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Ultra Fine Water Mist Total Flooding Fire Tests

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ABSTRACT

This work reports the results of ultra fine water mist total flooding fire tests conducted in a 22-m^3 enclosure. The ultra fine mist (UFM) with droplet diameter below 10-microns closely resembles gaseous agents in its transport behavior in cluttered spaces with an ability to diffuse around obstructions without significant loss of mist due to deposition. In order to explore the benefits of UFM and its potential commercial applications, work was carried out with the following objectives: 1) evaluate the gas-like behavior of UFM in a total flooding test scenario in an enclosure, 2) address the mist discharge and transport behavior in enclosures, 3) estimate scaling capability of ultra fine mist for real-scale fire protection installations.

The UFM total flooding behavior in a 22-m^3 room was carried out using NanoMist®, a proprietary ultra fine water mist technology. The methodology used was similar to clean gaseous agent total flooding tests. Twelve telltales were placed 1-foot away from the corners at three heights. Four telltales on the first level were placed at the base, the second set of four telltales at the mid-level and the third set of four telltales at 75% of the room height. The UFM was discharged with outlet ports oriented in a vertical direction. The atomizer carrier gas/air was pulled from outside in these tests. The extinction of telltale fires was estimated by multiple thermocouples placed inside the fire (above the telltale cup) which were connected to a data acquisition system. Telltales at the floor level were extinguished within 2-3 minutes, those at 50% of the room height were extinguished within 4 minutes, and those at 75% of the room height level were extinguished within 6-7 minutes.

The work reported here shows the gas-like transport behavior of UFM in reaching corners and extinguishing all telltales consistently, thus demonstrating the ability of mist to distribute both laterally and along the height in a total flooding scenario. The use of external air had implications on transport, cooling, and extinction processes. Drawing fresh air from outside also limited the ability to accelerate the mist discharge velocity inside without using excessive air. By using an internal gas mixture, the discharge rate and transport rates can be optimized and implemented in "real world" applications.

INTRODUCTION

Work for the last seven years on ultra fine water mist (droplet diameters below 10 μm) has created significant interest in using Ultra Fine Mist (UFM) as an alternative to gaseous agents in certain selected fire threat scenarios [1-9]. A considerable amount of work has been reported on the characterization and mist fire suppression behavior of UFM under different laboratory conditions [10-13]. Patent documents [14, 15] describe the details of UFM technology and its possible applications. Similar to a gaseous agent, UFM applications involve areas with obstructions and non-line of sight locations. UFM has the following unique features: 1) high cooling power of water mist (2.25 MJ/liter of water) while behaving like a *pseudo gas*, 2) tolerance to reasonable leaks since UFM water-mist can be continuously discharged, 3) little or no collateral damage in the event of a false discharge because of the small amount of water usage, and 4) environmentally–

friendly water fog without chemical agents.

The high efficiency of UFM comes from a large number of extremely fine water droplets with a huge surface area per 1.0 liter of water. With nearly micron sized droplets, a very small amount of water is sufficient to accomplish the same cooling and inerting capability found in conventional water spray systems. The graph in Figure 1 below shows that decreasing the droplet size by a factor of ten results in the increase of surface area by a factor of ten, and the number of droplets by a factor of a thousand. This contributes to the unique fire suppression efficiency of the UFM fire suppression agent.

