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Technological Trends and applications of Water Mist Fire Suppression Systems

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Abstract

Water mist fire suppression technology has attracted an increasing interest from the field of fire protection services such as fire safety for buildings, ships, spacecraft, libraries and museums due to its non-toxic and high efficiency in the suppression of a wide variety of fires. To support the technological development of water mist fire suppression system and its application areas, this review introduces the concept of water mist system and discusses its suppression mechanisms in comparison with other fire protection systems. The recent application areas of water mist system are surveyed for class A fires involving combustible solid materials such as wood, paper and textiles; class B fires involving flammable liquids such as petrol, oils, lubricants, paints and waxes; class C fires involving flammable gasses such as natural gas and liquefied petroleum gas; fires involving electrical (class E) equipment such as computers and information technology facilities; and the class F fires involving flammable cooking oils and fats. Finally, the paper concludes the review by identifying the current research trends, and providing the future direction for water mist technology and applications.

Keywords: water mist; fire suppression mechanisms; application areas

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1. Introduction

Halogen-based compounds are effective fire suppressing agents, however, due to the harmful effects on the ozone layer they have been banned from further production since the last century [1]. In order to find suitable replacement, there has been a notable increasing interest in the use of CO_2, inert gas and water sprinkler as substitutes [2]. But despite all the efforts made to substitute with alternative clean agents, the objective remains challenging because of some limitations [3]. For instance, the use of CO_2 will displace oxygen in the air to suppress the fire and could be more dangerous to human health [4]. Thus, fire suppressing technologies have become a hotspot in the field of fire protection. In recent years, water mist fire suppressing technology has been developed and considered a promising replacement agent due to the manner at which it suppresses fire so quickly and with little water without causing any harm to the environment [5]. The development of present-day water mist fire suppressing technology was driven by the limitations of the conventional sprinklers and inert gasses [6]. Today, researches relating to water mist technology have improved in leaps and bounds since the year 1990, making water mist the most acceptable alternative solution for a wide application areas [7].

The year 1990 has become a remarkable history in today's fire suppression technology [8]. After the fire incident that claimed 159 passenger's life on the MS Scandinavian star ferry during a voyage from Norway to Denmark in April 6, 1990 [9]. An event which gathered all pioneers of new technologies was held in Sweden on June 20 that same year [10]. This event was meant for pioneers to present their solutions, in which a new company named "Ultrafog" founded by Krister Giselsson, Sven Brutsner and Stephan Forsstrom showcased their new product, a high-pressure water mist fire suppressing system, to different companies such as the marine and insurance sectors [11]. Also, the Finnish company, Marioff, which became the first to commercialize the high-pressure water mist product on a global scale was among the groups present at the Balsta fire event.

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Ever since then, the application areas for water mist system have witnessed exponential growth [12]. Some of these areas are the food industry, IT industry and heritage buildings [13]. Achieving safety of environment, life and property have continuously remained the driver for further development of the present-day water mist technology [14]. Another milestone in the history of the present-day water mist technology is the foundation of the International Water Mist Association (IWMA) [15]. The purpose of the IWMA foundation is to connect together different groups of people with common interest in the development of water mist fire suppressing technology [16]. Today, this foundation has become a globally recognized body for manufacturing companies, academic researchers, engineers and professionals [17]. They jointly advance the technology, and also give advice on the best practices to make water mist more efficient and safe for use [18].

The success story of the present-day water mist technology is incomplete without a mention of the International Maritime Organization (IMO) which largely supported the use of water mist systems as a replacement for conventional sprinklers [19]. Between 1994 and 1995, several IMO resolutions which were undertaken are found to have accelerated the use of water mist system in the marine sector [20]. However, the wider application of the present-day water mist technology has suffered delay in the land based market [21]. The very significant starting point was the creation of the first NFPA code and standard (NFPA-750) for water mist fire suppressing systems published in the year 1996 [22]. Today, different standards and guidelines for water mist are now available [23]. Therefore, the system now has wider applications in protecting and controlling various types and classes of fires which includes: (a) class A fires such as heritage buildings, libraries and residential occupancies; (b) class B fires such as petrol, oils, lubricants, paints and waxes; (c) class C fires such as natural gas and liquefied petroleum gas; (d) fires involving

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electrical (class E) equipment such as computers and information technology facilities; and (e) class F fires such as flammable cooking oils and fats.

