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Status Report on Water Mist Fire Suppression Systems - 1996.

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Introduction

This status report will review a selection of recent developments in water mist fire suppression systems technology. Research and development work with water mist as a fire extinguishing medium began soon after the phase-out of Halon began with the signing of the Montreal Protocol in 1987. Still, in March 1996, the pace of development continues to be rapid and advances are occurring on several fronts. These include: full-scale testing to evaluate water mist on different fire scenarios; the development of test protocols to validate the performance of water mist; laboratory studies to advance the understanding of fire suppression using water mist; and developments in establishing design and installation standards and obtaining approvals listing of hardware associated with mist systems.

In collaboration with J.K. Richardson at the National Research Council in Canada (NRCC), I am co-authoring a summary review of current water mist research worldwide. A survey of water mist research activities was distributed by the NRCC in July 1995 to a broad range of agencies and individuals involved in water mist research. Table 1is an abridged list of subjects identified in the survey, which shows the directions of interest to researchers, approval authorities, and manufacturers as of the end of 1995.

There are many interesting subjects worthy of detailed discussion in Table 1. For this "status report" I have selected four issues from the Table for comment. They are: the International Maritime Organization (IMO) test protocols, the Factory Mutual approvals for Gas Turbine Enclosures; the use of mist in Heritage buildings, and developments in applying mist to telecommunications facilities. The activity regarding the IMO test protocols is stimulating much international exchange, product development and technology transfer. A great many organizations in Europe and North America are involved in discussing the tests, conducting them or reacting to the results by modifying products. The approval by Factory Mutual of a pre-engineered water mist system for gas turbine enclosures represents a second significant step toward establishing water mist systems in main-stream fire safety engineering. These test protocols are viewed in the context of the recently completed National Fire Protection Association Standard, NFPA 750, Standard on Water Mist Fire Protection Systems [1]. NFPA 750 defers to full scale testing, such as the IMO and the FM protocols, as the only way to validate the performance of a water mist fire suppression system.

The desire to use water mist to protect property that is sensitive to water damage sustains strong interest in using mist in Heritage buildings, and on electronic equipment. The status of work in these two areas is also discussed in the following text.

Table 1. Partial list of development activities pertaining to water mist fire suppression systems, as of August 1995.

Subject	Comments
Characterizing droplet sizes and velocities: - to advance understanding of extinguishment - to evaluate nozzles for listing purposes - to assist numerical modelling of sprays	Phased Doppler Anemometers. Listing agencies need to characterize sprays for listing purposes; CFD modelling groups need initial drop size and velocity distributions.
Spray momentum Spray dynamics Additives	A few agencies systematically studying the ability of spray to penetrate openings, and the effects of striking hot surfaces. Role of momentum in overcoming plume energy; spray dynamics revealed with CFD.
Water mist on Class A combustibles IMO cabin/public space test protocols Libraries, archives, mobile shelving Heritage Buildings, art work High-rack warehouses, 9 m	Equivalent to sprinkler system performance. IMO Light and Ordinary hazard tests; smoldering fires; shielded fires. Full-scale testing in progress. Rack Height, 9 m; corrugated cartons, polypropylene boxes, wood pallets.
Water mist on Class B hydrocarbon fires IMO test protocols - full-scale tests Marine machinery compartments Gas turbine enclosures	Machinery spaces; pool fires, spray fires, diesel fuel, lubrication oils; high pressure and low pressure sprays.
Standards development NFPA 750 IMO tests ULI - component testing	Much international technology exchange occurring.
Spray generation methods: nozzle innovations	Manufacturers developing variety of nozzles.
Computer Modelling: CFD	NRCC -TASCflow CFD; FRS - JASMINE ; validated against sprinklers; testing with water mist planned.
Watermist on electronics, telecommunication equipment	Several research groups working. Need to study non-thermal damage.
Spray generation methods: nozzle innovations	Manufacturers developing variety of nozzles.
Improved detection/activation, system controls	Zoning requirements to improve efficiency
Use of Additives:	Laboratory scale experiments Studying the interaction of water/additive droplets on hot surfaces
Combined water/inert gas sprays	Combining mist with nitrogen discharge. Mixing CO_2 and H_2O at discharge - unique cooling/inerting
Water mist systems for Aircraft	Aircraft passenger compartments - not applied Aircraft: Cargo Bay systems - recent experiments Aircraft: Jet engine nacelles - high challenge
Manual fire suppression using water mist	Using zone modeling; studying the efficiency of commercial fire hose nozzles of different quality sprays;
Health effects of inhaling water mist	Health panel formed to review issues; concluded fresh and sea water mist not a hazard to humans. Concerns remain about the effects of additives such as surfactants, biocides, suppression enhancing salts.

