# FURTHER STUDIES ON WATER MIST AND VENTILATION

**W.K. Cheung**
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

## ABSTRACT

Water mist technology for fire suppression is widely regarded as an alternative to gaseous fire suppression agents, such as Halon 1301 and carbon dioxide. Primary and secondary extinguishing mechanisms of the water mist fire suppression system (WMFSS) will be described. These include heat extraction, oxygen displacement and radiant heat attenuation for primary mechanisms; and dilution of vapour/air mixture and kinetic effects of mist on flames for secondary mechanisms. The advantages of WMFSS over gaseous agent systems and conventional sprinkler systems are also discussed in this paper. The effectiveness of WMFSS in pool fire is investigated with emphasis put on the variation of room temperature, required extinguishing time and water distribution. During the tests, whether low pressure single-fluid water mist systems can extinguish fires effectively under natural and forced ventilation will be reported. It is observed that not all, but most of the fires could be extinguished rapidly by discharging water mist.

## 1. INTRODUCTION

It was stated in the 1985 Montreal Protocol that Halon is to be phased out due to its environmental effect including ozone depletion and global warming. Due to this reason, it is necessary to develop the alternative means of active fire protection, and WMFSS might be a possible substitute. In the past few years, WMFSS for fire protection have been extensively investigated. The use of WMFSS for fire extinguishment and control is currently receiving considerable attention as one of the potential replacement for Halon 1301 by some big research institutes [1]. Using WMFSS for protecting equipment not only can extinguish a fire but also reduce the damage through smoke scrubbing with finer droplets. In accordance with NFPA 750, water mists have been defined as sprays which have 99 % of the water droplets less than 1000 μm in diameter. It is generally recognized that finely divided water sprays were more efficient than coarser sprays to absorb heat from the fuel or nearby objects, particularly with liquid fuel pool fires. In the 1970s, WMFSS were applied to suppress the fires in the machinery rooms. Now WMFSS is widely used in marine and many industrial applications [1]. The wide application of water mist is because of its many advantages.

- Advantages of WMFSS over gaseous agent systems

  As a matter of fact, water is non-toxic, non-corrosive, and readily available, less clean-up time and lower in cost than most chemicals or patented mixtures [2]. Water mist is safe to people and equipment. It is the most effective and common to use Halon gas for fire suppression, however, it is a CFC ozone-depleting product. Also, total flooding $CO_2$ system effectively extinguishes fires but suffocates people in their vicinity [3]. Comparatively, water mist has an advantage of being environmental-friendly. Therefore, fine water spray system is an alternative to gaseous system without the associated environmental or toxicity hazards.

- Advantages of WMFSS over conventional sprinkler systems

  WMFSS reduces the water flow rates and therefore less water damage to sensitive equipment or occupancies. Low water flow rate is also an obvious advantage in terms of space and weight requirements for the water supply. Since conventional sprinkler systems may damage high temperature equipment surfaces by too rapid cooling due to high water fluxes and large droplet diameters [2]. Water mist is able to control flammable liquid fires that conventional sprinklers cannot control due to splashing and spillage of the fuel. In this respect, WMFSS is better than conventional sprinkler system.

## 2. LITERATURE REVIEW

Detailed extinguishing mechanisms of WMFSS were discussed in the literature [4,5]. They are divided into three primary and two secondary mechanisms. Primary mechanisms include:

- heat extraction,
- oxygen displacement and
- blocking of radiant heat.

Secondary mechanisms, which are difficult to quantify their importance, consist of:

- vapour/air dilution and
- kinetic effects.

Heat extraction means cooling. Water is used for absorbing the heat in order to cool the fuel and the nearby objects to reduce fire spread and prevent re-ignition that may occur [4]. Once finer droplets are produced, the surface area of the water mass increases and thereby increases the rate of heat transfer. Oxygen displacement occurs when the water evaporates and becomes steam by expanding over 1600 times [4]. This facilitates displacement of the oxygen content in air. If the amount of oxygen decreases, the fire will be extinguished easily. Blocking fire radiation, water droplets are suspended in the air to reduce thermal feedback to burning and unburned object surfaces; vaporization or pyrolysis rate at fuel surface [4]. This prevents objects from radiant heat damage. Vapour/air dilution is to dilute the vapour/air mixture to below the flammability limit. Dilution is the mixing of water vapour and entrained air in flammable vapour area on the fuel surface. For kinetic effects, a "flare-up" often occurs in the first contact with water mist, and it is evident in some fire tests that the burning rate is increased for longer periods due to turbulence [4]. The "flare-up" is because of quick knockdown and extinguishment of the flames. The velocity of the flame front in flammable gas mixture may be inhibited or accelerated by dispersing water droplets in the flame depending on the spray dynamics [4].