2. Water mist suppression mechanisms

Water mist systems are exceptional fire protection systems capable of offering a very fine water spray for controlling, suppressing, or extinguishing wide varieties of fires [24]. Unlike the traditional sprinkler systems, water mist systems use less water which is mostly desirable in areas highly susceptible to water damage [25]. They are characterized by relatively fine water droplets for cooling through the process of evaporation [26]. The water droplets get to the location where the fire is deep-seated either by air convection or from above through high momentum [27]. A water spray in which the Dv0.99* value indicating the volumetric distribution of water droplets for a cumulative weighted-flow less than 1000 microns at certain operating pressure of the water mist nozzle is a typical NFPA 750 standards [28].

Several mechanisms are used for suppressing fire with water mist. In confined spaces, the atomized water droplets are immediately drawn into the base of the fire along with ambient air [29]. The water quickly evaporates into steam by displacing the oxygen needed for combustion [30]. This action makes water mist to be highly effective when they are properly constructed, coupled with the cooling and air scrubbing effects exhibited by the system [31]. In designing the water mist, we must consider that the system is less sensitive to enclosure openings [32]. Therefore, a finer water droplet is required for an effective system by blocking the radiant heat to prevent the adjacent combustible materials from ignition [33].

Water mist are recognized as effective systems based on their specific applications for; machinery spacing, combustion turbines, industrial oil cookers, continuous wood board presses, indoor transformers, wet benches, computer rooms, and ordinary hazard occupancies [34]. They are

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defined by some unique characteristics which are; operating pressure, water mist components and supply system, working principle and performance objective, and the application areas [35]. These will be further explained in details.

2.1 Operating Pressure

The NFPA 750 water mist standards is defined by three pressure distribution of the system piping; the low pressure, intermediate pressure and high pressure.

2.1.1 Low pressure water mist system

The Water Mist system operates at a low pressure less than or equal to 12.1 bar (175 psi) which is applicable for standard piping as well as the connection to the water plant and air supply [36]. It uses less water per discharge than any conventional sprinkler, providing unlimited protection timing and removing the need for water tanks [37]. Therefore, the cleaning time after discharge is negligible and consequential minimize the effect of damages and losses. A typical low pressure water mist and the volumetric midpoint water droplet is shown in **Fig. 1.**

Fig. 1: Low pressure water mist and volumetric distribution of water droplet @ Dv0.5 = 200-1000 µm.

Low pressure water mist systems are increasingly preferred by users because their installation and maintenance cost are less [38]. Apart from this, they contain simple piping as well as minimal risk of clogging. They can easily be operated by a unit of common pump and control system. Furthermore, they possess low power consumption requirements and consequently saves generator cost.

2.1.2 Intermediate pressure water mist system

The Water Mist system operating at a pressure greater than 12.1 bar (175 psi) but less than 34.5 bar (500 psi) is referred to intermediate pressure water mist system [39]. Examples of this category of system are self-contained skid units with water stored at atmospheric pressure and high pressure nitrogen as a means of water discharge [40]. This system possess a mean droplet larger in sizes than that of the high pressure type as depicted in **Fig.2**. However, the limited water supply of the intermediate pressure water systems are usually limited to size risk volume of certain 1000 cubic

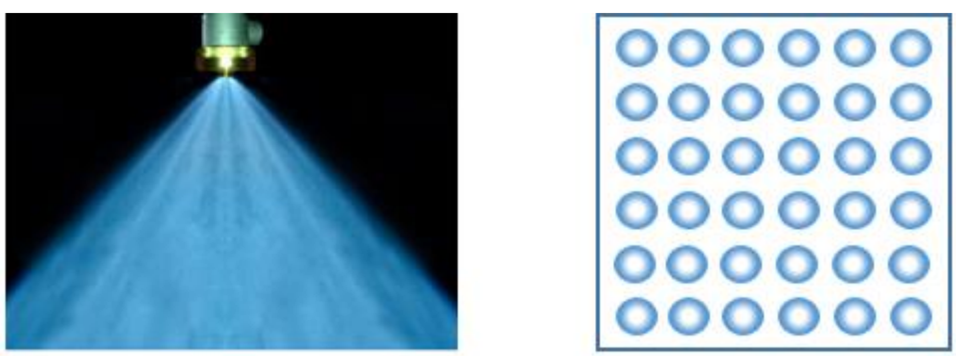

Fig. 2: Intermediate pressure water mist and volumetric distribution of water droplet @ Dv0.5 = 100-200 µm.

meters [41]. Some of the applications of this category of water mist systems are machinery spaces, hydraulic pump rooms, turbine enclosures etc.

