RADIATION BLOCKAGE OF WATER CURTAINS

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ABSTRACT

A preliminary laboratory experimental work is carried out to investigate the shape of water curtain and the radiation attenuation ability of water curtain subjected to thermal radiation. The objectives are to analyze the key parameters involved in the mitigation properties of this fire protection technique, key parameters include different working pressures, flow rates, fire sizes as well as different drencher nozzles. Investigating the shape of water curtain illustrated that water curtain discharged is not a continuous layer. Furthermore, the experimental results have shown that the higher the working pressure as well as flow rate, the better the radiation attenuation ability. For larger fire size, the attenuation efficiency of water curtain also increases. In addition, by comparing two different orifice diameter of nozzles, the smaller one (3/8") has better attenuation effect. A possible reason is that smaller nozzle can produce finer drops than those from larger nozzle (7/16"). And by studying the temperature profiles of the fire chambers, it has shown that water curtain has good cooling effects. However, the cooling effects were independent of the working pressure of the drencher system. Moreover, from literature review, the spray pattern, water curtain and the local practice of water curtain were reviewed.

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

1. INTRODUCTION

It is an important issue to investigate the attenuation ability of water sprays subjected to thermal radiation. Over the years, there are many studies on the issue, including theoretical analyses [2-4] and laboratory experimental work. For the theoretical analyses, they have helped understanding the main parameters controlling the attenuation efficiency of spray [5]. A spray curtain attenuates thermal radiation by combined absorption and scattering mechanisms due to water droplets, as well as by water vapor absorption mainly [6]. To maximize attenuation, the optimum droplet size must be considered. By using a simple radiation attenuation model and solving through iteration, the optimum droplet size can be determined [3]. The maximum attenuation factor was attained when the droplet radius was approximately equal to the infrared wavelength (0.6 to 25 μm). Moreover, optimum droplets of radius equal to the incident wavelength for minimum transmissivity [3].

In addition, based on the literatures, some experimental studies on thermal radiation blockage of heat by a water curtain were carried out [6-8]. The effects of many parameters such as the droplet size distribution, the spray nozzle type, feeding pressure and flow rate on radiation attenuation were studied. From the experimental result, the wavelength dependency of the spray attenuation properties is clearly shown [6]. Experimental spectral transmittances curves have clearly shown that the attenuation spectrum of water spray comprises a continuous zone (attenuation due to water droplets) and zones where both the gases (water vapor and carbon dioxide) and the droplets mitigate radiation. Furthermore, the experimental results have also shown that increase in pressure and flow rate improves the attenuation because of finer drops in high concentration [6]. The key parameters controlling the attenuation of water spray of water curtain were identified: the size and concentration of the droplets, the molar fraction of the gases, and the width of the curtain. Finally, the key element to improve the efficiency of a water curtain is that water is sprayed into droplets, rather than the quantity of water delivered [6]. All of the above are found in the literatures, but in this project, some modification of experimental study and investigation of the water curtain shape would be done.

2. APPLICATION OF WATER CURTAIN IN HONG KONG

Buildings have to be divided into compartments by different structural elements, such as walls and floors. In some cases, water curtain can act as an alternative for spaces with problems in compartmentation; for example, the introduction of the drencher system in the new KMB Lai Chi Kok bus depot in Hong Kong [11]. As defined by the Fire Services Department, drencher system is a system that provides a water curtain for protection against internal and external exposure to fire, and/or the large openings. Furthermore, by the requirements of Fire Services Department, the external drencher system shall be provided for all refuge floors inside a building to protect all the external wall openings [10]. Therefore, water curtain can act as an alternative for compartmentation and it is required for all external openings of refuge floors in Hong Kong.

3. DISCHARGED CURTAIN - A CONTINUOUS LAYER?

To investigate the properties of water curtain, it is important to observe the shape as well as the pattern of the discharged water film by the drencher nozzle. Therefore, by using a stroboscope, it was capable to freeze the image of water curtain at several time intervals. And by using a camera together with the stroboscope which was located at a fixed position, the water curtain was recorded down by means of photographs with typical examples at different time intervals as shown in Fig. 1.

