Fluorine-Free Foam Fire Tests Using Different Foam Delivery Configurations

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16. Abstract

A series of fire tests were performed at the FAA William J Hughes Technical Center using various 40-gallons-per-minute hand line nozzle configurations fighting a 30-foot-diameter Jet-A fire. The objective of this test series was to evaluate fluorine-free foam (F3) on a larger scale than the standard MilSpec and International Civil Aviation Organization (ICAO) tests to determine the effects different foam delivery technologies have on foam generation, performance, and dry chemical agent compatibility.

All foams were able to extinguish all fires in all test conditions. Changes in firefighting performance due to changes in foam delivery configurations were not consistent across the different foams tested. F3s generally saw slightly increased performance with the higher expansion ratio discharges like the foam tube and Compressed Air Foam System (CAFS) discharges. The dry chemical discharge reduced extinguishment performance for two of the three F3s tested.

Foam blankets were improved with the use of a foam tube or CAFS but were severely degraded when using additional dry chemical injected into the foam stream. This is also reflected in the different foam expansion ratios observed. In all tests, the agent application ended with the extinguishment of the fire and generally foam blankets were not fully formed in the pan. If foam was discharged for a time after extinguishment, better fuel coverage and a more stable foam blanket might have been achieved. The lack of an established foam blanket in the dry chemical discharges suggests that the addition of dry chemical into the foam stream negatively affects the ability for the foam to form a blanket.

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DISCLAIMER

This technical report outlines the research the Federal Aviation Administration (FAA) conducted on commercially available fluorine-free foam (F3) products and modifications to existing foam performance standards accepted in the United States and worldwide. The data collected in this research were generated to capture as broad a data set as possible on the capabilities of the commercially available foam products selected for this report. The names of the products used during this assessment are provided for information purposes only. They are not meant as an endorsement and/or a condemnation of the product in any way. The FAA does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objectives of the report.

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LIST OF ACRONYMS

AFFF	Aqueous Film-Forming Foam
CAFS	Compressed Air Foam System
F3	Fluorine-Free Foam
gpm	Gallons per minute
ICAO	International Civil Aviation Organization
NFPA	National Fire Protection Association
PKP	Purple-K Powder

EXECUTIVE SUMMARY

The objective of this test series is to evaluate fluorine-free foam (F3) on a larger scale than the standard MilSpec and International Civil Aviation Organization (ICAO) tests to determine the effects different foam delivery technologies have on foam generation, performance, and dry chemical agent compatibility. The following report will describe the use of multiple nozzle configurations and agent application systems to determine the efficacy of the foams, the effects of the different nozzle configurations, and the scalability of testing methods of F3s.

Tests were performed using a 40-gallons-per-minute (gpm) hand line nozzle in four different configurations: a standard configuration, one using an attached foam tube, one with entrained dry chemical powder, and one using a Compressed Air Foam System (CAFS). A 30-foot-diameter Jet-A fire was extinguished for each test, recording the time to 75% extinguishment, full extinguishment, and post-discharge fuel visibility through the remaining foam blanket. A test for each foam in each nozzle configuration was also performed for expansion ratio and 25% drain-down time. Throw distance was also performed for each configuration.

In this test series, no matter what configuration was examined, all foams were able to extinguish all fires in all test conditions. While there were differences between the performances of these foams, they were all effective fighting a 30-foot diameter fuel fire using a 40-gpm handline with or without supplemental air injection, air entrainment, or dry chemical injection. However, there were notable differences in how the different methods affect different foams.

Dry chemical entrainment reduced expansion ratio to between 1 (no expansion) and 2 in all cases. Drain-down times were essentially instantaneous throughout all foams. While this caused no foam blanket to develop in the test pan, all fires were still able to be extinguished. This also caused the most varied extinguishment times across all foams and across all test scenarios. Chemguard C306 was more consistent than the other foams that were tested in this series with dry chemical entrainment. It is important to note that while BioEx Ecopol A3+ had two tests with consistent results using the dry chemical discharge, it also had one outlier test where the fire was extinguished in 27 seconds (as opposed to 15.5 seconds for the other two tests performed). This suggests that it might also experience varied extinguishment performance despite some results being consistent.

