocouples were used to measure the glass bulb surface temperature.

3.2 Radiation Panel

Fig. 2 shows the component of the radiation panel. It consists of the heated panel, insulation part, connection cable and the asbestos board. The panel can generate heat or radiation by connecting the cable to the power supply. The insulation part is used for insulating the radiation panel against electric shock. As the asbestos board can withstand high temperature, it is used to prevent overheating of the radiation panel and destruction of the heated wind tunnel when the panel is placed inside the heated wind tunnel.

3.3 Plunge Test

Plunge Test [2,3] is developed by the Factory Mutual Research Corporation [3]. The detailed operating procedure is that the air temperature and velocity are set as constant. Then, the sprinkler at ambient temperature will be immersed into the hot air steam. Finally, the time for the sprinkler to actuate is recorded.

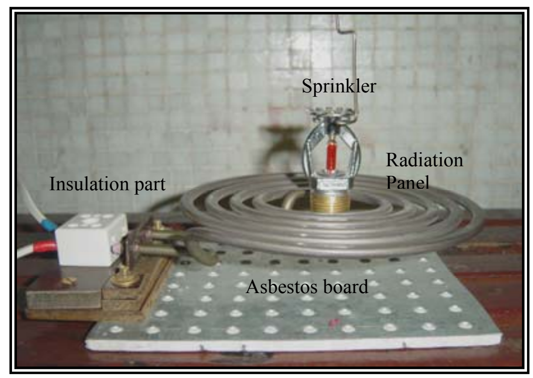


Fig. 2: Orientation of sprinkler

3.4 Response Time Index

Response time index (RTI) is one of the properties of the sprinkler head itself. It is independent of the gas velocity but depends on the properties of the sprinkler heads such as mass, specific heat capacity and surface area of the thermal sensing element. The values of the response time index lie from about 28 to 50 $m^{1/2}s^{1/2}$ for fast response sprinklers and about 100 to 360 $m^{1/2}s^{1/2}$ for standard response sprinklers.

4. THEORY

Two key equations in the Plunge test [2,3] developed by Factory Mutual Research Corporation [3] will be used:

The first one is on the time constant τ'_e given in terms of T_a, T_g, T_o and t_a,

$$\tau'_e = -t_a / \ln (1 - T_a - T_o / T_g - T_o) \qquad (1)$$

where T_a is the operation temperature of the sprinkler head, T_o is the initial temperature of the sensing element; T_g is the gas temperature and t_a is the activation time.

The second equation is to define RTI through the hot air speed V_g,

$$RTI = \tau'_e \sqrt{V_g} \quad (2)$$

With equations (1) and (2),

$$-t_a = RTI\,(\ln X/\sqrt{V_g}) \quad (3)$$

where X is given by:

$$X = 1 - T_a - T_o/T_g - T_o \quad (4)$$

After obtaining the Plunge test result, the time constant τ'_e can be calculated by a graph plotting on equation (1) with t_a against –ln X with X given by equation (4). The slope of the graph is tau factor τ'_e. And the RTI can be determined by plotting t_a against -ln $X/\sqrt{V_g}$ through equation (3) in order to minimize the error induced. The slope of the graph is the RTI.

5. RESULTS AND ANALYSIS

Plunge tests for standard and quick response sprinkler heads were carried out. The air temperature range of the test was from 90 °C to 110 °C, the air steam velocity was from 1 ms^{-1} to 3 ms^{-1}. Several sets of data were obtained:

- For standard and quick response sprinklers, the activation time of the sprinklers with and without radiation panel were recorded.
- The sprinkler glass bulb surface temperature was recorded by the K-type thermocouples.

5.1 Relationship between Activation Time, Gas Velocity and Gas Temperature

In general, from Tables 1 and 2, the operation time of the standard response sprinkler is longer than that of the quick response sprinkler no matter that the sprinkler is under the radiation effect or not. For instance, under the gas velocity of 2 ms^{-1} and temperature of 100 °C, the operation time of the standard response sprinkler is about 77 s which is longer than the quick response sprinkler. It is because the thickness of the glass bulb in the quick response sprinkler is only 3 mm which is less than 5 mm of the standard response sprinkler, so the liquid in the quick response sprinkler will expand much faster than in the standard sprinkler under heating. The operation time of quick response sprinkler will be faster.