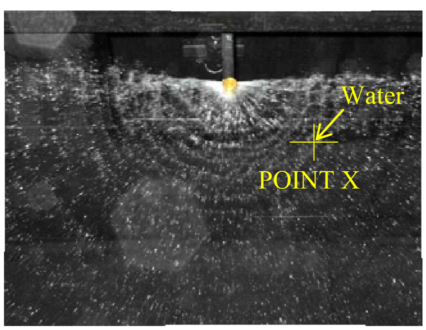
From Fig. 1, it indicated the transient water curtain pattern and Point X which is a fixed point with a constant distance from the drencher nozzle. For pale areas, it is the region containing water, but for the darker (black) area which is the air spaces. At the beginning (0 s), Point X was water and after 8 s, Point X changed to air and that phenomena was repeated at 16 s and 24 s. Therefore, water curtain is a not a continuous water layer, because the water curtain pattern is changing for every second and it is not stationary. However, when the image is not frozen by the stroboscope, we cannot see the air space in the curtain. It is because the water particle is moving very fast, therefore the human eyes is incapable to distinguish it. Hence, the discharged curtain is not a continuous water layer, and from this observation, the following experimental result can be explained.

4. METHODOLOGY

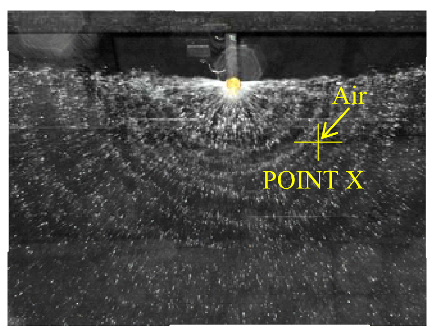
4.1 Proposed Experimental Setup

The experiments were carried out in a fire chamber at the laboratory of Department of Building Services Engineering, The Hong Kong Polytechnic University. The fire chamber was divided into two sides by discharging a water curtain. The chamber is length of 4 m, width 2.9 m and height 2.6 m as shown in Fig. 2. One side is the fire (F) side; and another side is the protected (P) side. The water curtain was formed by using Ø3/8” drencher head.

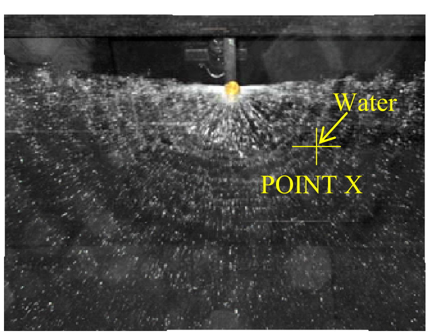
The experimental setup on the study of radiation blockage effects by water curtain is shown in Fig. 2. The temperature and radiative heat flux were measured and recorded by thermocouple and heat flux transducer respectively. The thermocouple trees (K-Type) were placed on both sides of the chamber to measure the temperature of particular points. A heat flux transducer was used to measure the radiative heat flux in different conditions. It was placed on the protected side of the chamber.