2.1.3 High pressure water mist system

Water mist with high pressure are those systems with operating pressures of 34.5 bar (500 psi) or greater [42]. A high pressure water mist often produce a fine water mist with notable nozzles at about 120 bar pressure [43]. Water supplied at this high pressure pump or at high pressure nitrogen cylinders (200 bar) are either connected to a continuous water tank or driven by a number of separate water containers respectively [44]. This type of water mist systems can be used in an open head configuration (deluge) or closed head configuration within a protected area of operation [45]. They are in many cases substituted for the traditional sprinkler systems by providing an equivalent protection with a little water [46]. Some of the applications for high pressure fine spray systems are turbines, flammable liquids, archives and museums, clean rooms etc. In each applications, the nozzle type and droplet distribution are determined separately, which also dictate the effectiveness

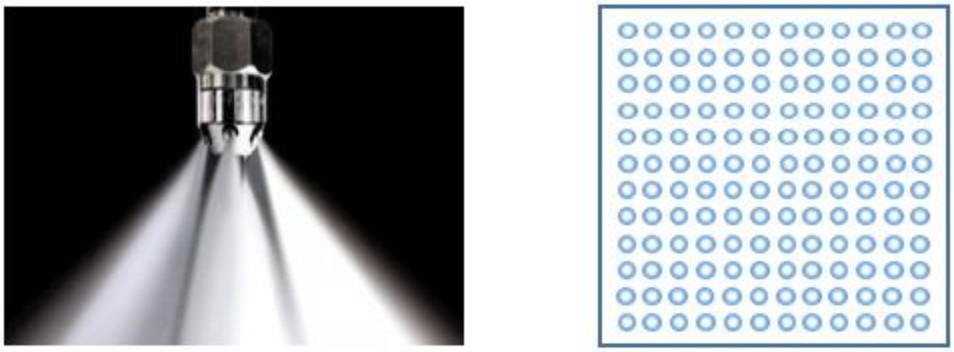

Fig. 3: High pressure water mist and volumetric distribution of water droplet @ Dv0.5 = < 100 µm.

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and optimum protection of the system [47]. The Fig. 3 shows a typical high pressure water mist and volumetric distribution of water droplet.

2.2 Water mist Components and supply system

Major components of water mist systems often used by various manufacturers such as the piping system, nozzles, the centrifugal or pump, an atomizing medium and the water supply system are discussed in this review.

- **Nozzles**

Similar to the sprinklers, nozzles are characterized as either open (deluge) or closed. The water consumption for each nozzle ranges between 2.8 and 25 liters (0.74 and 6.6 gallons) per minutes depending on the properties of the room [48]. This symbolizes a significant reduction when compared to a traditional sprinkler with 80-250 liters (21-66 gallons) per minute.

- **The piping system**

This system consists of a main pipe which is made of stainless steel and located at the center of a frost-free surrounding. Based on the situation, different pipes often leads to every designated fire sections in which the front end of each pipe is fitted with a shut-off valve. Like the traditional sprinkler system, water mist are arranged as a wet pipe, dry pipe or deluge system [49]. The nozzle heads are supplied with deluge (open) nozzles for dry piping systems, closed nozzles with melting fuses or glass bulbs for wet piping systems.

In a dry piping system, the deluge (open) nozzle head is made of a micro-nozzle mounted directly on the supply pipe. The water in an open nozzle is atomized immediately the high-pressure pump is activated either manually or by automatic sensors. On the other hand, the closed nozzle of the wet piping system consist of nozzle heads fitted with micro-nozzles that are well secured with

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glass or plastic bulbs which melts whenever the temperature exceeds the threshold beginning at 56^o C. Each nozzle is furnished with a filter to prevent clogging. The water consumption rate are determined separately based on the already existing fire load, and can be modified to the exact requirements by replacing the micro-nozzles [50].

To activate the system, the high-pressure **pump** is triggered. The centrifugal or positive displacement pump, also referred to electric motor-driven pump is used to convey the required water flow and pressure in the fluid systems. The systems are activated either manually or by a signal from a pressure controller or fire detector/fire alarm system [51].

