WATER ADDITIVES FOR INCREASED EFFICIENCY OF FIRE PROTECTION AND SUPPRESSION

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ABSTRACT

The Building and Fire Research Laboratory at the National Institute of Standards and Technology, under the sponsorship of the United States Fire Administration, has examined methods for demonstrating the fire protection and suppression effectiveness of water based fire fighting agents. NIST investigated smoke generation during suppression and conducted a broad-based study on fire protection and suppression effectiveness including laboratory scale experiments and large-scale fire suppression experiments. The following characteristics were investigated at laboratory scale: specific heat, drop size, cooling and penetration, contact angle, mass retention and ignition inhibition. Large-scale experiments were used to examine the suppression effectiveness of the agents on wood crib and tire fires.

1. INTRODUCTION

Water additives or agents have been utilized for many years to enhance the fire fighting capabilities of ordinary water. The most widely used of the water-based agents are the foams for use on Class B fires. Agents designed primarily for Class A fires have been used most extensively in conjunction with wildland fires.

There are a number of commercially available water-based fire suppression agents designed primarily for Class A fires. Generically these agents can be classified as surfactants, which reduce the surface tension of water, potentially modifying the fire-fighting capabilities. There are standards for assessing some characteristics of these agents, however most of the criteria do not address the fire fighting (protection/suppression) capabilities of the agent. An evaluation protocol is needed to measure the fire-fighting capability of an agent and to relate its performance to plain water or another agent in a given situation. This would enable the fire community to select the most cost effective fire suppression agent(s) to fit their specific needs, thus optimizing utilization of their resources.

The use of water-based fire-fighting agents raises the question of potential health and environmental effects. First is the exposure of fire fighters to the agent itself and the products of combustion produced when using the agent. Second is the impact as agent run-off enters the environment.

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2. WATER ADDITIVES

Given the time constraints and the developmental nature of this program only a limited number of agents could be used. These agents were chosen from a list of water-based fire suppression agents meeting the interim requirements of U.S. Forest Service Specification 5100 [1]. The agents on the qualified products list (QPL), dated January 18, 1995, were: Angus ForExpan S, Ansul Silv-Ex, Chemonics Fire-trol FireFoam 103 and 104, Monsanto Phos-Chek WD 881, Pyrocap B-136 and TCI Fire Quench [2]. All of these agents are recognized as meeting the U.S. Forest Service Specification 5100 Interim Requirements for environmental impact, human health safety, and physical properties. Utilizing agents from the QPL, provided products with an existing database of information which could not be collected within the time constraints of this project. Four agents, representative of a cross section of agents on the QPL, were chosen for this project based on differences in selected physical property data and differences in cost. In this report the names of these products are not identified.

3. AGENT ENVIRONMENTAL SAFETY AND PHYSICAL PROPERTIES CHARACTERIZATION

The Intermountain Fire Science Laboratory (IFSL) of the U.S. Forest Service, has been conducting a program to collect the environmental impact, human health safety, and physical property data, available through existing standardized tests on the water-based fire-fighting agents currently meeting Specification 5100. Utilizing the standardized tests, the IFSL has evaluated all of the agents with respect to biodegradability, mammalian acute oral and acute dermal toxicity, primary eye and skin irritation, and fish toxicity.

The physical properties of the liquid fire suppression agent are very important to determining "usability" of the agent in the field. The IFSL has characterized the following physical properties for each agent on the list: flash point, fire point, vapor pressure, pH, density, viscosity, pour point, miscibility, surface tension, conductivity, refractive index, stability, wetting and foaming ability, expansion and drain time and corrosion effects on materials in foam delivery systems. The agent characterization can be found in Chapter 2 of [3].

4. SMOKE GENERATION

NIST investigated smoke generation during suppression as it might relate to environmental impact and potential hazards to human health. Reproducible fuel packages composed of wood and plastic were burned under an instrumented exhaust hood [4]. Samples of combustion products, gases and particulates were taken before and during suppression. The fires were suppressed with water or one of the agent solutions. The same mass flow rate was used for water and each of the agents. The suppression liquids were discharged from fixed nozzles.