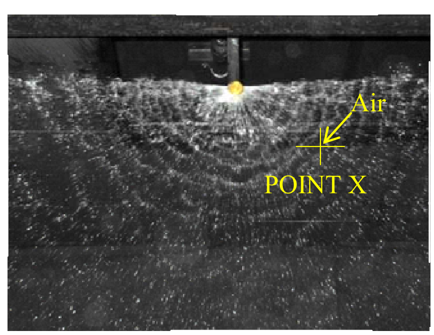
(a) At 0 s



(b) At 8 s



(c) At 16 s



(d) At 24 s

Fig. 1: Transient water curtain pattern

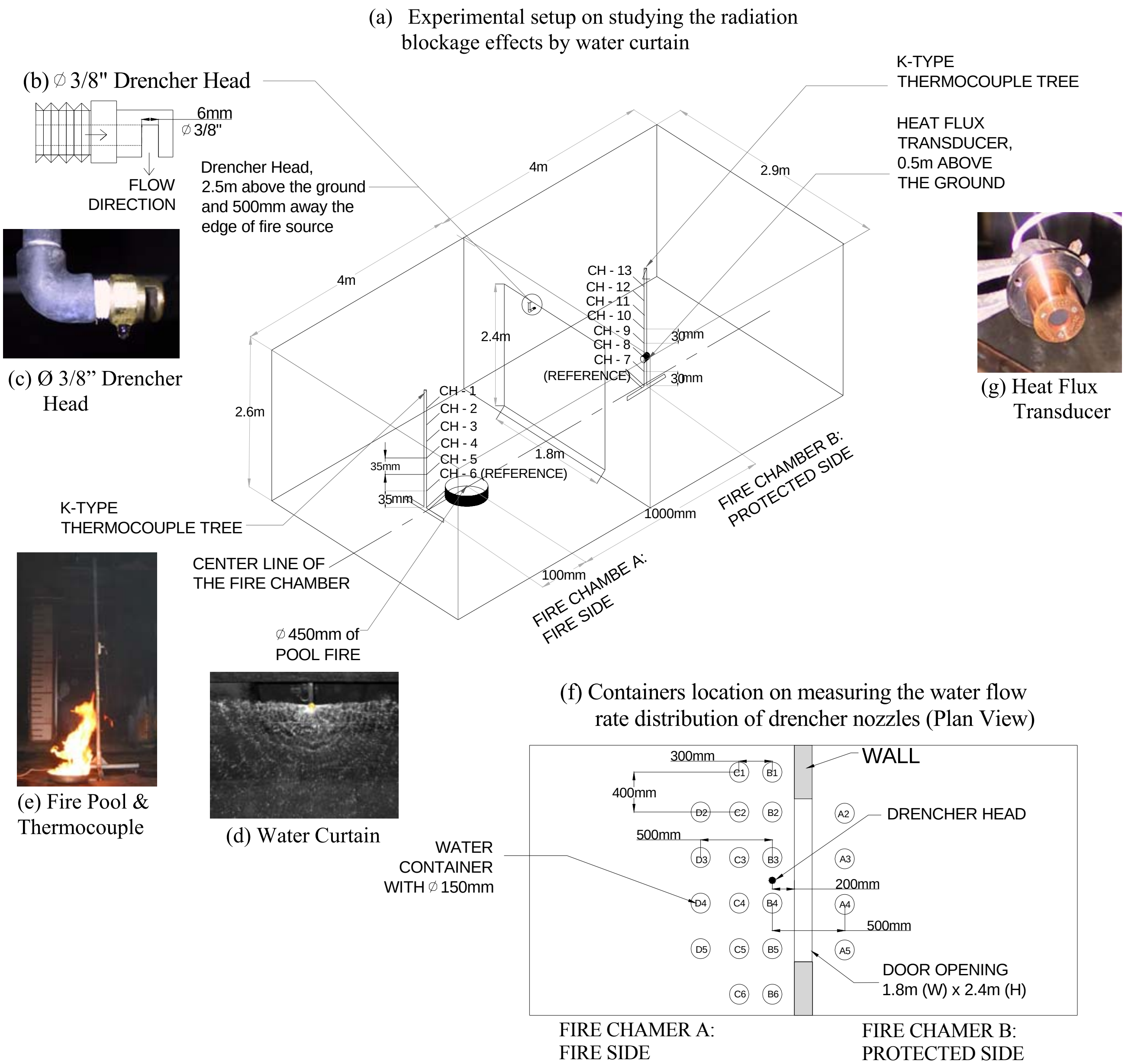


Fig. 2: Experimental setup for studying the radiation blockage effects by water curtain

4.2 Preliminary Experiment

Determination of the size of drencher nozzle and its working pressure

The drencher nozzle diameter of 3/8" (10 mm) was selected under working pressure of 4, 5 and 6 bars. The reason why 3/8" nozzle was chosen and its working pressure is based on that the nozzle can fulfill the requirements of water pressure and water flow rate recommended by National Fire Protection Association (NFPA) [9]. For NFPA, the minimum water pressure and water flow rate is 48 kPa and 56.8 l/min (or 37 l/min/m for water curtain) respectively. Moreover, drencher nozzle was placed at the center line of the chamber of height 2.5 m above the ground level. In addition, a preliminary experimental study on water distribution of drencher head size of 1/4", 5/16", 3/8" and 7/16" were carried out, in order to find out different water flow rate distribution for different nozzle sizes.

