

Experimental study on the interaction of fine water mist with solid pool fires

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Abstract This paper describes experimental study of the interaction of fine water mists with solid pool fires. Fine water mist was generated by a single pressure nozzle and solid pool fires were produced from solid red pine or polymethyl methacrylate (PMMA). The LDV/APV system was employed to determine the water mist characteristics. The water mist droplet sizes and velocities from the nozzle were measured under varying conditions and at different locations. The effects of solid type, water flow rate, and nozzle distance from the sample surface on extinguishment time were examined. At a given water flow rate, the extinguishment time is much longer for PMMA fires than for solid pine fires. The extinguishment time was found to decrease with increasing water flow rate. At very low water flow, the extinguishment time decreases when the nozzle is positioned further from the sample surface. On the contrary, at high water flow, the extinguishment time appears to be independent of the distance between the nozzle and the sample surface. The experimental results show that flame extinguishments is due primarily to fuel surface cooling and wetting.

Keywords: water mist, solid pool fire, mist characteristics, extinguishment time.

The Montreal Protocol was enacted in 1987 that sets a definite target that Halon fire suppressants are to be replaced by the beginning of 21st century. So research work on replacements for halogen-based suppressants, such as water sprinkler, CO₂, inert gas and foam, is in full swing. Water mist fire suppression systems are taken as one of the effective candidates for Halon replacement; they have many advantages: not pollutant to environment (unharmful to the ozone layer without bringing greenhouse effect), fast fire extinguishment, a small quantity of water consumption and little damage to protected objects. Water mist fire suppression technology has already received considerable attention^[1,2].

During the last decade, water mist has been used to replace current fire protection techniques that are no longer deemed environmentally acceptable, such as Halons, or to provide new answers to problems where traditional technologies have not been effective. The extinguishing capacity of water mist is determined by the drop size distribution, mist location, mist momentum, enclosure geometry, obstructions within the space and the type fuel. It is very important to study the interaction of water mists with a flame. The study of the interaction of water mists with a flame will en-

rich the knowledge of such processes and be useful for developing the water mist fire suppression systems, improving the fire suppression and control efficiency and extending their applications.

Many fine water mist suppression tests with flame have been investigated, but little has been done systematically to examine interaction of water mists with a solid flame, especially the effects of solid combustibles configuration, combustibles composition and properties, water flow rates, and combustibles location relative to the mist nozzle on the performance of a fine water mist system^[3–9]. The first objective of this work was to determine drop size and velocity distributions at various locations in the mist. The second objective is to examine how the solid combustible composition and properties and its location relative to the mist nozzle affect the mass flux of droplets required to extinguish the flame.

The laser Doppler velocimetry/adaptive phase Doppler velocimetry system (LDV/APV system) was used to determine the water mist characteristics. The measurement techniques and the system configuration have been described in detail before. In this paper, the characteristics of the water mists were measured mostly with this system.

Experiments were performed with solid combustibles including a thermoplastic (polymethyl methacrylate, PMMA) and wood (red pine). The results obtained from the extinguishment tests were expressed in terms of extinguishment time. The extinguishment time is defined here as the time from the initiation of water application to the disappearance of a visible flame above the sample surface. Extinguishment times were measured using a stop-watch with a resolution of 1/100s and the eyes of the operator. At the same time, a CCD camera(JVC DVM801) was used to record the extinguishment events onto VHS tapes for subsequent frame-by-frame analysis.

1 Experimental apparatus

The experiments were performed first by use of the LDV/APV system, and the characteristics of the water mists were measured^[10]. Water mist was generated by using a single pressure atomizer. Two operating pressures were set at 0.3 and 1.0Mpa, respectively. The cone angle of the nozzle was 60° and the volume mean diameter of the mist was about 80 μm.

A schematic of the interaction experimental apparatus is shown in fig. 1. The facility consists of a conical heater, a sample holder, an electronic balance, and a water mist/droplet generating device. The facility is housed inside the 0.6 m×0.6 m×0.7 m glass-walled enclosure in order to prevent perturbation of the flame from forced ventilation in the laboratory.

