# REVIEW ON WATER MIST FIRE SUPPRESSION SYSTEM

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## ABSTRACT

Water mist fire suppression system (WMFSS) is one of the candidates in substituting the Halogen-based total flooding system. The system with strong spray momentum gives a satisfactory performance in extinguishing solid fires, liquid fires as well as kitchen fires under no ventilation. Nozzle with high discharge momentum and low operating pressure are the goal. Water mist discharged is assumed to evaporate completely when they meet the flame. In this way, a WMFSS can be used to extinguish electrical fires. However, it is observed that very fine water drops are very easily affected by indoor aerodynamics. The mist might not able to reach the flame if there is a strong upward air movement induced by the plume, and mechanical ventilation if there is any. Therefore, understanding this phenomenon is important for integrating the design of a WMFSS with the mechanical ventilation system. Measuring the extinguishing time could also indicate the effectiveness of the WMFSS under different conditions. This paper will review some characteristics of the WMFSS like nozzle design, extinguishing time and interaction with ventilation. Currently, to develop a practical design and testing guide for general application in premise is the most urgent need.

**Keywords:** water mist, ventilation, extinguishing time, heat released rate, nozzle design

## 1. INTRODUCTION

Water Mist Fire Suppression System (WMFSS) is an active fire extinguishing system. It is a candidate to substitute the banned Halogen-based total flooding system after 1987. Its first application appeared in 1940s. However, it did not become popular like sprinkler systems due to high techniques requirements, high investment and no general guide to follow. At that period, WMFSS was mostly used in marine applications to protect the machine and cruises lives. The systems attracted the attention from the industry after the whole world has started to care about global environment. The system is very clean and green. There is no ozone depletion effect and global warming effect as the system makes use of water as the extinguishing medium. The WMFSS utilizes phase cooling, oxygen displacement and radiation attenuation as the major tactics to extinguish a fire. The total heat extraction consisted of two parts as heat transferred and heat evaporated [1]. It is known that with enough discharging momentum, the heat transfer coefficient could be maximized mostly. When the water drops size reduced, the total surface area of water droplets increased. The time for water mist to absorb heat and evaporate to steam was then reduced. Therefore, the extinguishing ability could be increased and water damage was minimized. The oxygen displacement also plays a major role in extinguishing fire [2]. Under normal atmospheric pressure, the water drop expanded around 1900-fold when evaporation at high temperature. The rapid expansion of water vapor displaced the air around the flame. As the oxygen concentration level was reduced below the flammable limit, the starving effects slowed down the development of the flame and even reduced the flame height. The radiation attenuation can prevent the fire spreading to the un-ignited fuel which enlarged the pre-flashover time effectively. The radiation emitted from the burning fuel did harm to the people and protected objects inside the compartment. Radiation blockage by the water mist inside the compartment could protect human beings and equipment in addition to extinguish the fires. It was reported that when the water droplets were smaller than 50 μm, they could attenuate the radiant heat more effectively. It was hypothesized that the fine water drops absorb the radiant heat from the flame and re-radiate the lower temperature droplet or vapor.

## 2. DESIGN OF WATER MIST NOZZLE

The system consists of pressure source, water source, pipe-net as well as the water mist nozzle. Every component in the system is important to ensure the stable extinguishing performance of the system. Among all, the nozzle seem to be the most critical part because a well designed and installed nozzle could ensure fine enough water drops and maintain the discharging distribution properly. Therefore, the design of the water should be studied clearly and carefully. There are three types of nozzles in the major streams of the market based on the water mist generation principles. They are impingement nozzle, pressure jet nozzle and twin-fluid nozzle. In addition to these three, there are also some innovations on generating fine or ultra-fine water mist [3].