IMO Test Protocols.

The International Maritime Organization (IMO) is close to finalizing a test protocol to validate the use of water mist as equivalent to sprinkler systems on ships [2] [3] [4]. Test protocols have been developed for machinery spaces, where Class B liquid fuels are involved, and cabins, corridors and public spaces on ships, where Class A combustibles are involved. In the past 8 years, most of the NATO Navies (Norway, Sweden, Denmark, Germany, the Netherlands, United Kingdom, Canada, the US) have conducted full-scale machinery room tests using water mist. These were the tests that established the basic expectations for water mist. Attention has now focused on the details of a set of tests that will confirm performance of water mist in Class I machinery rooms up to 500 m^3 volume; and in larger Class II and III engine rooms up to 3000 m^3 and larger. Activity in support of the IMO test protocols for both cellulosic fuels (Class A) and liquid fuels (Class B) scenarios is occurring in Finland, at VTT; at the Swedish Testing laboratories (SP) in Borås, Sweden; at the Norwegian fire testing laboratories (SINTEF) in Trondheim; in separate projects funded by the US Department of Defense and the US Coast Guard on board two fire test ships located in Mobile, Alabama; and at Factory Mutual's test facility in West Gloucester, Rhode Island. Virtually all manufacturers of nozzles and equipment for water mist systems have contributed products for testing under these protocols.

It is interesting to note that the starting point for the IMO machinery space test protocols is defined by the engineering constraints on ships, rather than the optimum performance conditions for water mist. That is to say, it is assumed that total flooding of the compartment by water mist is the only practical design approach, because subdivision into smaller "zones" is too complex to be carried out reliably on merchant ships. Further, the IMO protocol requires water mist nozzles to be mounted at ceiling level only, not at "strategic" positions in the compartment which might improve performance. The reason for such a restriction is because it is considered impractical to situate nozzles ideally for all possible fire origins in an engine compartment. Again, it is assumed that under typical maritime conditions, there will be a ventilation opening into the compartment, therefore the water mist system cannot rely on "enclosure effects" of reduced oxygen concentration to achieve suppression. And, the performance objective for the mist system is set at nothing less than full extinguishment, given that, for a merchant ship with limited manual fire fighting capacity, "control" for a limited time may only delay the catastrophe. Although this "practical" approach is understandable, it poses difficulties for water mist, particularly in very large machinery compartments where the conditions needed for water mist to extinguish fires are seldom met.

Testing to the IMO protocol has been performed by the US Navy, US Coast Guard, and Factory Mutual, in North America, and at SP (Sweden), SINTEF (Norway), and VTT (Finland) in Europe. The tests confirm that water mist can be effective against diesel fuel spray and spill fires in marine machinery spaces up to 500 m^3, and possibly up to 1000 m^3. Various agencies are expressing doubt about the ability to meet the IMO test performance objectives in spaces larger than 1000 m^3. The expectations of a low water demand system ("low" as opposed to sprinkler water demand, for example) are not met, because of the inefficiency of applying water in a deluge system mode in a large compartment. The economics of meeting the water storage, pumping energy, and piping requirements for deluge-type water mist systems on merchant ships has not yet been established.

Based on the results of full-scale testing the US Navy has concluded that water mist performance, supplemented by bilge foam system, provides adequate protection. The US Navy estimates that the cost of a water mist system for a large Naval machinery room (> 3000 m^3) will be competitive with the other Halon replacement alternatives [5]. The US Army is reported to have plans to install water mist systems in machinery compartments (< 500 m^3) on their inland waterways ships.