Besides, nozzle limitations and classifications; application systems and piping requirement were stated in NFPA 750 Standards for WMFSS. Comparison of WMFSS with other main types of fire suppression technologies and common classification of water mist system were performed by Yao and Chow [1]. WMFSS has more benefits over the other types of fire suppression technologies.

The most common study was on temperature distribution. The result of temperature distribution with respect to time was analyzed by Liu et al. [6]; Yao et al. [7]; Andersson and Holmetedt [8] and Downie and Polyneropoulos [9]. The relationship between the skin temperature of human simulator and time using super-heated water in full-scale experiment was stated by Andersson and Holmetedt [8]. The temperature greatly increased at the later time. The thermal field visualization for the large liquid sample before and after the water mist application under different pressure was reported [7]. There were some graphs shown between time and room temperature which was measured at thermocouple trees for different fires compared between no ventilation (door is closed) and natural ventilation with single-fluid system, and also forced ventilation with twin-fluid system [8].

The gas concentrations (CO, $CO_2$, $O_2$) were measured [6-8]. Nevertheless, the gas concentration with respect to distance from the burner, when others used time from ignition, was only measured by Downie and Polyneropoulos [9]. Gas concentrations with and without ventilation in both types of fluids were compared [6]. The $CO_2$ concentration with door open was slightly higher than that with door closed, but $O_2$ concentration was slightly lower. However, only twin-fluid was used to compare gas concentration in different ventilation conditions. Five fire scenarios (tell-tale, square-pan, round-pan, spray and wood crib fires) in different locations within the compartment included various ventilation conditions and two kinds of water mist system (single- and twin-fluid) were tested [6].

Furthermore, the fire size (kW) and extinguishing time are shown. Not all but most fires could be extinguished by water mist. Besides, the results of heat release rate of the two liquid fuel samples, which weighed 34 g and 100 g of ethanol respectively, before and after the activation of water mist were given [7].

Next, two sizes of flames (26.5 kW and 53 kW) were applied [9]. The relative radiation readings for a period of 3 min after application of water mist and the relationship between heat release rate and initial spray angle are shown. Radiation readings of 53 kW were much higher than that of 26.5 kW. The resulting spray angle increase resulted in larger dispersion of the droplets, and then heat release rate increased. It can be concluded that water mist had a more complex effect on solid fuel, and fuel characteristics and ventilation condition can significantly affect water mist suppression capability [7].

On the other hand, high-pressure system, twin-fluid system and super-heated water system were suggested [8] to produce water mist. They involved different locations and numbers of nozzles, and different results (including water content with time) of extinguishments were presented. Also, 150 to 200 g water per $m^3$ protected volume was required to extinguish a fire in total flooding applications. If the water is in vapour phase, twice as much water is required [8]. The limitations in distributing water mist evenly in the entire room were also stated, namely, difficult to produce small water droplets; lifetime of water mist was short in higher temperature; and relative density was different between droplets and vapour mixture.

Moreover, the size and velocity measurements made by using a self-contained laser probe operating on the shadowing principle, the sizes of individual droplets recorded by a computer, and the information used to calculate the velocity were tested [10]. The droplet size distribution for the water spray was measured in 29 locations within the compartment. The velocity of water mist was calculated based on the time required for each droplet to pass through the probe image field.

Besides, spray characteristics, droplet distribution, flux density, spray momentum, calculations of different systems (low-, intermediate- and high-pressure with single-fluid systems, declining pressure system and twin-fluid system) and detection systems were analyzed by the National Fire Protection Association, USA.

