NISTIR 6191

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

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CHAPTER 6

CLASS B FIRE SUPPRESSION EXPERIMENTS

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CLASS B FIRE SUPPRESSION EXPERIMENTS

6.1 Introduction

Under the sponsorship of the United States Fire Administration (USFA), the National Institute of Standards and Technology (NIST) is developing methods for demonstrating biodegradable, environmentally safe, nontoxic fire suppression liquids which are effective on Class A, B, and many D fires. As part of this project, the Naval Research Laboratory (NRL) was tasked with conducting a series of standardized Class B fire tests. In addition, a series of large-scale Class B fire experiments was conducted in order to evaluate the standardized fire tests.

The objective of this Class B fire study was to develop test data and investigate test methods for evaluating the fire extinguishment and burnback resistance capabilities of selected Biodegradable, Environmentally friendly, Nontoxic (BEN) liquid firefighting agents on Class B hydrocarbon pool fires. Agent selection was limited to products currently on the U.S. Forest Service's list of approved agents [1]. Four agents were selected by NIST, none of which was listed as Class B fire fighting foams by either Underwriters Laboratories Inc. (UL) or the U.S. Military.

6.2 Approach

Testing was performed in three phases: foam expansion and drainage characterization, standard small-scale fire extinguishment and burnback testing, and large-scale pool fire testing. The first phase of testing evaluated expansion and drainage characteristics using both a full-scale, constant flow, air-aspirating nozzle and a small-scale, variable flow, air-aspirating nozzle. The flow from the small-scale nozzle was adjusted by exchanging a removable orifice, which allowed a desired flow to be obtained at various operating pressures. Tests were conducted with the small-scale nozzle first, using a number of different orifices to obtain results at a range of flow/pressure combinations. Testing was then conducted with the large-scale nozzle. Based on the results of these tests, a set of three orifices was selected that gave expansion and drainage characteristics from the small-scale nozzle which most closely replicated the large-scale nozzle results. Expansion and drainage characteristics tests conducted in conjunction with the fire test provided additional data for both small- and large-scale air-aspirating nozzles as well as data for a non-aspirating nozzle.

After selecting the appropriate orifices for the small-scale nozzle, a series of 4.6 m^2 (50 ft^2) fire tests were conducted. The tests were performed in accordance with UL 162 [2], Type III application method. Tests were conducted at flow rates of 7.6 lpm (2.0 gpm), 11.4 lpm (3.0 gpm), and 22.7 lpm (6.0 gpm). This resulted in application rates of 1.67 lpm/m^2 (0.04 gpm/ft^2), 2.44 lpm/m^2 (0.06 gpm/ft^2), and 4.88 lpm/m^2 (0.12 gpm/ft^2), respectively. Because the extinguishment characteristics of the BEN agents were marginal at the 11.4 lpm (3.0 gpm) flow rate, testing at the 7.6 lpm (2.0 gpm) flow rate was conducted with the AFFF agent only.

The final phase of testing was a series of large-scale 92.9 m^2 (1000 ft^2) fire tests. These tests were conducted with both an air-aspirating nozzle and a non-aspirating nozzle. Both nozzles were operated at a nominal flow rate of 454 lpm (120 gpm), resulting in an application rate of 4.88 lpm/m^2 (0.12 gpm/ft^2).

6.3 Agents Tested

The agents used for these tests included four (4) different biodegradable, environmentally friendly, non-toxic agents selected from the U.S. Forest Service's List of Approved Products [1]. These agents are referred to in this report as Agent A, B, C, or D. All testing was performed with premixed fresh water solutions, which were prepared in 1514 l (400 gal) batches for the large-scale tests and 150 l (40 gal) batches for the small-scale tests. All agents were initially mixed at the manufacturer's recommended concentrations. For Agents A and B, this was 1 percent (e.g., 99 parts water, 1 part concentrate), for Agent C, 6 percent and for agent D, 3 percent. In an effort to obtain more complete results, 4.6 m^2 (50 ft^2) fire tests were also conducted with Agent C at a 3 percent concentration and Agent D at a 6 percent concentration.

To provide a baseline and a measure of comparison, testing was conducted with an AFFF agent. This 3 percent concentrate agent is both UL Listed®[3] and is on the U.S. Military's Qualified Products List (QPL) [4]. To provide an additional baseline, a single large-scale fire test was also conducted with water only.