- **Impingement nozzle**

The impingement nozzle has some similarities to a conventional sprinkler nozzle on the appearance as well as the inner structure aspects. The impingement nozzle has a deflector in front of the small orifice. Sometimes, the diffusers are in ball-shape, plat shape or other special spiral-shape. When the water is discharged from the water inlet, it strikes onto the diffuser and break-up into water mist. Most impingement type nozzles have screens to filtrate the water and prevent the small orifice from blocking by some substances in the water. The impingement nozzles are directly connected to a water source, in most cases the water pump and could be controlled either manually or automatically.

- **Pressure jet nozzle**

The high water pressure only type nozzle has no diffuser or deflector. The generation principles of pressure jet nozzle are to make use of high pressure to push the water through the small orifice with high velocity. After leaving the orifices, the jet of water breaks up into fine water drops due to the complex physical change including fluid viscosity, jet diameter and the velocity of the jet. In order to create fine enough drops, the operation pressure needed is higher than that of impingement nozzle. The higher pressure offered, the finer the water drops will be. However, there is an upper limit for the pressure required. When the pressure reaches the upper limit, further increase will not lead to the increasing of the fine magnitude of water drops from the nozzle. Many companies provide removable nozzle cap for the easy clean and maintenance of the nozzle head.

- **Twin fluid nozzles**

In addition to the single-phase flow type nozzle, twin fluid nozzle is also widely adopted in the industry. It makes use of compressed gas as the atomizing medium. The compressed gas shear the water into fine water drops in the mixing chamber and discharging from one or several orifices. The advantages of using the twin-fluid nozzles are that the system could use low pressure to generate fine enough water droplets. Therefore, the common types of pipes and valve could be used. However, the dual pipe-system increasing the initial input and the balance of air and water pressure also raises the complexity of the system design.

Recently, Yang et al. [4] have developed a twin-fluid nozzle by using the emulsible substance as the atomizing medium. The operating principles are that when the compressed air is passing though the air atomizing orifice, the velocity of the air is further increased to a higher level. Meanwhile, the under pressure water passes through the water atomizing orifice and raises the velocity also. When the high velocity water flow strikes and collides with several high velocity air flows from the orifices, the water begins to have emulsification phenomenon in the mixing chamber. It is known that after emulsification, the viscosity and surface tension of the water drops are decreased. The characteristics of emulsible water are very unsteady and easy to break up into smaller pieces when meeting the disturbance. The emulsible water inside the mixing chamber is still remaining very high pressure. When it is discharged from the discharging orifices, it could break up to the water mist with expected water droplet sizes.

- **By flashing of superheated water**

There is a generation method which is not applied so widely, i.e. generating water mist by flashing of superheated water. The main principles of this method are to make use of the change of pressure and temperature. When the superheated water which is with 175$^{o}$C in an under-pressure container with 10 bar released to atmosphere, certain percentage of superheated water flashes into the vapor, and then condenses into fog form. By using this method, much finer water droplets could be produced than by any mechanical generation methods. The sudden energy release leads to the intense cooling of the spray. Therefore, after traveling for about 30 cm, the temperature of the water mist could reach not higher than 35$^{o}$C. This method is developed by Brown and York in 1962 [5]. Recently, Mawhinney has carried out some studies on this topic that led to a conclusion that ultra-fine water droplets may not be more effective than the normal water mist droplets in extinguishing the liquid pool fire [6].

## 3. EXTINGUISHING PERFORMANCE REVIEW

There are many factors to indicate the effectiveness of the WMFSS. For instance, change of HRR, change of room temperature, change of the gas concentration inside the compartment as well as the extinguishing time can reveal the extinguishing performance of the WMFSS to some extent. Integrated all these factors could show the true scenarios and system performance more concrete and accurate. However, only using one or some of the factors could simplify this engineering problem when comparing the different systems on the same basis. Picking extinguishing time as the indicator is the consideration for easy comparison as well as better understanding for users.

