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Project Summary

Development of Alternative, Non-Halon Fire Protection System

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With the phaseout of halon production, two alternative technologies—water misting and low-residue particulates—have come to the forefront. These technologies use water or dry chemicals in reduced quantities to provide acceptable fire protection. A review and an assessment of the state-of-the-art for these technologies was conducted. From this information, water misting was recommended as the most promising near-term technology. An experimental program defined and optimized the operating parameters for a water mist system at laboratory-scale, followed by room-scale testing. In the laboratory, a water flux of 0.6 L/min-m^2 effectively extinguished Class A and Class B (heptane) fires. Below this water flux level, the extinguishment times varied significantly, while water fluxes above this level did not increase extinguishment times in comparison to the amount of water used. Room-scale experiments demonstrated that scale-up from the laboratory is straightforward and can minimize the requirements for room-scale tests. A cost comparison of water mist systems with respect to the equivalent halon system indicates that water mist is competitive in many applications. Water misting fire suppression system design and costs are estimated at $90 to $150/m^3 across a range of technologies. Low-pressure, water-only mist systems, could be installed for below $30/m^3. Halon systems now average $125/m^3 in many applications.

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Introduction

In the late 1940s and during the 1950s, low-residue particulate and water mist fire suppression technologies were being developed as specialty applications substituting for dry chemical and water sprinkler systems, respectively, in areas where weight and materials compatibility problems were encountered. The introduction of halons in the early 1960s caused these systems to be set aside. With international environmental agencies agreeing to phase out halons, low-residue particulate and water mist fire suppression systems have re-emerged as possible alternatives to halon fire suppression systems.

Dry chemical agents have been used for many years to extinguish fires. Such agents are at least as effective as halons in suppressing fires and explosions in many applications; however, they can cause unacceptable levels of secondary damage. Recent research indicates that fine particulate aerosols, low-residue particulates, can effectively suppress fire while eliminating some of the disadvantages caused by larger dry chemical particles. Studies of pyrotechnically generated aerosols, that produce a fine particle by reaction (combustion) between an oxidant and a reductant, offer the ability to distribute a particulate cloud uniformly throughout a complex space and, if the particle size is small enough, remain suspended in the protected space for times on the order of tens of minutes. These suspension times could allow fine particles to act as "total-flood agents," yielding significant advantages over present dry chemical systems and, potentially, some halon systems.

Alternatively, on a weight basis, water is a more effective fire extinguishant than halons if near-complete evaporation is achieved. Water suppresses or extinguishes fires through three predominate mechanisms: (1) heat extraction using water's latent heat of vaporization and gas-phase cooling; (2) oxygen displacement by steam expansion; and (3) radiant heat attenuation involving surface cooling by surface wetting/evaporation and blocking of radiant heat transfer. Water misting systems use fine water sprays to provide fire protection, the mists are tentatively defined as having droplets 200 micrometers (µm) or less in size. Since small droplets evaporate significantly faster than large droplets, the small droplets produced with water misting systems provide the above capability while reducing water requirements and collateral damage.

Project requirements were threefold. (1) Information on low-residue particulate and water misting systems for fire protection was collected, and the state-of-the-art for low-residue particulate and water misting systems with regard to fire protection was assessed. Based on the evaluation, water misting was selected as the most promising near-term technology. (2) An experimental program to develop a water misting fire protection system was conducted. The program had two phases, a laboratory-scale experimental study to determine basic parameters needed for developing the fire suppression system including selecting and optimizing the components of the water mist fire suppression system. Followed by room-scale experiments using the optimized equipment and operating parameters to determine the overall effectiveness of the fire suppression system in actual use. The system's ability to suppress fire, protect against reignition and/or explosion, and prevent damage to powered equipment, paper records, and electronic data storage contained in the room was assessed. (3) Finally for three current halon applications and the equivalent water mist fire suppression system, an econometric analysis was conducted to determine whether water misting systems could economically replace halon systems.