In a detailed interpretation, the operation time of sprinkler is different under the same constant temperature but at different gas velocity. The higher the gas velocity, the faster the sprinklers operate. For instance, from Table 1, at gas temperature 100 °C and gas velocity of 1 ms^{-1} and 2 ms^{-1}, the operation time is shorter at higher gas velocity (2 ms^{-1}). It is because the hot gas at higher velocity will enter the sprinklers much faster than that at lower gas velocity, so the liquid in the glass bulb will expand faster and the operation time will be shorter at higher gas velocity. Moreover, the operation time is shorter under the same gas velocity but at higher gas temperature. For instance, from Table 1, at constant gas velocity 1 ms^{-1} and gas temperature of 90 °C and 100 °C, the operation time at higher gas temperature is shorter. It is because the glass bulb needs a shorter time for the sprinkler to heat up to their pre-determined temperature at a higher gas temperature, so the glass bulb will expand much faster at higher temperature than at lower temperature, the sprinkler will activate first after the bulb is broken.

Table 1: Operation time of two response type sprinkler (without radiation panel)

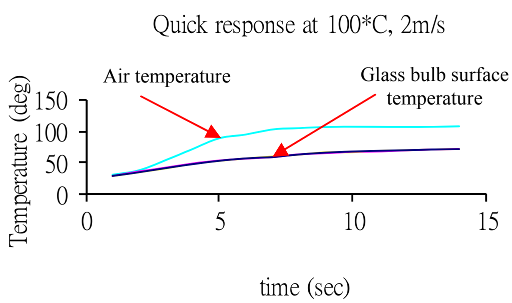
	Standard response			Quick response		
Gas	Gas temperature					
velocity	90 °C	100 °C	110 °C	90 °C	100 °C	110 °C
1 ms^{-1}	107 s	89 s	70 s	45 s	23 s	18 s
2 ms^{-1}	91 s	77 s	63 s	42 s	20 s	16 s
3 ms^{-1}	80 s	69 s	55 s	38 s	18 s	13 s

Table 2: Operation time of two response type sprinkler (with radiation panel)

	Standard response			Quick response		
Gas	Gas temperature					
velocity	90 °C	100 °C	110 °C	90 °C	100 °C	110 °C
1 ms^{-1}	95 s	82 s	60 s	37 s	16 s	15 s
2 ms^{-1}	83 s	70 s	52 s	33 s	14 s	12 s
3 ms^{-1}	72 s	59 s	43 s	29 s	11 s	8 s

5.2 Glass Bulb Surface Temperature

From Graph 1, the temperature of the glass bulb surface of the standard and quick response sprinkler is around 72 °C or 73 °C. The sensing element inside the glass bulb is 68 °C which is given by the manufacturer. The glass bulb surface temperature is a bit higher than that of 68 °C because it still needs some time for the hot gas to enter through the glass bulb surface into the liquid inside. Therefore, there is a thermal lag of bulb mass.



Graph 1: Glass bulb surface temperature

5.3 Comparison between With or Without Radiation Panel

From Graph 2, it can be seen that the activation time is faster with radiation panel than that without radiation panel (the radiation curves are lower than the no radiation curves) no matter it is the standard or quick response sprinkler. It is because there is one more heat source which acts on the sprinkler heads rather than only the heater in the wind tunnel when a radiation panel is added. Consequently, the temperature of the liquid inside the glass bulb will rise more rapidly and expands and then activates. Besides, there is not only the convective and conductive heat transfer to the sprinkler. Instead, the radiation heat transfer is acted on the sprinkler. Therefore, the activation time of sprinkler will be faster under the source of radiation panel.

Furthermore, the measured heat flux is 0 kWm^{-2} without radiation panel and the measured heat flux is about 0.62 kWm^{-2} to 0.74 kWm^{-2} when there is a radiation panel. Therefore, the measured heat flux with a radiation panel is much larger than that without a radiation panel. That means when a radiation panel is added inside the wind tunnel, there is more heat flux or radiation heat transfer to the sprinkler. Therefore, the measured heat flux can clearly show the reason why the operation time of sprinkler is shorter with the radiation panel.

Besides, the measured heat flux increases with the increase in gas temperature but the measured heat flux is independent of the gas velocity. For instance, at gas velocity of 1 ms^{-1} and gas temperature of 90 ^oC and 100 ^oC, the measured heat flux is increased from 0.62 kWm^{-2} to 0.7 kWm^{-2}. However, when the gas velocity is increased from 1 ms^{-1} to 2 ms^{-1}, there are no changes in the heat flux.

