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NISTIR 6191

Demonstration Of Biodegradable, Environmentally Safe, Non-Toxic Fire Suppression Liquids

Daniel Madrzykowski
David W. Stroup, Editors

July 1998

U.S. Department of Commerce
Technology Administration
National Institute of Standards and Technology
Gaithersburg, MD 20899

Prepared for:
Federal Emergency Management Agency
U.S. Fire Administration
Emmitsburg, MD 21727-8998

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U.S. Department of Commerce
William M. Daley, *Secretary*
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Prepared for:
Federal Emergency Management Agency
James Lee Witt, *Director*
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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Building and Fire Research Laboratory (BFRL) of the National Institute of Standards and Technology (NIST), under the sponsorship of the United States Fire Administration (USFA), has conducted a series of experiments to demonstrate the suppression effectiveness of water-based fire fighting agents. Accepted test procedures for suppression effectiveness do not currently exist. Therefore, the results of these experiments are a first step toward establishing standardized tests for evaluating the fire fighting effectiveness of water-based agents. Because issues of toxicity and environmental effects of commonly used agents are of paramount concern to the fire fighting community, this report includes as an appendix, Wildland Fire Foam Characterization. This characterization study includes methods for demonstrating environmental safety and toxicity as developed by the United States Department of Agriculture (USDA). The work reported here addresses a broad range of tests in order to determine those parameters that most critically effect fire-fighting performance.

This project was a result of Public Law 103-327 which provided funding to the USFA, to demonstrate biodegradable, environmentally safe, nontoxic fire suppression liquids which are effective on Class A, B and many D fires. Since no standardized test methods or protocols were available to demonstrate the effectiveness of water-based fire suppression liquids, USFA tasked BFRL with developing a methodology for conducting a demonstration. This task is consistent with NIST's mission to advance measurement science and develop standard test methods and with BFRL's program to improve fire safety.

Introduction

Water based fire fighting 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. More recently these agents have been promoted for use on a wider range of Class A and in some cases Class B and D fires. These agents are frequently advertised as more effective than plain water while being environmentally safe. In some cases they are also claimed to reduce the quantity and toxicity of smoke.

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. This is particularly true for Class A and Class D fires. 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.

Approach

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. 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 [1]. 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 data base 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 properties data and differences in cost. In this report the names of these products are not identified.

The demonstration project was divided into four tasks:

1. Conduct a workshop with users, manufacturers and researchers interested in biodegradable, environmentally safe, nontoxic fire suppression liquids.

2. Collect information on fire suppression agents which are considered by their manufacturer to be biodegradable, environmentally safe, nontoxic fire suppression liquids which are effective on Class A, B and many D fires.

3. Develop methods as required and assess the biodegradability, environmental safety, toxicity and physical properties of a limited number of water based fire fighting agents.

4. Develop methods as required and demonstrate the fire fighting effectiveness of a limited number of water based fire fighting agents for Class A, B, and many D fires.

TASK 1

A workshop was held in Gaithersburg, MD on June 27, 1995. The workshop had three objectives; 1) to brief the attendees on the objectives, scope and approach of the demonstration project, 2) to solicit comments and suggestions on the demonstration project and obtain any available information on previous fire suppression effectiveness test results and 3) collect field use experience from the fire service on water based fire suppression agents. The meeting was attended by fire fighting agent

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1 Certain equipment or materials are identified in this report. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology or the U.S. Fire Administration, nor does it imply that the equipment or materials identified are necessarily the best available for the purpose.

manufacturers, fire fighters, researchers and special experts in the field of fire fighting with water based fire fighting agents.

The primary recommendations of the attendees are listed below:

1. Class A fire fighting effectiveness should be the focus of the project.

2. Utilize existing standardized tests to demonstrate the fire fighting effectiveness on Class B and D fires.

3. Experimental scenarios should include fire knockdown, "overhaul," and exposure protection.

4. Experiments should be conducted at "real life scale" when possible.

5. Efforts characterizing the physical, environmental safety and toxicity attributes of liquid fire fighting agents should continue.

These recommendations were incorporated into the research program.