For the experiment of water flow rate distribution of different nozzle sizes, the experimental setup is shown in Fig. 2f. And the result for Ø3/8" drencher head is shown in Fig. 3. Based on the result, it is capable to determine the distance of the fire pool, thermocouple and heat flux transducer from the drencher head in order to minimize their distance but in least disturbance by the water spray.

Determination of volume of propanol needed for each experiment

A propanol fire pool with diameter 0.45 m and 0.83 l was put in F side to generate 41 kW of heat release rate for 5 mins for each experiment. The volume of propanol needed depended on the mass loss rate of propanol, size of fire pool and duration of burning. In this case, the mass loss rate was determined in the laboratory and the result is shown in Fig. 4.

Measurement Procedure

Two measurements were carried out during the experiments: Radiative heat flux without water curtain (the incident heat flux), and another with water curtain (attenuated radiative heat flux). Moreover, the temperature profiles for thermocouples at different height level were measured.

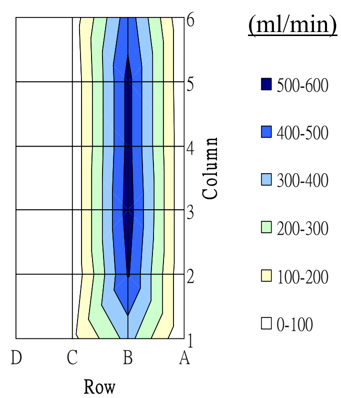


Fig. 3: Water flow rate distribution of 3/8" drencher head at 4 bars working pressure

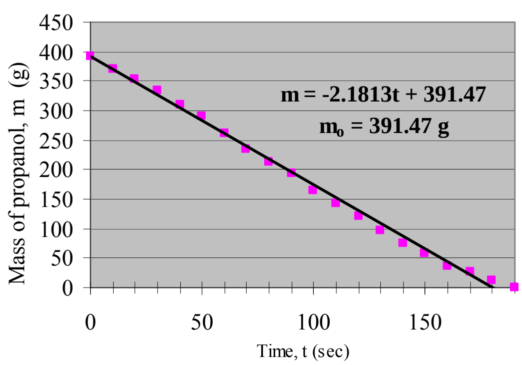


Fig. 4: Experimental result of mass loss rate (g/s) of propanol

5. RESULTS AND ANALYSIS

5.1 Comparison between Fire Sizes and Working Pressures

After collection of experimental results, firstly the radiative heat flux was recorded and the radiative heat flux for the fire size of 160 kW under three different conditions are shown in Fig. 5. It included the measurement of radiative heat flux under the conditions without curtain and with curtain of 4 bars and 6 bars working pressures. From Fig. 5, it is shown that the radiative heat flux of without discharging curtain is the highest, because there is no any blockage media for radiation; but the radiative heat flux is lowest when the discharged curtain is at 6 bars working pressure. Furthermore, it is necessary to convert the radiative heat flux to the radiation attenuation which can show the percentage of attenuated radiation through different medium. The radiation attenuation α (%) can be defined as percentage of transmitted radiative heat flux (I_0 - I) to the incident heat flux (I_0) without discharging curtain (kWm^{-2}). An assumption is made that identical heat radiation is generated from the same fire size. α is given by:

$$\alpha = (I_0 - I) / (I_0) \qquad (1)$$

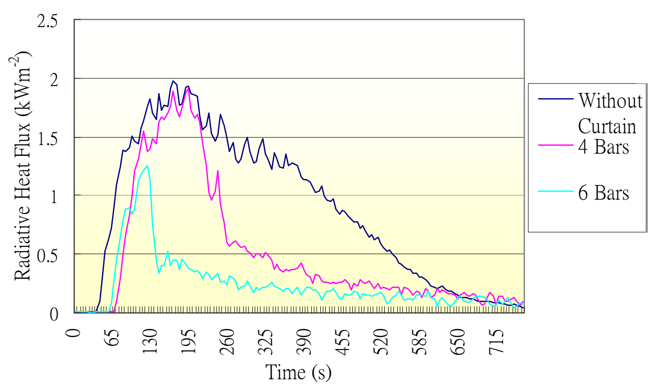


Fig. 5: Radiative heat flux for fire size of 160 kW

From Fig. 6 and Table 1, it indicated that the higher the working pressure, the higher the radiation attenuation effect, that means the water curtain with higher working pressure would achieve a better radiation blockage effects. Moreover, from Fig. 6, the curve of 4 bars working pressure, the value of radiation attenuation is nearly zero from 150 s to 200 s. According to equation (1), when I is equal to I_0, the radiation attenuation result would become zero. Two reasons why the incident heat flux is equal to the transmitted heat flux are: First, the heat radiation generated from the fire sources of measurements of incident and transmitted heat flux should be the same. Second, when there is no blockage media in between the sensing point of the heat flux transducer and the fire source, radiation can be transmitted to the protected zone directly. Because of the transient pattern of water curtain, air space is formed at the sensing area of the heat flux transducer. Therefore, the incident and transmitted heat flux is the same and eventually the results of radiation attenuation become zero.

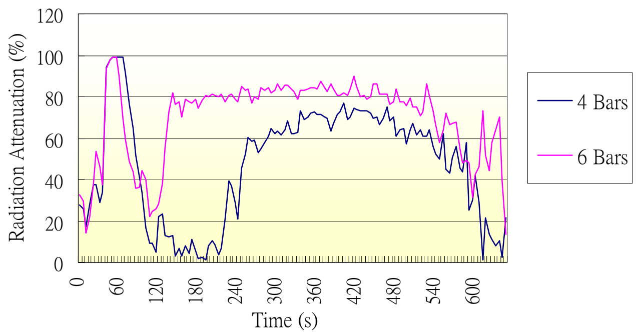


Fig. 6: Radiation attenuation for fire size of 160 kW under 4 and 6 bars

Table 1: Summary of the average radiation attenuation for different pressures and fire size

Working pressure (bars)	Fire size (kW)	Average attenuation (%)
6	160	69.67
4	160	47.40
6	41	52.76
5	41	41.95
4	41	36.00

Fig. 7 shows the radiation attenuation of water curtain under different working pressures of 4, 5 and 6 bars. It indicated that the attenuation ability for 6 bars working pressure is higher than the others. However, the results were fluctuating due to the fire as well as the curtain is transient that is changing for every second. Therefore, the reading became lower when there was no water in between with the sensing point of heat flux transducer and the fire source. Whereas, when there was water in between with the sensing point of heat flux transducer and the fire source, certain radiation was blocked and the reading of radiation attenuation became higher. Furthermore, as it is difficult to compare the result of 4 bars and 5 bars by just using Fig. 7, the average attenuation of each result was calculated and shown in Table 1 which demonstrated that the higher the working pressure of water curtain, the better the radiation attenuation capability. Moreover, by comparing the fire sizes, the larger the fire size, the better the radiation attenuation ability.

5.2 Comparison between Different Flow Rates of Discharging Curtain

Fig. 8 shows the radiation attenuation effects with variation of the discharge flow rate of water curtain. At the beginning from 0 s to 50 s, the results of radiation attenuation are very unstable. For the curve of 1.02 l/s flow rate, some attenuation results are negative values. It is because the fluctuation of fire and actually the radiation generated is not the same in different testes, although the fire sizes are the same. The radiation generated from the experiment of measurement of incident heat flux is higher than that of transmitted heat flux, so by equation (1) the result would become negative. This situation was improved after 60 s and the fire developed steadily.

Furthermore, Table 2 demonstrates the average attenuation of different flow rates. It showed that the higher the working flow rate, the better the attenuation effect. And for each experiment, the flow rate was increased by 0.14 l/s, and the attenuation effect was increased almost 10%. For the last experiment, the flow rate was increased by 0.28 l/s, and the attenuation ascended almost 27% with reference to 1.02 l/s. The results can be explained by the shape of the water curtain. If the flow rate was increased, the air space in the curtain would decrease. Therefore, the fewer the air space, much less radiation can transmit through the air space of water curtain to the receiver. In conclusion, the higher the flow rate, the lesser the air space, and the better the radiation attenuation ability.