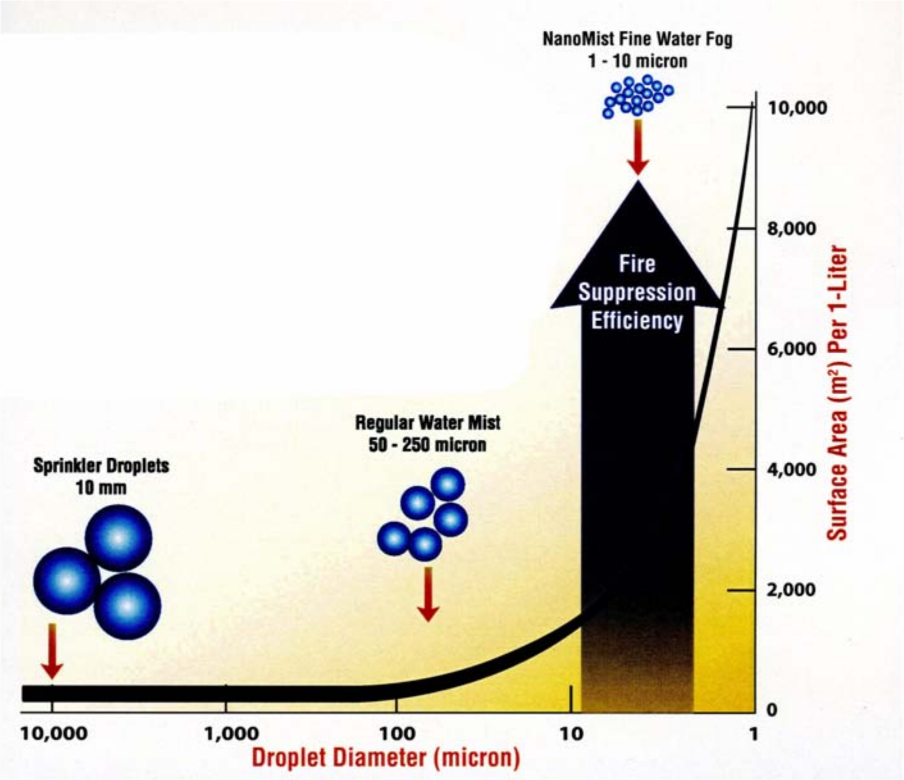

Figure 1: Increasing efficiency of fire suppression with decreasing droplet diameter

The objective of this work was to investigate the gas-like nature of UFM in a 22-m^3 fire test compartment, treating UFM as a gaseous agent and using corner telltales at various heights. In addition to low velocity UFM, some “high-momentum” discharge scenarios demonstrating the ability to increase the mist “throw” height/distance and accelerated transport process are also illustrated.

TEST METHOD

As indicated in the objective, based on the gas-like transport of UFM, we have selected tests that are used to confirm the efficacy of gaseous systems.

FIRE TEST COMPARTMENT

Figure 2 shows the fire test room used. A ~22 m^3 compartment with dimensions of 3.6 m x 2.2 m x 2.8 m was used.

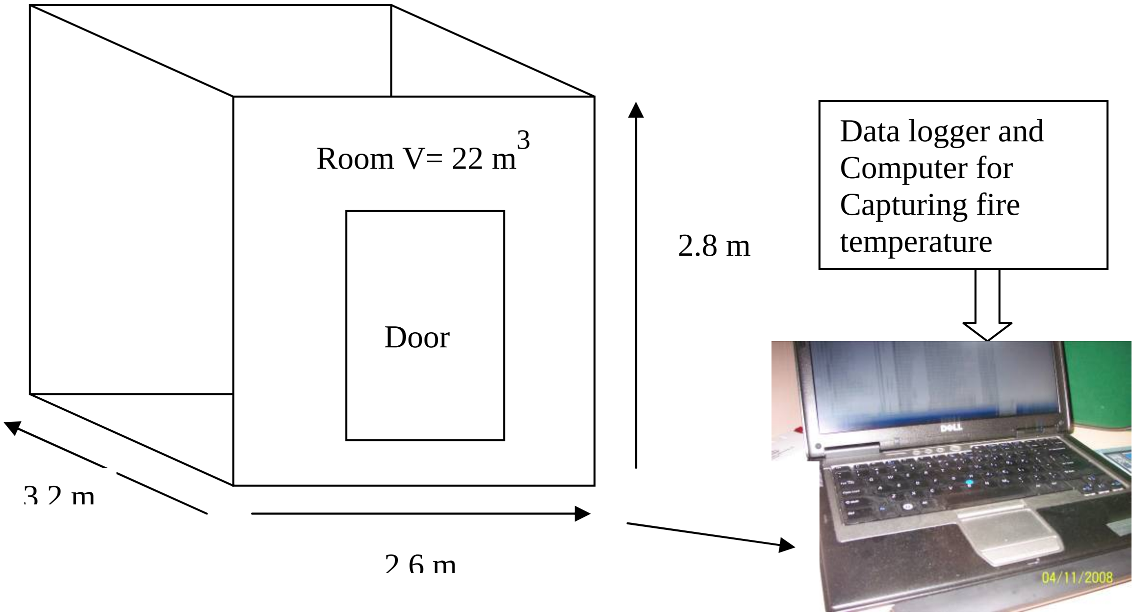

Figure 2: Fire test compartment

NANOMIST AGENT DISCHARGE

Figure 3 shows the UFM discharge outlay used in these tests. 1.00 - 2.5 LPM of mist was discharged into the chamber from the sidewall. The velocities at the mist discharge outlets varied from 1.8-2.2 m/s. Discharge outlets have a diameter of 5-6 inches