Procedure

A literature review of low-residue particulate and water mist systems was conducted. Although little information has been reported in the open literature on low-residue particulates, the review focused on (1) a survey of existing compounds and possible suppression mechanisms; (2) quantifying the performance and qualities of existing compounds; (3) measurement of particulate size; (4) interaction of particulates with fire; and (5) damage to electronic equipment by the particulates. The water misting review focused on (1) the production of fine droplets; (2) measurement of fine droplets; (3) types of nozzles (e.g., dual-fluid, high-pressure); (4) interactions of water droplets with fire (including flame/plume penetration, evaporation, and transportation phenomena); (5) damage to equipment, particularly electronic circuits, by water mists; and (6) systems currently being investigated or tested in the field. Following the technology review, the state-of-the-art for low-residue particulate and water mist fire suppression systems was assessed, taking into consideration the stage of development, engineering design requirements, operation, maintenance, overall performance potential, and potential impact of these fire suppression systems. It was proposed that water misting technology development be carried out in subsequent tasks since it was the more promising near-term technology.

In laboratory studies, the effects of droplet size, droplet size distribution, droplet velocity, and obstacles in the path of the spray were studied with respect to how they affected the water flux needed to extinguish incipient fires. The information obtained was used to characterize and optimize the operation of water mist spray nozzles used in developing a water mist fire suppression system. Heptane telltale fires (50.8-cm diameter cups filled to within 2 mm of the top with water and 10 mL of n-heptane) were chosen for this phase of testing since they represented incipient fires. Additionally, the literature and researchers currently performing room-scale fire extinguishment testing indicated that these fires were the hardest to extinguish.

A range of single-fluid nozzles allowed a wide spread in water mist characteristics without the additional variables added with dual-fluid systems. Selected nozzles represented the range of products available — low pressure/high momentum nozzles (2.7-mm orifice diameter), intermediate pressure/momentum impingement nozzles (1.0- and 1.4-mm orifice diameter), and low-momentum humidification nozzles (0.2- and 0.5-mm orifice diameter). For each nozzle and test condition the spray pattern and water flux in L/min-m^2 was determined. Based upon the different spreads (ranges) in water flux for the nozzles, positions were chosen for the placement of 50.8-cm telltales, which were filled with water and 10 mL of heptane and were ignited. After a 30-sec preburn, the times required to extinguish telltales with each system were recorded. A primary objective was to determine the critical concentration of water required to extinguish the fires. In this case, critical concentration was defined as the most effective use of water; i.e., a minimum regarding the amount of water used and the time required to extinguish the fire. Water mist fire suppression system goals are to minimize system requirements without adding to collateral damage.

Following selection of a nozzle and determination of the required water flux, additional laboratory-scale water flux tests were carried out to develop the optimum nozzle spacing to provide a uniform water flux across the entire protected space for room-scale testing.

Room-scale experiments were proof-of-concept and scale-up tests. Room-scale testing of the selected and optimized water mist fire suppression system was conducted to determine the overall effectiveness of the fire suppression system in actual use. The ability of the system to suppress and extinguish Class A (wood and paper) and Class B (heptane) fires, protect against explosion or reignition, and limit the damage to powered equipment, paper records, and electronic data storage contained in the room was assessed.

Due to uncertainties in National Board of Fire Underwriters requirements and those of the forthcoming National Fire Protection Association Standard 750 on water mist fire protection system installation, operation, and testing procedures, the marketer of the final nozzles tested was unwilling to set system costs. To complete the third phase of the project, three generalized water mist systems where enough information was available to complete an econometric analysis were used.