The **water supply** can either be public or private supply. Example of such supply is the dedicated water tank which must be reliable and similar to potable water or natural seawater based on particulates. In order to deliver the water supply in twin fluid systems, an **atomizing medium** consisting of compressed sir or nitrogen is often applied. The **Fig. 4** shows the general arrangement of the water mist components and the supply pump system, and their system activation at various timing [52].

2.3 Working principle and performance objective

The operation principle of the water mist fire protection system involves the production of a very fine and pressurized water sprays in controlling, suppressing and extinguishing fire flames. In this process, the sprays first cools off the combustion by displacing the oxygen that fuels the vehement fire. Lastly, the droplets of water then suppresses the fire [53]. The effectiveness of the water mist fire suppression system is determined by the characteristics of the spray which includes; size of the water droplets, pressure and water density which have been discussed earlier. It is also important to consider the components such as the nozzles (deluge or automatic), pipes and pump. The deluge nozzles are always opened such that immediately water flows into the system, they

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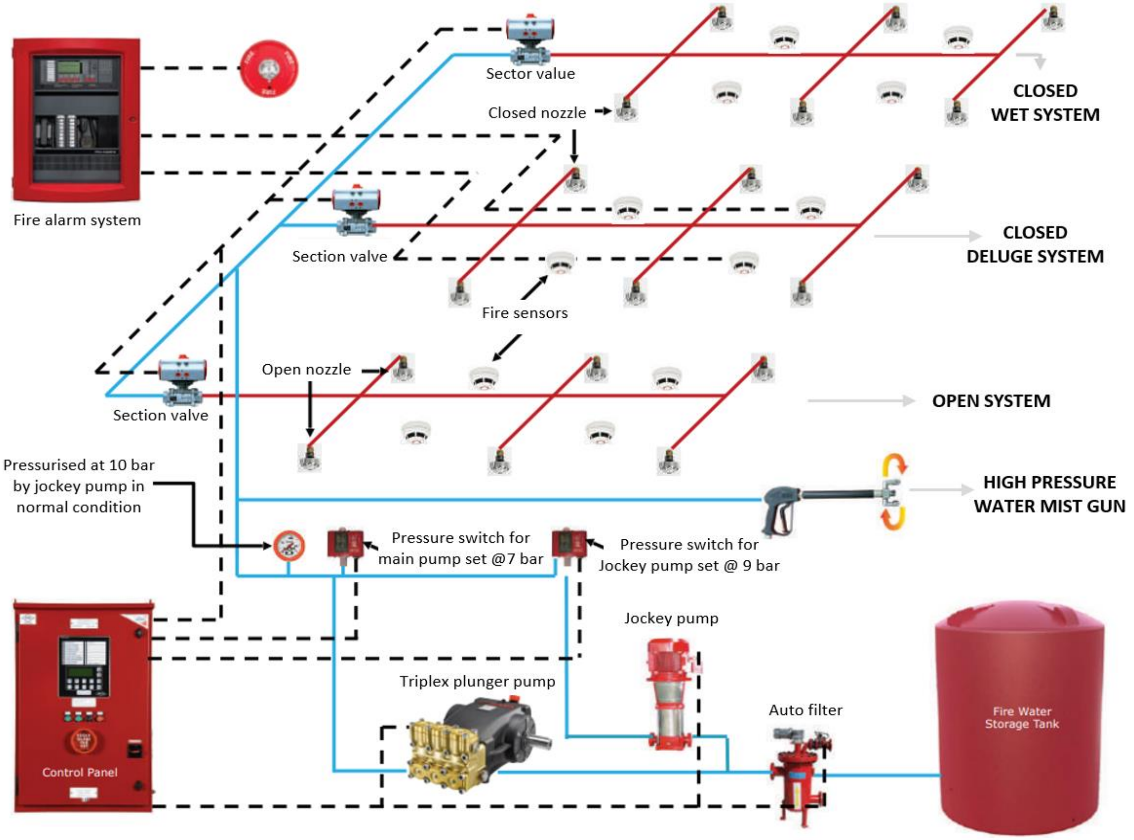
begin to release water directly into the flames. Meanwhile, the automatic nozzles are specifically designed with a covering of thermal element on the head of the nozzle that triggers under high temperatures and further allows the flow of water to suppress and extinguish the fire. The piping systems are also very important in conveying the water to the nozzles. They are usually made of stainless steel pipes because of the durability, cost and resistance to corrosion [54].

Three stages of operation are involved in the water mist fire suppression process such as; cooling, oxygen depletion, and lastly the separation and shielding effect. The **Fig. 5** shows the triangular operational process of the water mist fire suppression system which is discussed in this review.