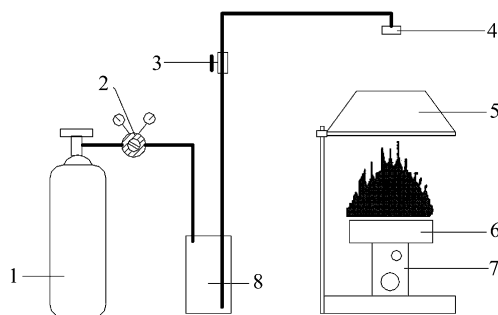


Fig. 1. Schematic of the experimental apparatus. 1, High pressure nitrogen; 2, pressure regulator; 3, valve; 4, water mist nozzle; 5, radiant conical heater; 6, fuel sample; 7, electronic balance; 8, water tank.

The solid combustible was located on the electronic balance, and there was a 20 kW/m² radiant conical heater over the sample to keep the combustion stable. The nozzle was placed downwards 10 or 20 cm over the fuel sample. Sample size was 10 cm×10 cm×1 cm, PMMA weighed 115g and red pine weighed 100 g with 8% water content. The water mist was injected onto solid combustible surface at 100 s after ignition. Extinction time was obtained by using a stop-watch or by counting frames from the video record captured by using a CCD camera.

2 Result and discussion

2.1 The characteristics of fine water mist

In the present experiments, pressure swirl atomizing was used to produce finely atomized droplets in a cone mist pattern.

Fire extinguishing capacity is determined by the characteristic parameters of the water mists. Some APV results measured at 20 cm away along the nozzle axis are shown in fig. 2. The operation pressure was 1.0 MPa. Fig. 2(a) shows the relationship between the drop size and the nozzle axial velocity. Fig. 2(b) shows the relationship between axial mean velocity, volume mean diameter and droplet size. Fig. 2 (c) and (d) shows axial velocity and droplet size histogram respectively. Figs. 3 and 4 show the radial distribution of the axial mean velocity and volume mean diameter of the water mists under 0.3 and 1.0 MPa respectively.

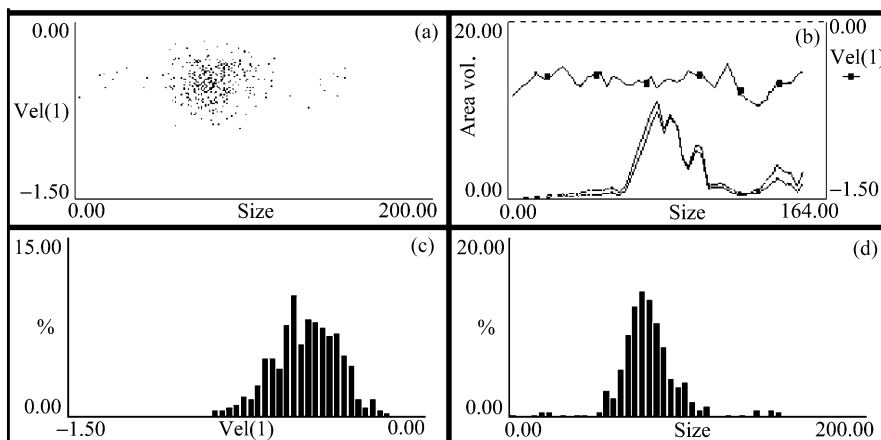


Fig. 2. The typical characteristics of the water mists employed to the diffusion flame in the confined space (1.0 MPa).

2.2 The flame extinguishment of solid pool fire

For PMMA and red pine samples, visual observations revealed the following processes. At the instant the water mist first impacted the sample surface, local flame extinction was immediately observed at the point of impact, the flame was perturbed by the arrival of the water mist, and flame luminosity was reduced. As the water mist continued impinging the sample surface, a water layer began to form, spread across, and wet the horizontal sample surface. Flame size was gradually reduced, and eventually total extinguishment resulted.

