ELECTRONIC SPACE FIRE PROTECTION: FALSE DECK MOCKUP FIRE TESTING OF NANOMIST SYSTEMS

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ABSTRACT

Reduced manned Naval vessels require automated fire suppression systems to compensate for the reduced size of damage control parties. Fine water mist systems are attractive from a total ship protection standpoint. However, the interaction between the applied mist and the compartment boundaries and obstructions in the sub-floor causes excessive mist loss because of flow obstructions

NanoMist Systems, LLC, has a patented technology (NanoMist®) that generates and discharges ultra fine mist (UFM) at ambient pressure with average drop sizes smaller than 10 microns. This drop size is significantly lower than that generated in conventional water mist systems that utilize high fluid pressure or shearing air flows to generate the water mist. Mist characterization testing on mist samples withdrawn from the back of the mock-up revealed an average drop size, Dv_{50}, of 7 microns. The mist behaves like a dense gas in terms of transport and dispersion inside a cluttered volume. In the constant search for a nearly clean-gas-like water mist system, NanoMist® ultrafine water mist was investigated for fire suppression in electronic space fire suppression in a sub-floor mockup using telltale flames behind obstruction caused by a baffle. The electronic exposure test was conducted using a modem card.

The ultrafine mist (UFM) extinguished the telltale fire with a 0.053 LPM/m^2 water application flux in approximately 3 minutes. The lower water application flux tested, 0.037 LPM/m^2 after 8.5 minutes which corresponded to 2.6 air changes. The polypropylene array fire was more readily extinguished by the NanoMist® tested. The external communication modems exposed to the generated water mists were able to continue operating for at least 7 minutes after mister actuation.

The ultra fine water mist showed significant promise in this application. The small drop size and high initial mist water concentration enabled the generated mist to extinguish the test fires located behind a baffle spanning a third of the enclosure width and the entire enclosure height.

INTRODUCTION

Fine water mist systems are attractive from a total ship protection standpoint. Application of this technology to electronics spaces, however, is problematic in terms of collateral damage to equipment, performance for involved cabinets, and performance in sub-floors. A previously conducted fire hazard analysis identified gaseous agent systems as the system of choice for critical/high value spaces in a peacetime fire scenario [1]. However, in wartime scenarios where the enclosure integrity cannot be assured or the primary fire threat is in an adjacent space, the effectiveness of gaseous agent systems is severely compromised. A recent analysis of protection options indicates that there is not an optimum system when all factors of manning, automation, and performance are considered for both peacetime and wartime scenarios [2].

The concept of an inert gas and water mist hybrid fire suppression system was proposed to address this issue [3]. The proposed technology involves the combined use of fine water spray and inert gas fire suppressants (e.g., nitrogen).

Fine water spray or mist systems have not been effective when applied to complex false deck/sub-floor areas. The interaction between the applied mist and the compartment boundaries and obstructions in the sub-floor causes excessive mist loss. The obstructed flow paths available cause only the smallest drops in the mist to be able to reach all areas in the protected space. A water mist system that generates smaller drops may yield better dispersion and more even protection throughout false deck/sub-floor spaces.

NanoMist Systems, LLC has patented ultra fine mist (UFM) technology that utilizes high throughput ultrasonic techniques to generate, extract and deliver extremely fine water mist with average drop sizes smaller than 10 microns. This drop size is significantly lower than that generated in more conventional water mist systems that utilize either high fluid pressure or shearing air flows to generate the water mist. The NanoMist System employs a carrier air stream to deliver the generated mist to the enclosure. The exit momentum of mist is extremely low, behaving almost like a dense gas. Varying the carrier air stream flow rate results in initial mist water loadings of 10% to 30% water by weight or 150 to 470 g water/m^3air.

This paper presents the results of a parametric study of an ultrafine water mist (NanoMist®) application in a 2.3 m^2 sub-floor mockup with heptane telltales near the baffle obstructing the line of sight mist flow.