TASK 2

The Alliance for Fire and Emergency Management compiled a list of names and addresses of manufacturers of "Alternative Liquid Fire Extinguishing Agents" that are marketed in the U.S. as being suitable for Class A fires, Class A and B fires and Class A, B and D fires. Information was found on twenty nine commercially available agents. The list includes agents which are described as wetting agents, emulsifiers, foams, and gels. According to the agent manufacturers', all of these agents are "environmentally safe" or "biodegradable". Of the twenty nine agents, all are advertised as being effective on Class A fuels, twelve of the agents are also advertised as being effective on Class B. Three of the agents are advertised as being effective on Class A, B and D fuels.

While this list of agents is by no means a complete listing of liquid fire fighting agents, it does demonstrate that there are a wide range of fire suppression liquids commercially available. It also highlights the problem fire departments have, when choosing an agent for use. With no standardized test methods available to measure the fire fighting effectiveness of these agents, a fire chief, typically, has limited information on effectiveness when making a decision concerning use of a new agent.

TASK 3

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 have 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. In order to make efficient use of project funds and to avoid redundant efforts, NIST contracted with the IFSL to develop a report on all of the standardized testing conducted under their direction for all of the agents currently on the Forest Service QPL. Their agent characterization can be found in Appendix C of this report.

TASK 4

This broad-based study on fire-suppression effectiveness of water-based fire fighting agents utilized laboratory-scale experiments and large-scale fire suppression experiments. Four commercially available fire suppression agent solutions were selected. Water was used as the basis for developing performance data because of its well known physical characteristics and wide use in the fire fighting community. It was found that some of the test methods provide a basis for clear differentiation of fire fighting effectiveness between water and fire-fighting agents. Others demonstrated little capability to differentiate fire-fighting effectiveness. This does not mean that these properties do not effect fire fighting efficiency, rather that the measurement is not particularly sensitive to the application.

Based on the limited results of this study, the following test methods have the highest degree of differentiation between water and the fire-fighting agents: surface cooling and fuel penetration, agent retention on surfaces, ignition inhibition, tire fire suppression and Class B fire suppression.

Based on the limited results of this study, the following test methods have small or no discernable capability to differentiate between water and fire-fighting agents: specific heat, drop size, contact angle, wood crib fire suppression, smoke generation and Class D fire suppression.

Summary

For demonstration purposes, tests examining the following properties and conducted in accordance with the methods identified in this report can be used to provide information on some important characteristics contributing to measures of the fire fighting effectiveness of liquid fire suppression agents relative to water.

- specific heat
- fuel cooling and penetration
- mass retention
- ignition inhibition
- tire fire suppression
- wood crib fire suppression
- heptane fire suppression
- magnesium fire suppression

The results presented here provide preliminary data upon which fire fighting effectiveness tests may be developed. Certain plausible scenarios can be constructed regarding the action of the agents in extinguishing fires. However, additional research efforts are necessary to develop a broader base for such development. Areas recommended for further study include:

- effectiveness of agent application technique (i.e. fog nozzle vs. compressed-air foam),
- fire suppression effectiveness test methods should be designed to reflect the training of fire fighter to include the complexities necessary to expeditiously extinguish a fire,
- investigation into a test to measure emulsification capability, and
- experiments involving structural-fire suppression.

The fuel cooling and penetration experiment should be developed further, since it incorporates the benefits of the surface tension and contact-angle tests as well as cooling and penetration aspects for a given fuel.

ACKNOWLEDGEMENTS

The authors would like to thank Laurean DeLauter, Gary Roadarmel, William Twilley, Jack Lee, Jay McElroy, Richard Harris, Betty Thames and Marco Fernandez of the Building and Fire Research Laboratory for their efforts supporting the full scale experiments, instrumentation and logistics required to complete an effort of this magnitude. The authors express appreciation for the support of Dr. John Small, Scot Wight, and Dr. Bruce Benner of the Chemical Science and Technology Laboratory.

A wide variety of fire test facilities were required to accommodate the broad spectrum of experiments needed for this demonstration. Appreciation is extended to the staffs of the following facilities: University of Maryland, Maryland Fire and Rescue Institute Princess Anne Training Center; University of Maryland, Maryland Fire and Rescue Institute Western Regional Training Center; U.S. Naval Research Laboratory, Chesapeake Beach Detachment and Underwriter's Laboratories, Northbrook. John Hoglund of the University of Maryland, Maryland Fire and Rescue Institute; Tom Wilson of the University of Maryland, Maryland Fire and Rescue Institute Princess Anne Training Center; Ronald R. Bowser, Charles H. Wood, and Debbie Sklodowski of the University of Maryland, Maryland Fire and Rescue Institute Western Regional Training Center; and William Carey and Martin Pabich of Underwriters Laboratories, Inc. deserve special recognition for their support of this project.