Use of a foam tube increased the expansion ratio by 4–5 compared to the standard discharge for all foams. The foam tube also increased all drain-down times for all foams. Chemguard C306 and one F3 gained 1 to 2 minutes while the other two F3s gained more than 6 minutes. CAFS discharge increased the expansion ratio between 0.5 and 1.8 over the standard discharge across the foams tested while drain-down time dramatically increased. For 25% drain-down time, Chemguard C306 increased from 1:59.7 minutes with the standard discharge to 6:58.8 minutes using CAFS, National Foam Avio KHC Green F3 increased from 2:21.6 minutes with the standard discharge to 24:32.3 minutes using CAFS, BioEx Ecopol A3+ increased from 7:44.6 minutes in the standard discharge to 22:51.3 minutes using CAFS, and Solberg AviGard increased from 4:06.2 minutes with the standard discharge to 11:33.8 minutes using CAFS.

In all tests, the agent application ended with the extinguishment of the fire and, generally, foam blankets were not fully formed in the pan. Foam blanket coverage and visible fuel were assessed at time of extinguishment. Reapplication and establishing a protective foam blanket were not part of this evaluation. Foam tube and CAFS application resulted in the most blanket coverage of all discharge types. Discharging foam for a time after extinguishment might have allowed for better fuel coverage and a more stable foam blanket, at least for the non-dry chemical discharges. The lack of any established foam blanket at all in the dry chemical discharges suggests that the addition of dry chemical into the foam stream negatively affects the ability for the foam to form at all, meaning that additional discharge time might not change the final foam blanket significantly.

Changes in firefighting performance due to changes in foam delivery configurations were not consistent across the different foams tested. F3s generally saw slightly increased performance with the higher expansion ratio discharges like the foam tube and CAFS discharges. The dry chemical discharge reduced extinguishment performance for two F3s, Solberg AviGard and National Foam Avio F3 Green KHC. Improved expansion ratio for any foam generally led to more cohesive foam blankets and longer times to fuel visibility following the end of discharge, while the use of dry chemical significantly reduced the expansion ratio of all foams and led to a much less well-developed foam blanket.

THE 30-FOOT FIRE TEST

INTRODUCTION

This test series was developed to examine the effects on fire extinguishment performance of different foam application configurations with different fluorine-free foams (F3s) when dispensed through a handline. This included an unmodified nozzle, use of a foam tube, use of a Compressed Air Foam System (CAFS), and use of in-stream injection of dry chemical powder. Previous testing indicated that the use of these systems can affect the performance of Aqueous Film-Forming Foams (AFFF), but it is not well-established if F3s are affected in the same manner.

OBJECTIVE

The objective of this test series was to evaluate F3s on a larger scale than the standard MilSpec and International Civil Aviation Organization (ICAO) tests to determine the effects different foam delivery technologies have on foam generation, performance, and dry chemical agent compatibility. This document outlines the use of multiple nozzle configurations and agent systems to determine the efficacy of the foams, the effects of the different nozzle configurations, and the scalability of testing methods of F3s.

TEST EQUIPMENT

This test series was performed at the Building 311 Fire Test Area in the FAA William J. Hughes Technical Center. A 30-foot-diameter (707-sq-ft) fire test pan with a fuel load of 100 gallons of Jet A fuel was used for this test series. The pan was filled with a layer of water and the fuel prior to ignition. The resulting fire was attacked in a series of evaluations using a handline with AFFF, F3s, and Purple-K Powder (PKP) dry chemical supplied by Crash 14 (Figure 1), a Class 1 fire apparatus with a capacity of 100 gallons of premix foam solution and 500 lb of PKP.