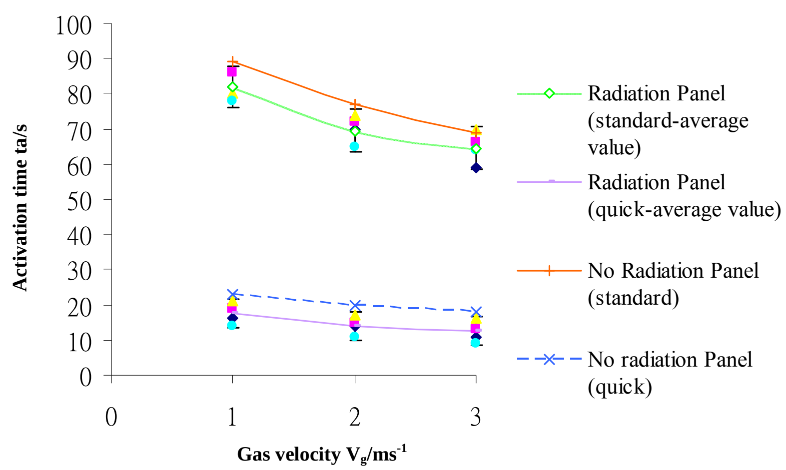
5.4 Time Constant

5.4.1 Comparison of time constant between standard and quick response sprinkler

From Tables 3 and 4, it can see that the time constant for the quick response sprinkler heads is much smaller than that for the standard response sprinkler whether the radiation effect is present or not. Time constant means that how fast the sprinkler responds to the temperature change. The smaller the time constant, the faster the sprinkler response. Therefore, the quick response sprinkler operates much faster than the standard response sprinkler due to the smaller time constant value.

5.4.2 Comparison of time constant with and without radiation effect

From Tables 3 and 4, the time constant with radiation effect is smaller than that without radiation effect. It is because when there is radiation effect, one more heat radiation transfer is acted on the sprinkler that makes the sprinkler bulb temperature rise more quickly. As previously described, the activation time with radiation effect is shorter. Therefore, the sprinkler response is faster with radiation effect and finally the smaller time constant is obtained.



Graph 2: Activation time result

Table 3: Time constant of standard response sprinklers

Standard response sprinklers			
Without radiation panel		With radiation panel	
Gas velocity/Vg	Time constant	Gas velocity/Vg	Time constant
1 ms^{-1}	83.228	1 ms^{-1}	74.734
2 ms^{-1}	71.998	2 ms^{-1}	64.496
3 ms^{-1}	63.585	3 ms^{-1}	56.24

Table 4: Time constant of quick response sprinklers

Quick response sprinklers			
Without radiation panel		With radiation panel	
Gas velocity/Vg	Time constant	Gas velocity/Vg	Time constant
1 ms^{-1}	30.675	1 ms^{-1}	25.242
2 ms^{-1}	27.944	2 ms^{-1}	21.53
3 ms^{-1}	24.858	3 ms^{-1}	18.413

5.5 Response Time Index

5.5.1 First approach

From the calculated time constant, the RTI can be found by the equation (2) with known gas velocity. It can see that the range of RTI become narrower from gas velocity of 1 to 3 ms^{-1}. That means the error induced from the experiment is getting smaller and smaller and the RTI should be within this range. Therefore, the RTI with no radiation effect is 110 $m^{1/2}s^{1/2}$ and 43 $m^{1/2}s^{1/2}$ for the standard and quick response sprinkler respectively. The RTI with radiation effect is 98 $m^{1/2}s^{1/2}$ and 32 $m^{1/2}s^{1/2}$ for the standard and quick response sprinkler respectively.