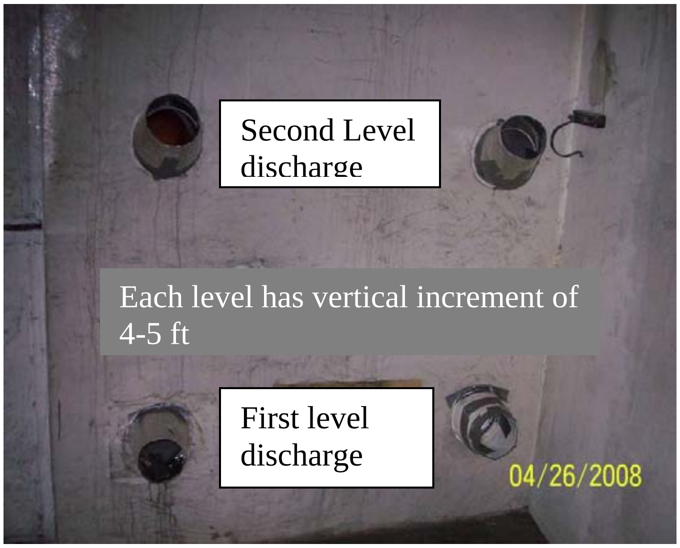

Figure 3: NanoMist discharge configuration

FIRE TESTS - TELLTALES

Using the protocol utilized in clean gaseous agent tests, telltale (TT) fires are used to determine the extinguishing ability of UFM-NanoMist. Telltale cups are made out of stainless steel of dimensions: 4-inch height, 3-inch diameter, and 0.25 inch wall thickness. Kerosene fuel (~120 ml) was floated on water with a freeboard of 1.5-2.0 inches. Figure 4 shows telltale fires located inside the test room.

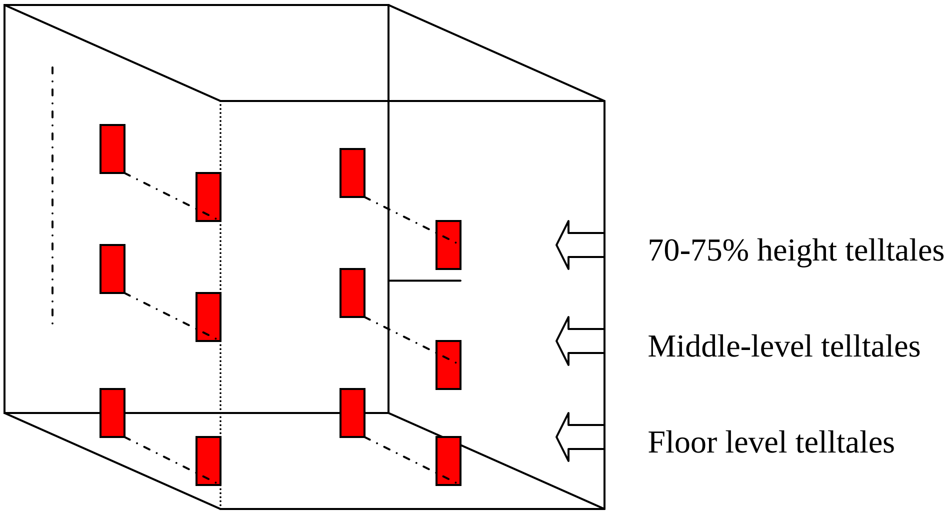

Figure 4: Telltale fire inside the room

Figure 5 shows a photograph of telltales at the corners of the floor.

Figure 5: Telltales on floor corners

VENTILATION CONDITION

The top vent was open to ambient in order to account for the small pressure rise inside the room during the test due to carrier gas/air pulled from the outside by the misters.

