WATER PENETRATION RATIO OF A SPRINKLER WATER SPRAY

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ABSTRACT

The 'water penetration ratio' of a sprinkler spray was studied in this paper. Experiments were conducted inside a fire chamber of size 4m × 2.96m and height 2.9m. A sprinkler spray was discharged and water was collected in 120 positions at the floor level. Wood cribs were burnt to provide a growing plume. The water collection rates with and without a fire were measured to determine the water penetration ratio. Results of this kind are useful for both improving the design of sprinklers and validating fire field models.

INTRODUCTION

Automatic sprinkler systems[1] are commonly installed in buildings for fire control. From statistical record, it can provide excellent protection to both building properties and human life. When the sprinkler is actuated, fire is controlled by at least three mechanisms[(2)-(7)], singly or combined: (1) cooling of the combustion products and the room to reduce the thermal feedback to the combustible elements; (2) direct contact of water droplets with the burning material to prevent further generation of combustible vapor by cooling the burning fuel; and (3) prewetting the combustible material to prevent fire spread. Associated with the first mechanism are two other effects: (1) inerting of the gas mixture inside the room by the evaporated water; and (2) the displacement of large volume of air from the room by steam. However, it was estimated that the actual water flow rate required to extinguish a fire is only one-third to one sixth of the normal flow rates given by sprinklers at a surface radiation flux of 8 W/cm^2. The main reason why larger flow rates of water are needed is because not all the water droplets discharged from the nozzle can reach the lower level[(8)-(10)]. Therefore, the effectiveness of the system is highly reduced.

The most important part of a sprinkler system is the sprinkler head. It can be regarded as a thermally actuated valve and an orifice with deflection plates. Water discharged from it would strike the deflection plate and form a spray composing water droplets with different sizes. These water droplets are expected to reach the burning objects or the surroundings. However, not all of them can reach at the burning combustibles because their terminal velocities might be less than the upward fire plume velocity[(8-11)]. Evaporative mass loss while traveling through the smoke layer is another possibility but this effect is only obvious when the droplets size is very small[(6)]. This paper presents an experimental study on this phenomenon. The following section describes the water penetration ratio and a self-developed experimental set-up. It is then followed by a description on the experiments performed in a sprinklered chamber with wood crib fires. Results are then presented and the paper ends in the last section with a conclusion.

WATER PENETRATION RATIO

Physically, the amount of water discharged from the sprinkler which is able to penetrate through the plume to act on a fire can be described by a "penetration ratio"[(8),(9)]:

$$\text{Penetration Ratio} = \frac{V_f}{V_i} \times 100\% \qquad (1)$$

where V_f is the volume of water collected at a lower level in the present of a fire plume and
V_i is the volume of water collected at the same positions without the fire.

This can be determined by measuring the water collected at lower levels. An instrument was devised to measure the water collection rate continuously during the burning process. A strain gauge can be used but the cost is too expensive, i.e. more than HK$900,000 for collecting water at 120 points. But the cost of this self-developed instrument is only about HK$10,000 and this set-up would fulfil the requirement of:

(1) continuous measuring of the volume collected inside the measuring cylinder at any time interval;
(2) having a controllable time interval.

This is a paper tape marker attached to a measuring cylinder through a marker hanger as shown in Fig. 1. An addressable paper tape is connected to a mass which is fixed to a float inside the measuring cylinder. When water flows into the measuring cylinder, the float would move up with the mass and pulled the paper tape through the mark gradually. As the paper tape falls down, the marker would punch a clear point mark on the paper at a constant time interval (e.g. 20 seconds) set by the signal generator. The separation of two point marks will give the amount of water collected within such interval.