OBJECTIVE

The objective of this work was to evaluate the ultrafine water mist produced by NanoMist® technology in sub-floor/false deck applications and to examine if it can overcome obstructions. This evaluation is to determine if the ultrafine mist (UFM) produced by NanoMist® can be effective in these applications and the system design parameters, water mist application flux and initial water mist concentration, required to apply these systems successfully.

APPROACH

In this work, the water mist application flux and initial water mist concentration or water loading were evaluated relative to their impact on the water mist system performance. This performance was measured with respect to extinguishment of fires within the sub-floor space using heptane tell tales and polypropylene block fires. The effect of UFM on damage potential to operating electronics was also investigated.

Test Enclosure

The simulated sub-floor dimension was 2.0 x 1.9 x 0.3 m (6.5 x 6.1 x 1.0 ft), as shown in Figure 1. The top deck consisted of nine 0.61 x 0.61 m (2 x 2 ft) panels that can be lifted off in order to gain access to the sub-floor area

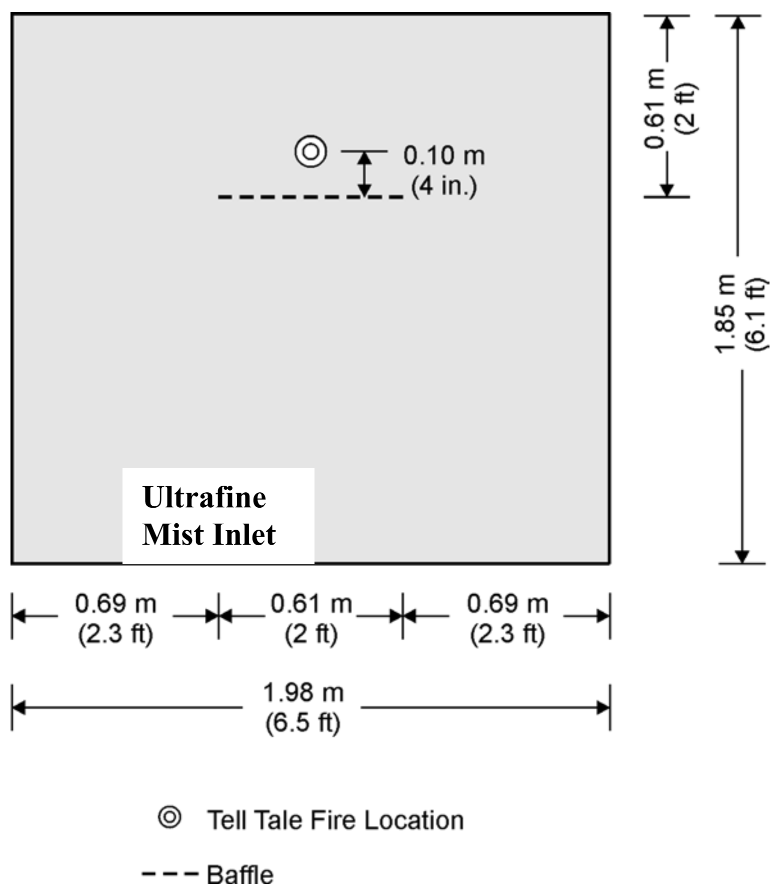

Figure 1. The 2.3 m^2 electronics space sub-floor mockup.

Fire Scenarios

Two fire scenarios were utilized during these tests. The first of these involved a “telltale” n-heptane can fire. This telltale can fire was similar in construction to that specified by

Underwriters Laboratories in their clean agent standards UL-2127 [4] and UL-2166 [5]. The cup was 7.6 cm (3 in) in diameter, had a wall thickness of 5.50 mm (.216 in) corresponding to schedule 40 steel pipe, 10 cm (4 in) in height and fueled with 120 ml of n-heptane floating on a water substrate to result in a 2.5 cm (1 in) freeboard. The telltale cup was placed 10 cm (4 in) from a vertical baffle located 0.61 m (2 ft) from the back wall and 0.61 m (2 ft) in length.