6.4 Expansion and Drainage Characteristics Tests

6.4.1 Test Setup

The expansion and drainage characteristics tests were conducted using the equipment described in Section 8.2 of UL 162 [2]. The foam expansion value is the ratio of the volume of foam produced over the volume of solution used in its production. The 25 percent drainage time is the time required for 25 percent of the total liquid contained in the foam sample to drain out of the foam. The backboard and 1600 ml collection cylinder used for these tests are described in the UL standard. A quarter-turn valve installed on the bottom outlet of the collection cylinder was used to control flow of the solution which had drained off of the expanded foam. As this solution was drained off, it was collected and measured in a 1000 ml graduated cylinder at 30-second intervals.

Expansion and drainage tests were conducted using three different nozzles. Two of these nozzles were of the air-aspirating type, and the third was a non-aspirating nozzle. The first nozzle, referred to as the large-scale air-aspirating nozzle was designed to flow 227 lpm (60 gpm) at an operating pressure of 552 kPa (80 psi). The initial expansion and drainage tests were conducted using the "factory" configuration. For the large-scale fire tests, this nozzle was modified (the orifice was enlarged) so that it could flow 454 lpm (120 gpm) at 690 kPa (100 psi).

The second nozzle, referred to as the small-scale test nozzle, was a modified version of the 7.6 lpm (2 gpm) nozzle described in the AFFF Military Specification (MIL-SPEC), MIL-F-24385F [5]. This nozzle is also an air-aspirating nozzle. The basic MIL SPEC test nozzle was modified by drilling and tapping the metering orifice so that it would accept any one of a set of metering orifice inserts.

These inserts in turn had various sized orifices which allowed an unlimited number of flow and pressure combinations at which the nozzle could be operated. This nozzle apparatus is used for Standard UL 162 fire testing. Tests were conducted at several different flow/pressure combinations with this nozzle.

The final nozzle, the large-scale, non air-aspirating nozzle, was a non air-aspirating, constant flow, variable stream nozzle that discharged 473 Lpm (125 gpm) at 690 kPa (100 psi). This nozzle is typical of those used by fire departments to discharge water on Class A fires. It is also used to discharge AFFF.

For the large-scale tests, the agent was premixed in a 1700 l (450 gal) stainless steel premix tank. The solution was then supplied to the nozzle through 30.5 m (100 ft) of 3.8 cm (1.5 in.) diameter canvas-jacketed rubber-lined fire hose by a 3785 lpm (1000 gpm) fire department pumper which took suction off of the premixed tank. For the small-scale tests, the agent was premixed in a 189 l (50 gal) closed-top storage tank. The tank was then charged with nitrogen, and solution was supplied to the nozzle through 7.6 m (25 ft) of 1.9 cm (0.75 in.) diameter rubber garden hose.

6.4.2 Test Procedures

The procedures used for conducting these tests were in accordance with UL 162 [2]. The procedures were identical for both the small- and large-scale tests. After the foam solution was premixed, the nozzle was flowed to assure the nozzle pressure was properly set. The nozzle was positioned at a distance of 12-15 m (40-50 ft) away from the backboard for the large-scale test and 2 m (6 ft) away from the small-scale tests. The discharge stream was directed against the backboard, and foam was collected in the 1600 ml collection cylinder. Measurement of drainage time began when the collection cylinder was observed to be full. The cylinder was then removed from the backboard, cleaned, and placed in a holding stand. The solution which drained out of the foam was removed from the collection cylinder using the quarter-turn valve and the cumulative amount measured at 30-second intervals over a 5-10 minute period. At the end of this period, the solution was returned to the collection cylinder, and the entire sample was weighed. The net weight of solution was determined, and from that, the expansion ratio was calculated. The 25 percent drainage time was then interpolated from the recorded drainage volumes.

An initial series of tests was conducted with the small-scale test nozzle using several different orifices and Agent A to scope the effects of flow rate and pressure on expansion and drainage characteristics. Since these tests showed that flow rate had a more significant impact than nozzle pressure, it was decided to conduct the remaining tests with the small-scale test nozzle at the 11.4 lpm (3.04 gpm) and 22.7 lpm (6.00 gpm) flow rates. These were the two flow rates to be used initially in the 4.6 m^2 (50 ft^2) fire tests.

After testing was completed with the small-scale test nozzle, a series of tests were performed with the large-scale air-aspirating nozzle to confirm that it would produce approximately the same expansion and drainage characteristics as the small-scale nozzle. In addition to these scoping tests, expansion and drainage tests were also conducted after each fire test with the solution remaining in the premix tank or pressurized storage tank. It was during these post-fire test experiments that data were collected for the large-scale non air-aspirating nozzle.

6.4.3 Test Results

The results of all small-scale expansion and drainage tests, including those performed with solutions used for fire tests, are presented in Table 1.