DATA CAPTURE AND ANALYSIS

Thermocouples were placed at the top of the telltale cups. The fire temperature was plotted using an OMEGA 10-channel data logger simultaneously capturing thermocouple data from all telltales. Fire extinction behavior was confirmed by observing the temperature curve going to ambient condition in each case.

DESIGN CONCENTRATION OF AGENT UFM

The cup burner extinction concentration reported in open literature for NanoMist-like extremely fine water is ~ 0.20 L/m$^{3.}$ Based on this extinction concentration, and a pre-determined discharge time, the mist generator capacity can be calculated. For example, for a room of ~20 m^3, we need 4.00 liters of water (20m$^{3\ x}$ 0.20 L/m^3). We can choose four NanoMist generators of 1.00 LPM each to achieve a design concentration of 0.2 L/m^3 in 1-minute discharge. Or, in order to reduce the number of units, we can choose 2-4 minutes of discharge.

TEST PROCEDURE

Misters were checked for normal operation before starting the test by conducting mist rate tests without fire in the compartment. Telltales were prepared by filling with kerosene (n-heptane was not available). Data loggers were started, and telltales were ignited using a premixed flame. The fire test room door was closed, and normal ventilation was opened at the top. After a pre-burn time of 1-2 minutes, UFM (NanoMist) was discharged.

The fire temperature-time histories (plots) show temperatures lowering upon the discharge of NanoMist. This shows the telltale suppression behavior in the presence of the UFM agent. This is followed by a “fire-out” (or extinction) condition when the water concentration reaches the extinction concentration level. If the gas phase did not attain the extinction concentration of water, the telltale continued to burn. A stopwatch was also used to make instantaneous records of extinction times for each telltale. From the plot, the rate of “heat extraction,” which is a measure of suppression efficiency, can also be plotted. Because of the fluctuations, only mean values can be estimated.

Since fire is not a deterministic process, each test was repeated several times (5-8 times) to establish the frequency of occurrence of complete extinction.

After completion of the test, fires which were not extinguished were manually extinguished by blocking oxygen using a fire blocker plate. The combustion gases were exhausted by a high capacity exhaust fan.

RESULTS AND DISCUSSION

Temperature histories for the base level telltales are shown in Figure 6. Note that the absolute temperature readings are relatively low due to the lack of calibration and recorder setup. However, the "fire out condition" does not change. Upon the mist discharge, fire temperatures start decreasing and finally reach ambient temperature indicating extinguishment. In the case of floor telltales, all telltales go out within approximately 2-3 minutes, at a mist rate of 1.4 liter/min. The extinction time 2-min gives an extinction concentration of 130 grams/m3. This is much lower than the expected ~200 grams/m3.

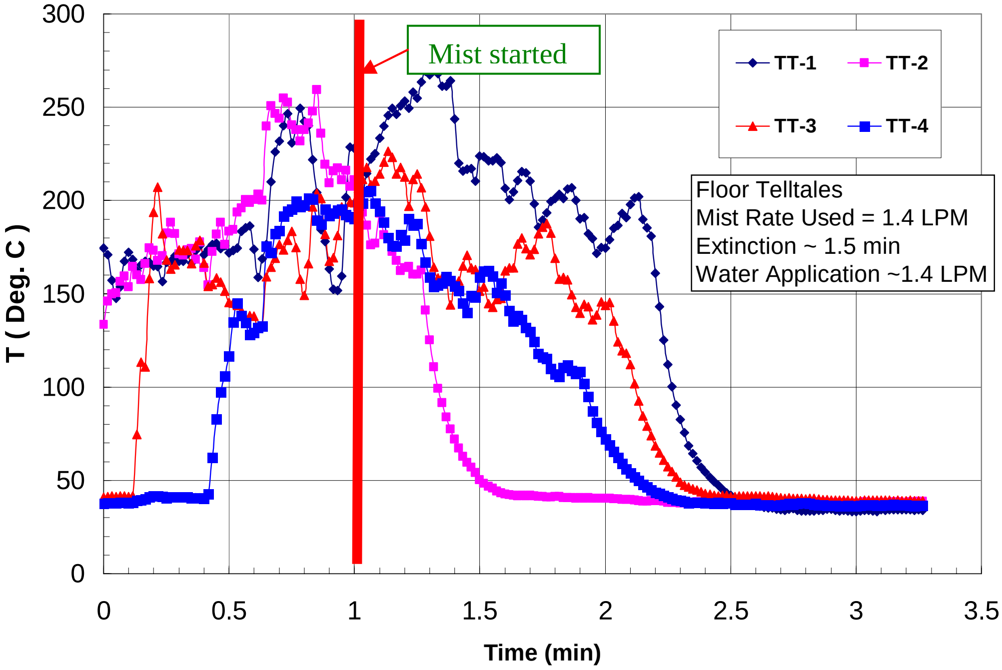

Figure 6: Fire temperature histories of telltales at the corner of the floor of 22 m^3 room.