The agent characterization found in Appendix C was prepared by Charles W. George and Cecilia W. Johnson of the U.S. Department of Agriculture, U.S. Forest Service, National Wildfire Suppression Technology (NWST) Program. Their efforts toward the success of this project are greatly appreciated.

The authors would also like to thank Dr. David D. Evans and Erik Johnsson of the Building and Fire Research Laboratory and Dr. James Whetstone and Dr. Wing Tsang of the Chemical Science and Technology Laboratory for their thorough reviews of this document.

Finally, we would like to thank the Administrator of the U.S. Fire Administration, Carrye B. Brown, the Deputy Administrator of the U.S. Fire Administration, Donald G. Bathurst, and Robert T. McCarthy, Chief of the Fire Technical Programs Branch. Without the support of the U.S. Fire Administration and its leadership, this demonstration project could not have been conducted.

Demonstration of Biodegradable, Environmentally Safe, Non-Toxic, Fire Suppression Liquids

D. Madrzykowski and D.W. Stroup, Editors

ABSTRACT

The Building and Fire Research Laboratory (BFRL) of the National Institute of Standards and Technology (NIST), under the direction of and funding by the United States Fire Administration (USFA), has conducted a series of experiments to demonstrate the suppression effectiveness of water-based fire fighting agents. Accepted test procedures for suppression effectiveness do not currently exist. Therefore, the results of these experiments are a first step toward establishing standardized tests for evaluating the fire fighting effectiveness of water-based agents. Because issues of toxicity and environmental effects of commonly used agents are of paramount concern to the fire-fighting community, this report includes as an appendix, Wildland Fire Foam Characterization. This characterization study includes methods for demonstrating environmental safety and toxicity as developed by the United States Department of Agriculture (USDA). The work reported here addresses a broad range of tests in order to determine those parameters that most critically effect fire-fighting performance.

This project was a result of Public Law 103-327 which provided funding to the USFA, to demonstrate biodegradable, environmentally safe, nontoxic fire suppression liquids which are effective on Class A, B and many D fires. Since no standardized test methods or protocols were available to demonstrate the effectiveness of water-based fire suppression liquids, USFA tasked BFRL with developing a methodology for conducting a demonstration. This task is consistent with NIST's mission to advance measurement science and develop standard test methods and with BFRL's program to improve fire safety.

This study focused on fire-suppression effectiveness of water-based fire fighting agents utilized laboratory-scale experiments and large-scale fire suppression experiments. Four commercially available fire suppression agent solutions were selected. Water was used as the basis for developing performance data because of its well-known physical characteristics and wide use in the fire fighting community. It was found that some of the test methods provide a basis for clear differentiation of fire fighting effectiveness between water and fire-fighting agents. Others demonstrated little capability to differentiate fire-fighting effectiveness. This does not mean that these properties do not effect fire fighting efficiency, rather that the measurement is not particularly sensitive to the application.

Based on the limited results of this study, the following test methods have the highest degree of differentiation between water and the fire-fighting agents: surface cooling and fuel penetration, agent retention on surfaces, ignition inhibition, tire fire suppression and Class B fire suppression.

Based on the limited results of this study, the following test methods have small or no discernable capability to differentiate between water and fire-fighting agents: specific heat, drop size, contact angle, wood crib fire suppression, smoke generation and Class D fire suppression.

Key words: class A fires; class B fires; class D fires; compressed air foam; fire extinguishing agents; fire suppression; large scale fire tests

CHAPTER 8

FINDINGS

FINDINGS

This broad-based study on fire-suppression effectiveness of water-based fire fighting agents utilized laboratory-scale experiments and large-scale fire suppression experiments. Four commercially available fire suppression agent solutions were selected. Water was used as the basis for developing performance data because of its well know physical characteristics and wide use in the fire fighter community. It was found that some of the test methods provide a basis for clear differentiation of fire fighting effectiveness between water and fire-fighting agents. Others demonstrated little capability to differentiate fire-fighting effectiveness. This does not mean that these properties are do not effect fire fighting efficiency, rather that the measurement is not particularly sensitive to the application.