The second fire scenario consisted of a plastic sheet array similar to that utilized in UL 2127 [4] and UL 2166 [5]. This array was scaled down to utilize two 5 x 10 x 0.95 cm (2 x 4 x 0.375 in) sheets of natural polypropylene with a 1.27 cm (0.5 in) gap between the sheets. The array was held in place by a 6.8 mm (0.25 in) all thread rod suspended from an angle aluminum frame. The array was ignited by a 5 cm (2 in) square pan, fueled with 3 ml of n-heptane. The array was centered behind the baffle with the plastic sheets running parallel to the baffle. The center of the array was 10 cm (4 in) from the baffle.

Water Mist System

The ultrafine water mist was introduced into the mock-up through a 10 cm (4 in) duct installed in a cover plate 15.2 cm (6 in) beyond the front wall of the mock-up. The airflow from the mist generators into the mock-up ran continuously during these tests and was present during all of pre-burn periods of these tests.

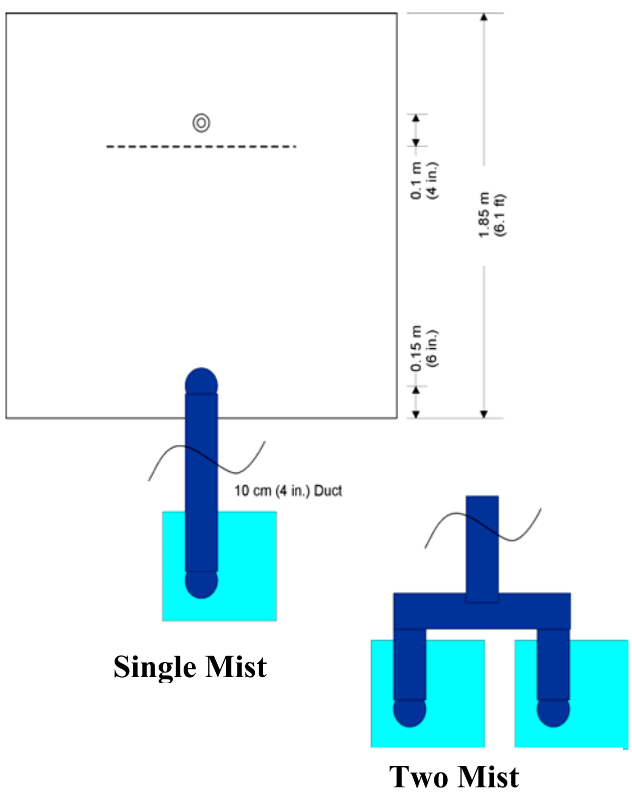

Figure 2. Ultrafine mist generator configuration and mist.

Figure 3. UFM generator configuration configured for single generator operation.

Figure 4. Photograph of the UFM mist flow at the inlet inside the mockup.

Omega Engineering Model KMQSS-062E-120 stainless steel sheathed exposed junction thermocouples were utilized to monitor the test fires for extinguishment.

A Malvern Series 2600 Drop Size Analyzer was utilized to characterize the generated water mists. It was equipped with a 63 mm focal length lens to result in a 1.2 micron to 122 micron drop size range. It was configured for a 25 mm (1 in) active measuring path. The mist was withdrawn from the backside of the mock-up behind the baffle through a 100 mm (4 in) PVC pipe that was reduced down to a 25 mm (1 in) pipe stub. The pipe stub ended prior to encountering the laser from the analyzer. The instrumentation connection to mockup is outlined in Figure 5.

