Water Mist Fire Suppression for Raised Subfloor Spaces

Woon Hyung, Kim, Ph.D.

Department of Fire Protection Engineering, University of Maryland, U.S.A

James A. Milke, P.E., Ph.D.

Department of Fire Protection Engineering, University of Maryland, U.S.A

ABSTRACT

Over 100 experiments have been conducted at the University of Maryland to evaluate the performance of a water mist fire suppression system for protection of an interstitial space below a raised subfloor. Experiments are conducted as part of an ongoing research effort to compare the fire suppression capabilities of various water mist system designs in a raised subfloor space. Water mist system design parameters considered in the investigation include means of actuation, concentration of water mist required for extinguishment of fires, and delivery mechanisms of water mist within close proximity to the fire. Delivery of the required concentration of water mist within close proximity to the fire is a principal factor governing the adequacy of water mist systems. Two sets of experiments have been conducted to document the performance of water mist system designs. One set is involved in documenting the concentration of water mist as a function of position within the space. The second set of experiments is concerned with the ability of water mist system designs to control fires in the space. One result of the research is the assessment of the ability of a water mist system to control fires at particular locations as a function of water mist density at that location.

INTRODUCTION

Recently, significant interest has been expressed in the capabilities of water mist as a fire suppression system considering the minimal water flow rate requirements and associated reduction in collateral damage caused by water [1]. The extinguishment mechanisms typically associated with water mist are [2-4]:

1. flame cooling via the absorption of heat by evaporating water droplets,
2. surface wetting of nearby fuels to reduce the likelihood of flame spread,
3. local oxygen displacement as a result of steam generation in close proximity to the fire.

The suitability of a water mist system with the associated reduced water flow has been demonstrated for various applications, including library stack areas and electronic equipment facilities [5-7]. The reduced water flow requirement is attributed to prompt actuation of the water mist system, allowing it to respond to a smaller fire and the discharge of smaller water droplets to evaporate a greater proportion of water and remove heat from the proximity of the fire.

Considering the unique characteristics of water mist, successful performance is dependent on effecting at least one of the extinguishment mechanisms. Thus, the performance of a water mist system is influenced by the means of actuation, concentration of water mist and delivery of water mist within close proximity of the fire.

As with other fire suppression systems, the actuation time of a water mist system affects the water flow required to control the fire. Consequently, minimizing the water flow necessary for suppression requires that actuation be prompt and identify the location of the fire. Being prompt suggests that the detection mechanism needs to be relatively sensitive. Identifying the location of fire origin and applying water only to the area involved in fire limits the total amount of mist discharged into a space and subsequent unnecessary wetting of remote materials. Once the water mist system is actuated, inadvertent actuation of adjacent zones is possible. These challenges can be minimized via the selection of multi-sensor detectors, such as combination smoke and heat detectors or a "smart detector" [8]. A smart detector is able to distinguish between smoke from a fire and airborne contaminants from non-fire sources.

The water mist density required is a function of the size of the fire (mass loss rate or heat release rate) and fuel characteristics (composition, shape and orientation). The size of the fire is dependent on the ignition scenario and actuation time, in addition to the fuel characteristics such as thermal material properties, shape and orientation.

Delivery of the required density of water mist within close proximity to the fire is a principal factor governing the performance of water mist systems. Water mist may be diverted away from the fire as a result of air and smoke movement induced by the fire or mechanically provided airflow currents within the area, plating losses on internal surfaces and evaporative losses remote from the flaming region. Because the location of a potential fire is unknown, the goal of a delivery system is to provide a uniform density of water mist throughout the space.

EXPERIMENTAL PROGRAM

The experimental facility consists of a raised subfloor located outdoors at the training facility of the Maryland Fire and Rescue Institute. The 9.8 m square subfloor assembly consists of 610 mm square metal sandwich floor tiles placed on a steel frame supported by steel pedestals. The top of the floor tiles is 305 mm above ground level. The sides of the subfloor are enclosed by a wooden frame supporting 12.7 mm plywood sheets, with caulk to seal the edges. A variable speed exhaust fan with a capacity of approximately 0.19 m^3/s is installed in the space with 2 louvers placed on each side of the plywood enclosure for make-up air.