WMFSS could be applied differently like total-flooding system, local applied system or even portable extinguisher. For the total flooding application, many researches have been conducted. Series of experiment were carried out by Pepi to reveal the intermediate pressure WMFSS for extinguishing the flammable liquid fire [7]. It was found out that WMFSS spent around double time to extinguish the high pressure spray fire than that with low pressure. For Class A fires, the extinguishing time was exceeding 10 minutes in the experiments which is quite long and could be regarded as an unsatisfactory performance.

For the local application, the Minimum Spray Heat Absorption Ratio (SHAR) is more important to be considered than that in total-flooding system [8]. Enough mass of water should be provided by the nozzle to reach the minimum heat extraction value. Through some case studies, it was also found that the extinguishing time could be very short which is in the order of seconds for a good nozzle location. However, if the burning objects have a longer pre-heat period, a much longer spraying time is required to prevent the re-ignition.

For water mist portable extinguisher, it was found that the extinguishing time for the liquid fire like cooking oil and flammable liquid fire was very short within 5 s [9]. For the solid fire, no fire flare-up was observed and the fire was quickly controlled. The extinguishing performance for the solid fire was highly dependent on that the water mist applied.

In addition to the different applications, different fuel type, fire size and fire location, the extinguishing times are also affected greatly. For instance, according to Table 1, it is obviously to see that for different fuel type, the extinguishing time is different even for the same fire size [10]. When the fire size, i.e. the Heat Released Rate (HRR) increases, the extinguishing time reduces. It indicates that the WMFSS is more effective for extinguishing bigger size fires.

**Table 1: Comparison of extinguishing time for different flash-point liquid fires**

| Types of fires | HRR | Extinguishing times |
|---|---|---|
| Heptane spray fire | 1.0 MW | 1:34 |
| Diesel spray fire | 1.0 MW | 3:13 |
| Heptane spray fire | 2.0 MW | 0:20 |
| Diesel spray fire | 2.0 MW | 0:38 |
| Heptane spray fire | 6.0 MW | 0:26 |
| Diesel spray fire | 6.0 MW | 0:50 |

## 4. INTERACTION WITH VENTILATION CONDITIONS

As the water droplet is so fine that they are very easily affected by the aerodynamic circumstances inside the compartment, therefore how the mechanical ventilations affect the performance of the WMFSS should be studied in more detail. The ventilation conditions could affect the extinguishing time, gas concentration, the water discharge pattern as well as other performances of the WMFSS. In several design guides, like NFPA 750 and SFPE handbook, it generally assumed that all the MVAC system for thermal comfort should be shut down upon activation of the WMFSS [2,11]. If the MVAC system was still working or there was some natural ventilation existing, the performance of WMFSS might be affected.

A study on the performance of WMFSS under ventilation conditions were carried out by Liu et al. [12]. Three ventilation circumstances including no ventilation, natural ventilation and forced ventilation were tested. From experiments, they showed that the ventilation would not have so big impact on the water mist discharged with strong spray momentum and vice versa. It is concluded that in order to achieve a better fire extinguishing performance, enough spray momentum should be offered. A series of experiments were conducted to investigate the performance of the low pressure WMFSS and it was concluded that it was most difficult to extinguish a low flash point liquid pool fire in a ventilation compartment.

From Fig. 1 and Fig. 2, it was clear that no extinguishment happened when the door was open. At the position near the ceiling, the room temperature is 5$^{o}$C higher in the case of natural ventilation than that with no ventilation. The possible explanation was that the water mist drops might escape from the door way and the system lost some extinguishing capacities.

In order to give a clearer picture on the ventilation effect for the WMFSS, some small-scale experiments were carried out in the fire chamber of Department of Building Services Engineering of The Hong Kong Polytechnic University. The results are shown in Fig. 3. It is shown that when the room was under forced ventilation conditions, the room temperature remained in high level as the fire was only controlled but not extinguished. In the natural ventilation case, the extinguishing time was a little longer than that with no ventilation.