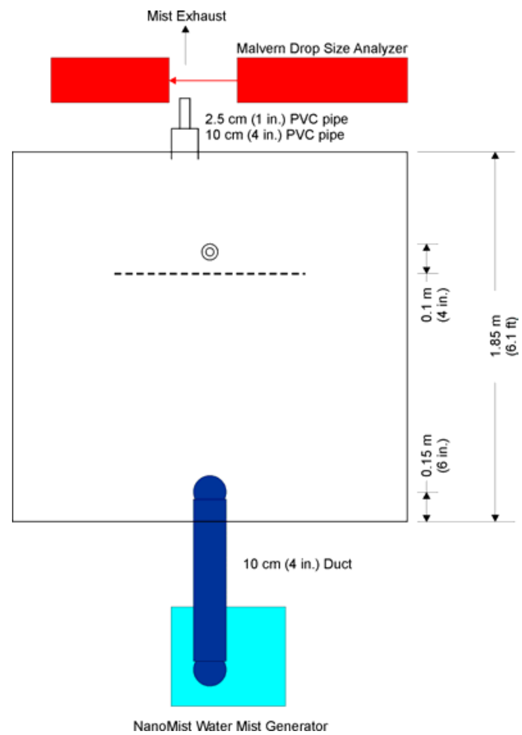

Figure 5. Malvern droplet size analyzer configured for mist characterization tests.

Electronics Exposure Targets

Two types of electronics targets were exposed to the mist generated. The first type was an external modem, Boca Research Model B100, which was monitored during exposure utilizing ULTRA-X QTPRO diagnostic testing software. The modem was removed from its plastic housing and mounted horizontally near the single telltale location. The second type was an uncoated printed circuit board. A comb circuit was imprinted on the board with alternating lines charged with 5 VDC with a line separation distance of 1.6 mm (0.0625 in). The comb circuit covers an area of 30.6 cm^2 (4.75 in^2) on the board. Two boards were exposed in each test, one horizontally oriented and the other vertically oriented. The current across the circuit were monitored during the exposure utilizing a 1 MΩ resistor for an effective range of 0 to 5 µA.

RESULTS AND DISCUSSION

Mist Characterization Testing Results

The measured drop size and concentrations are given in Table 1

Table 1. Mist Characterization.

NanoMist Setup						In Box (Withdrawn through 1" PVC pipe - 63 mm Lens on Malvern)					
Type	Number of Misters	Total Flow Rate		Water Concentration in Inlet Mist Flow		Drop Size			Concentration		Relative to Theoretical Extinguishing Concentration
		Water	Air			(Dv_{10})	(Dv_{50})	(Dv_{90})			
		[LPM]	[SLPM]	[% wt]	[g/m^3]	[micron]	[micron]	[micron]	[%Vol]	[g/m^3]	[%]
NanoMist with Original Fans	1	0.16	681	16.3%	234	1.5	7.3	11.4	0.0048	48	24.0%
	1	0.16	341	28.1%	469	1.4	6.9	10.1	0.005	50	25.0%
	2	0.22	681	21.2%	322	1.5	7.2	11.2	0.0067	67	33.5%
NanoMist with Larger Fans	1	0.14	876	11.7%	160	1.6	7.7	12.1	0.0056	56	28.0%
	1	0.14	486	19.3%	287	1.5	7.5	11.6	0.0067	67	33.5%
	2	0.20	876	16.0%	228	1.5	7.2	11.7	0.0083	83	41.5%

Telltale and Polypropylene Extinguishment Tests

During tests with the telltale n-heptane fires, the fire was ignited and allowed to burn for 60 seconds prior to mister activation. The cover plate directly above the telltale was removed during this pre-burn time period to minimize the effects of oxygen depletion. The airflow through the misters was actively pushing air through the mock-up during this time period.

During tests with the polypropylene array, this pre-burn time period was extended to 120 seconds. The 3 ml of n-heptane in the igniter pan provided an approximate 90 second burn duration and burned out prior to water mist application.

The results from testing the UFM mist with the telltale fire and the polypropylene array fire are summarized in Tables 2 and 3. The telltale fire was extinguished in all of the tests that utilized two operating misters, but only extinguished once utilizing a configuration involving a single mister. That one test, HYBD141, involved the highest inlet water concentration and the extinguishment of the telltale did not occur until 8.5 min after the mister was activated.

Table 2. Result Summary from Testing with Telltale Fire.