Table 5: Calculated response time index for standard response sprinkler

Standard response sprinklers			
Without radiation panel		With radiation panel	
Gas velocity/Vg	RTI	Gas velocity/Vg	RTI
1 ms^{-1}	83.228	1 ms^{-1}	74.734
2 ms^{-1}	101.82	2 ms^{-1}	91.21
3 ms^{-1}	110.13	3 ms^{-1}	97.41

Table 6: Calculated response time index for quick response sprinkler

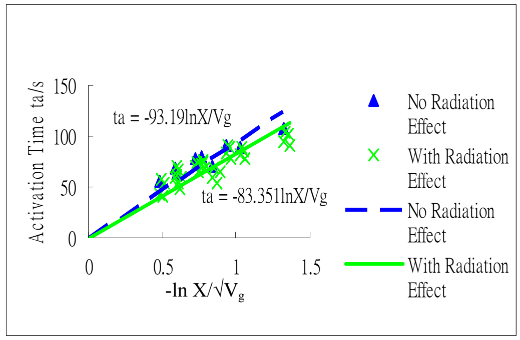
Quick response sprinklers			
Without radiation panel		With radiation panel	
Gas velocity/Vg	RTI	Gas velocity/Vg	RTI
1 ms^{-1}	30.675	1 ms^{-1}	25.242
2 ms^{-1}	39.519	2 ms^{-1}	30.44
3 ms^{-1}	43.056	3 ms^{-1}	31.89

5.5.2 Second approach

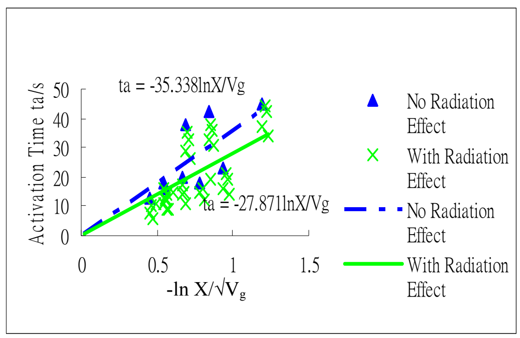
Instead of finding the time constant to calculate the RTI, the RTI can be calculated directly with equation (3) by plotting activation time t_a against -ln $X/\sqrt{V_g}$.

From Graph 3, the RTI with no radiation effect is about 94 $m^{1/2}s^{1/2}$ and 84 $m^{1/2}s^{1/2}$ with radiation effect for the standard response sprinkler.

From Graph 4, the RTI with radiation effect is 36 $m^{1/2}s^{1/2}$ and 28 $m^{1/2}s^{1/2}$ with no radiation effect for the quick response sprinkler.



Graph 3: RTI of standard response sprinkler



Graph 4: RTI of quick response sprinkler

5.5.3 Discussion on the calculated response time index

No matter using the first or second approach, the response time index with radiation effect is smaller than that without radiation effect. From equation (3), it can clearly explain the reasons. If the gas velocity and activation time is getting smaller, the RTI will also be getting smaller. When a radiation panel is added into the wind tunnel, there is conductive, convective and radiative heat transfer together which is acted on the sprinkler and makes the response time faster. As a result, as the response time is smaller, the response time index will be smaller according to equation (3).

5.5.4 Comparison between first approach and second approach

The response time index by using the first approach is larger than that with the use of second approach. It is because the experimental or calculation error induced from the first approach is much larger than that of the second approach. It needs to calculate the time constant first and then use equation (2) to calculate response time index. Therefore, the larger response time index is given out. And the second approach only directly plot the graph with the equation (3), the calculation error is much smaller by only calculating one times. Consequently, the response time index by using the second approach is much accurate.

Table 7: Comparison the RTI with the first and second approach

	Standard response sprinkler		Quick response sprinkler	
	With radiation effect	No radiation effect	With radiation effect	No radiation effect
First approach	98 $m^{1/2}s^{1/2}$	110 $m^{1/2}s^{1/2}$	32 $m^{1/2}s^{1/2}$	43 $m^{1/2}s^{1/2}$
Second approach	84 $m^{1/2}s^{1/2}$	94 $m^{1/2}s^{1/2}$	28 $m^{1/2}s^{1/2}$	36 $m^{1/2}s^{1/2}$

6. CONCLUSION

The following conclusions can be drawn from this study on response time index:

- Standard response sprinkler operates much faster than the quick response sprinkler no matter having the radiation panel or not.
- Heat flux with radiation effect is larger than that without radiation effect.
- The activation time of sprinkler is faster under the radiation effect when compared with no radiation effect.
- The time constant of the standard response sprinkler is larger than the quick response sprinkler.
- The time constant of the sprinkler without radiation effect is larger than that with radiation effect.
- The calculated response time index of quick response sprinkler is almost 3 times that of the standard response sprinkler.
- The response time index of sprinkler is smaller with radiation effect.
- The smaller the time constant and response time index, the faster the sprinkler response.

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