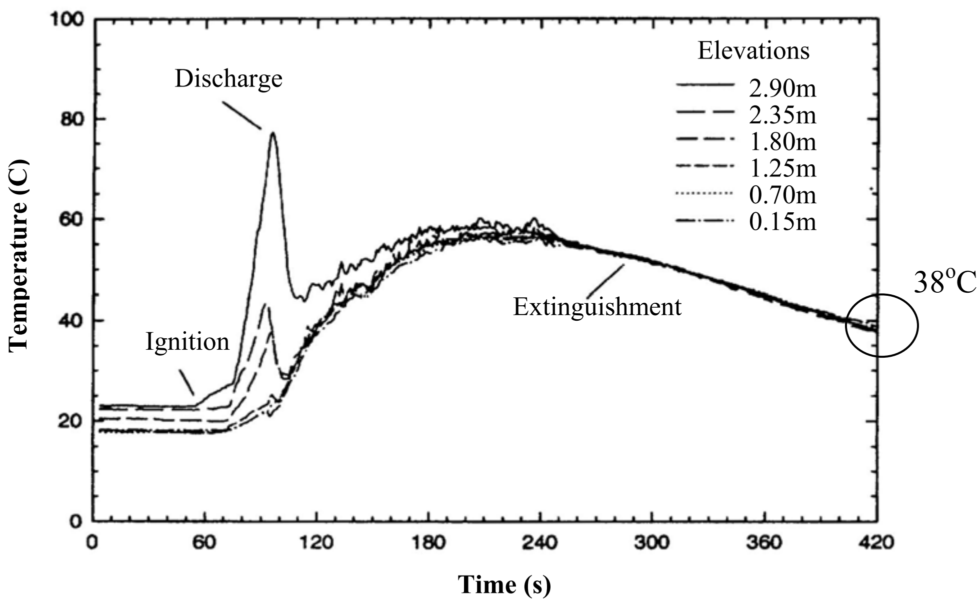


**Fig. 1: Room temperature for pool fire with door closed**

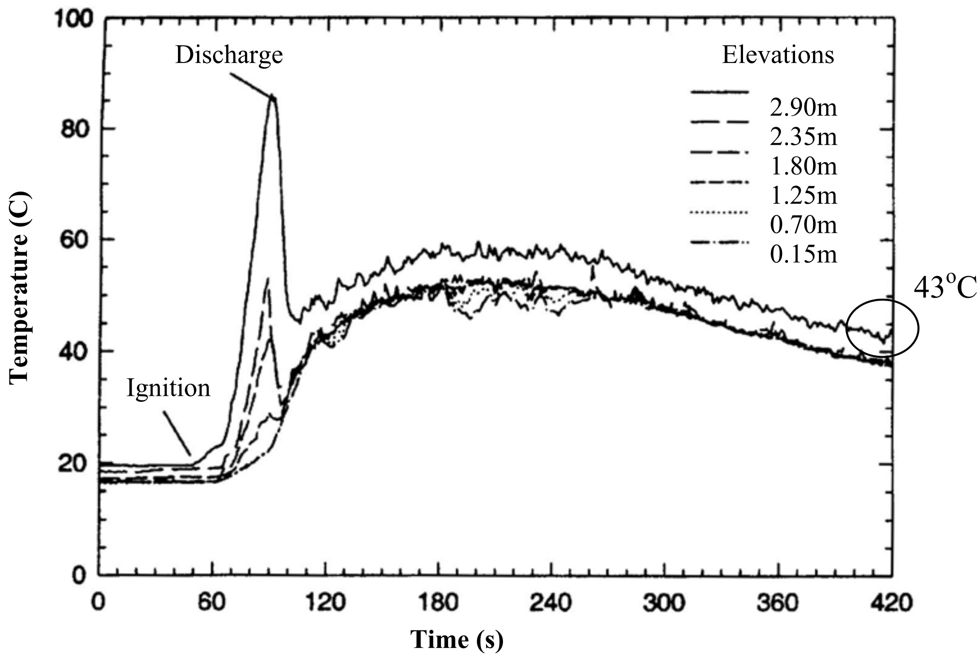


**Fig. 2: Room temperature for pool fire with door open**

In addition to affecting the room temperature, it can be clearly seen from Table 2 that the extinguishing time increased when the WMFSS was operated under ventilation conditions. When the ventilation system in the compartment is operated, the main extinguishing mechanisms might be changed as the ventilation rate [13]. With limited ventilation and heat entrapment, the oxygen concentration in the compartment can be reduced rapidly. However, in the case of well-ventilated fire, the total discharged water should be enlarged dramatically even to 10 times.

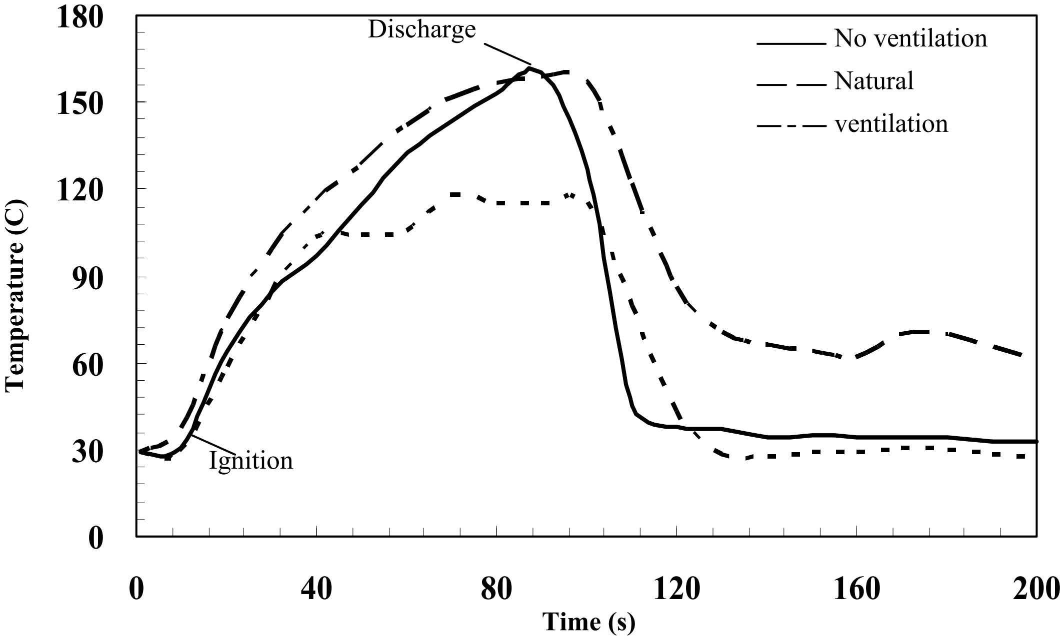


**Fig. 3: Room temperature for pool fire with different ventilation conditions**

**Table 2: Comparison of extinguishing time for different ventilation conditions**

| Case | Type of fire | Fire size | Ventilation conditions | Extinguishing time |
|---|---|---|---|---|
| **Case 1** | 1 shielded round fire | 500 kW | No ventilation | 1:55 |
| | 1 shielded round fire | 500 kW | With ventilation | 2:48 |
| **Case 2** | 1 shielded spray fire | 520 kW | No ventilation | 1:53 |
| | 1 shielded spray fire | 520 kW | With ventilation | 3:47 |

## 5. CONCLUSION

The WMFSS is a good alternative for the Halogen based total flooding system. It has no damage to the environment and also has a strong capability in extinguishing liquid fires under no ventilation conditions. The water mist nozzle is a key component for ensuring the system performance and therefore, WMFSS designers and researchers should pay attention to nozzle design. Although the WMFSS has many advantages, the case-dependent and varying performance of the WMFSS under ventilation conditions creates a significant problem in practical applications. Therefore, more studies both by experiments and by modeling should be conducted further.


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