Test	Number Of Misters	Water Flow		Air Flow		Water Concentration		Ext Time	
		Flow Rate	Flux	Flow Rate	Changes				
		[mLPM]	[mLPM/m^2]	[L/s]	[#/hr]	[%wt]	[g/m^3]	[sec]	[changes]
HYBD141	1	160	42.78	5.68	17.92	28.1%	469	523	2.60
HYBD152	1	138	36.90	8.11	25.60	19.1%	283	N/E	N/E
HYBD161	1	100	26.74	11.35	35.84	10.9%	147	N/E	N/E
HYBD142	1	160	42.78	11.35	35.84	16.3%	234	N/E	N/E
HYBD160	2	200	53.47	11.35	35.84	19.6%	293	183	1.82
HYBD139	2	220	58.82	11.35	35.84	21.2%	322	149	1.48
HYBD140	2	220	58.82	11.35	35.84	21.2%	322	151	1.50
HYBD154	2	200	53.47	14.59	46.08	16.0%	228	186	2.38

Table 3. Results Summary from testing with Polypropylene Array Fire.

Test	Number Of Misters	Water Flow		Air Flow		Water Concentration		Ext Time	
		Flow Rate	Flux	Flow Rate	Changes				
		[mLPM]	[mLPM/m^2]	[L/s]	[#/hr]	[%wt]	[g/m^3]	[sec]	[changes]
HYBD144	1	160	42.78	5.68	17.92	28.1%	469	172	0.86
HYBD153	1	140	37.43	8.11	25.60	19.3%	287	95	0.68
HYBD168	1	128	37.43	11.35	35.84	14.6%	205	464	4.62
HYBD143	2	220	58.82	11.35	35.84	21.2%	322	94	0.94
HYBD155	2	200	53.47	14.59	46.08	16.0%	228	69	0.88

The ultrafine mist (UFM) parameters that resulted in the extinguishment of the telltale fire are plotted in Figure 6. The expected relationship of reducing extinguishment times with increasing mist concentrations can be seen in this figure. Figure 7 illustrates the measured temperature above the telltale cup with ignition, system activation and fire extinguishment times marked for one the two mister tests with an airflow rate of 11.35 L/s.

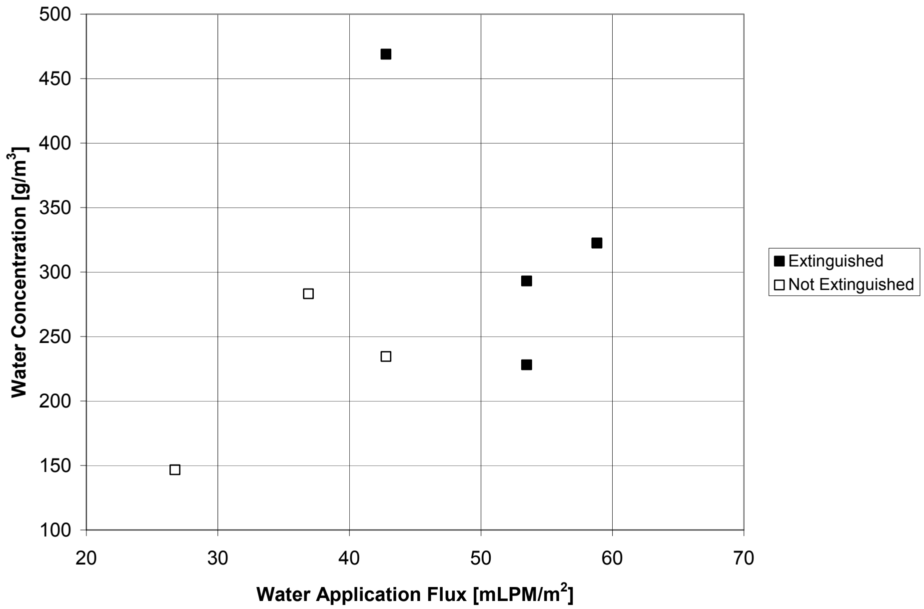

Figure 6. UFM mist system parameters correlated to extinguishment of heptane telltales.