Temperature histories for middle-level telltales are shown in Figure 7. The extinction time is ~ 4 min which is longer than for floor telltales. This is because of the slow build up of the mist concentration at this level. This is mainly due the mist transport delay.

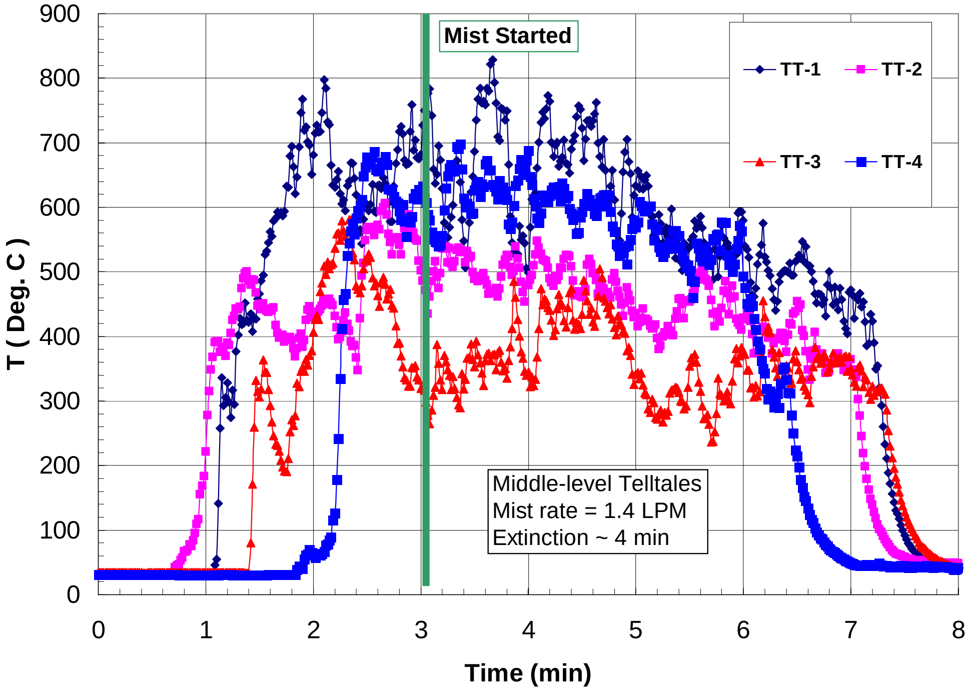

Figure 7: Fire temperature histories of middle- level (50% height) telltales fires located in 22 m^3 room

The temperature histories for the top (70-75% of room height) telltales are shown in Figure 8. Two telltales were extinguished within 2 minutes, but the third took up to 6 minutes. These extinction times vary depending on the spatial concentration of water. The concentration fluctuates due to conditions inside volume such as turbulence, leaks and flow interactions. In the case of the top telltales, the extinction behavior was influenced by the proximity of the ventilation outlet. Also, it is expected that additional time is required for mist concentration build-up as it moves up in the room since UFM-NanoMist is heavier than air. The ability to put out telltales located at 75% of the room height resembles the performance of gaseous agents. The results also confirm the gaseous nature of ultra-fine mist in terms of reaching hard-to-reach corners.

