FIRE PROTECTION WITH WATER MIST—THE NRL APPROACH

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ABSTRACT

Water in the form of a small droplet mist has attractive properties for providing fire protection. However, liquid droplets experience complex aerodynamic and fire interaction dynamics. includeing momentum and energy transfer and phase change. A formalism for designing water mist fire protection systems to address the different needs dependent on fire threat scenarios does not currently exist. There are scientific research efforts on understanding droplet-flame interactions, and engineering efforts to develop fire suppression systems. However. there is a comparative lack of programs to incorporate scientific/ technology base information into practical system design guidance. This paper addresses the NRL efforts to use evolving science to develop fire test plans aimed at evaluating specific issues and providing feedback on realistic threat suppression processes. Our fire testing program is oriented to not just validate a particular system for a specific configuration and fire threat, but to bridge the gap between research and empirical design. yielding generic water mist system design guidance for challenging scenarios.

BACKGROUND

The Naval Research Laboratory (NRL) has long investigated Halon 1301 substitutes. An early NRL study on cup-burner extinguishment concentrations led us to develop an empirical model based on physical extinguishment mechanisms [1, 2]. The model predicted it would take tlie same volume of liquid water. and only two-thirds the mass, as would Halon 1301 to achieve extinguishment [3]. This high efficiency assumes that the latent heat of water evaporation is completely efficacious in the extinguishment process. That is. all the liquid water gets to the fire where the energy required for liquid water evaporation comes entirely from the flames.

On a larger scale, an NRL report in 1977 [4] entitled “Fire Suppression - Why Not Water’?” discussed fine water mist, including additives that generate a fine solid aerosol, which would then act as a fine dry chemical extinguishant. Large-scale total-flooding fine water mist testing, including some with additives, followed shortly in a 324 m^3 (11,400 ft^3) chamber at NRL. However. further development was not pursued. While we had completed a kinetics paper study in 1976 that showed Halon 1301 to be at least as deleterious to the stratospheric ozone layer as CFCs, there were no requirements to replace halons until much later. Consequently, there was no driver for halon replacement program funding, for either alternative gaseous or water mist approaches.

Consideration of water mist as a viable generic option for supplying fire protection where gaseous agents have been used has received a crucial push due to environmental concerns. The primary driver is the need to rind substitutes for the halons now that their production, and in many cases. their use, is restricted or eliminated. Research has been conducted on mathematical modeling of water mist fire suppression, laboratory flame-water interactions, and water mist suppression systems. It would seem that matters should be well in hand. However, how to use water most effectively remains an issue.

Navy mandates for utilizing zero Ozone Depleting Potential (ODP) materials led to NRL reinitiating limited laboratory and extensive empirical large-scale water mist tests in the mid 1990s. The objective of the large-scale tests (under US Naval Sea Systems Command sponsorship, conducted with Hughes Associates. Inc.) was to rapidly develop mist system specifications for the machinery spaces of the Navy’s new LPD-17 ship class [5]. While a specific application iterative development path can be highly successful, and in this instance did yield design specifications for the high-pressure water mist system to be employed on the LPD-17, the results are not readily transferable. General design guidance was not obtained.

WATER MIST PERFORMANCE

Most halon replacements, with the exception of iodine-containing fluorocarbons, are significantly less efficient than Halon 1301, have substantial space and weight penalties, and may carry potential usage limitations due to environmental constraints such as for global warming or toxicity. But gaseous replacement systems, when properly designed, will provide complete extinguishment. This extinguishment guarantee is not true for water mist systems where fire suppression performance is very scenario specific. The user must he prepared to consider conditions under which to accept incomplete extinguishment, or to very carefully design the suppression system. However, there is little information available to guide water mist system design to achieve complete suppression without extensive and expensive empirical testing.

Water is a very good firefighting agent, but only when intelligently employed. On one extreme, much of the water stream from a fire hose passes through the flame without having sufficient time for heat transfer to vaporize it. This leads to the typical issues of water damage, and for ships, water pooling and the possibility of affecting ship stability. On the other extreme, very fine droplets will completely evaporate in a flame, but may do so well before reaching the fire. Convection currents may also deflect them. Smaller droplets will have difficulty getting to the fire unless entrained into it by the fire's own induced convection dynamics. Information on drop size distribution and spatial distribution is essential for determining suppression success criteria.