Figure 1. Crash 14

This test series used Chemguard C306 AFFF as the baseline for which all F3 results are compared. A selection of F3s that demonstrated high performance in previous research efforts was used in this test series. These F3s are National Foam Avio F3 Green KHC, BioEx Ecopol A3+, and Solberg AviGard.

The agent was discharged through a Williams Dual Agent fog nozzle (Figure 2), which can be adjusted for both flow (by altering the fog deflector position) and pattern (by twisting the head of the nozzle).

Figure 2. Williams Dual Agent Nozzle

The target solution flow rate is 40 gallons per minute (gpm) (0.057 gpm/sq ft application density) with a nozzle pressure of 100 psi. This is a slightly lower application density than the 50 sq ft MilSpec pan test (which is 0.0596 gpm/sq ft) (Naval Sea Systems Command, 2023). This nozzle has a pattern adjustable between fog and straight stream applications. The firefighter has control of the pattern during foam applications (without foam tube attached) but was encouraged to maintain a constant nozzle setting to achieve accurate measurements of foam quality. For the standard discharge, the nozzle was set in a “fight position” between full straight stream and full fog settings. This position was determined to be a good balance between throw distance and foam spread. The fight position was marked on the adjustment rings (seen on the red tape in Figure 2) to ensure the setting was repeatable. For the dry chemical discharge, the nozzle was set to the straight stream position to provide the best dry chemical entrainment in the foam stream. Crash 14 also has a CAFS. When discharged using the CAFS, the nozzle was set to the flush setting to maintain the solution flow rate while minimally shearing the foam.

A foam tube (Task Force Tips Foamjet foam tube) was attached to the Williams Dual Agent fog nozzle in some tests. This foam tube is rated for 10–100 gpm but can only be used with a straight stream nozzle pattern. Figure 3 shows a picture of the foam tube installed on the Williams Dual Agent fog nozzle.

Figure 3. Williams Dual Agent Nozzle with Foam Tube Installed

Onsite backup equipment was also present for each test. The backup extinguishing systems were the TriMax extinguishing system (primary backup solution) loaded with Chemguard C306 and PKP dry chemical and a Novec 1230 flightline extinguisher (secondary backup solution), shown in Figure 4.

Figure 4. Novec 1230 Flightline Extinguisher (Rear Left) and TriMax Extinguishing System (Front Right)

A water handline supplied by an onsite hydrant was also present in each test to be used for cooling concrete or test fixtures, if necessary.

A splashboard and cut 1,000-mL graduated cylinder as defined in the expansion ratio and drain-down tests described in National Fire Protection Association (NFPA) 412 (NFPA, 2020) were used for measuring expansion ratio and drain-down times for each discharge method. A marker and wheeled measuring stick were used when measuring throw distances. Figure 5 shows the splashboard and graduated cylinder.

Figure 5. National Fire Protection Association 412 Splashboard with 1,000-mL Graduated Cylinder

Jet-A fuel was used as the test fuel in each fire test. The fuel was dispensed from drums using a transfer pump into the fire pan. Each test used 100 gallons of fuel. There was no time limit for the fuel to remain in the pan prior to the start of the test, but efforts were made to keep the time as short as possible. Fuel was only dispensed once the rest of the equipment was ready, right before the start of the test.

DATA COLLECTION

Data collection for this test series consisted of both objective and subjective criteria. This was accomplished through instrumentation, camera footage, and observer recorded data points.

Crash 14 has a flow meter installed for solution measurements. The flow meter was used initially to set and measure the solution flow rate. After the nozzle was adjusted, the flow meter measured the foam necessary to extinguish each fire through the totalizer function. This was reset preceding each test and the final solution total used for each test was recorded to check that the flow rate was consistent across all tests.