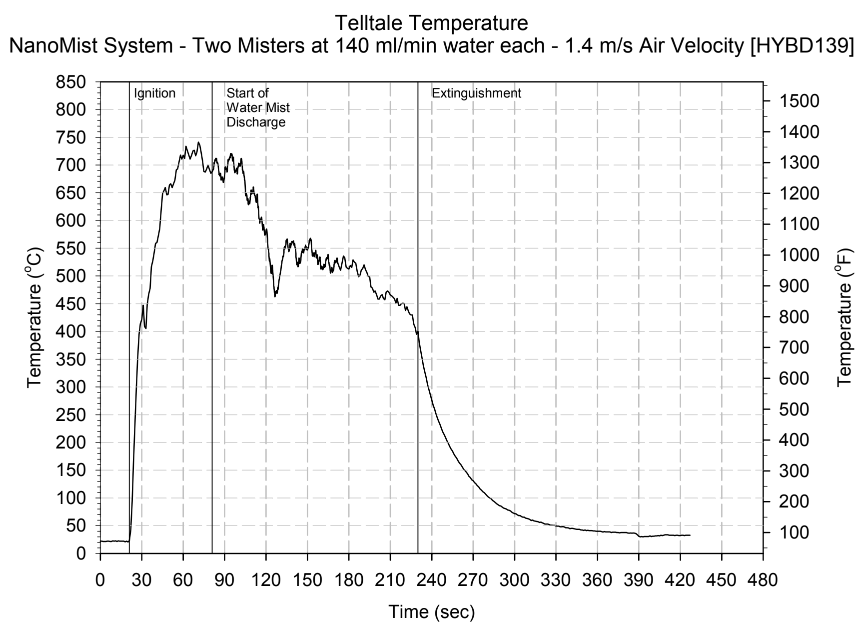

Figure 7. Telltale fire temperature during test with two operating misters with a total water flow of 220 mLPM and 11.35 l/s air.

The polypropylene array fire was extinguished successfully in each of the configurations tested. Figure 8 correlates the UFM parameters that resulted in extinguishing the polypropylene array in less than three minutes. Figure 9 illustrates the measured temperature above the polypropylene array with ignition, system activation and fire extinguishment times marked for the two mister test with an airflow rate of 11.35 L/s.

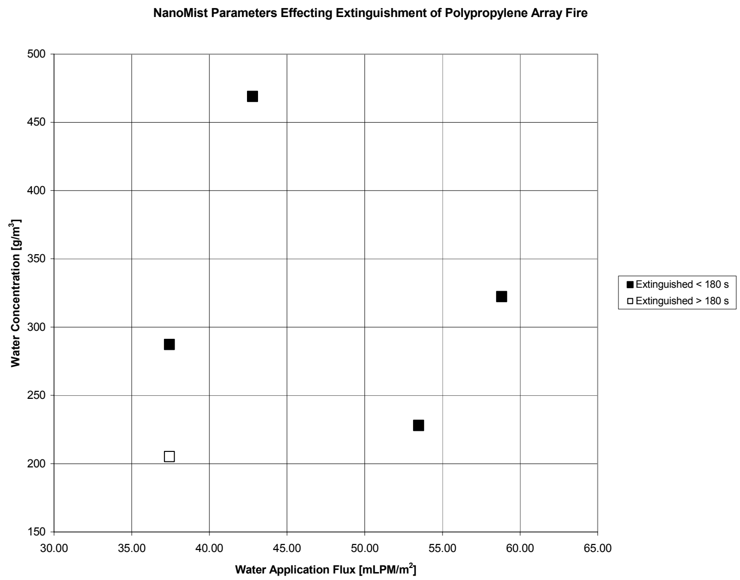

Figure 8. UFM parameters correlated to extinguishment of the polypropylene array fire.