## 3. METHODOLOGY

In order to understand and investigate suppression time, water and temperature distribution of WMFSS, it is important to conduct experiments on water mist. The local application system was conducted in an empty enclosure. A class B fire, 0.41 m in diameter (500 ml 2-propanol), was placed in the center of the room (4 m × 2.9 m × 2.6 m). The test compartment had a 2.3 m × 0.9 m door. One brass nozzle was located at the center of the ceiling. The single-fluid type WMFSS was used. Suppression time, water and temperature distribution were recorded. Besides, the ventilation conditions in the compartment included natural ventilation (door open) and forced ventilation (door open with two exhaust fans running). The flow rates of the two exhaust fans were 0.31 $m^3s^{-1}$ and 0.17 $m^3s^{-1}$ (Table 1). One K-type thermocouple tree with 7 channels (Fig. 1) was set up to measure room temperature and the effect of ventilation on fire suppression. It was located at 0.8 m from the fire. Water pressure was set at 10 bar measured by the pressure gauge; also the extinguishing time was measured by a stopwatch and observation. As shown in Table 2, water flow rates were 0.531 $Ls^{-1}$ and 0.542 $Ls^{-1}$ under 10 bar under natural and forced ventilation respectively. Water distribution was measured by measuring cylinders which were evenly distributed in the compartment (Fig. 2 and Fig. 3). Test fires were allowed 1 min pre-burn period before suppression commenced. The door was kept open to allow fresh air to enter the room during the entire process. For the tests with forced ventilation, the exhaust fans were turned on at the same time. After the first trial, lots of measuring cylinders did not contain any water (Table 3), as the measuring cylinders were placed outside the water coverage area produced by the nozzle. Therefore, another approach was carried out with the measuring cylinders placed in a circular shape around the fire (Fig. 4).

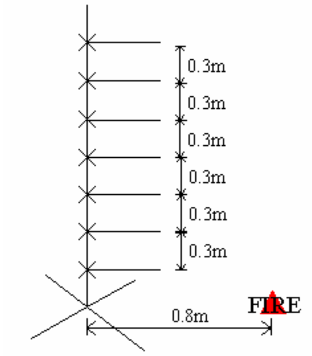


**Fig. 1: K-type thermocouple tree**

**Fig. 2: Measuring cylinders evenly distributed**

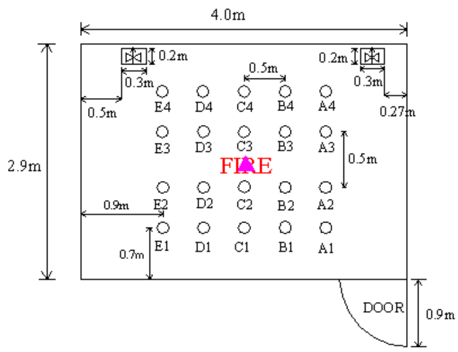


**Fig. 3: Initial arrangement**

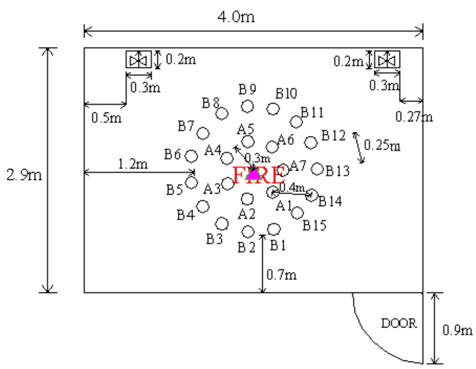


**Fig. 4: Second arrangement**

**Table 1: Exhaust fan flow rate**

| Exhaust fan 1 | Exhaust fan 2 |
|---|---|
| Temp. = 21.2 °C | Temp. = 21.4 °C |
| Flow rate = $0.31 m^3 s^{-1}$ | Flow rate = $0.17 m^3 s^{-1}$ |

**Table 2: Water flow rate**

| Natural ventilation | Forced ventilation |
|---|---|
| water flow rate = 0.531 L/s | water flow rate = 0.542 L/s |

**Table 3: Water distribution from 1st approach**

| Position | Water content / ml | Position | Water content / ml | Position | Water content / ml | Position | Water content / ml | Position | Water content / ml |
|---|---|---|---|---|---|---|---|---|---|
| A1 | 0 | B1 | 0 | C1 | 10 | D1 | 0 | E1 | 0 |
| A2 | 0 | B2 | 20 | C2 | 20 | D2 | 10 | E2 | 0 |
| A3 | 0 | B3 | 30 | C3 | 50 | D3 | 10 | E3 | 0 |
| A4 | 0 | B4 | 0 | C4 | 0 | D4 | 0 | E4 | 0 |