Table 1 Results of Expansion and Drainage Tests Conducted with Small-scale Nozzles

	Orifice Size (mm (in.))	Pressure (kPa (psi))	Flow Rate (lpm (gpm))	Expansion Ratio	25% Drainage Time (s)
Agent A, 1% Concentration	2.69 (0.106)	896 (130)	11.4 (3.02)	9.2	274
	3.05 (0.120)	552 (80)	11.5 (3.04)	8.8	270
	4.24 (0.167)	596 (85)	22.7 (6.00)	6.6	218
	3.73 (0.147)	993 (144)	22.7 (6.00)	6.7	310
	3.05 (0.120)	552 (80)	11.5 (3.04)	8.9	197
	4.24 (0.167)	586 (85)	22.7 (6.00)	7.3	195
	4.24 (0.167)	586 (85)	22.7 (6.00)	7.0	141
Agent B, 1% Concentration	3.05 (0.120)	552 (80)	11.5 (3.04)	8.8	138
	4.24 (0.167)	586 (85)	22.7 (6.00)	7.6	136
	4.24 (0.167)	586 (85)	22.7 (6.00)	6.4	137
	4.24 (0.167)	586 (85)	22.7 (6.00)	7.7	152
	3.05 (0.120)	552 (80)	11.5 (3.04)	9.0	148
Agent C, 6% Concentration	4.24 (0.167)	586 (85)	22.7 (6.00)	10.0	240
	3.05 (0.120)	552 (80)	11.5 (3.04)	11.8	225
	4.24 (0.167)	586 (85)	22.7 (6.00)	9.5	216
	3.05 (0.120)	552 (80)	11.5 (3.04)	12.0[1]	136[1]
Agent D, 3% Concentration	4.24 (0.167)	586 (85)	22.7 (6.00)	6.1	84
	3.05 (0.120)	552 (80)	11.5 (3.04)	10.3	82
	3.05 (0.120)	552 (80)	11.5 (3.04)	8.7	92
	4.24 (0.167)	586 (85)	22.7 (6.00)	8.7	65
	3.05 (0.120)	552 (80)	11.5 (3.04)	12.5[2]	77[2]
AFFF, 3% Concentration	3.05 (0.120)	552 (80)	11.5 (3.04)	8.1	162
	3.05 (0.120)	552 (80)	11.5 (3.04)	8.5	144
	2.31 (0.091)	758 (110)	7.7 (2.03)	13.1	158
	4.24 (0.167)	586 (85)	22.7 (6.00)	10.7	125

Notes:
1. Test conducted with solution mixed at a 3 percent concentration.
2. Test conducted with solution mixed at a 6 percent concentration.

The expansion and drainage results for all of the large-scale tests performed with both nozzles are presented in Table 2. Nozzle operating pressures and flow rates are included to show the impact on expansion and drainage characteristics, particularly evident with the small-scale test nozzle. A comparison between the small-scale and large-scale air-aspirating results shows that with three of the five agents tested, there is good agreement in expansion and drainage characteristics between small-scale and large-scale tests (Agents A, C, and AFFF). With Agents B and D, the large-scale air-aspirating nozzle produced an expansion ratio that was greater than that produced with the small-scale nozzle. It can also be seen from these data that the 25 percent drainage times obtained with the small-scale nozzle were generally longer than those obtained with the large-scale air-aspirating nozzle. Based on these results, it was decided that the degree of agreement between the small-scale and large-scale air-aspirating nozzle tests was sufficient to proceed with the 4.6 m^2 (50 ft^2) fire tests. Accordingly, the 2.31 mm (0.091 in.), 3.05 mm (0.120 in.), and 4.24 mm (0.167 in.) orifices were selected to conduct the fire suppression tests.

Table 2 Results of Expansion and Drainage Tests Conducted with Large-scale Nozzles

	Nozzle Type	Pressure (kPa (psi))	Flow (lpm (gpm))	Expansion Ratio	25% Drainage Time (s)
Agent A, 1% Concentration	Aspirated	690 (100)	454 (120)	7.7	156
	Non-aspirated	690 (100)	473 (125)	2.8	<30
Agent B, 1% Concentration	Aspirated	552 (80)	227 (60)	13.0	66
	Aspirated	552 (80)	227 (60)	13.4	90
	Aspirated	690 (100)	454 (120)	11.7	135
	Non-aspirated	690 (100)	473 (125)	4.4	<30
Agent C, 6% Concentration	Aspirated	552 (80)	227 (60)	13.5	150
	Aspirated	552 (80)	227 (60)	18.0	102
	Aspirated	552 (80)	227 (60)	15.5	114
	Aspirated	690 (100)	454 (120)	17.2	114
	Non-aspirated	690 (100)	473 (125)	5.4	<30
Agent D, 3% Concentration	Aspirated	690 (100)	454 (120)	9.5	<30
	Non-aspirated	690 (100)	473 (125)	3.2	<30
AFFF, 3% Concentration	Aspirated	690 (100)	454 (120)	10.0	62
	Non-aspirated	690 (100)	473 (125)	4.0	<30