Five color cameras were used around the test fixture for each test. The three firefighters each had a camera mounted to their helmet set to record through the duration of each test. Two more cameras were set up to be permanently recording and saved to a Network Video Recorder in Building 311. One was positioned in the L2 doorway of the L1011 test aircraft for an elevated view of the test and the other was mounted on a tripod on the upwind side of the fire on the test pad.

A minimum of two recording observers were on site for each test. One recording observer served a dual purpose as test coordinator and recording observer. The test coordinator made announcements to indicate to the team for readiness checks, fire ignition, and fire attack initiation. Both recording observers timed and recorded events. These events included time of discharge, time to 75% control, time to full extinguishment, and time to post-extinguishment fuel visibility. Post-extinguishment fuel visibility is defined as the time at which the foam blanket diminishes enough to reveal raw fuel after the end of discharge. Furthermore, following the test, the recording observers recorded the amount of foam discharged in each evaluation to check that the flow rate averaged over the test was correct. Fire outside the pan or re-ignitions after initial extinguishment were not counted for the extinguishment time, and discharge ended as soon as the fire inside the pan was extinguished. Once the discharge ended, the firefighter used the nozzle to extinguish any remaining fire. The length of these extra discharges was recorded and double-checked with video to ensure that the flow rate calculation was as accurate as possible. Following each evaluation, one recording observer measured and recorded the 25% drain-down time and expansion ratio of each foam. The other recording observer measured the throw distance for each nozzle and foam configuration.

TEST MATRIX

Table 1 shows a test matrix for each type and quantity of test performed for each foam.

Table 1. Test Matrix

Foam	Fog Nozzle	Foam Tube	Dry Chemical	CAFS	Foamability	Throw Distance
Chemguard C306	2	2	2	2	4	4
National Foam Avio F3 Green KHC	2	2	2	2	4	4
BioEx Ecopol A3+	2	2	2	2	4	4
Solberg AviGard	2	2	2	2	4	4

Each fire scenario requires two successful evaluations. One foamability evaluation is conducted for each discharge configuration for each foam. One throw distance evaluation is conducted for each discharge configuration for each foam. The tests were conducted in series with a single foam used. This was to reduce rinsing and wasted product, as the foam solution tank must be rinsed thoroughly between each type of foam used to prevent cross-contamination. The agent tank was refilled when the flow meter totalized indicated a low volume of foam mixture in the tank and between tests when necessary to ensure the agent did not run out during a test.

TEST PARAMETERS

These tests were conducted outdoors on the Building 311 test pad. Each test was performed only when winds (both sustained and gusts) were below 7 mph. All safety equipment was positioned on the upwind side of the test fixture. No tests were conducted when there was any precipitation (e.g., rain, snow).

The 30-ft test pan was filled with water so that the shallowest area was at least 3/8 in. deep. The foam solution temperature was between 65 °F and 85 °F. The solution flow rate was set to a target of 40 gpm. When using the CAFS or a dry chemical discharge, flow rates were found to be less stable, but still close to the target 40-gpm flow rate. For the tests performed, flow rates were generally 38 gpm ±3 gpm.

Three firefighters were present and in full turnout gear, including self-contained breathing apparatus for each test. Each firefighter rotated through each position between each test. The three positions of the firefighters were nozzle man, hose man, and igniter/backup. The nozzle man fought the fire in the test pan, the hose man assisted the nozzle man in maneuvering and adjusting the hose line to allow the nozzle man to move freely and extinguish the fire as expeditiously as possible, and the igniter/backup position ignited the fire in the pan using a propane torch. After a sufficient amount of fuel was ignited, the igniter/backup relocated the torch to a safe location. For the remainder of the test, the igniter/backup manned the backup extinguishing system and monitored the test.

TEST PROCEDURES

The following sections describe the methods used for conducting each evaluation outlined in this plan. For all tests, the location was on the Building 311 test pad.