## 4. RESULT

From Fig. 5, most of the measuring cylinders did not contain any water in the first approach. However, after the second arrangement of measuring cylinders as in Fig. 4, and discharging water for 30 s, different results were observed. More measuring cylinders contained water (Fig. 6). The second approach was carried out with natural and forced ventilation. In the experiment, dissimilar results were observed in water mist performances under natural and forced ventilation. Once the fire burned with water discharge only, the volume of water obtained under natural and forced ventilation was different. In Fig. 7 and Fig. 8, water measured under forced ventilation was concentrated in the centre of the compartment than that of natural ventilation. Although in the same condition with forced ventilation, the results were not the same (Fig. 8 and Fig. 9). WMFSS was not stable to discharge the water.

On the other hand, water and temperature distribution were also measured. As shown in Table 4, for the test with natural ventilation, most of the maximum temperatures in different channels appeared after the activation of the water mist system. But that of the test with forced ventilation appeared before the operation of water mist. Also, the average room temperatures near the floor will be lower than temperatures in the upper portion of the compartment due to the cold fresh air flowing into the room. Compared to the tests with natural ventilation, tests with forced ventilation had larger water content, since the air mass exchange between the room and the surrounding increased when there was forced ventilation. Generally, air inflow rate into the room through the door was proportional to the flow rate of exhaust fans. Considerably, the average room temperature in natural ventilation condition was higher than that of forced ventilation condition. As a result, more water mist evaporated in the surrounding with higher temperature. As shown in Table 4, the water quantity obtained in natural ventilation was slightly less than that in forced ventilation. There was less water quantity covered in natural ventilation than in forced ventilation as shown in Fig. 10 and Fig. 11. Temperature distribution with natural and forced ventilation varied frequently as shown in Fig. 12 and Fig. 13. On the other hand, however, both extinguishing times of natural and forced ventilation were very short and difficult to define accurately. Besides, the fire load of 500 ml 2-propanol with coefficient of upper and lower heat of combustion also decreased with respect to time (Fig. 14). As shown in Table 5, extinguishing time had changed with different fuel volume and water pressure. The water pressure decreased, the extinguishing time increased. Nevertheless, it is not sensible that a 500 ml 2-propanol fire was extinguished faster than a 300 ml 2-propanol fire.

## 5. CONCLUSION

After the experimental studies on WMFSS in different ventilation conditions, it can be concluded that water mist can extinguish the fires and cool the compartment quickly. Different ventilation conditions largely affected the temperature and water distribution, and even the effectiveness of water mist. Forced ventilation reduced the extinguishing capability of the water mist system. However, summing up the experimental results, WMFSS was not stable to extinguish the fire. In the next semester, detailed experiments will be carried out. Fire suppression, water and temperature distribution, gas concentration of WMFSS will also be investigated and analyzed.