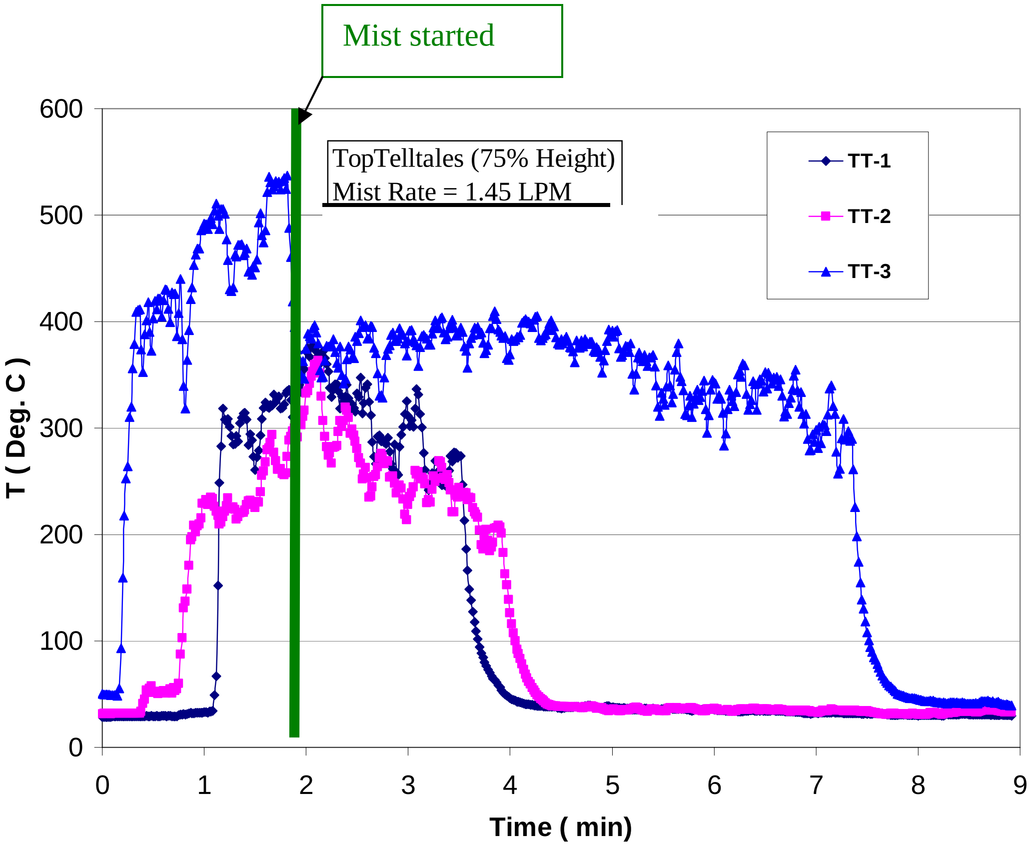

Figure 8: Fire temperature histories for telltales located at 75% height. The final extinction time varied 5- 7 min for several repeats

Flow obstructions and raised floor simulation

In order to assess the effect of blockage to mist flow on extinction behavior, tests were also conducted using a raised floor configuration as shown in Figure 9. Four telltales were placed underneath a 3 ft (wide) x 5 ft (long) table supported by cement blocks of 16-inch height. Baffles were placed to block mist coming directly from the outlets and reaching the telltales, as shown in Figure 10.

Fire temperature plots for flow obstructed scenario tests are shown in Figure 11. Note that the absolute temperature readings are relatively low due to the lack of calibration and recorder setup. As seen by the temperature plots, the fire out conditions did not change in spite of the flow blockage, and all the telltales were extinguished. In fact, the extinction time was ~2 min which is close to the baseline (no flow obstruction) case. This shows the near gaseous nature of the NanoMist agent demonstrated by the ability to reach hidden areas in a typical total flooding situation. This feature of UFM, to reach hard-to-reach non-line of sight places, makes it an attractive agent for “hidden area” fires.

Figure 9: Telltales under extended baffle plate; raised floor simulation 16-inch height