The IMO test protocols extend also to Class A fire hazards involving cabins, crews quarters and public spaces on passenger ships [3, 4]. Water mist systems are tested to show equivalence with a sprinkler system designed to the SOLAS regulations. Testing agencies have been involved in designing the fuel packages and fire scenarios, and testing different mist generating equipment against fires in Class A combustibles. The ability to achieve fire suppression with significantly less water than a standard marine sprinkler system has been demonstrated. Testing is now progressing to many other scenarios involving Class A combustibles, including ordinary hazard fuel loadings in public spaces on ships, and libraries, museums and large wooden structures on land.

Turbine Enclosures.

The turbine enclosure is a subset of the marine machinery space. The first water mist systems to receive insurance industry "approval" in North America have been for the turbine enclosure scenario. Full-scale testing for this application began with SINTEF in Norway in the late 1980's [6]. Recently, Factory Mutual Research Corporation completed the approval process for a water mist system for turbine enclosures and (similar machinery spaces) up to 80 m^3 in volume. Testing is currently underway to evaluate similar systems for compartments up to 260 m^3. Testing of turbine enclosure scenarios has also been carried out by John Dyer and Associates for British Gas, in the United Kingdom [7]. Several installations of water mist systems based on the British Gas design are presently in progress.

The following aspects of the turbine enclosure systems are noteworthy.

1. Unlike the IMO constraints on the machinery spaces systems, the turbine enclosure system is not restricted to nozzles at the ceiling in a ventilated space. Nozzles can be placed strategically at several levels to address shielded, hidden spray fires. The room is assumed to have the same limited ventilation as was expected for the performance of Halon 1301.

2. The potential to damage turbine blades by overly-rapid cooling introduces a unique performance criterion to these tests. FM uses the results of cooling tests on a hot steel plate, combined with a computer model, to predict the rate of cooling for a given spray application rate. The results of the plate cooling are compared with the output of a computer simulation of the surface heat transfer. If the cooling rate of the surface does not exceed 25°C in 22 seconds, the thermal distortion of the turbine blades is expected to be within acceptable limits. One system design achieves this by using sequential short bursts of mist. Using the same criterion, a British group doing turbine enclosure tests for British Gas achieved the cooling-rate objective without cycling the spray [7]. Differences in turbine design, such as blade clearances, may account for the different outcomes.

3. Testing encompassed total system performance, including the detection and activation equipment; the water mist system component reliability; the effects of the mist on the protected object; and the degree of control or extinguishment provided. This is the level of comprehensive testing contemplated by NFPA 750 [1], which, as noted earlier, defers to full scale testing to validate a design.

4. The first system given approval is the Securiplex twin-fluid system, for volumes up to 80 m^3. Now that a test protocol exists, mist system manufacturers can submit their equipment for testing. At least two other manufacturers are seeking to pass the 80 m^3 tests, and all candidates are extending application to 260 m^3 spaces. The importance of the emergence of a first North American approval listing for a water mist fire suppression system cannot be underestimated. This comprehensive testing approach, involving evaluations of system performance with respect to fire suppression,

detection and actuation, cooling impact, and system reliability, defines the model for how water mist system designs will be validated in the future.

Heritage Buildings

Full-scale fire tests have been conducted in Norway and in the US to assess the ability of water mist to extinguish fires but limit water damage to valuable cultural property. The expectation is that if fire control or extinguishment can be achieved using very small total volumes of water, non-thermal (water) damage to the protected property will be minimized. This is appealing to managers of libraries, archives, museums, art galleries, and heritage buildings. In the US, at least one manufacturer is working on tests to demonstrate the ability of water mist to extinguish library fires in fixed shelf systems [8]. Testing is in progress for the fixed library shelving scenario; and plans are being made to do preliminary testing in 1996 on mobile shelving units.

In Norway, full-scale tests were conducted through SINTEF, to demonstrate the potential for water mist to protect small 13th century wood stave churches in remote areas [9]. In addition to being constructed of wood, located in areas of limited water supply and a cold climate, they contain irreplaceable icons painted with water soluble paint. Preliminary tests indicate that flashover can be prevented in the church, using water mist, without irreparable harm to the icons. The Norwegian fire engineering firm, IGP/AS in Trondheim, is planning further tests for 1996 for this application.