6.5 4.6 m^2 (50 ft^2) Fire Tests

6.5.1 Test Setup

The 4.6 m^2 (50 ft^2) fire tests were conducted using the equipment described in UL 162 [2] for Type III discharge devices. This discharge scenario is intended to simulate direct application of foam to a spill or pool fire, e.g., from handlines and monitors. The test pan, which was located outdoors on the concrete mini-deck at the Chesapeake Beach Detachment (CBD) of NRL, was made of 6.4 mm (0.25 in.) thick carbon steel and was built in accordance with Section 3.6 of UL 162. It was 30.5 cm (12 in.) deep and was elevated off the ground 7.6 cm (3 in.) by structural channel welded to the bottom. Fuel for these tests was commercial grade heptane. A total of 237 l (62.5 gal) was used for each test. The fuel was floated on a 5.1 cm (2.0 in.) deep water substrate, resulting in 20.3 cm (8 in.) of freeboard.

All tests were conducted with premixed solutions. The storage tank/small-scale test nozzle setup was identical to that described above for the small-scale expansion and drainage characteristics tests. Flow rates for these tests were as follows:

Orifice Size (mm (in.))	Pressure (kPa (psi))	Flow (lpm (gpm))	Application Rate (lpm/m^2 (gpm/ft^2))
2.31 (.091)	758 (110)	7.57 (2.0)	1.67 (0.04)
3.05 (.120)	552 (80)	11.4 (3.0)	2.44 (0.06)
4.24 (.167)	586 (85)	22.7 (6.0)	4.88 (0.12)

Tests with Agents A, B, C, and D were conducted at the 11.4 lpm (3.0 gpm) and 22.7 lpm (6.0 gpm) flow rates only because the performance at 11.4 lpm (3.0 gpm) was marginal, indicating that extinguishment would not be achieved at 7.6 lpm (2.0 gpm). Tests with the AFFF product were conducted at all three flow rates.

All tests were initially conducted at the manufacturer's recommended concentrations. After the initial set of tests, Agents C and D had not achieved 100 percent extinguishment at the 11.4 lpm (3.0 gpm) flow rate. Two additional tests were conducted, one with Agent C at 3 percent (half strength) concentration and the other with Agent D at 6 percent (double strength) concentration, to examine the difference, if any, in extinguishment performance.

6.5.2 Test Procedures

All test procedures were in accordance with Section 10 of UL 162 [2] except as noted. Prior to each test, ambient wind conditions and air, fuel, water substrate, and solution temperatures were measured and recorded. The preburn and extinguishment portions of the test were conducted as described in UL 162. After the fuel was poured, all temperature measurements were recorded, and the nozzle was flowed to check the pressure; the fire was ignited and allowed to preburn for a total of 60 seconds. The firefighter then began his attack from the upwind side of the pan. Agent was initially applied to the near side of the fire area, which resulted in a buildup of the foam blanket on the far side of the fire area. When it appeared that this foam blanket had extinguished about 30-50 percent of the fire, the nozzle was elevated slightly so that the foam was being applied to the far side of the fire pan on top of the established foam blanket. This allowed the foam blanket to flow back to the near side, extinguishing all of the fire around the edges. Up to this point, the firefighter was restricted to applying agent from one side of the pan only.

When 90 percent of the fire was extinguished, the firefighter was allowed to move around two sides of the pan to extinguish the last remaining fire at the edges. Complete extinguishment proved to be difficult because of the hot temperature of the steel and the amount of exposed steel freeboard. The time to achieve 50 percent control as well as 90 percent control and 100 percent extinguishment were recorded. Total application time for tests conducted at the 11.4 and 22.7 lpm (3.04 and 6.00 gpm) flow rates was 5 minutes. Total application time for tests conducted at the 7.6 lpm (2.0 gpm) flow rate was 3 minutes.

The burnback portion of the test was also conducted as described in UL 162. Immediately after the end of agent application, the first torch test was performed. A burning torch was passed over all areas of the foam blanket at an elevation of approximately 15.2 cm (6.0 in.) above the foam blanket. This procedure was performed over a one minute time period. In some cases, the first torch test resulted in candling (e.g., small flames usually not more than 15.2 cm (6.0 in.) tall) around the edges of the foam blanket which eventually self-extinguished. In other cases, the candling progressed to sustained burning of larger areas and eventually complete reinvolvement. In cases where the candling flames from the first torch test self-extinguished, the foam blanket was allowed to sit for a total of 13 minutes from completion of the first torch test (14 minutes from the end of agent application). At this time, a second torch test was performed using the same procedures. In all cases, the foam blanket was sufficiently broken down to allow reignition of the fuel. The major factor affecting the integrity of the foam blanket appeared to be ambient wind conditions, which tended to push the foam blanket away from the downwind side of the pan. Once the foam blanket had pulled away from the side of the pan, it never flowed back to reform a complete seal. UL 162 does not specify maximum wind speed for conducting the burnback test.