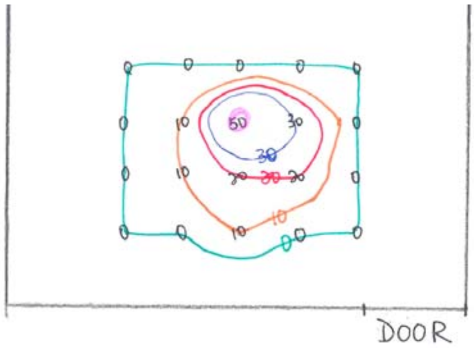


**Fig. 5: 1st approach (Natural)**

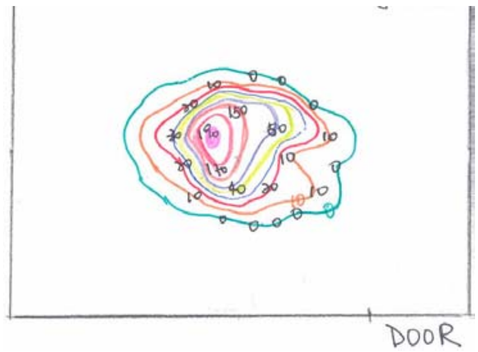


**Fig. 6: 30 s water discharge (Natural)**

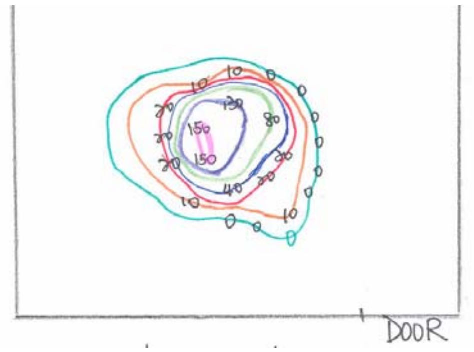


**Fig. 7: 2nd approach (Natural)**

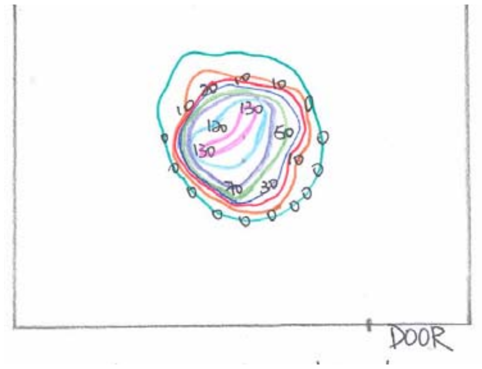


**Fig. 8: 2nd approach (Forced)**

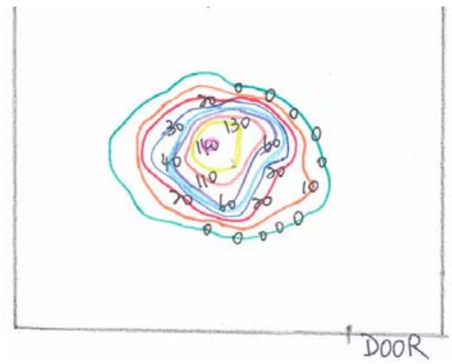


**Fig. 9: 2nd approach (2nd trial - Forced)**

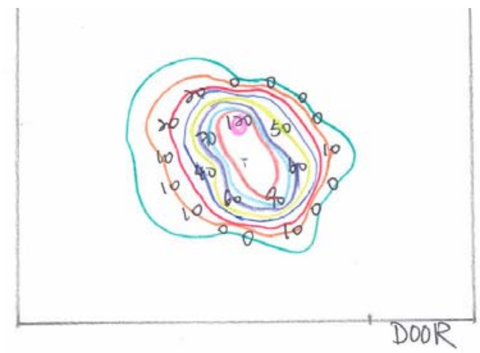


**Fig. 10: 2nd approach with temp measurement (Natural)**

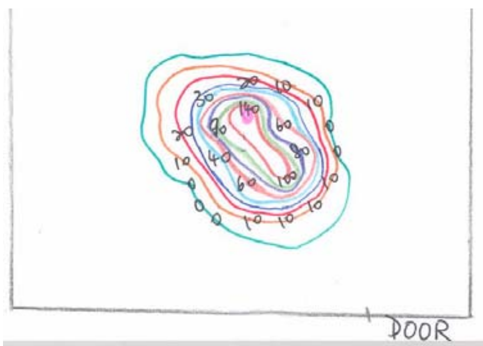


**Fig. 11: 2nd approach with temperature measurement (Forced)**

**Table 4: Suppression time, water and temperature distribution (2nd approach)**

**Natural Ventilation** $t_{ext}$ = 2 s Pre-burn = 1min Water discharge = 30 s

| Channel no. | $T_o$ / °C | $T_{max}$ / °C | Location | Water content / ml | Location | Water content / ml | Location | Water content / ml |
|---|---|---|---|---|---|---|---|---|
| 2 (lowest) | 24 | 69.4 at t=84s | A1 | 50 | B1 | 0 | B8 | 0 |
| 3 | 24 | 66.7 at t=81s | A2 | 60 | B2 | 0 | B9 | 10 |
| 4 | 24 | 61.9 at t=81s | A3 | 90 | B3 | 10 | B10 | 10 |
| 5 | 24 | 68.2 at t=81s | A4 | 60 | B4 | 0 | B11 | 10 |
| 6 | 24 | 77.3 at t=81s | A5 | 40 | B5 | 0 | B12 | 20 |
| 7 | 24 | 77.9 at t=81s | A6 | 70 | B6 | 10 | B13 | 20 |
| 8 (highest) | 24 | 77.5 at t=81s | A7 | 120 | B7 | 0 | B14 | 0 |
| | | | | | | | B15 | 0 |