Telecommunications and Electronic Equipment

There continues to be strong interest in adapting water mist for application in telecommunications and electronic equipment facilities. These facilities were exclusively protected by Halons until recently. Although the incentive to find an affordable alternative to Halon sustains interest in the area, there is a strong prejudice against the use of water in electronics or electrical equipment which dampens enthusiasm. The tests to date suggest that water mist can be used on a wide range of electronic switch-gear equipment, without incurring unacceptable levels of water damage. Because of the reluctance to apply water to the equipment, the approach to design of a water mist system in an electronic room is the opposite of a total-flooding approach. A study conducted at NRCC in Canada [10] emphasizes the advantages of subdividing a water mist system into zones, and of providing a detection system that supports the zoning of the water mist system. Then, water is only applied in the actual fire location, not on all equipment in the room. The following issues are noteworthy.

1. The fire hazards in telecommunications facilities include electronic cabinets, underfloor cable plenums, overhead cable trays, and general work areas involving Class A combustibles. Fires originating in electronic equipment cabinets are rare, and fire growth is slow when it does occur. Fire in underfloor cable plenums and cable trays is more likely, as with a short circuit followed by ignition from the uninterruptible power supply. Fires in ordinary combustibles (desks, chair, waste paper) can occur. Each of these fire scenarios requires a different approach to suppression with water mist.

2. Several manufacturers of fire suppression equipment and users of telecommunications equipment have conducted demonstration tests in the UK, Europe, and the US, with nozzles placed inside different types of electronic cabinets, or in the aisles between open-door cabinets. The tests show that water mist is capable of extinguishing fires in some circumstances. Although trials continue, progress is slow because of a limited commitment to the concept by owners/users of telecom and

electronic equipment. There is no consensus that the passive fire control measures built-into cabinets are not enough to exclude the need for in-cabinet active suppression systems.

3. There are very few studies that properly quantify the nature of "water damage" to electronics. Without reputable evaluations of the non-thermal damage to electronics, it is not possible to refute arguments that the damage would be "unacceptable". The few studies that do exist [11] [12], suggest that different types of equipment have different levels of sensitivity to damage, and that in many cases, damage due to water is negligible compared to the damage done by smoke from an unsuppressed fire. The Norwegian firm, IGP/AS is proposing to study the potential for water damage to electronics in 1996. There is a need for more work in this area.

4. Laboratory testing of water mist for telecommunications equipment was conducted in New Zealand, at University of Christchurch, which was funded by NZ Telecom. More recently, testing was done in the US at NIST and FM; in Canada at NRCC; in Norway at SINTEF; in Sweden at SP; and in Finland at VTT. The New Zealand study [11] confirmed that water mist is suitable for use on main distribution frames, and that the use of distilled or de-mineralized water reduced water damage to energized printed circuit boards (PCBs) to negligible levels. A study conducted at NIST [13], in which the ability of water mist to extinguish fires in an array of PCBs was studied, demonstrated that the ability of spray to penetrate between the parallel PCBs is limited, so the range of effectiveness is limited.

5. Recently completed studies at NRCC in Canada observed the same phenomena, in which the arrays of parallel circuit boards limited the ability of spray to penetrate to the seat of a fire [10] [14]. The experimental work at NRCC identified strategies to overcome the challenge imposed by the rigid geometry of printed circuit boards, and described the spray characteristics suitable for in-cabinet fire suppression [11].

6. The NRCC study points out the need for advances in fire detection and signal processing in order to effectively zone a system. The ability to subdivide a system into zones, and then to activate the correct zone for a given fire, becomes increasingly challenging as compartment complexity increases. Further work is required to assemble multi-sensor detectors with an "intelligent" signal processing center that can reliably identify the fire location within a compartment.

7. Safety concerns about using water mist on high voltage electrical equipment are frequently raised. Studies conducted by SINTEF in Norway [15] indicate that conductivity through mist is very low. However, particularly on ships, the accumulation of water on conductive floors in rooms containing an uninterruptible power supply remains a concern. A systematic study of when it is acceptable to use water mist around high voltage equipment is needed.