Approximations are useful approaches at least in understanding suppression. One model *[6]* allows the calculation of maximum fire size that will not be extinguished, based on water mist vaporization and accompanying oxygen concentration reduction. Assumptions include totally homogeneous distributions and specific limiting oxygen concentration criterion. Another treatment **[7]** approaches this oxygen determination empirically via experimentally measured "dry gas basis" concentrations corrected using a measured water vapor concentration. This is complicated in the presence of liquid water droplets and at best can only provide an approximate oxygen concentration. The key point is that the amount of suppressant needed to extinguish a fire is a strong nonlinear function of the oxygen concentration [3, 9]. Oxygen concentration, together with other significant components including agent, needs to be quantified. Approximation approaches describe suppression in general terms, hut do not provide mist system design guidance. Considerable study is required to determine the optimum characteristics for specific threat scenario applications. A number of papers at the ***HOTWC*** 2000 contribute to the required water mist technology base.

While there are efforts to design water mist systems, in general there is a lack of transitioning mechanisms from the science of water mist suppression to extinguishment system technologies. Optimum design of a gaseous agent discharge/distribution system is complex. The dynamics of water mist are much more complex yet. It cannot he just released and expected to disperse. Water mist with the proper characteristics needs to be generated, disseminated, and distributed. Water mist is being used as a total-flooding gaseous agent, but it is not a gaseous agent. Flow restricting obstacles produce reduced concentration regions, Small fires do not generate compensating entrainment currents. Production at the fire of the required quantity of desired size drops, with appropriate momentum, in the presence of fall-out due to gravity, and in an implementable system, is indeed a scientific and engineering challenge. Information on the droplet characteristics from generation through transport to the fire is required.

Success criteria can be very different for gaseous and water-based mist fire protection. Complete extinguishment is the end point for gaseous systems. Water mist has difficulties in guaranteeing complete extinguishment, especially for smaller, obstructed fires. Residual tlamelets can then reignite into major conflagrations. However, water mist can control the intensity of fires. The energy abstraction capabilities can restrict fires to some energy output level. Damage control personnel can subsequently enter the space and extinguish the residual inhibited fires. This does require that the water mist continue to be applied. However, condensed phase droplets will fall out after some time period. depending on droplet size, resulting in loss of protection.

The requirement for continual application of water mist to control residual fires in large part can negate agent weight advantages. The agent weight required is then not limited to that needed to obtain quick extinguishment, but that needed to satisfy the continual demand for water necessary to sustain a suitable concentration of water dispersed in the air. If there is a non-dedicated reliable replenishment source, then the increased water weight issue can be partially finessed.

An advantage of continuous application of water mist is that significant openings/breaches can be tolerated and still retain fire protection. This “forgiveness” does not exist for gaseous suppression systems. Once there is a boundary breach, the agent will dissipate. Once below the required critical agent concentration, protection is lost. Worse, byproduct production (except for purely inert physical agents) will skyrocket as the agent is converted into reaction products without extinguishing the fires.