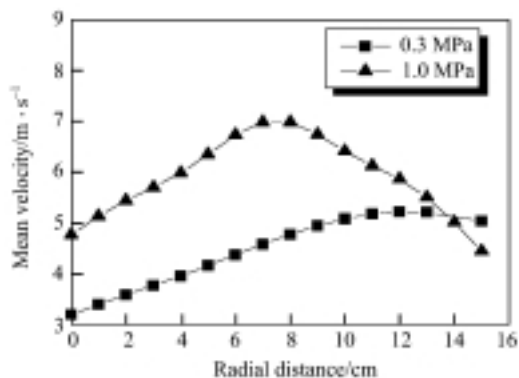


Fig. 3. The radial distribution of the axial mean velocity of water mists.

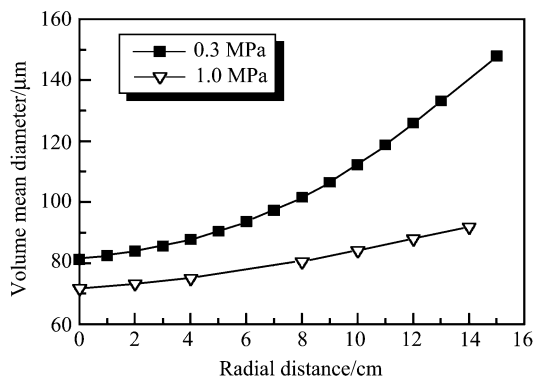


Fig. 4. The radial distribution of the volume mean diameter of water mists.

Although flame extinguishment mechanisms by water mist have been suggested to be (i) heat extraction (flame cooling and fuel surface cooling), (ii) oxygen displacement (or dilution), and (iii) radiation attenuation, it is difficult to differentiate the relative importance of these three mechanisms.

If one assumes that direct flame cooling is due primarily to the extraction of heat from the flame to vaporize the fuel, the residence times of water droplets in the flame zone (or their times of flight through the flame zone) would determine whether flame cooling is the dominant mechanism to suppress the flame. If the residence time of a droplet is longer than its evaporation time in the flame zone, then the droplet will vaporize completely before it reaches the fuel surface. In this case, flame cooling could be significant. On the other hand, if the residence time is shorter than the complete vaporization time, the droplet mass may not be reduced significantly through vaporization. Under this circumstance, significant flame cooling may not be realized.

Direct flame cooling is not thought to be very significant in most of our tests because the residence times of individual droplet in the flame zone were much shorter than the characteristic times for droplet heating and complete evaporation. Since the temperature of the droplet just introduced into the flame zone has not yet reached its final equilibrium value, there is an initial transient droplet heating period. For a small droplet, say, 80 μm in diameter (fig 4), exposed to an ambience of 800 K and assuming a lump capacitance model^[11], the characteristic droplet heat-up time is estimated to be of the order 0.1 s. The flame height was of the order 10 cm based on visual observations. The droplet velocity was typically of the order 10 m/s or less in our experiments (fig 3). Therefore, the residence time of the droplet in the flame zone was typically of the order 0.01 s. For an 80 μm droplet evaporating at an ambience of 800 K, the complete evaporation time of the droplet was estimated by using the classical d^2 -law to be at least an order of magnitude ($\sim 0.1\text{s}$) more than the residence time^[12]. Therefore, droplet mass loss due to evaporation by extraction of heat from the flame could be considered negligible in the flame zone, and significant flame cool-

ing was unlikely to occur.

Radiation blockage by droplets does not play a significant role in extinguishing our flames because at most the space occupied by the streams was only a small fraction of the total flame volume. Oxygen displacement due to the generation of water vapor within the flame zone as a result of droplet vaporization would neither contribute significantly to the flame extinction process, based on the residence times argument.

Therefore, it is postulated that the observed flame extinction in the experiments was due largely to fuel surface cooling. As the droplet stream continued impinging the sample surface, cooling of the surface occurred because of the heat transfer between the sample surface and water droplets deposited on the surface. As the surface temperature decreased, the evaporation rate of water droplets and the gasification rate of the sample decreased. A water layer began to form due to continuous droplet deposition on the surface and reduced evaporation rate. The layer, which spread and grew, further reduced the exposed sample surface and the surface temperature by wetting. Eventually, a condition was reached that the sample gasification rate was so low that combustion could not continue, and total flame expired.