The water mist system is a single fluid system, with a nominal pressure of 6.9 MPa provided by a pump (capacity of 0.69 l/s) is located in a separate room on the north side of the test building. Water is supplied by a 50 mm fire hose from an on-site fire hydrant. Three configurations of water mist nozzles are included in the two sets of tests. The nozzles used for all of the tests have an orifice size of 0.30 or 0.38 mm. The DV_{90} for the water mist droplets is on the order of 100 μm. Water mist nozzles are distributed every 15 or 30 mm along tubing installed at the top of the subfloor space and are oriented at angles of 0 - 60° with respect to the vertical axis. Water mist nozzles used in these tests are "open", such that all nozzles in the zone discharge mist. A schematic of the water mist system in the raised subfloor is presented in Fig. 1.

The purpose of the experiments is to characterize the extinguishment capabilities of variations in the design of a water mist system in the subfloor application. Water mist system designs are varied only in terms of the type, distribution and orientation of the nozzles. The two sets of experiments included in the investigation document the distribution of water mist within the subfloor for a water mist system design and assess the extinguishment capabilities of the water mist system design.

Water Distribution Experiments

The water distribution experiments are conducted without a fire. Water mist is captured in small cups placed throughout the space. The water mist density is determined by weighing the water mist collected in a cup and dividing by the flow duration and cross-sectional area of the mouth of the cup. The density is determined at two elevations within the space, approximately 50 mm and 150 mm above the ground. The raised elevation is intended to simulate the situation of a subfloor containing numerous cables, filling approximately half of the interstitial space.

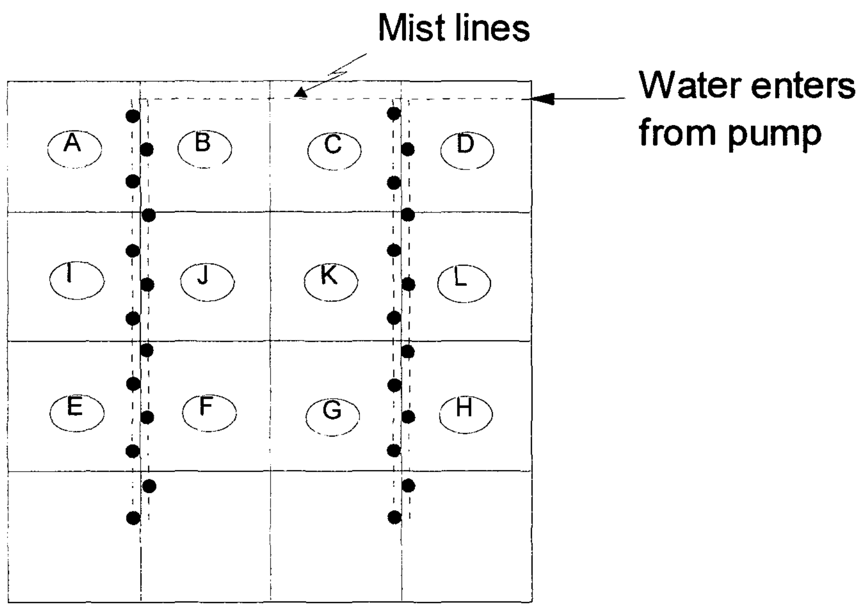
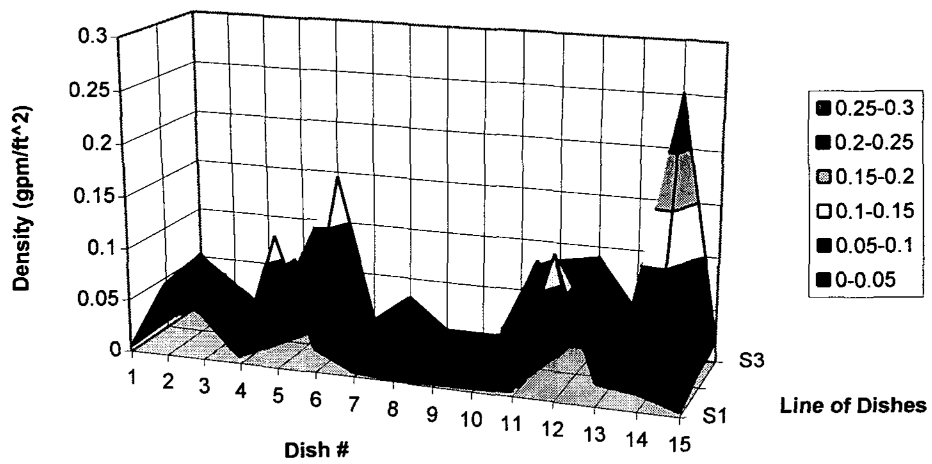