Figure 10: Direct flow of mist underneath the raised-floor was blocked

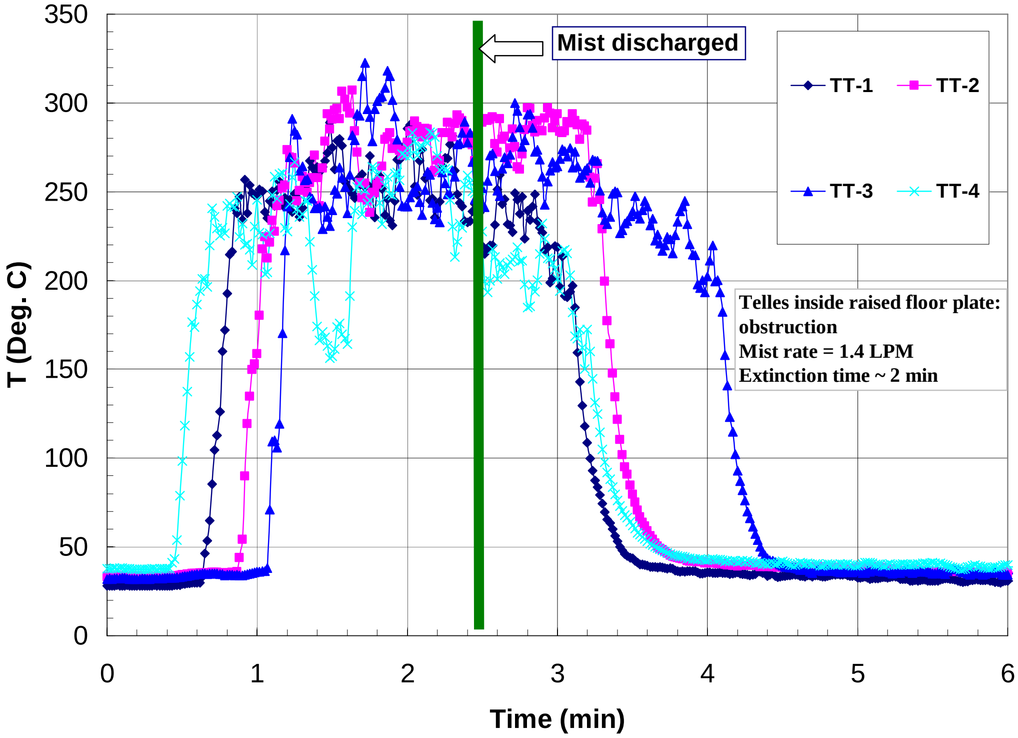

Figure 11: Fire temperature histories for flow-blocked telltales in a raised floor scenario

UFM High Velocity Discharge

The results discussed so far include only low velocity (1-2 m/s) discharge. As seen, such low velocity mist discharge causes transport delays resulting in long extinction times for fires at higher levels in the room. However, low velocity (low momentum) mist is desirable to reduce droplet loss due to the impact on the surfaces in a "cluttered" space. Because of the extremely low droplet mass (6.54 x 10^{-14} kg for a 5-micron droplet), a reasonable acceleration of mist discharge velocity (10-15 m/s) does not reduce its effectiveness as a gaseous agent with reduced droplet loss due to impact.

Figure 12A and 12B show photographs of relatively high velocity UFM discharge. The initial discharge velocity is 10-15 m/s which is relatively high compared to 1-2 m/s in low momentum UFM discharges. Although results are not presented here on the fire scenarios, the added turbulence and mixing behaviors of high-momentum discharge should help in reducing overall extinction times of telltales at all levels. This will also further minimize the amount of water required for fire extinction.

Figure 12: Accelerated UFM mist discharge to accelerate the transport process.

SUMMARY

All four telltales at the floor level are extinguished within 2-3 minutes using approximately 1.4 LPM NanoMist. This extinction time in a 22 m^3 room gives an extinction concentration of 0.130-0.19 L/$m^{\mathbf{3}}$ (130-190 grams/m^3**).** All telltales at the 50% of room height level are extinguished within 4 minutes using about 1.4 LPM. This gives an extinction concentration of 0.250 L/m^3 (250 grams/m^3**).** Telltales at the 70-75% of room height level are extinguished within 6-7 minutes. A reduction in this water requirement may be accomplished by accelerating the transport rate of mist. In addition, using low velocity discharge, a nominal increase in extinction times for telltales located near the ceiling is expected based on the higher bulk densities of NanoMist compared to the air density.

The results of simulated raised floor tests indicate the near gaseous nature of UFM in its ability to reach hidden areas in a typical total flooding situation. This feature of UFM to reach non-line-of-sight shows its possible use in “hidden area” fires.

UFM agent demonstrates the gas-like total flooding behavior in a room of 22 m^3. Test results also showed the ability of the UFM agent to pass around obstacles and extinguish telltales located in corners and hidden areas. The observed high-speed discharge behavior indicate the ability to accomplish faster mist transport and the potential to accomplish quicker extinction of fires in a total flooding context.

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