Since breakdown of the foam blanket was significant in all cases, the "stove pipe" test specified by UL was never performed. Burnback time, which was the time to achieve 100 percent reinvolvement, was recorded based on reignition from the torch test. Because some tests reignited after the first torch test, zero time for measurement of burnback was the end of agent application. At the end of each test, an expansion and drainage test was performed to provide additional foam quality data.

6.5.3 Test Results

The results of the 4.6 m^2 (50 ft^2) fire tests are presented in Table 3. In addition to 100 percent extinguishment time, the time to control 50 percent and 90 percent of the fire area is reported. The 50 percent control time provides a measure of initial knockdown ability and effectiveness of an agent. The 90 percent control time provides a measure of fire extinguishment in which the fire is essentially contained. In most cases, the time required to extinguish the last 10 percent of fire area was almost as long, if not longer, than the time to achieve 90 percent fire control. This is an indication of the difficulty for the foam to seal against the hot edges of the test pan. Air temperatures recorded during these tests were in the range 21-33EC (70-91EF), fuel temperatures were in the range 21-31EC (70-88EF), and solution temperatures were in the range 24-30EC (75-86EF).

None of the BEN agents performed as well as the MIL SPEC AFFF, which had 100 percent extinguishment times at the 7.6 lpm (2.0 gpm) flow rate that were comparable to the extinguishment times of the BEN agents for the 11.4 lpm (3.04 gpm) flow rate. At the 22.7 lpm (6.00 gpm) flow rate, Agents A and B performed best with extinguishment times only 12-22 seconds longer than those of MIL SPEC AFFF. It can also be seen that the performance of Agent C at the 11.5 lpm (3.04 gpm) flow rate was improved by reducing the concentration to 3 percent (half-strength of manufacturer's recommendation). Increasing the concentration of Agent D to 6 percent (twice the manufacturer's recommendation) provided no advantage at all.

The torch test results and 100 percent burnback time data are similar to the extinguishment data. Again, Agents A and B performed the best. Agent C progressed past the initial torch test only at the 22.7 lpm (6.00 gpm) flow rate. With Agent D, the first torch test resulted in complete reinvolvement in all cases. There were also differences between the burnback characteristics of the BEN agents and the MIL SPEC AFFF. With AFFF, the second torch test resulted in candling only even though there were what appeared to be exposed areas of fuel. While this candling did eventually become sustained burning, the length of time to achieve 25-60 percent reinvolvement was 2-4 minutes longer than the time for 100 percent reinvolvement with the best BEN agents.

6.6 92.9 m^2 (1000 ft^2) Fire Tests

6.6.1 Test Setup

The 92.9 m^2 (1000 ft^2) fire tests were also conducted on the mini-deck at CBD (Figure 1). The fire area was created using earth berms, built up on a non-permeable plastic lining placed on the concrete deck. The fire area was contained within a berm having inside dimensions of 9.6 m (31.6 ft) square. An outer berm measuring 13.7 m (45 ft) square enclosed the 92.9 m^2 (1000 ft^2) fire area and provided secondary containment for fuel or agent that splashed out of the fire area. Fuel used for these tests was unleaded motor gasoline. A total of 945-1134 l (250-300 gal) was used for each test. The fuel was floated on a 10.2 cm (4 in.) water substrate which leveled the bottom of the test area and protected the plastic liner.

All tests were conducted with premixed solutions. The premixed tank/fire department pumper setup was identical to that described above for the large-scale expansion and drainage characteristics tests. For safety purposes, an additional 3.8 cm (1.5 in.) backup handline was provided, supplied by a second fire department pumper which had onboard AFFF proportioning capabilities. This backup pumper discharged MIL-SPEC AFFF.

The original test plan called for the agents to be tested at an application rate of 2.44 lpm/m^2 (0.06 gpm/ft^2) in accordance with the design application for foam agents in UL 162 [2]. Since substantially better performance was observed in the 4.6 m^2 (50 ft^2) tests at application rates of 4.88 lpm/m^2 (0.12 gpm/ft^2), this rate was selected for the large-scale tests. The 4.88 lpm/m^2 (0.12 gpm/ft^2) application rate also approximates the minimum design rate for AFFF hand lines (4.07 lpm/m^2 (0.10 gpm/ft^2)) recommended by NFPA 11 [6]. For a 92.9 m^2 (1000 ft^2) fire area, this application rate was achieved by using a nominal flow rate of 454 lpm (120 gpm).