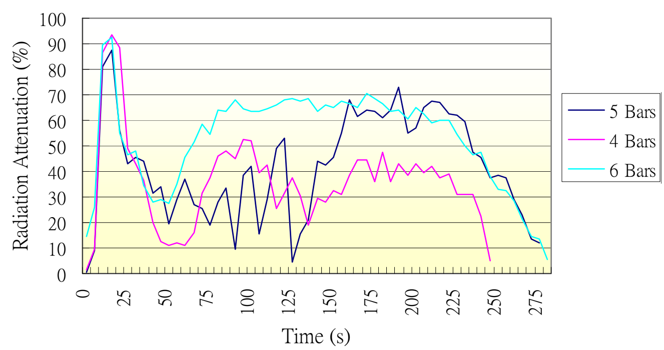


Fig. 7: Radiation attenuation for fire size of 41 kW under 4, 5 and 6 bars

Table 2: Summary of average radiation

Working flow rate (l/s)	Fire size (kW)	Average attenuation (%)
1.02	41	31.82
1.16	41	41.53
1.30	41	59.15

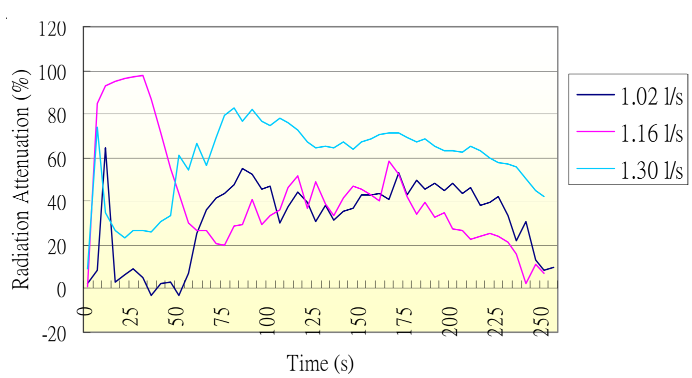


Fig. 8: Radiation attenuation (%) of different flow rates (l/s)

5.3 Comparison with Different Types of Drencher Nozzle Head

Fig. 9 shows the attenuation efficiency of two different types of nozzles. The orifice diameters of the nozzles are 3/8" (9.5 mm) and 7/16" (11 mm). The attenuation ability of the smaller size nozzle is better than that of larger size nozzle. The drencher system was actuating after 30 s, so Fig. 9 indicted that after the actuation of drencher system, the attenuation abilities of two different nozzles were clearly distinguished. Moreover, Table 3 showed the average attenuation for the result shown in Fig. 9. The radiation attenuation of smaller nozzle was 52.76%, which is 9.46% higher than that of the larger nozzle. It is because the analysis of the influence of the flow rate has proved that for the same quantity of water, the smaller orifice nozzle with finer drop achieves higher attenuation than that of larger orifice nozzle, which provides larger drops [6]. Therefore, to improve the efficiency of a water curtain, the key element is the way that water is sprayed into droplets, rather than the quantity of water delivered [6].

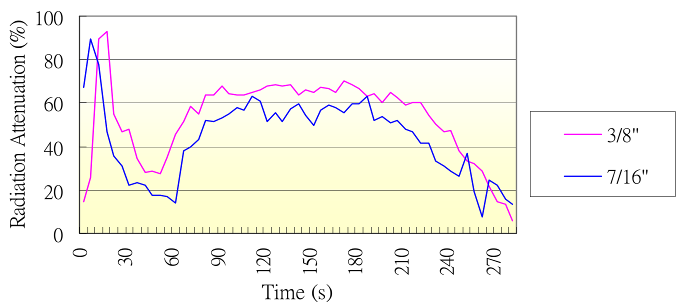


Fig. 9: Radiation attenuation of two different nozzles under 6 bars working pressure and 1.02 l/s flow rate

Table 3: Summary of average radiation attenuation of different nozzles

Diameter of drencher nozzle (inch)	Fire size (kW)	Average attenuation (%)
3/8"	41	52.76
7/16"	41	43.30

5.4 Temperature Profiles in the Fire Chambers

The temperature profiles in the fire chambers are shown in Fig. 10. The profiles included the temperatures on the fire side, temperatures on the protected side with and without discharging curtain. Firstly, the temperatures of the fire side was the highest, it was due to the shortest distance between the thermocouples and fire source, so the radiation can be transmitted to the temperature sensor in that short distance as well as least reduction of radiation transmitting.