Fig. 1. Schematic Diagram of Water Mist System in Raised Subfloor

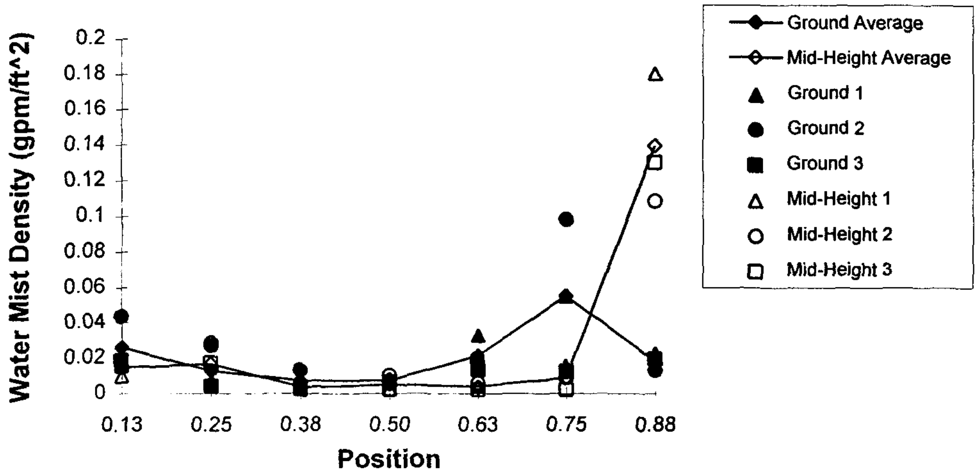
Results from the water distribution tests provide a profile of water density throughout the subfloor, such as that presented in Fig. 2 at the 15 cm elevation for tests conducted with 3 lines of nozzles at -45, 0 and 45°. The greater water mist densities are associated with positions closest to the mist lines. Because the density is measured at discrete points and nozzles are staggered along the lines, appreciably greater densities are measured where the cup or dish was positioned within a cone of mist extending from the nozzle. Other than the limited number of locations with appreciably greater densities, the density of water mist is nominally the same throughout the remainder of the space.

Variation of the water mist density as a function of distance from the mist lines is presented in Fig. 3 (independent of location in the direction parallel to the mist line). Other than for x/s Orientation values near 0.0 and 1.0, the density is approximately the same at both the 15 and 30 cm elevations for the 3-line 45° system. However, an appreciably greater density is achieved near the middle of the space by the 3-line, 45° system because of the increased coverage area of a cone of mist emanating from the nozzle at the steeper angle and greater elevation.



1.0 gpm/ft^2 = 0.68 l/s·m^2

Fig. 2. Distribution of Water Mist Density, 6 in. Below Top of Subfloor, -45, 0, +45° Orientation of Nozzles



1.0 gpm/ft^2 = 0.68 l/s·m^2

Fig. 3. Water Mist Density vs. Distance from Water Mist Line, 45°

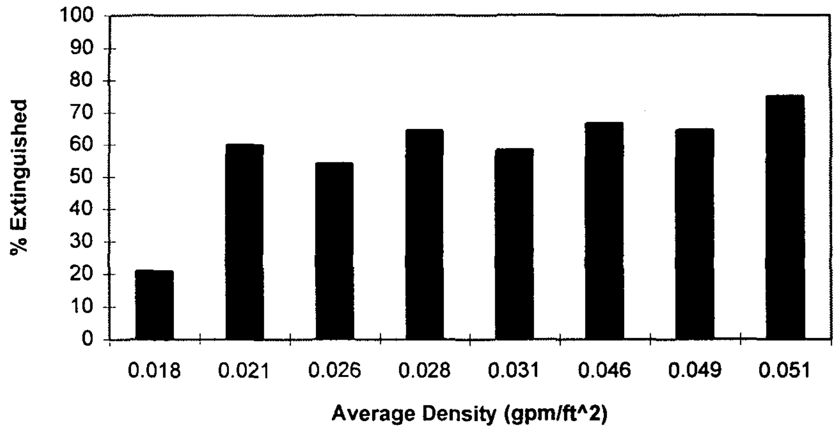
Heptane Fire Experiments

One of the fire sources used in the second set of experiments is 50 ml of heptane in a 83 mm diameter metal can. The water mist system is actuated approximately 10 s after igniting the last can of heptane by initiating operation of the pump. The water mist is discharged into the space for a maximum of 5 minutes. Upon terminating the discharge, selected subfloor tiles are removed to determine the number of heptane fires which are extinguished. For any extinguished cups, re-ignition of the heptane is attempted to confirm that the fire is extinguished due to the water mist and not due to consumption of all of the fuel.