Two tests were conducted with each agent using the 4.88 lpm/m^2 (0.12 gpm/ft^2) application rate. In one test, the foam was generated using the large-scale air-aspirating nozzle. The orifice assembly of this nozzle was enlarged so that it could flow 454 lpm (120 gpm) at 690 kPa (100 psi). The second test was conducted using the large-scale non air-aspirating nozzle. This nozzle discharged 473 lpm (125 gpm) at 690 kPa (100 psi). This nozzle was also used for one additional baseline test where water only was discharged at a 4.88 lpm/m^2 (0.12 gpm/ft^2) application rate.

6.6.2 Test Procedures

Prior to each test, ambient wind conditions were recorded and video cameras were started. A torch was used to ignite the upwind edge of the fire area. The fire quickly spread to full area involvement within 5-8 seconds. The firefighter initiated the attack after a total preburn time of approximately 10 seconds. In some cases, the preburn time was extended to assure complete involvement of the fire area. The nozzleman, supported by a backup firefighter, attacked the fire from the upwind corner of the fire area. Foam was first applied to the upwind corner of the fire area to gain a "bite" (extinguished area). Agent was then applied to the upwind edge of the fire and swept across to the opposite edge of the fire area. This sweeping motion was continued with the firefighter pushing the fire to the back edge of the bermed area. When the non-aspirating nozzle was used, the initial nozzle pattern was a narrow angle fog (30° pattern). This pattern was adjusted to straight stream as needed for reach as the fire was controlled. Final extinguishment was then accomplished using either a gentle fog application or using a straight stream to push foam to extinguish flickering fires along the dirt berm. With Agent C, a plunging technique was used initially at the leading edge in accordance with the manufacturer's recommendations.

Total application time for all tests was two (2) minutes from the initiation of fire attack. If the fire was extinguished within this 2-minute period, a burnback test was performed by placing a lit torch in the upwind corner of the fire test area. This torch was positioned within 30 seconds of the end of agent application. The time for 25 percent of the total fire area to become reinvolved was recorded as the 25 percent burnback time. For those situations where the fire could not be extinguished within the 2-minute period, the backup AFFF handline was used to control and extinguish the fire. When needed, this handline was generally brought in at about 1.5 minutes after ignition, but in some cases where 75 percent or less of the fire was controlled it was used earlier (Tests LSC9 and LSC11). After each fire test, an expansion and drainage test was conducted to characterize the foam with these test nozzles.

6.6.3 Test Results

The results of the large-scale tests are shown in Tables 4 and 5 for air-aspirating and non air-aspirating nozzles respectively. In addition to the 50 percent and 90 percent control times, the significance of which was discussed previously, these tables also include a 99 percent control time value. This value can be used as a measure of performance for near-total extinguishment to address the variability resulting from dirt berm wicking and ambient wind effects. This is evident in Tests LSC1, LSC3, LSC6, LSC9, and LSC10 where the time between 99 percent control and total extinguishment generally equaled or exceeded the time to gain 90 percent control of the fire. In other words, as with the hot surfaces in the 4.6 m^2 (50 ft^2) test, extinguishment of the last residual fire often took as long as gaining control of the fire.

In the tests where the air-aspirating nozzle was used, Agents A and B extinguished the fire while the backup handline had to be used with Agents C and D. AFFF controlled and extinguished the fire more quickly than Agents A and B. Burnback time was substantially greater for AFFF (7 min 19 sec) compared to Agents A (55 sec) and B (1 min 49 sec).

Table 4. Results of 92.9 m^2 (1000 ft^2) Fire Tests with the Air-aspirating Nozzle

Agent	Test No.	Control Time (min:sec)			100% Exting. Time (min:sec)	25% Burnback Time (min:sec)	Comments
		50%	90%	99%			
A	LSC1	0:16	0:30	0:45	1:11	0:55	--
B	LSC3	0:18	0:31	0:44	1:09	1:49	--
C	LSC5	0:20	0:56	--	--	--	Fire burned back after 90% control; AFFF applied at 2:08
D	LSC7	0:30	--	--	--	--	Fire control limited to 75% or less of fire area; AFFF applied 2 min. after initiation of fire attack
AFFF	LSC10	0:10	0:19	0:32	0:55	7:19	--

Table 5. Results of 92.9 m^2 (1000 ft^2) Fire Tests with the Non-aspirating Nozzle