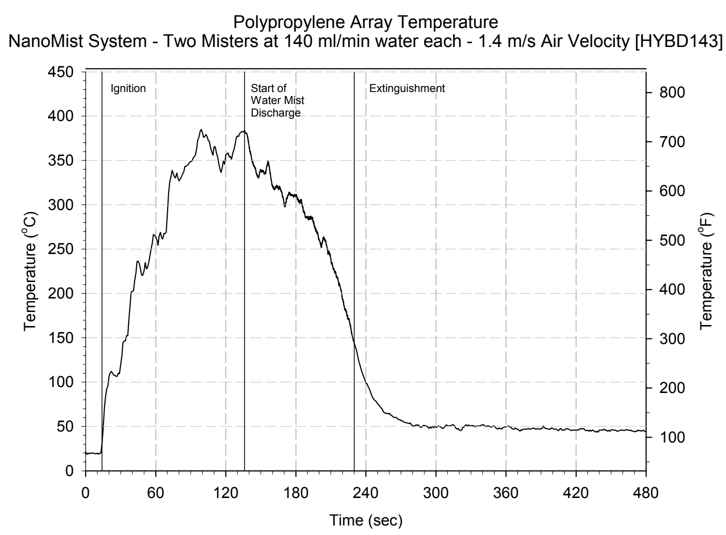

Figure 9. Polypropylene array fire temperature during test with two operating misters.

Electronics Exposure Tests

The results of these exposures are summarized in Table 6. As can be seen from this table, the modem continued to operate normally for at least seven minutes in each of these tests. In the test with a single mister with the original fan, the modem continued to function normally until 13 minutes after the mister was started. In all of these tests, the comb circuit on the horizontally oriented board quickly shorted, within two minutes of mister activation, with residual resistances less than 50 kΩ.

The modem failures roughly correlated to the vertically oriented board. In two of the four tests, the measured leakage current was ~ 2 μA at the time of Modem failure, however it had grown to 3.7 μA before modem failure in one test and the actual current was not recorded during the remaining test.

After exposure, the modems were shook and dried with a paper towel. The modems were then tested with the diagnostic software. None of the modems responded at that time. The modems were then set upside down on a paper towel overnight. All four modems responded and passed all of the diagnostic tests the next morning.

Table 4. Summary of Electronic Exposure Test Results.

Test	Number Of Misters	Water Flow		Air Flow		Water Concentration		Modem Fail Time	Leak Current at Modem Failure		Max Leak Current	
		Flow	Flux	Flow	Changes				Vert.	Hor.	Vert.	Hor.
		[mLPM]	[mLPM/m^2]	[L/s]	[#/hr]	[%wt]	[g/m^3]	[sec]	[uA]	[uA]	[uA]	[uA]
HYBD149	1	128	34.22	5.68	17.92	23.8%	375	780			0.22	4.81
HYBD151	1	143	38.23	8.11	25.60	19.6%	293	600	1.9	4.7	1.92	4.78
HYBD148	2	220	58.82	11.35	35.84	21.2%	322	463	1.75	4.9	2.24	4.92
HYBD150	2	220	58.82	14.59	46.08	17.3%	251	420	3.7	4.75	3.98	4.85

SUMMARY

The ultrafine mist provided by NanoMist® generator is capable of generating large concentrations of fine water drops. Mist characterization testing on mist samples withdrawn from the back of the mock-up revealed an average drop size, Dv_{50}, of 7 microns.

The UFM/NanoMist® was able to extinguish the telltale fire with a 0.053 LPM/m^2 water application flux and inlet mist water concentration ranging from 228 g/m^3 to 322 g/m^3 in approximately 3 minutes. The lower water application flux tested, 0.037 LPM/m^2, was only able to extinguish the telltale fire with a higher mist water concentration of 497 g/m^3 after 8.5 minutes, which corresponded to 2.6 air changes.

The polypropylene array fire was more readily extinguished by the NanoMist systems tested. and the lowest mist water concentration of 205 g/m^3 where the fire was extinguished after 7.7 minutes corresponding to 4.6 air changes.

The external modems exposed to the generated water mists were able to continue operating for at least 7 minutes after mister actuation. With the lowest water application rate and lowest air flow rate, the modem continued to operate for 13 minutes after mister application. The horizontally oriented comb circuit board was quickly shorted during all four exposure tests with leakage currents exceeding 4.0 μA within 2 minutes of mister activation. The vertically oriented comb circuit leakage current was approximately 2 μA at time corresponding to modem failure during two of the three tests where the current was monitored at the time of modem failure.

ACKNOWLEDGEMENT

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