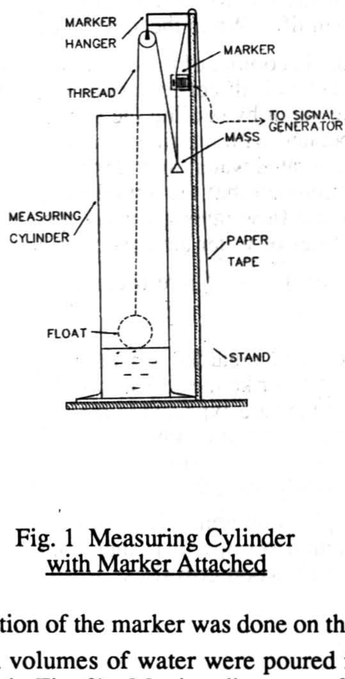

Fig. 1 Measuring Cylinder
with Marker Attached

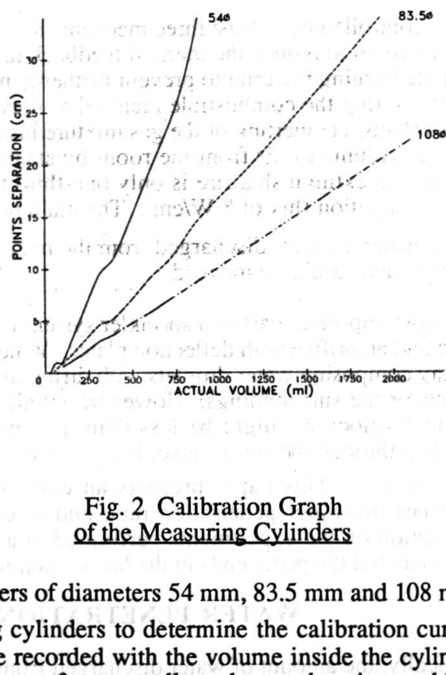

Fig. 2 Calibration Graph
of the Measuring Cylinders

Calibration of the marker was done on three measuring cylinders of diameters 54 mm, 83.5 mm and 108 mm.

Known volumes of water were poured into these measuring cylinders to determine the calibration curves (shown in Fig. 2). Moving distances of the paper tapes were recorded with the volume inside the cylinder plotted against the points separation. In this way, the amount of water collected at each point could be determined by measuring the separation distance of each point from the paper tape and their corresponding calibration curves.

EXPERIMENT

An ideal space for testing an Ordinary Hazard Class sprinkler[1] is in a laboratory of area bigger than $12m^2$ (3m × 4m). However, due to the space limitation, the experiments were carried out inside a fire chamber of size 4m × 2.96m and height 2.9m[10]. In order to provide a free spray within the space without any obstruction, the tested sprinkler was fitted under the ceiling near a corner of the chamber. A spray divider was introduced near the sprinkler to divide the water spray pattern into four quarters. Only one quarter of the spray could be discharged freely into the space and all the other portions were drained away. This spray divider was constructed such that it was symmetric about the axis of the sprinkler.

The experimental set up is shown in Figs. 3 with 3(a) showing the isometric veiw, 3(b) the plan view of the grids and 3(c) the schematic diagram of the sprinkler system. The fire chamber was divided into 10 × 12 grid points, labelled from A to L in one axis and 1 to 10 for the other. For example, the point A10 is just beneath the sprinkler head. Moreover, the chamber was filled with 120 addressable collection pans of size 0.25m × 0.25m. All of them were elevated 0.6m above the ground by means of aluminium frames. The space left below was used to place the measuring cylinders. The pans were included so that water received could be drained immediately to the measuring cylinders. After positioning the paper tapes to the markers, all the markers were wired to a signal generator.