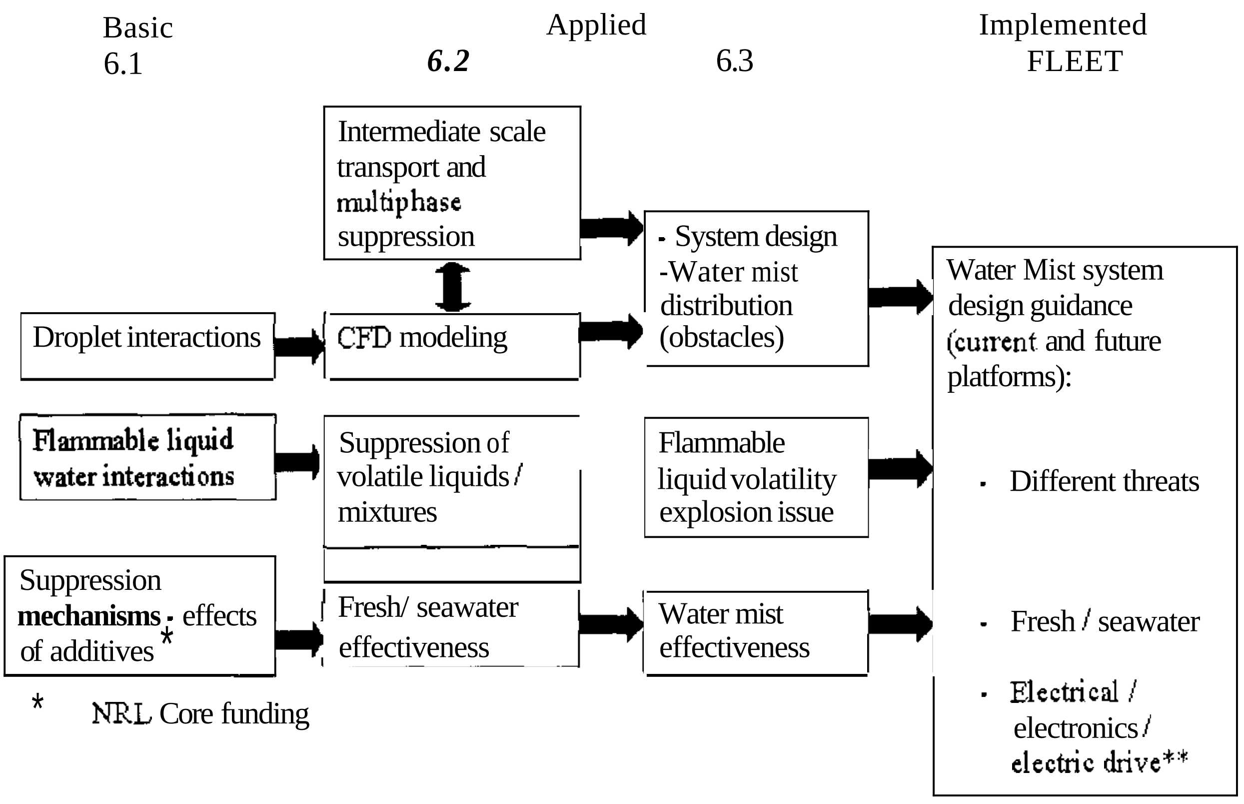
INTEGRATED WATER MIST APPROACH

The objective of the current NRL water mist program is to develop the understanding needed to design optimized water mist systems with predictable performance, without extensive empirical system development and validation. The R&D approach includes laboratory studies, and intermediate and large-scale highly instrumented testing. One of the limitations of many previously conducted water mist evaluations is the very limited quantification of the atmospheric composition and water mist droplet distribution. To determine the performance of water mist the various parameters affecting suppression must be deconvoluted. In particular, the actual oxygen concentration near the fire, not a dry gas-based measurement, is required. Other key parameters include water vapor content and the droplet concentration and size distribution.

Several projects whose results would have been directly applicable for development of Navy water mist fire protection had been formerly programmed as SERDP NGP tasks for 2000. continuing for 2001 and beyond. Funding constraints, however, required limiting the original scope of the NGP. This was achieved by refocusing the FY00 program on halon replacement in airframes, to the exclusion of ship applications. The result was the cancellation of the following component tasks previously scheduled to have been funded at over $1,500,000 per year:

- Water mist additive mechanisms
- Water mist suppression (with additives)
- H_2O vapor concentration instrumentation development
- O_2 concentration instrumentation development
- Water mist flow visualization
- Computational fluid dynamics (CFD) modeling of water mist in obstructed compartments

Some of these tasks are now being incorporated into ongoing efforts at NRL sponsored primarily by the US Naval Sea Systems Command. Other proposed tasks would complement the overall Navy water mist program and are described on a conceptual level in Figure 1. The "Roadmap" shows a progression from basic research topics leading to applied research, ultimately transitioning into shipboard applications. The laboratory efforts will be closely coordinated with larger scale evaluations, help to design critical parameter tests, and also aid in result interpretation.



Specific endeavors will include development of instrumentation to measure oxygen concentration in the presence of both liquid and gaseous water, and incorporation of suitable optical techniques to determine the liquid droplet concentration and momentum. Results of the oxygen monitoring efforts are documented at this meeting [8]. Oxygen concentration can be determined directly via laser diode absorption spectroscopy. Water mist characteristics can be determined optically and will be measured at two locations simultaneously, following dynamic changes. This will allow quantization of droplet parameters as they move from the nozzle, through the hot gas layer, around obstacles, and to the fire vicinity. In this way, the characteristics of the mist generation can be related to its distribution and delivery to the fire.

SUMMARY

General design guidance for water mist fire protection systems can only be generated by:

- knowing the scenario dependent mechanisms and dynamics of extinguishment
- measuring the relevant parameters near the fire
- understanding how to produce the water mist properties at the nozzle that result in the desired properties at the fire

While the NRL effort is focused on shipboard applications, many of the findings on the extinction requirements for water mist will be applicable to non-shipboard facilities. (This work is supported by the US Naval Sea Systems Command.)

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