1. Physical Characteristic Test Methods for Fire Fighting Agents

A. The following test methods have the highest degree of differentiation between water and fire-fighting agents.

Surface Cooling and Fuel Penetration

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. 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. The initial penetration time through the hardboard was similar for water and the four agent solutions. 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 clearly differentiates between the agent solutions and water and demonstrates one of the most distinct advantages of the agents, a wetting capability superior to that of water.

Agent Retention on Surfaces

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 had been coated with 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 were retained on the wood siding material for a longer period of time. On the vinyl siding material the agent solutions drained off the sample panel faster than water. At the end of the six-hour measurement period the unstained plywood samples, which were 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

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. 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%.

B. The following test methods have small or no discernable capability to differentiate between water and fire-fighting agents.

Specific Heat

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 agent solutions, which were composed of at least 97 percent water, had specific heats lower than water by an amount reflecting a simple mixture of the two liquids.

Drop Size

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 ½ 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 within 20% of that of water. A change in droplet size could be beneficial or detrimental depending on the application. This potential effect as well as the droplet measurements could benefit from further research.

Contact Angle

Contact angle also provides a measure of the fire fighting material's 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. 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. Because both water and the agent solutions were absorbed rapidly by the unstained plywood, measurements were not possible.

2. Large-Scale Experiments

The following is a listing of the results of the large-scale tests in terms of their effectiveness of fire fighting agent in comparison to water. To provide a measure of fire suppression effectiveness, the water-based agents were evaluated relative to water. In addition to water, aqueous film-forming foam (AFFF) was used as a reference for comparison on the Class B fires and a dry agent powder was used as a reference for the Class D fires.

Class A Fires

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. The ventilation limited structure fire experiments were completed in March of 1998. The results will be reported by NIST at a later date.

Automobile Tires

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 began. After fire knockdown, the tire pile was observed for re-ignition, 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 agents, each of the agents was applied in three different ways: spray nozzle, "tube type" aspirating nozzle and compressed air foam. Based on this limited set of experiments application of approximately one third the amount of agent solutions appeared to produce the same results as plain water, with similar rekindle times.

Smoke Generation

NIST also examined smoke generation during the crib suppression experiments. The qualities which this test methodology examined as critical smoke characteristics were mass concentration and sized distribution of smoke particulates and concentration of combustion gases, carbon dioxide, carbon monoxide, hydrogen cyanide, hydrogen chloride, and nitrogen oxides. These properties of suppressant agents were evaluated in a series of laboratory scale experiments that also utilized water as a benchmark. While these experimental measurements did provide data for post-extinguishment smoke, the qualities of the smoke during extinguishment can not be ascertained from these measurements. The reduction in mass concentration of smoke particulates and combustion gases appears to be dominated by the extinguishment process itself which makes it more difficult to ascertain the impact of specific suppressant agents during the extinguishment process. If the smoke properties during extinguishment are deemed crucial elements, then additional measurements which focus on this aspect should be incorporated in future versions of this protocol.

Crib Fires

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 for this limited set of tests. As noted earlier similar using a fire fighter rather than the fixed position nozzles used in this test lead to results very similar to the tire fire results. This may indicate that the method of application of the suppressant is very important.

Class B Fires

A series of Class B fire suppression tests were conducted in conformance with UL 162, Standard for Foam Equipment and Liquid Concentrates. These tests utilize a 4.6 m^2 (50 ft^2) **heptane** pool fire and consist of the suppression of the fire and then testing for re-ignition and burn-back resistance. Agent was applied at 2.44 and 4.88 L/min/m^2 (0.06 and 0.12 gpm/ft^2), which is one and a half and three times the rate required by the standard for AFFF application. The higher flow rates were used because the agents could not extinguish the fire at the standard AFFF application rate. The four agents had fire knockdown (control) times similar to AFFF but two of the agents C and D did not completely extinguish the fire in all of the tests. AFFF had a higher resistance to burn-back, longer time to re-ignition, than the other four agents.