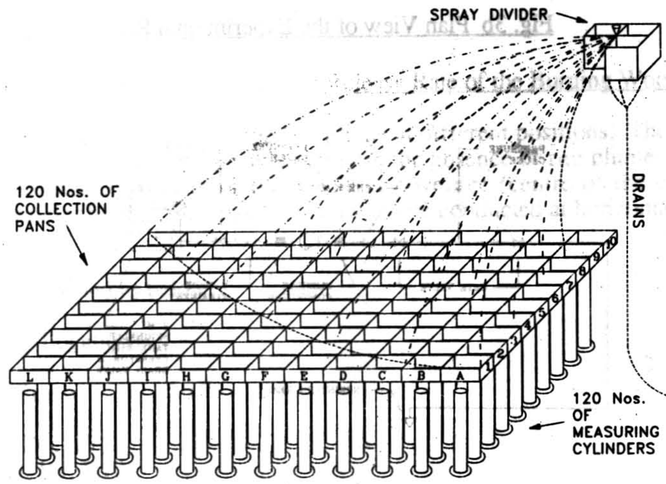

Fig. 3a Diagram of the Experimental Set Up

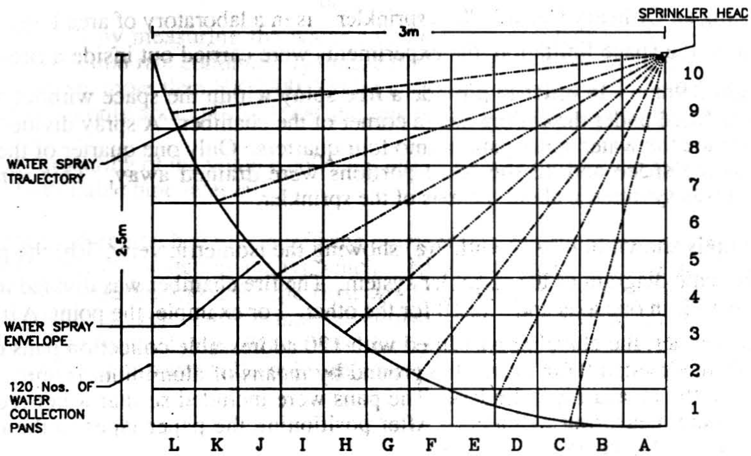

Fig. 3b Plan View of the Experimental Rig

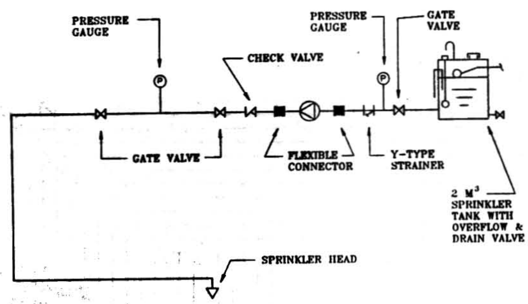

Fig. 3c Schematic Diagram of the Sprinkler Set-Up

Two thermocouples were installed inside the chamber. One was put adjacent to the fire plume for measuring the air temperature around the fire. This would provide information on the temperature growth rate of the wood crib fire throughout the experiment. The other thermocouple was mounted just beside the sprinkler head. Forty 'sugar pine' sticks, each of size 25 mm × 25 mm × 310 mm, were stacked in eight layers to form a crib. An electronic balance was used to measure the transient mass of the crib for estimating the free burn heat release rate. The crib was ignited by burning 150g of alcohol and 20g of cotton wool and the mass loss curve of the wood crib is shown in Fig. 4. The water discharge rate was maintained at a constant value. The flow rate of the sprinkler head was set to be 57.6 1/min with a pressure of 2.7 bar at the installation valve.

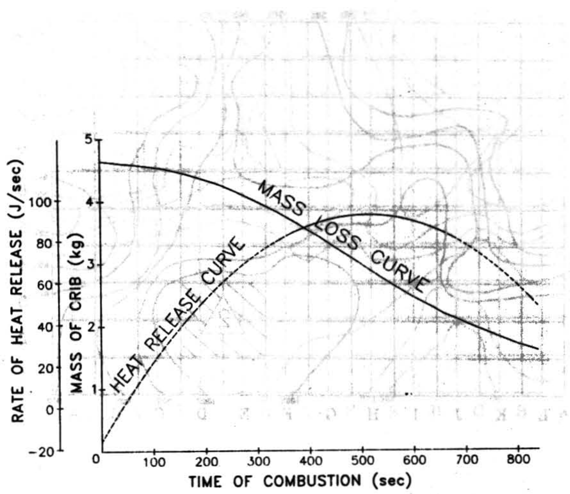

Fig. 4 The Graph of Mass Loss & Heat Release Rate of the Burning Wood Crib

A series of experiments was conducted under the fire plume at different positions. The first one was carried out to obtain the water distribution of the sprinkler spray in the absence of fire plume. The second one was carried out with a fire located at the rim of the sprinkler coverage (centre of the crib was about 1.5 m horizontally from the sprinkler head). Whereas the last two were conducted at horizontal distances of 1m and 0.3 m from the sprinkler head.

The tests carried out were labelled as below:

Test No.	Fire Plume Locations
1	No Fire Plume
2	(D2, D3, E2, E3)
3	(C6, C7, D6, D7)
4	(A9, A10, B9, B10)

RESULTS AND DISCUSSIONS

The experimental data for the amount of water collected and the penetration ratio at different locations were analyzed. The penetration ratio measured at many points was less than unity but some points was found to have a value greater than 100%. This was due to changes of the water droplet trajectories when there were fires. Fig. 5, 6 and 7 illustrated the effect by varying the position of the fire plume from 0.3 to 1.5m from the sprinkler head. Fire plume in Fig. 5 was placed at grids D2, E2, D3, E3, (i.e. Test 2) while the locations were C6, C7, D6, D7 (i.e. Test 3) and A9, A10, B9, B10 (i.e. Test 4) for Figs. 6 and 7, respectively.