FIRE TEST PREPARATION

1. Ensure all equipment is functional and staged in the proper position, upwind of the fire and in accessible areas of the test pad.
2. Brief all personnel on their roles, positions, and the test scenario.
3. Fill the pan with water so that the shallowest area is at least 3/8 in. deep.
4. Have fuel available and ready to be pumped.
5. Ensure the hose line is positioned so it does not catch on objects or obstruct movement when the firefighter is repositioning.
6. Ensure backup extinguishment systems are readied and charged.
7. Enable the helmet camera recording and ensure stationary cameras are recording.
8. Ensure the pad area has been wetted down to protect the concrete.
9. Ensure air bottles on Crash 14 have sufficient charge for evaluation.
10. Ensure there is a sufficient quantity of foam in the tank for the test being performed.
11. Ensure all valves on Crash 14 are set in the correct positions for the test being performed.

FIRE TEST

1. Ensure the nozzle is attached to the hose line and is primed and ready for discharge. Ensure the nozzle is in the correct configuration for the evaluation being performed:
    a. Standard discharge—fight position
    b. Foam tube discharge—straight stream with foam tube installed
    c. Dry chemical discharge—straight stream
    d. CAFS discharge—flush setting
2. Dispense 100 gallons of fuel into the fire pan.

3. Ensure the firefighters are "on air" and conduct personnel readiness checks.
4. Ignite the fuel with a torch and wheel away when a sufficient amount of fuel has been lit.
5. Begin the timer when the pan reaches full involvement. The test coordinator will announce the beginning of pre-burn.
6. Allow the fire to burn for 45 seconds.
7. The test coordinator announces the end of pre-burn with a 10-second countdown. Firefighting operations begin with foam solution at the end of the countdown. The firefighter is free to adjust the stream pattern to extinguish the fire as rapidly as possible. The time when discharge starts is recorded.
    a. For the dry chemical discharge, the nozzle operator initiates the foam solution and dry chemical discharge simultaneously.
    b. For the CAFS discharge, the nozzle operator begins the foam discharge away from the pan at the beginning of the 10-second countdown. This allows for the compressed air and foam solution mixture to reach the end of the hose, ensuring only the correct mixture is used to fight the fire, as the initial few seconds of discharge usually contain just foam solution. The recording observer marks both the start of discharge and the start of firefighting.
8. Record the times to 75% control, edge flickers, and extinguishment.
9. End discharge when the fire is extinguished. Record the time that discharge ends.
    a. If any fire is outside the pan, the firefighter extinguishes it using the nozzle. Record the length of these discharges.
10. Observe the foam blanket until the fuel layer is revealed and record the time.
11. Record the amount of solution discharged during evaluation.
12. Begin cleanup procedures.

FOAMABILITY EVALUATION

1. Ensure the foam sample collector is clean and dry and that the 1,000-mL beaker is in place.
2. Hold the nozzle at hip height and begin discharge.
    a. Begin discharge away from the foam sample collector until the foam stream is fully developed.
    b. Once the foam stream is fully developed, move it over the foam sample collector.
3. Continue discharging over the sample collector until the 1,000-mL beaker is full, then direct the stream away from the collector and end discharge.
4. Collect the beaker and strike excess foam from the top. Start the timer.
5. Weigh the beaker and record the drained solution every 30 seconds until 25% has drained down.
6. Calculate the expansion ratio and 25% drainage time.

THROW DISTANCE EVALUATION

1. Mark the location of the nozzle. The nozzle operator will hold the nozzle in a level position at hip height.

2. Begin discharge when all team members are ready.
3. The recording observer will mark the location where the majority of the solution is landing.
4. End discharge.
5. Measure the distance between the two points to record the throw distance of each configuration.

RESULTS

Tests were performed over a period of 7 months (longer than initially planned, but there were repeated delays due to weather conditions), with minimal repeated tests required. Figure 6 shows one of the tests in progress, during the initial pre-burn period.

Figure 6. Test in Progress

Standard discharge configuration tests displayed consistent extinguishment performance across all foams, with F3s showing a larger variation in extinguishment times in our limited sample size. Results from the tests performed are in Tables 2 through 4.