**Forced Ventilation** $t_{ext}$ = 2 s Pre-burn = 1min Water discharge = 30 s

| Channel no. | $T_o$ / °C | $T_{max}$ / °C | Location | Water content / ml | Location | Water content / ml | Location | Water content / ml |
|---|---|---|---|---|---|---|---|---|
| 2 (lowest) | 24 | 70.5 at t=36s | A1 | 60 | B1 | 10 | B8 | 0 |
| 3 | 24 | 61.9 at t=36s | A2 | 80 | B2 | 0 | B9 | 0 |
| 4 | 24 | 65 at t=36s | A3 | 100 | B3 | 0 | B10 | 0 |
| 5 | 24 | 60.1 at t=36s | A4 | 60 | B4 | 10 | B11 | 10 |
| 6 | 24 | 61.7 at t=36s | A5 | 40 | B5 | 10 | B12 | 20 |
| 7 | 24 | 76.9 at t=24s | A6 | 90 | B6 | 10 | B13 | 30 |
| 8 (highest) | 24 | 69.2 at t=79s | A7 | 140 | B7 | 10 | B14 | 20 |
| | | | | | | | B15 | 10 |

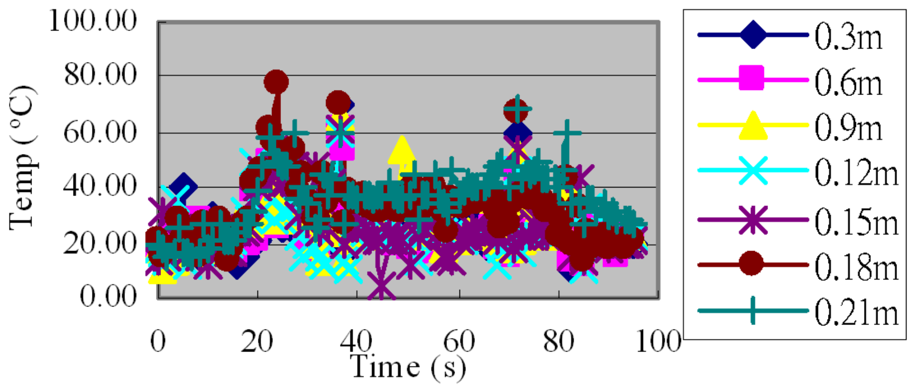


**Fig. 12: Temperature distribution (Forced)**

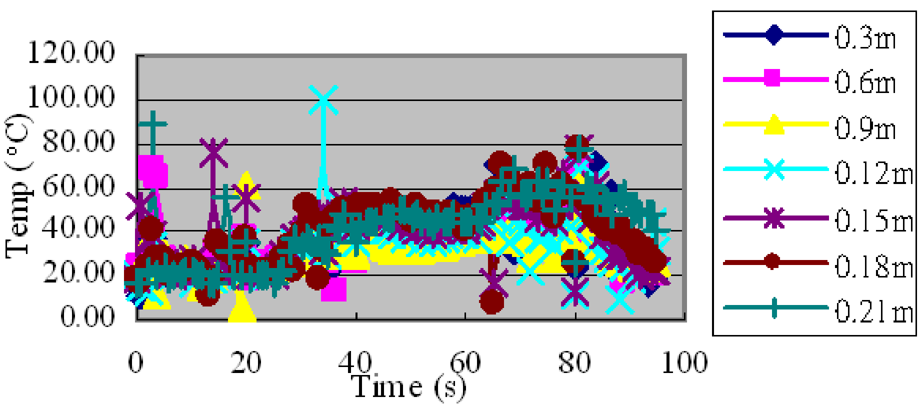


**Fig. 13: Temperature distribution (Natural)**

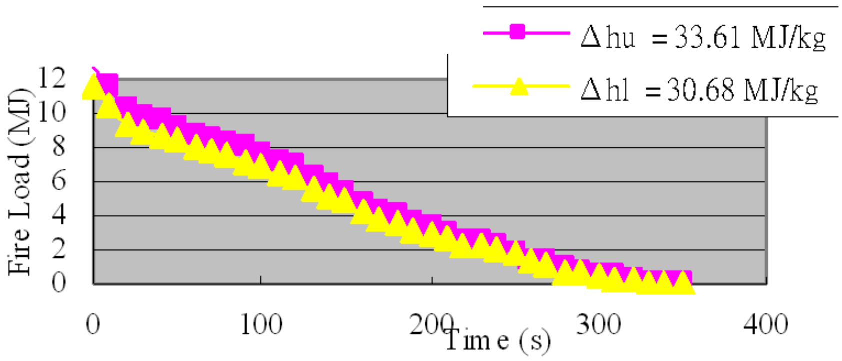


**Fig. 14: 2-propanol fire load**

**Table 5: Extinguishing time in different conditions**

| Fuel volume | Frequency inverter | Pressure | Extinguishing time |
|---|---|---|---|
| 300 ml | 37 Hz | 10 bar | 5 s |
| 300 ml | 37 Hz | 10 bar | 2 mins |
| 300 ml | 37 Hz | 10 bar | 4 s |
| 300 ml | 30 Hz | 7 bar | 5 s |
| 500 ml | 37 Hz | 10 bar | 3 s |

## ACKNOWLEDGEMENT

The author would like to thank Prof. W.K. Chow and Dr. N.K. Fong for their inestimable encouragement, guidance, valuable suggestions and information during the course of work. Special thanks are extended to Mr. Rocky Ho of the Spraying Systems Co. Ltd. for providing information of the water spray nozzles and Mr. Angus Cheng Chak-kit of the Laboratory of Building Services Engineering Department for giving help in the laboratory works.

## REFERENCES

1. B. Yao and W.K. Chow, "Overview on water mist fire suppression system", Journal of Architectural Engineering, Vol. 7, No. 3, pp.59-60 (2001).
2. T.N. Knoxville, "Water mist fire suppression systems", Proceedings of Technical Symposium on Halon Alternatives, Society of Fire Protection Engineers and PLC Education Foundation, 27-28 June (1994).
3. J.R. Mawhinney, "Characteristics of water mists for fire suppression in enclosures", Proceedings of Halon Alternatives Technical Working Conference, 10-11 May, Albuquerque, NM, USA (1993).
4. National Fire Protection Association, "Water mist fire suppression systems", Fire Protection Handbook, Section 6, Chapter 15, Quincy, Mass, pp. 216-248 (1997).