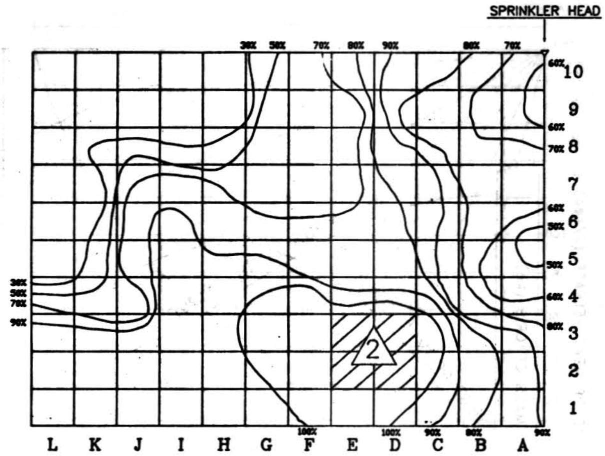

Fig. 5 Contour Diagram for the Penetration Ratio of Test 2

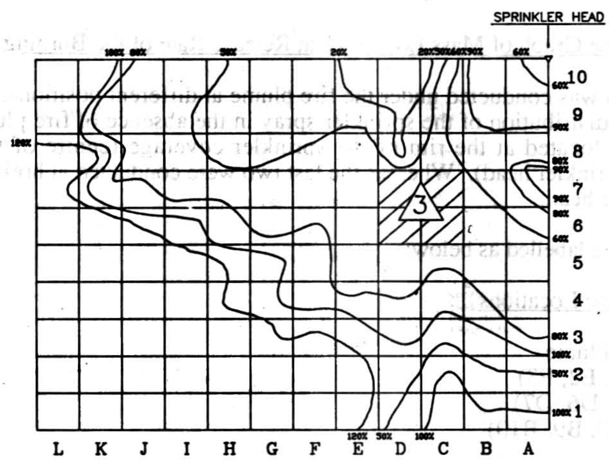

Fig. 6 Contour Diagram of the Penetration Ratio of Test 3

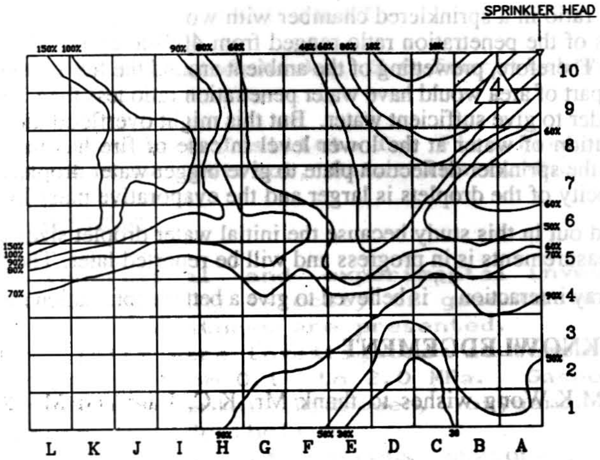

Fig. 7 Contour Diagram for the Penetration Ratio of Test 4

The results in Fig. 5 and 6 indicated that along the direction of the sprinkler and the fire plume, the penetration ratio was increased with increasing distance away from the sprinkler. At some locations, the ratio was greater than 100%. No water was found on the rim. It was shown from Fig. 7 that comparatively low penetration ratio of values lying between 40 to 60% was measured. This phenomenon was due to the effect of the location of the fire plume. As this crib fire was placed below the sprinkler, the sprinkler head was operated rapidly when the fire started. However, the sprinkler water spray failed to extinguish the fire and so the plume was still growing at the later stages. Thus not much water could reach the burning combustibles as illustrated by the temperature curve in Fig. 8.

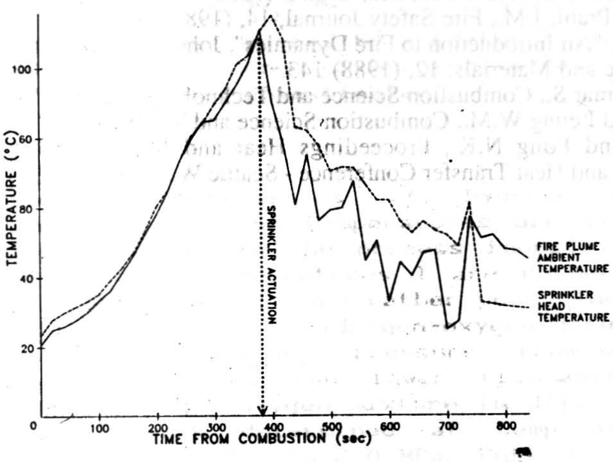

Fig. 8 The Graph of Sprinkler Head & Fire Ambient Temperature

CONCLUSIONS

The water penetration ratio in a sprinklered chamber with wood crib fires located at different positions are measured. The values of the penetration ratio ranged from 40% to above 150% with higher values found behind the fire plume. Therefore, prewetting of the ambient around the fire is better in the direction away from the sprinkler. A large part of area would have water penetration ratio less than 100%. Larger amount of water has to be applied in order to give sufficient water. But this might overflood the lower level. To avoid this, a more uniform distribution of water at the lower level in case of fire has to be achieved. Modifying the geometrical feature of the sprinkler deflection plate to give bigger water droplets might be a solution. In this way, the terminal velocity of the droplets is larger and the evaporative mass loss is smaller. No theoretical works [(6),(8),(9)] are carried out in this study because the initial water droplet sizes and velocities have not been measured. Further measurements is in progress and will be reported later. The field modelling technique of fire plume sprinkler spray interaction [(15)] is believed to give a better explaination on the problem.

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