In the **cooling process**, as a result of the suppression water system being split up into droplets, a surface reaction is generated through which the heat from the fire is absorbed. Heat energy needed to transform the temperature of water from 20 to 100^{o} C is 335 KJ, and an addition energy of 2257 KJ is needed to change water to steam. When the surface reaction is large, the cooling effect will potentially be high. The cooling effect is said to be efficient when the mean droplet size is small, in which the smaller droplets descend slowly than the larger droplets. This means that the air and gases around a fire experienced cooling, and not the fire load itself. Hence, water mist systems are referred to the highest heat absorption medium capacity [55].

In the **oxygen depletion** process stage, evaporation increases the water level by 1640 times leading to a reduction of oxygen in the air at the fire source. As a result, the fire is smothered and eventually suppressed because of the absence of sufficient oxygen required for combustion. This process



(a)

Activation @T= 5 s   Activation @T= 15 s   Activation @T=5 s

(b)

Fig. 4 (a) General arrangement of the water mist components and the supply pump system, and (b) their system activation at various timing

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(reduction of oxygen) takes place at the very center where there is high temperature of vehement flame, thus allowing the occupants to escape through other exits [56].

In the **separation effect,** water droplets that are found between the flame and fuel surface reduces the thermal radiation by the fuel surface, causing the heat to reflect effectively. At the same time, there is drastic reduction in the burning rate, and the thermal radiation caused by any fire loads in the surroundings are reduced, decreasing the chances of flame spread due to this effect. A very small water droplets are sufficiently generated, increasing the capacity of the effect when the size of water droplet is decreased. On the other hand, the s**hielding effect** will help to prevent the fire from spreading by reducing the thermal radiation from the surrounding objects, thereby protecting occupants by escaping away from the fire while the emergency services approach the fire [57].

The performance objective are mainly three; fire control, fire suppression and fire extinguishment.

Fire control helps to contain fire spread by spraying water on the fire to reduce the heat circulation rate and pre-wet the combustible materials nearby, ensuring the temperatures of the ceiling gas are controlled to avoid damaging the structure.

Fire suppression is an abrupt reduction of heat release rate and the prevention from regrouping.

Fire extinguishment refers to total suppression of a fire until there are no burning combustibles.

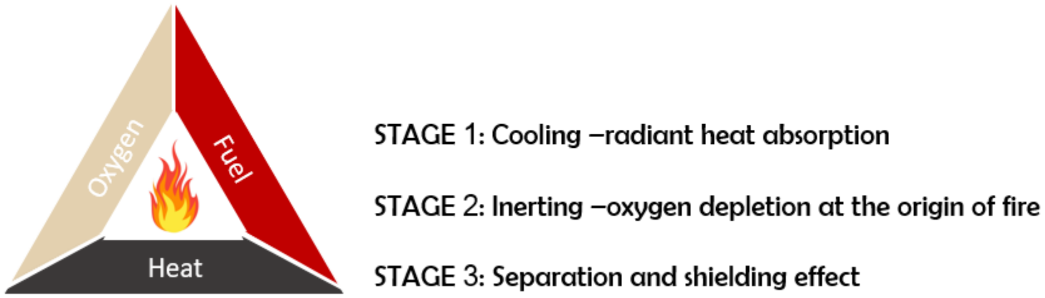

Fig. 5: Stages of the operational process of water mist fire suppression system

2.4 The application areas

Types	Fuel types	Application Areas
Class A	Wood Crib Red pine, Polymethyl, methacrylate Plywood Perspex, Bookrack	Water extinguishers are mostly suitable to fight Class A fires which are fuelled by solid materials. They are simple to use and least expensive. Some contain additives to make the water more effective as well as reducing the weight of the device. They are the easiest to maintain. They cool the fire by soaking it together with the materials. They absorb heat from burning the objects, and thus extinguishing the flames. Water extinguishers includes; water jet, water spray, water with additives and water mist or fog. The water jet operates by spraying the jet of water at the burning materials to cool them off and thus prevent re-ignition. The water spray operates by using a very fine spray of water droplets surrounded by a non-conductive air. Most of these sprays have been tested on a 35 kV dielectric. The one with additives such as foaming chemicals can soak into the burning materials effectively and can produce the same fire rating as that of a larger water extinguisher. For the water mist, water are applied in the form of mist or fog. It contains droplets which are smaller than those of water spray extinguisher. The