5. J.R. Mawhinney, B.Z. Dlugogorski and K. Kim, "A closer look at the fire extinguishing properties of water mist", Fire Safety Science - Proceedings of the Fourth International Symposium, pp. 47-60 (1994).
6. Z. Liu, K. Kim and Z. Su, "Examination of performance of water mist fire suppression systems under ventilation conditions", Journal of Fire Protection Engineering, Vol. 11, No. 3, pp. 164-193 (2001).
7. B. Yao, W. Fan and G. Liao, "Interaction of water mists with a diffusion flame in a confined space", Fire Safety Journal, Vol. 33, No. 2, pp. 129-139 (1999).
8. P. Andersson and G. Holmetedt, "Limitations of water mist as a total flooding agent", Journal of Fire Protection Engineering, Vol. 9, No. 4, pp. 31-50 (1999).
9. B. Downie and C. Polyneropoulos, "Interaction of water mist with a Buoyant Methane diffusion Flame", Fire Safety Journal, Vol. 24, No. 4, pp. 359-381 (1995).
10. A.D. Putorti, T.D. Belsinger and W.H. Twilley, "Determination of water spray drop size and velocity from a low pressure, high momentum, water mist nozzle. Report of test", FR 4000, May (1995).

## Q & A

**Q1:** Have you measured the air flow rate in the forced ventilation conditions?
**Cheung:** Yes. Due to the forced ventilation conditions are created by using two exhaust fans with the door opened, the air flow rate could be measured in the exhaust air duct. I just divided the duct into 9 parts and used the hot wire to measure the air velocity to calculate the air flow rate and get the average value.

**Q2:** For your conclusion, you said that different ventilation conditions will affect the extinguishing time of the water mist fire suppression system (WMFSS). How could you differentiate it when they are so short?

**Cheung:** In the past studies, as the fire size is very small, the WMFSS just uses 1 or 2 seconds to extinguish the fire. It is very difficult to distinguish the difference between natural and forced ventilation. In future study, I will either increase the fire size or reduce the operating pressure to get a more obvious difference between the two.

**Q3:** Have you measured the water droplet size?

**Cheung:** No. First because the main focus and scope of my work is on the water discharge density, extinguishing time as well as the gas concentration inside the room. Second, also very important, is due to facility limitation.