Agent	Test No.	Control Time (min:sec)			100% Exting. Time (min:sec)	25% Burnback Time (min:sec)	Comments
		50%	90%	99%			
A	LSC2	0:17	0:38	--	--	--	Fire held to 80-90% control; AFFF applied at 1:49
B	LSC4	0:26	0:46	1:40	--	--	Fire held steady at 95-99% control; AFFF applied at 2:05; may have extinguished with longer flow duration
C	LSC6	0:18	0:32	0:50	1:37	0:08	Residual fire outside bermed area ignited foam at 2:22; 25% burnback in 8 sec
D	LSC8	0:31	--	--	--	--	Fire quickly flashed back after 50% control; AFFF applied 45 sec after initiation of fire attack
AFFF	LSC9	0:16	0:21	0:37	0:46	1:57	Wind affected results (stronger than that of previous tests)
Water	LSC11	0:28	--	--	--	--	75% control at 47 sec; AFFF handline brought in at 47 sec

In the tests where the non air-aspirating nozzle was used (i.e., standard firefighting nozzle), only Agent C and AFFF were able to fully extinguish the fire. AFFF was the only agent with any significant burnback resistance (1 min 57 sec), which was much less than that achieved with the air-aspirating nozzle. Control and extinguishment times with the AFFF were roughly equivalent between aspirated and non air-aspirated tests. Agent B was almost able to totally extinguish the fire although the last 10 percent of the fire area was difficult to extinguish. Similar results were observed with Agent A. Water was able to control a maximum of 75 percent of the fire area before the backup handline was brought in at 47 seconds.

6.7 Small- and Large-scale Comparison

A comparison of the small-scale and large-scale air-aspirating nozzle tests results for the 4.88 lpm/m^2 (0.12 gpm/ft^2) application rate shows very good agreement between extinguishment times for Agents A, B, and AFFF and good agreement for 50 percent and 90 percent control with Agent C. However, both Agent C and Agent D were not able to extinguish the 92.9 m^2 (1000 ft^2) fire even though they were able to extinguish the 4.6 m^2 (50 ft^2) fire.

6.8 References

1. U.S. Department of Agriculture, U.S. Forest Service, "Interim Requirements and Manufacturers Submission Procedures for Wildland Fire Foam," Special Report No. 86511803, August 1986.

2. Underwriters Laboratories Inc., "UL 162, Standard for Foam Equipment," Seventh Edition, Northbrook, IL, March 30, 1994.

3. Underwriters Laboratories Inc., "Fire Protection Equipment Directory," 1995 Edition, Northbrook, IL.

4. Qualified Products List, "Products Qualified under Military Specification MIL-F-24385, Fire Extinguishing Agent, Aqueous Film-forming Foam (AFFF) Liquid Concentrate, for Fresh and Salt Water," QPL-24385-25, May 1992.

5. Military Specification MIL-F-24385F, "Fire Extinguishing Agent, Aqueous Film-forming Foam (AFFF) Liquid Concentrate, for Fresh and Seawater," 7 January 1992.

6. National Fire Protection Association, "NFPA 11, Standard for Low Expansion Foam and Combined Agent Systems," 1994 Edition, Quincy, MA.

Table 3 Results of 4.6 m^2 (50 ft^2) Fire Tests

Agent	Test No.	Solution Concentration	Flow Rate (Lpm (gpm))	Control Times (min:sec)		100% Exting. Time (min:sec)	Torch Test Results		100% Burnback Time[1] (min:sec)	Maximum Wind (mph)
				50%	90%		First	Second		
A	FT7	1%	11.5 (3.04)	0:17	0:44	1:56	Cand., SE	Reflash	14:40	12
	FT8	1%	22.7 (6.00)	0:19	0:40	1:12	Cand, SE	Reflash	14:55	4
	FT9	1%	22.7 (6.00)	0:15	0:33	1:08	Cand, SE	Reflash	14:55	10
B	FT6	1%	11.5 (3.04)	0:45	0:54	2:23	Cand, SE	Reflash	14:18	11
	FT4	1%	22.7 (6.00)	0:28	0:40	1:08	Flash, SE	Reflash	14:40	5
	FT5	1%	22.7 (6.00)	0:25	0:42	1:18	Cand, SE	Reflash	16:05	13
C	FT14	3%	11.5 (3.04)	0:45	1:29	3:00	Sust burning	--	2.55	--
	FT1	6%	11.5 (3.04)	0:26	3:23	NA	--	--	--	3
	FT2	6%	22.7 (6.00)	0:20	1:00	2:14	Flash, SE	Reflash	14:17[2]	--
	FT3	6%	22.7 (6.00)	0:26	0:46	2:00	Flash, SE	Reflash	14:30[3]	7
D	FT12	3%	11.5 (3.04)	0:40			--	--	1:00	9
	FT17	6%	11.5 (3.04)	0:24	1:20	NA	--	--	0:52	6
	FT10	3%	22.7 (6.00)	0:17	1:20	NA	Sust burning	--	4:13	3
	FT11	3%	22.7 (6.00)	0:30	1:00	2:11	Sust burning	--	3:44	4
					0:55	2:27				
AFFF	FT15	3%	7.68 (2.03)	0:30	1:20	2:43	Flash, SE	Candling	18:27[4]	8
	FT13	3%	11.5 (3.04)	0:18	0:37	1:14	Cand, SE	Reignition	16:55[5]	11
	FT16	3%	22.7 (6.00)	0:15	0:35	0:56	Flash, SE	Candling	18:43	11