Extinguishment observations are summarized in Fig. 4 for heptane cups. The general trend indicated in the figures supports intuition, *i.e.* an increase in water mist density should yield an increase in likelihood of extinguishment.

Cellulosic Fuel Package Experiments

The other fuel package is cellulosic and is utilized to investigate the ability of the water mist system to control a spreading fire. The main fuel package consists of a 150 x 150 x 510 mm cardboard tube open on the top and enclosed by a wire mesh. Four targets are placed 25 mm away from the four corners of the tube, as indicated in Fig. 5. The main fuel package and targets are filled with crumpled newspaper. Tests are conducted with the main fuel package oriented parallel and perpendicular to the water mist lines and with and without ventilation. A pre-burn time of 90 s is permitted for the cellulosic fuel package prior to discharging water mist. The water mist is discharged into the space for a maximum of 10 minutes.



1.0 $gpm/ft^2 = 0.68\ l/s \cdot m^2$

Fig. 4. Extinguishment of Heptane Cups

30 tests were conducted with the cellulosic fuel package. Temperature measurements from one of the tests is provided in Fig. 6. The 45° water mist system prevented fire from involving all of the main fuel package in 83% of the cases. In only 8% of the tests did fire spread to a target.

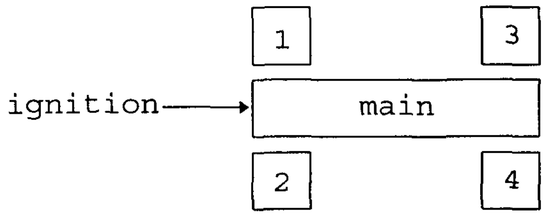


Fig. 5. Schematic Diagram of Cellulosic Fuel Package and Targets

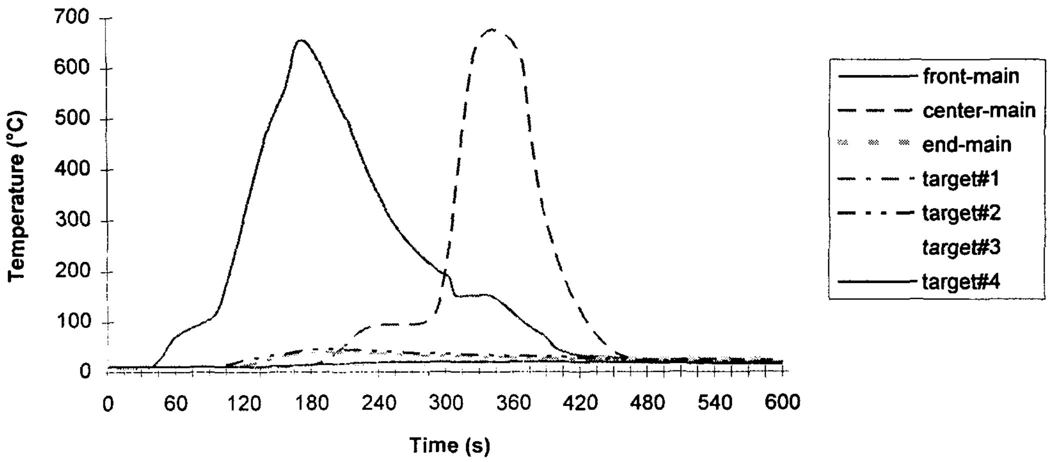


Fig. 6. Performance of 45° Water Mist System on Cellulosic Fuel Package Fire

CONCLUSION

The tests indicate that water mist suppression merits further consideration as a possible method of protection for interstitial spaces under raised subfloors. Different levels of performance are indicated for the various nozzle arrangements. A reasonably uniform distribution of water mist is achieved throughout the space. Based on the limited number of tests conducted with fires involving small heptane pools and cellulosic fuel packages, a minimum water flow density on the order of 0.015 $l/s{\cdot}m^2$ appears to be necessary to achieve rapid control of both the heptane and cellulosic fuel fires.

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