Table 2. Standard Discharge 75% Extinguishment

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:09.0	00:08.0	00:09.0	00:10.0
Test 2	00:08.5	00:07.0	00:14.5	00:12.5
Average	00:08.8	00:07.5	00:11.7	00:11.3

Table 3. Standard Discharge Extinguishment

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:25.5	00:24.5	00:28.5	00:33.0
Test 2	00:27.0	00:30.0	00:35.5	00:31.0
Average	00:26.3	00:27.2	00:32.0	00:32.0

Table 4. Standard Discharge Post-Extinguishment Fuel Visibility

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:11.0	00:01.0	00:06.5	00:22.5
Test 2	00:07.0	00:00.0	00:07.0	00:18.0
Average	00:09.0	00:00.5	00:06.7	00:20.3

It should be noted that it was difficult to collect accurate data for the 75% extinguishment due to the observers' views of the test fires sometimes being obscured by smoke and steam or the foam stream during extinguishment. It was also difficult to get accurate data for post-extinguishment fuel visibility due to the short duration.

All foams tested demonstrated similar 75% extinguishment times (with most tests showing a 75% extinguishment in under 10 seconds) with the standard discharge configuration. Some of the differences in 75% extinguishment times can be attributed to slight differences in technique, as the fire is not able to be fought identically in each test. Extinguishment times were also similar, with Chemguard C306 and National Foam Avio F3 Green KHC extinguishing the fire approximately 5 seconds faster than BioEx Ecopol A3+ or Solberg AviGard.

All foams had fuel showing within 30 seconds, with most under 10 seconds. National Foam Avio F3 Green KHC actually had fuel showing immediately after the end of discharge, usually caused by the foam blanket pulling away from the edge of the pan. The short duration for all of the foams is likely due to the lack of post-extinguishment foam discharge, which means the foam could not create more of an established blanket. This could explain why Solberg AviGard, the foam with the longest extinguishment times, had the longest period before fuel visibility. All foams did have some foam blanket present immediately after the end of discharge. Figure 7 shows an example of foam blankets following extinguishment using the standard discharge configuration with Chemguard C306 and Solberg AviGard.

Figure 7. Chemguard C306 (Top) and Solberg AviGard (Bottom) Foam Blanket After Standard Discharge

The addition of the foam tube significantly improved extinguishment performance compared to the standard discharge for Solberg AviGard (8 seconds on average), with Chemguard C306 and BioEx Ecopol A3+ showing a slight change (2.1 seconds and 3.7 seconds on average respectively), and National Foam Avio F3 Green KHC showing almost no change (0.2 seconds on average). In all cases, the foam blanket was thicker than the standard discharge, and created a more cohesive foam blanket. This means that the foam blanket created more complete coverage over the fuel layer, and the foam remained in the pan for longer. The better coverage can be seen in the post discharge foam blanket pictures for the standard discharge and the foam tube discharge (Figure 8).

Figure 8. Foam Blanket After Standard (Top) and Foam Tube (Bottom) Discharges

This observation is mostly qualitative, based visually on the appearance of the foam blanket. Results from the tests performed are in Tables 5 through 7.

Table 5. Foam Tube Discharge 75% Extinguishment

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:10.0	00:09.5	00:12.0	00:09.5
Test 2	00:08.0	00:06.5	00:08.5	00:10.0
Average	00:09.0	00:08.0	00:10.2	00:09.8
Comparison to Standard Discharge	00:08.8	00:07.5	00:11.7	00:11.3

Table 6. Foam Tube Discharge Extinguishment

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:25.5	00:24.5	00:31.0	00:24.0
Test 2	00:23.0	00:29.5	00:25.5	00:24.0
Average	00:24.2	00:27.0	00:28.3	00:24.0
Comparison to Standard Discharge	00:26.3	00:27.2	00:32.0	00:32.0