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		smaller droplets increases the surface area and quickly evaporates to absorb heat energy faster. It has so many advantages when compared to the other types. They can be used in homes, residential apartments, museums o heritage buildings and libraries.
Class B	Kerosene Diesel, petrol, oil Flammable liquids, Airstream	The water mist are very powerful fire suppression systems. They are safe and effective to be applied to Class A, B, C, and F fires. It is multipurpose and effective. Some are suitable to fight class E fires (i.e electrical fires like computers and phones) up to 1 kV. They operate by cooling off and reducing the oxygen supply. Instead of the wet chemical extinguishers, the water mist system can be used to extinguish deep fat fryer fires, leaving no residue. Like the water extinguishers, the water mist are recyclable without any traces of chemicals. Although other extinguishers like foam extinguisher and carbon dioxide (CO2) extinguishers are being used, but because of the limitations and challenges the water steam have become promising in this area of application.
Class C	Methane, Propane, Butane	The dry powder fire extinguishers comes in two varieties; the standard type and the specialist type. The

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	Flammable gases, Hot airflow Natural gas, hydrogen mixture	standard dry powder fire extinguishers are very versatile and can put out virtually most categories of fire. But, they can't be used in an enclosed spaces. They are referred to multi-purpose fire extinguishers, dry chemical fire extinguishers and suitable for class A, B and C fires. They are identified by BLUE coloured label called "Powder". They come in different sizes; 1 kg, 2 kg, 3 kg, 6 kg and 9 kg. It operates by forming a barrier between the fuel and the source of oxygen. They have tendency for re-ignition when it doesn't cool the fire. Although they work on most fires, but they are dangerous when the fire re-ignite. When discharge can spread over a large area leaving behind a residue. Can also block vision, and can be inhaled when in an enclosed areas. Thus, they are ideal for outdoor environments and applicable for risks involving chemicals, fuel or vehicles such as; garage forecourts, large commercial boilers room, flammable liquid storage facilities, large workshops and fuel tankers and other vehicles.
Class D	Titanium Aluminium Magnesium	The specialist powder extinguishers are designed to fight Class D fires such as lithium, magnesium or aluminum. They operate by forming a crust which

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	Other Metals	suppresses the fires and sops the fire from spreading. There are two specialist dry powder types; the one that only fights lithium fires is referred to 'L2', and the one that is used to fight other flammable metal fires is referred to 'M28'.
Class E (Technically does not exist)	Electrical apparatus Computers phones	CO2 fire extinguishers are predominantly applied in places with lot of electrical equipment such as computers, server, phones and other electrical appliances in the information technology room. They are safe to be used on class E fire. Although the name 'class E' does not technically exist, but for simplicity it has become a household name.
Class F	Cooking gas Oils and Fats	Wet chemical extinguishers are the only type apart from the water mist appropriate for Class F fires. They are mainly applied in kitchens with deep fat fryers commonly. They consist of a Pressurised solutions of alkali salts in water which creates a fine mist when operated. It thus cools the flames and prevents splashing.

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3. Conclusions

Water mist fire suppression systems have attracted the interest and attention of fire safety and protection researchers and professionals across the globe. They have demonstrated their potentials in extinguishing Class A, B, C, E and F fires efficiently with their cooling mechanism and non-toxicity to the environment. As a result, they have become useful in many application areas such as gas turbine enclosures, marines, homes, public spaces, pump rooms, electrical/electronic rooms, heritage buildings, protection of machinery spaces etc. Their effectiveness is determined by some factors including the spray characteristics, the configuration and size, piping system and operating pressures.

Remarkable progress has been made on improving water mist effectiveness over the last decades. New approaches have been developed such as combining the total flooding and local applications, cyclic water mist discharge, hybrid water mist and the intelligent water mist that combines zoned water mist with the intelligent detection. In order to further move this research forward in the future, the followings are suggested. A qualitative and quantitative analysis is required to study the fire suppression mechanism of water mist in different cases of fire approach. Secondly, several research studies on the characteristics of water mist system are mainly performed at the macro level, and it is important to also demonstrate its working process and efficiency at the micro perspective. Thirdly, different factors affect the fire suppression performance of water mist such as the fuel types, flame scales, ventilation conditions, and should be adjusted accordingly in potential fire scenarios. Finally, additives could be a possible way of improving the performance of water mist systems. It is however necessary to select the additives with stronger inhibition effect.

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