NIST found that the application of fire suppression agents, including plain water, to the crib fires does effect the chemical composition and size distribution of the soot particles above the burning fuel. Extinguishment of the fire caused a significant reduction in the concentrations of carbon monoxide, carbon dioxide, hydrogen chloride, hydrogen cyanide, nitrogen oxides, and soot particulates measured in the stack. With the exception of small reductions in smoke particulate size when using the foaming agents, there are no significant differences in the post-extinguishment smoke relative to using water.

The agent solutions expedite evaporation of water by reducing the surface tension and increasing the surface area of the water in contact with the hot fuel. The agent solutions also provide additional particulates, which may serve as condensation nuclei. Under certain conditions, the additional water and particulate would promote the condensation of water into droplets, which may develop into a cloud of water vapor or "cool white smoke".

5. FIRE FIGHTING EFFECTIVENESS

NIST conducted a broad-based study on fire protection and suppression characteristics including laboratory scale experiments and large scale fire suppression experiments. The following characteristics were investigated at laboratory scale: specific heat, drop size, cooling and penetration, contact angle, mass retention and ignition inhibition. Large-scale experiments were used to examine the suppression effectiveness of the agents on wood crib, tire, heptane, gasoline, magnesium and titanium fires. A series of ventilation-limited structure fires was also conducted and will be reported separately.

5.1 LABORATORY EXPERIMENTS

The laboratory scale studies were conducted to examine specific agent characteristics possibly influencing fire suppression mechanisms of water and the liquid agents for Class A fires. The following paragraphs outline these studies.

The **specific heat** of each agent and each concentrate was tested to determine the amount of heat the solutions and the concentrates absorb relative to plain water. The tests were conducted with a scanning differential calorimeter. The specific heat of the agent concentrates were 9 to 30 percent lower than that of water. The four agents, which were composed of at least 97% water, had specific heats lower than water by an amount simply reflecting a mixture of two liquids.

An optical array probe water droplet measurement system was used to measure the **drop size** generated with solutions as compared to those generated with water. A water spray from a 38mm (1 ⅄ in) fog nozzle at a given pressure was characterized by droplet size and distribution. The experiment was then repeated with solutions of the four fire-fighting agents using the same nozzle and pressure. The droplet distribution indicates a shift in the droplet diameter in various portions of the spray. The median drop size, D_{v90}, for the solutions was similar to that of water, being within ±20%. A change in droplet size could be beneficial or detrimental depending on the application. This effect as well as the droplet measurements could benefit from further research.

Surface cooling of the fuel and **penetration of the fuel** are important aspects in the suppression of Class A fires. Hardboard, 6 mm (0.24 in) thick, was used as the fuel material for the cooling and penetration experiments because while it is still a "wood product" it is also a homogeneous material. This fact makes the affected-area measurement easier since the liquid is not following grain lines but is spreading radially in a fairly uniform manner. Water and agent solution droplets would be placed on the top surface of the hardboard sample [5]. An infrared camera was focused on the bottom side of the hardboard sample. Time to penetration was measured as was the temperature and the area of the hardboard being cooled by each droplet [6]. The initial penetration time through the hardboard was similar for water and the four agents. However, the area being cooled by the agents was approximately 4 times the area being affected by the water. At the end of each experiment, a portion of the droplet of water was still beaded up on the surface of the hardboard, while the agents had all been absorbed into the sample. This experiment demonstrates one of the most distinct advantages of the agents, a wetting capability superior to that of water.

Contact angle also provides a measure of water's ability or the solutions' ability to coat and cool a fuel surface. Previous research conducted on a hot steel plate showed that by decreasing the contact angle of a drop of water from 90° to 20° by using a surfactant, the heat transfer to the droplet increased by a factor of two [7,8]. The contact angle measurements were attempted with stainless steel, unstained and stained plywood siding, hardboard and rubber from automotive tires. For stainless steel and rubber the agents typically reduced the contact angle of water by a factor of four thereby increasing the area of contact by a factor of 2. Comparative contact angle measurements could not be made on the stained plywood and hardboard since the agent solutions would soak into the substrates within a few seconds. Both water and the agent solutions were absorbed rapidly by the unstained plywood.

Retention of an agent on an exterior siding material is an important factor for exposure protection. Three different substrates were used for this study: unpainted T1-11 textured plywood, stained T1-11 textured plywood and vinyl siding. A 1.2 m x 2.4 m (4 ft x 8 ft) sample of each siding material was supported by a load cell. After the siding samples have been with coated one of the agents, the mass of each sample was monitored for 6 hours to observe the mass loss (i.e. water loss) from each sample. The temperature and relative humidity were also measured and recorded. Each agent was to be tested with two types of application: fog nozzle and compressed air foam. Again water served as the benchmark.