The task evaluated three applications of water mist fire suppression systems as replacements for Halon 1301 total-flood systems. Cost estimates were based on the following assumptions: (1) where water pumps are required, sufficient electrical power is available; (2) all systems assume Underwriters approval for all hardware components; (3) a current Halon 1301 price of $50/kg; (4) cost estimates based on approximate equipment list prices and installation cost that are reasonable for comparison purposes; (5) approximately equivalent maintenance costs for both water mist and Halon 1301 systems; and (6) life cycle cost comparisons driven by the probability of an accidental discharge, minimal for water whereas Halon 1301 costs are on the order of $10/m^3 of protected volume.

Results and Discussion

Low-residue particulate research is centered on development of (chemical) agent formulations, determination of concentrations required to extinguish Class A and Class B fires, documentation or elimination of any potential acute inhalation toxicity problems, and development of particle generator systems.

Water mist fire suppression technology is further along in its development, since it has drawn upon the broad base of hardware and theoretical knowledge developed for controlling air pollution aerosols, industrial scrubbing, humidifying, air cooling, dust suppression, foam control, moistening, and water sprinkler fire suppression. At present, at least 17 water mist fire suppression systems are available or are being developed by different manufacturers. Additionally, the potential suppliers of nozzles and systems greatly exceed this number if this area of application expands.

From laboratory-scale experiments, a water flux of 0.6 L/min-m^2 is the critical concentration for extinguishing heptane telltales (representing difficult to extinguish incipient fires) with a water mist fire suppression system. Water fluxes above 0.6 L/min-m^2 did not significantly increase extinguishment times in comparison to total water usage. While water flux levels below this range were able to extinguish the telltales, the extinguishment times became longer and more erratic. Extinguishment times for water fluxes between 0.025 and 0.60 L/min-m^2 show standard deviations on the order of their extinguishment times. Water fluxes below 0.025 L/min-m^2 were not able to extinguish the fires. Crowding the nozzles so as to increase the water flux decreased their fire extinguishment effectiveness, at least for heptane fires.

Room-scale testing for the water mist system was proof-of-concept and involved a center-fed ceiling system design with a nozzle spacing of 40.6 $\pm$ 5 cm; the array was adjusted within these parameters for a best fit to the room. For a nozzle spacing designed to yield a uniform water flux, the most efficient system for nozzles having a small circular spray pattern was a rhombohedral patterned array. Laboratory-scale flow rate tests indicated a water flux of 0.47 L/min-m^2 at 3.45 MPa for the optimized nozzle spacing. Increasing the operating pressure to 6.90 MPa increased the water flux to 0.76 L/min-m^2 without changing the droplet size distributions. The initial water flux for the water mist fire suppression system was below the critical concentration of 0.60 L/min-m^2, the system's capacity allowed an increase in water flux to levels beyond the critical concentration. To allow a direct comparison to the laboratory-scale experiments, the room-scale tests were conducted at 0.47 L/min-m^2.

At a water flux level of 0.47 L/min-m^2, the water mist system was capable of extinguishing all unobstructed, partially obstructed, and fully obstructed Class A (wood crib and paper) and Class B (32 and 292 kW pan) fires. Increasing the water flux to 0.76 L/min-m^2 showed that water usage increased at a greater rate (1.44 times) than did the decrease in extinguishment time (1.07 times). An operating personal computer, books, and newspapers were exposed to unobstructed wood crib fires during a room-scale extinguishment. Most of the damage to the personal computer and paper related materials was caused by smoke, which was easily cleaned off, and heat. The water mist formed only a thin film on the computer and papers, which evaporated quickly after the water mist system was shut down. Post-fire, long-term storage of the personal computers show no adverse effects caused by exposure to the water mist.