Fig. 5 shows the extinguishment time as a function of water flow. The water mist was applied

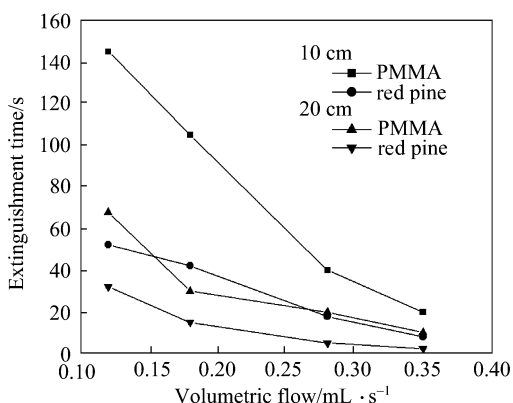


Fig. 5. Average extinguishment time versus volumetric water flow for red pine and PMMA.

perpendicularly to the sample surface. An external radiant heat flux of 20 kW/m^2 was used. Two groups of data are shown in the figure. One group was taken with the nozzle located 10 cm above the sample surface and the other group with the nozzle at 20 cm. PMMA and red pine were used in these tests. Each data point in fig. 5 is the average of at least three runs.

In fig. 5, the extinguishment time decreases with increasing water volumetric flow. The extinguishment time is much longer for PMMA fires than for red pine fires because the gasification rate of red pine decreases due to char formation during the 100 s preburn before water application. When the nozzle is located further from the sample surface (20 cm), the extinguishment times are shorter at very low water flow than those obtained when the nozzle is located closer to the sample surface (10 cm). One plausible explanation is as follows. When the nozzle is further from sample surface, droplets in the mist have sufficient time to interact with one another before their arrival to the sample surface. The droplet interaction processes appear to enhance the dispersion of droplets and the coverage area of the droplet mist, even though the initial droplet velocities are slow due to low exit water flow rate from the nozzle. The greater water application coverage area benefits flame extinguishments.

Fig. 6 shows the relationship of extinguishment times and high water flow. From fig. 6, it is

inferred that the extinguishment time will eventually reach an asymptotic value as water flow rate increases, implying that there is a critical water flow rate for minimum extinguishment time. Further increase in water flow beyond this critical value may not reduce the extinguishment time significantly.

3 Conclusion

From the experimental observations and measurements using the single pressure atomizer, some important conclusions can be drawn:

- 1) Spatially resolved information on droplet size, velocity distributions, and volume flux of the fine water mist has been obtained in the single pressure-atomized fine mist using LDA/APV system.
- 2) The time required for extinguishments generally decreases with increasing water application rate, irrespective of the nozzle distance from the burning surface. The extinguishment time appears to approach an asymptotic value as the water flow rate increases.
- 3) At low water flow, the extinguishment time decreases when the nozzle is positioned further from the sample surface. On the contrary, at the high water flow, the extinguishment time appears to be independent of the distance between the nozzle and the sample surface.
- 4) Flame extinguishments is due primarily to fuel surface cooling and wetting in these sets of experiments.

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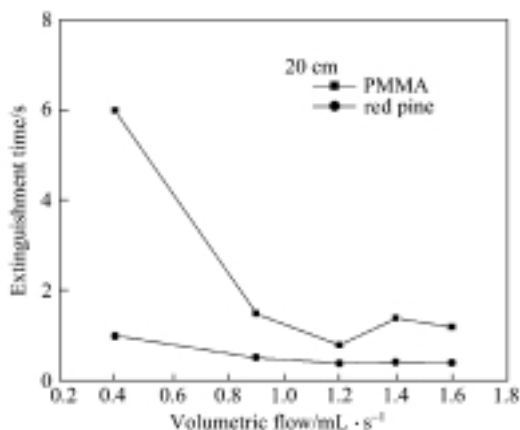


Fig. 6. Average extinguishments time as a function of high volumetric water flow.

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