Full-scale fire experiments were conducted with 92.9 m^2 (1000 ft^2) **gasoline** pool fires. Agent application was made with a 454 L/min (120 gpm) hose stream (i.e. 4.88 L/min·m^2 (0.12 gpm/ft^2)). Two application techniques were used with each of the four agents in the large-scale tests. One application was made with a self-aspirating tube nozzle and one application was made with a non-aspirating adjustable fog nozzle. AFFF and water were used as benchmark agents for these tests. Plain water could not extinguish this fire. Based on this data set, the results of the UL 162 fire suppression tests correlated well with the full-scale fire suppression demonstration, especially for the aspirated application.

Class D Fires

A series of Class D fire suppression experiments has been conducted based on UL 711, Standard for Rating and Testing of Fire Extinguishers, Chapter 8. The fuel bed was composed of **magnesium** chips. Water and a UL listed Class D dry powder were used as bench mark agents in these tests. The four agents were applied as a straight stream and as a spray. In the case of the liquid agents, the application rate was 38 Lpm (10 gpm). Only the dry powder was effective in extinguishing the fire. When water was applied the fire intensity increased and sparks were produced. This limited set of experiments produced results, which did not allow differentiation between the liquid agents and plain water.

A second series of experiments using oiled, **titanium** turnings was conducted. A 9 kg (20 lb) fuel bed similar 0.6 m (2 ft) on a side and 150 mm (6 in.) high was easily suppressed with 38 Lpm (10 gpm) of plain water. When the flow rate of water was reduced to 3.8 Lpm (1 gpm), suppression was no longer accomplished with the plain water. Again, the results from this limited set of experiments were similar for the liquid agents and plain water.

Summary

For demonstration purposes, tests examining the following properties and conducted in accordance with the methods identified in this report can be used to provide information on some important characteristics contributing to measures of the fire fighting effectiveness of liquid fire suppression agents relative to water.

- specific heat
- fuel cooling and penetration
- mass retention
- ignition inhibition
- tire fire suppression
- wood crib fire suppression
- heptane fire suppression
- magnesium fire suppression

The results presented here provide preliminary data upon which fire fighting effectiveness tests may be developed. Certain plausible scenarios can be constructed regarding the action of the agents in extinguishing fires. However, additional research efforts are necessary to develop a broader based for such development. Areas recommended for further study include:

- effectiveness of agent application technique (i.e. fog nozzle vs. compressed-air foam),
- fire suppression effectiveness test methods should be designed to reflect the training of fire fighter to include the complexities necessary to expeditiously extinguish a fire,
- investigation into a test to measure emulsification capability, and
- additional tests involving structural-fire suppression.

The fuel cooling and penetration experiment should be developed further, since it incorporates the benefits of the surface tension and contact-angle tests as well as cooling and penetration aspects for a given fuel.

APPENDIX A

WORKSHOP ATTENDEES

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	MANUSCRIPT REVIEW AND APPROVAL	PUBLICATION REPORT NUMBER: NISTIR 6191	CATEGORY CODE
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TITLE AND SUBTITLE (CITE IN FULL)

Demonstration of Biodegradable, Environmentally Safe, Non-Toxic, Fire Suppression Liquids

CONTRACT OR GRANT NUMBER

TYPE OF REPORT AND/OR PERIOD COVERED

AUTHOR(S) (LAST NAME, FIRST INITIAL, SECOND INITIAL)

Madrzykowski, D.
Stroup, D.W., Editors

PERFORMING ORGANIZATION (CHECK (X) ONE BOX)

- [x] NIST/GAITHERSBURG
- [ ] NIST/BOULDER
- [ ] JILA/BOULDER

LABORATORY AND DIVISION NAMES (FIRST NIST AUTHOR ONLY)

Building and Fire Research Laboratory, Fire Safety Engineering Division

SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

U.S. Fire Administration
Emmitsburg, MD 21727-8998

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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 suppression effectiveness of water based fire fighting agents. This report includes methods, as developed by the United States Department of Agriculture, for demonstrating environmental safety and toxicity of these agents. NIST investigated smoke generation during suppression and conducted a broad-based study on fire 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, tire, heptane, gasoline, magnesium and titanium fires.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)

class A fires; class B fires; class D fires; compressed air foam; fire extinguishing agents; fire suppression; large scale fire tests, small

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