The third requirement of this project was a direct system cost comparison of three present halon applications and the equivalent water mist fire suppression system. Due to uncertainties in Underwriters requirements and those of the forthcoming National Fire Protection Association Standard 750 on water mist fire protection system installation, operation, and testing procedures, the marketer of the final nozzles tested was unwilling to set system costs. To complete the third phase of the project, three generalized water mist systems were considered, where enough information was available to complete an econometric analysis. The systems chosen were (1) marine engine room and machinery spaces (1500m^3), where an installed water mist system would cost $120 to $147/m^3 ($180,000 to $220,000) for open and enclosed bilges, respectively, whereas a Halon 1301 system would cost $150/m^3 ($225,000); (2) combustion turbine enclosures (320 m^3), where the order of magnitude cost estimates would be $150/m^3 ($48,000) for the water mist system compared to approximately $125/m^3 ($40,000) for Halon 1301; and (3) emergency generator (320 m^3), engine test cells, and similar facilities costing $141 to $156/m^3 ($45,000 to $50,000) for low and high pressure water mist systems, respectively, compared to $234/m^3 ($75,000) for an installed Halon 1301 system.

Conclusions

Low-residue particulate fire suppression technology, particularly pyrotechnically generated aerosols, is at a developmental level. While the potential for low-residue particulate fire suppression technology exists, its development is still in its infancy. Meanwhile, water mist fire suppression technology is further along in its development since it has been able to draw upon the broader base of hardware and theoretical knowledge developed for water sprinkler fire systems and other applications. With this greater foundation to draw upon, water mist fire suppression technology was recommended as the most promising near-term technology.

The critical concentration for heptane telltale fires was 0.6 L/min-m^2 based upon laboratory studies. The concentration was initially proposed as the total mass of water in droplets per unit volume (or area) required to extinguish various classes of fire. A better definition of critical concentration would be the most effective fire extinguishment concentration, represented by the minimum concentration where extinguishment times versus water flux become essentially constant. At this point, fires are extinguished quickly, but with the least amount of water and water related collateral damage.

Water fluxes above 0.6 L/min-m^2 did not significantly increase extinguishment times in comparison to total water usage. For water flux levels below this range, while able to extinguish the telltales, the extinguishment times became longer and more erratic. Extinguishment times for water fluxes between 0.025 and 0.60 L/min-m^2 show standard deviations on the order of their extinguishment times. Water fluxes below 0.025 L/min-m^2 were not able to extinguish the fires. Increasing water flux rates for these nozzles had the opposite effect on extinguishment times, indicating interactions between droplets and changes in droplet size and distribution may be more important than the total amount of water present in the protected space.

Room-scale experiments demonstrated that scale-up from the laboratory is straightforward. Significant findings from the room-scale testing were (1) at a water flux of 0.47 L/min-m^2, the water mist can neither inert the space nor stop reignition of a hydrocarbon pool fire; (2) upon reignition, the water mist contained the fire during repeated extinguishments; and (3) fires can be extinguished without collateral damage to books, papers, and energized electrical (computer) systems.

The engineering design and cost of water mist fire suppression systems indicate a high-end cost estimate of \$90 to \$150/m^3 across a range of technologies. For a low-pressure, water-only mist system, this cost could be reduced to below \$30/m^3. The cost of water mist systems should decrease over time as additional competitors enter the market and R&D costs are recovered. Given the high cost of available Halon 1301 (approximately \$50/kg), halon systems now average \$125/m^3. Therefore, water mist fire suppression systems are cost competitive with Halon 1301 in many applications.

Recommendations

Potential future research involves studying the extent of the interaction between individual nozzles, the dependence upon nozzle spacing, and the subsequent effect on drop size distribution on fire extinguishment and extinguishment time. Additionally, determining the droplet size range that will allow significant amounts of water mist to flow around obstacles in sufficient concentration to extinguish fires will be of great benefit. It was proposed that at higher concentrations, the water mist coalesced into larger drops, which then fall out of the protected space. Additionally, these studies could be enhanced by determining the size range of the drop that in addition to falling into the fire, could be swept into the side of the fire from a distance, and thereby aid in extinguishing the fire by horizontal flame penetration and cooling at the flame/fuel interface.

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The complete report, entitled "Development of Alternative, Non-Halon Fire Protection System," (Order No. PB97-147961; Cost: $41.00, subject to change) will be available only from:
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