Conclusion

As indicated in the introduction, there are many interesting subjects worthy of discussion in Table 1. The four issues discussed in this presentation were selected because they represent significant milestones in the development of water mist fire protection systems technology. The activity regarding the IMO test protocols has stimulated much international exchange, product development and technology transfer. Providing that these international efforts continue, more applications will be validated over the next few years. Considerably more research effort will be required before the application of water mist to a new fire scenario becomes a routine design problem.

REFERENCES

1. NFPA 750 - "Standard on Water Mist Fire Protection Systems", First Edition, National Fire Protection Association, Quincy, MA, 1996.
2. International Maritime Organization, (IMO). "Draft Test Method for Equivalent Sprinkler System for Class A Machinery Compartments (up to 500 m^3) Volume," I.M.O. Fire Test Procedures Correspondence Group submittal for the I.M.O. Fire Protection Sub-committee, July, 1995.
3. International Maritime Organization, (IMO). "Water-Based Fire Extinguishing Systems in Accommodation and Public Space Areas on Board Ships", I.M.O. Fire Test Procedures Correspondence Group submittal for the I.M.O. Fire Protection Sub-committee, June 1994.
4. International Maritime Organization, (IMO). "Draft Test Protocol for Equivalent Sprinkler System for Cabin and Corridor Fires," July, 1995.
5. Personal correspondence, R. Darwin, NAVSEA, Crystal City, VA, July, 1995.
6. Berner, F.; Vemmestad, J., "Development of Fine Water Spray Technology for Application on BP Norwegian Continental Shelf Offshore Installations ULA and GYDA", in Proceedings:
7. Personal correspondence, J. H. Dyer, J.H. Dyer & Associates, North Lincolnshire, England, January, 1996.
8. Milke, J., "University of Maryland Tests of a Water Mist Fire Suppression System for Library of Congress", in Proceedings of SFPE Symposium, Orlando, FL, September, 1995.
9. Meland, Øystein; Jensen, Geir; Sjur Helseth; "Water Mist to Protect Wooden Historic Structures", in Second International Symposium on Fire Protection of Ancient Monuments, Cracow, Poland, October 17-21, 1994.
10. Mawhinney, J.R. and Taber, B., "Summary Report for the Combined Intelligent Fire Detection and Water Mist Fire Suppression System Project," Client Report A4078.1, National Research Council Canada for National Defense Canada, Ottawa, Canada, January 1996.
11. Botting, R.; Beaumont, P. "Research Project Concerning Fire Protection of BPO Type Main Distribution Frames in Telephone Exchanges," Telecom New Zealand, Limited, August, 1993. (Advanced draft copy).
12. Morgan, R., "The effects of water borne electrolytic corrosion on live electronic equipment, Part II", Research Report, School of Engineering, University of Canterbury, Christchurch, New Zealand, September 1, 1994.
13. Grosshandler, W., Lowe, D., Notarianni, K., Rinkinen, W., "Protection of Data Processing Equipment with Fine Water Sprays", NISTIR 5514, National Institute of Standards and Technology, Gaithersburg, MD. 1994.
14. Mawhinney, J.R.; Taber, B.; Su, J.Z. "The Fire Extinguishing Capability of Mists Generated by Flashing of Super-Heated Water," in Proceedings: American Institute of Chemical Engineers, 1995 Summer National Meeting, Boston, MA., July 30 to August 2, 1995.
15. Verlo, T. "The Use of Water as an Extinguishant in Live Electrical Installations", a study conducted for the Norwegian Electric Power Research Institute, by SINTEF, Trondheim, Norway, October 1991.

Discussion

Masahiro Morita: I have one question with regard to the water mist and whether the drop should be small or large. When you apply water to methanol, the mechanism of water would be quite different then the conventional sprinkler system. In Japan, we have also studied the difference when you apply water mist in a small room or large room, and each time the mechanism is different. Do you have any study on that?

Jack Mawhinney: Yes. I would refer first to the paper that I prepared with my colleagues at NCL looking at the extinguishing mechanisms from water mist and identifying enclosure effects where you get the benefit of reduced oxygen and the benefit of the recirculation of oxygenated gases at higher evaporation rates. Yes, it was very true that water mechanisms differ depending on the fire scenario and depending on the volume size of the compartment, and depending on the nature of the fuel.