Notes:
1 Unless noted otherwise, all burnback times are measured from the end of agent application until 100 percent of the fuel surface is reinvolved.
2 Second torch test was not started until 14:17 after the end of agent application; immediate reflash and complete reinvolvement of the fuel surface resulted.
3 Second torch test was not started until 14:30 after the end of agent application; immediate reflash and complete reinvolvement of the fuel surface resulted.
4 At 18:27 after the end of agent application, only 25 percent of the fuel surface became reinvolved; the fire had to be suppressed due to possible damage to the concrete deck.
5 At 16:55 after the end of agent application, only 60 percent of the fuel surface became reinvolved; the fire had to be suppressed due to possible damage to the concrete deck.

NA = 100% extinguishment not achieved.
Cand = Candling around edges that continued in excess of 30 seconds, but eventually extinguished.
Flash = Quick flashes or candling that lasted less than 30 seconds.
Sust burning = Candling that never self-extinguished.
S.E. = Self-extinguished
Reflash = Reignition of an area of the fuel surface greater than 10 square feet.
Reignition = Reignition of an area of the fuel surface less than 10 square feet

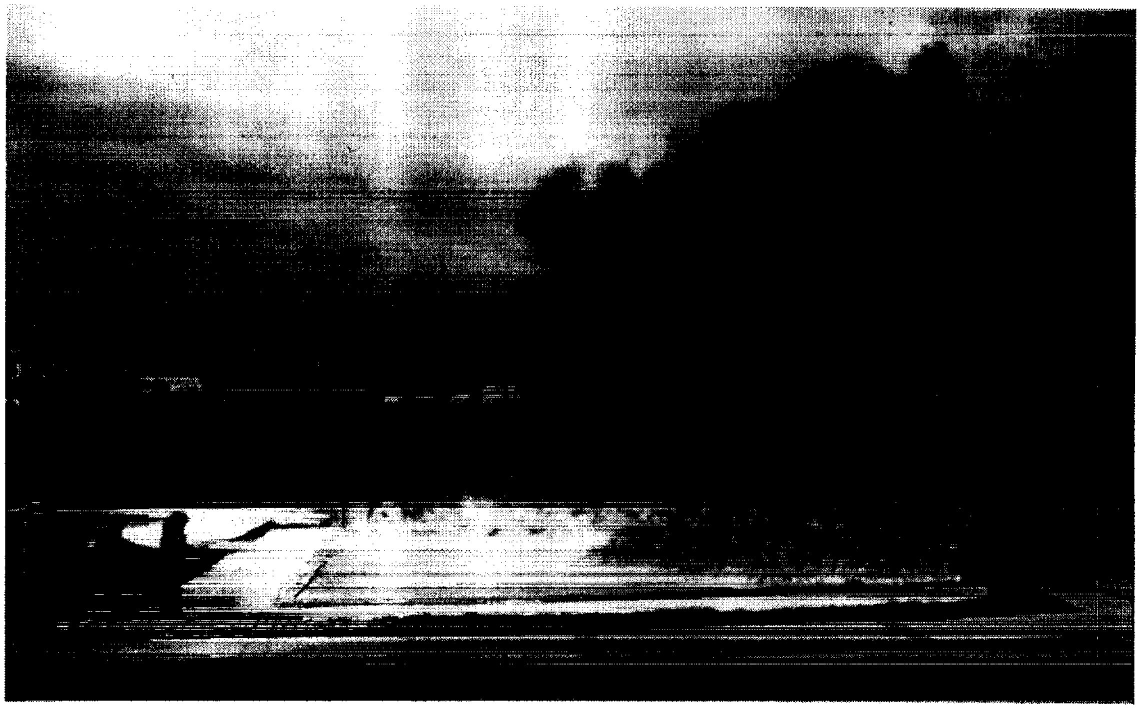

Figure 1. Large scale (92.9 m ^{2}) gasoline fire suppression experiment.