Secondly, the temperatures of the protected side with discharging curtain are much lower than that of without curtain. The temperature difference between them can be as great as 130°C and the average temperature difference is 77.96 °C. Therefore, water curtain is quite effective in cooling the space air. Moreover, from Fig. 10, there was no great difference in changing the working pressure of curtain. Therefore, it can be concluded that water curtain is quite effective in cooling, but the cooling effect of water curtain is independent on the working pressure.

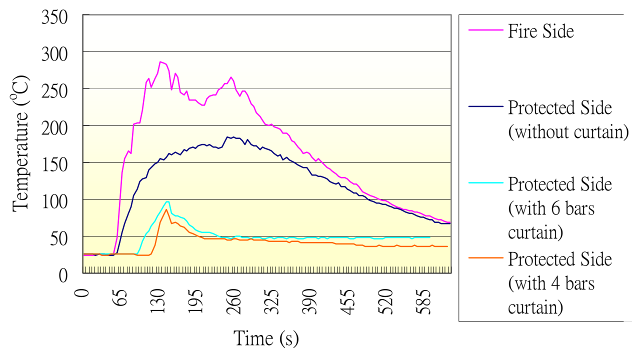


Fig. 10: Temperature profiles in the fire chambers

5.5 Error Analysis

By consideration of experimental errors, there were some parameters causing the inaccuracy of the results. Firstly, the results of radiation attenuation and radiative heat flux were fluctuating. It is due to the fluctuation of fire, and the fire was not burned steadily for each test. However, as the incident and transmitted heat flux could not be measured at the same time, that means the fire was not the same. Therefore, by using the attenuation equation on α given by equation (1) would not equal to the actual attenuated radiation. Nevertheless, due to the reasons of resources limitation and the problem of smoke generation, it was not possible to repeat the experiment, so the error cannot be minimized by averaging the experimental results. Moreover, as the fire is fluctuating, so this error would not be eliminated by repeating the experiment. Therefore, it is necessary to evaluate the error bars, in this the case the error bar is equal to 610%. The results taken from 0 s to 30 s is not used for analysis, because the fire is not in a steady burning state, therefore the error bar was computed only from 30 s to 110 s.

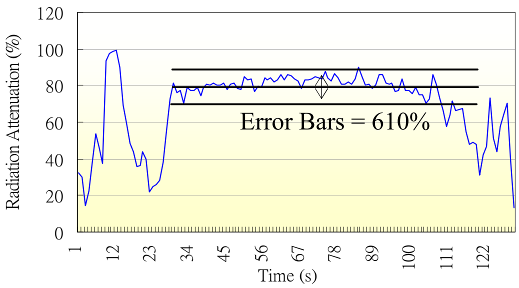


Fig. 11: Determination of the error bars of the radiation attenuation

6. CONCLUSIONS

The experimental work presented in this paper has provided useful and valuable information about the attenuation parameters of water curtain subjected to thermal radiation. The observations of water curtain under stroboscope have clearly shown that the discharging curtain is not a continuous water layer, but a transient pattern with much air space inside the curtain. Therefore, water curtain is not capable to use for the blockage of smoke spreading, as the smoke particle would transmit through the transient air space. The experimental results have also shown that the higher the working pressure, the better the radiation attenuation ability. When the working pressure increased from 4 bars to 6 bars, the radiation attenuation increased from 36% to about 57%. For larger fire size, the attenuation efficiency of water curtain also increases, it can be increased to 69.67% for heat release rate of 160 kW fire size. Moreover, for the increase in the flow rate from 1.02 l/s to 1.30 l/s, the radiation attenuation ability would almost double, from 31.8% to 59.2%.

Furthermore, by comparing two different orifice diameter of nozzles, the smaller one (3/8”) have almost 10% better attenuation effect than the larger nozzle (7/16”), it is due to the smaller nozzle can produce more finer drops with the same quantity of water as the larger nozzle. Therefore, to improve the efficiency of a water curtain, the key element is the way that water is sprayed into droplets, rather than the quantity of water delivered [6]. In addition, by studying the temperature profiles of the fire chambers, it has shown that water curtain has a good cooling effect, the temperature difference between two chambers is at least 50°C and even up to 125°C just after 200 s of actuation of the drencher system, but the cooling effect is independent on the working pressure of the drencher system.

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