All of the agent solutions performed better than water on the wood siding material. On the vinyl siding material the agent solutions drained off of the sample panel faster than water. At the end of the six-hour measurement period the unstained plywood, which was treated with agent solutions, retained approximately twice the mass as those treated with water. Similarly the stained plywood samples retained approximately four times the mass as those treated with water. The unstained and stained plywood when treated with the solutions in the form of compressed air foam yielded mass retention effectiveness of 3 and 6 respectively, relative to treatment with water. The results from these tests were then used for the ignition inhibition experiments.

Ignition inhibition experiments utilizing the cone calorimeter were conducted. Unstained and stained samples of T1-11 textured plywood, treated with agent solutions, foamed and non-foamed were exposed to a 30 kW/m^2 external radiant heat source [9]. The time to ignition was measured. Tests were conducted at three different times: immediately after agent application, 3 hours after agent application and 6 hours after agent application. When applied as solutions, the agents performed best at the three hours after application for both the unstained and stained samples. The increase in time to ignition ranged from 4 to 56% relative to samples treated with plain water. When the agents were applied as compressed air foams, the increase in time to ignition ranged from 13 to 100%.

5.2 LARGE SCALE EXPERIMENTS

Controlled experiments were conducted to examine the fire-fighting effectiveness of water-based fire suppression agents for two types of fire situations: fuel limited fires and ventilation-limited structure fires. Results from the ventilation limited structure fires are reported separately.

Suppression experiments using cribs composed of wood and plastic as the fuel were conducted. Each crib consisted of 10 layers, with each layer containing seven 55.9 cm (1.8 ft) long sticks of 3.8 cm (1.5 in) x 3.8 cm (1.5 in) cross section and each successive layer laid crosswise to the previous layer. Fixed spray nozzles were located next to each side of the crib so that the spray pattern from each nozzle covered two thirds of the top surface and three-fourths of the side facing the nozzle. Flow rates used during the suppression experiments ranged from 4.8 L/min (1.3 gpm) to 8.4 L/min (2.2 gpm). Plain water was compared with the four agent solutions; no significant differences in fire suppression capability were observed.

Piles of nine **automobile tires** were used as the fuel package for a series of 31 fire suppression experiments. The tire pile was ignited from a diesel fuel fire located in a pan underneath the tires. After the tire pile was well involved in the fire and the diesel fuel fire had burned out, suppression would begin. After fire knockdown, the tire pile was observed for reignition, up to 30 minutes. The suppression agents were applied manually at a flow rate of approximately 30 L/min (8 gpm). In addition to comparing water with the four different agents, each of the agents was applied in three different ways: spray nozzle, "tube type" aspirating nozzle and compressed air foam.

The water experiments had an average suppression time of 286 seconds and an average reignition time of 365 seconds. The results of the five water experiments ranged from a low of 125 seconds to a high of 390 seconds for suppression time. The agents, independent of application method, performed in a similar manner. The average times to suppression for the spray, aspirated, and CAF applications were 89, 99 and 73 seconds respectively. These results indicate that approximately one third the amount of solution produces the same results as plain water, with similar rekindle times.

6. SUMMARY

The four agent solutions as a group demonstrated increased performance relative to plain water in the following experiments: fuel cooling and penetration, contact angle, mass retention, ignition inhibition (fire exposure protection) and suppression of tire fires.

These experiments demonstrate that reduced surface tension and increased contact with the fuel provide the scenario for an increased level of fuel cooling and wetting relative to plain water. Based on the experiments performed, this is the fundamental means of increased performance relative to plain water. The tire-fire experiments indicate that a measure of emulsification might be another means for demonstrating potential fire-fighting capability, especially on fuels with a high carbon content.

Recommendations for further study include effectiveness of agent application technique (i.e. fog nozzle vs. compressed-air foam), investigation into a test to measure emulsification capability, and additional tests involving structural-fire suppression. Since it incorporates the benefits of the surface tension and contact-angle tests as well as cooling and penetration aspects for a given fuel, the fuel cooling and penetration experiment should be developed further.

7. REFERENCES

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