Table 7. Foam Tube Discharge Post-Extinguishment Fuel Visibility

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:21.0	00:20.5	00:18.5	00:19.5
Test 2	00:29.0	00:22.5	00:08.5	00:09.5
Average	00:25.0	00:21.5	00:13.5	00:14.5
Comparison to Standard Discharge	00:09.0	00:00.5	00:06.7	00:20.3

Seventy-five percent extinguishment times were around a second quicker than the standard discharge, but not enough to conclude that the foam tube definitively increased performance. Extinguishment times were improved compared to the standard discharge: decreased by 2 seconds for Chemguard C306, 0.2 seconds for National Foam Avio F3 Green KHC, 4 seconds for BioEx Ecopol A3+, and 8 seconds for Solberg AviGard. This could be related to the better foam blanket generated by the improved foam quality.

Improved foam quality was the most noticeable change when using a foam tube, which led to noticeably longer times to fuel visibility after the end of discharge for some foams. Chemguard C306 had an average fuel visibility time of 25 seconds (an increase of around 15 seconds), and BioEx Ecopol A3+ and National Foam Avio F3 Green KHC increased to an average of 13.5 seconds and 21.5 seconds, respectively. National Foam Avio F3 Green KHC had immediate fuel visibility with the standard discharge, so this shows a definite improvement at least to the coverage of the foam blanket. Solberg AviGard did show a decrease, from an average fuel visibility time of 20.3 seconds with the standard discharge to 14.5 seconds with the foam tube discharge. Given the speculation in the previous section that the longer fuel visibility times for Solberg AviGard could be due to the longer extinguishment time, as the extinguishment times were shorter when using the foam tube, that trend might have also led to shorter fuel visibility times here. Figure 8 shows an example of the foam blanket after the fire was extinguished using the foam tube discharge with Solberg AviGard compared to the standard discharge.

Like the foam tube tests, use of the CAFS on Crash 14 generally improved extinguishment performance compared to the standard discharge. For Chemguard C306, extinguishment times were reduced by an average of 6.8 seconds compared to the standard discharge; National Foam Avio F3 Green KHC and BioEx Ecopol A3+ were reduced by 2.2 seconds and 2.5 seconds, respectively; and Solberg AviGard showed very little reduction (0.7 seconds on average). In all cases, the foam blanket was thicker than the standard discharge and created a more cohesive foam blanket with a visibly different bubble structure from both the standard discharge and foam tube discharge. Tables 8 through 10 show the results from the tests performed.

Table 8. CAFS Discharge 75% Extinguishment

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:09.0	00:09.0	00:09.5	00:11.0
Test 2	00:13.5	00:06.0	00:11.0	00:09.5
Average	00:11.2	00:07.5	00:10.2	00:10.3
Comparison to Standard Discharge	00:08.8	00:07.5	00:11.7	00:11.3

Table 9. CAFS Discharge Extinguishment

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:24.0	00:29.5	00:30.0	00:25.0
Test 2	00:15.0	00:20.5	00:29.0	00:37.5
Average	00:19.5	00:25.0	00:29.5	00:31.3
Comparison to Standard Discharge	00:26.3	00:27.2	00:32.0	00:32.0

Table 10. CAFS Discharge Post-Extinguishment Fuel Visibility

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:12.5	00:12.0	00:09.5	00:15.0
Test 2	00:26.0	00:20.5	00:29.0	00:13.5
Average	00:19.3	00:16.3	00:19.3	00:14.3
Comparison to Standard Discharge	00:09.0	00:00.5	00:06.7	00:20.3

Seventy-five percent extinguishment and time to fuel visibility were very similar to the results from the foam tube discharge. The addition of compressed air allowed for similar foam blanket coverage compared to the foam tube, but without using the additional expansion chamber attached to the nozzle. The foam produced also showed a finer bubble structure than that of either the standard or foam tube discharges. Figure 9 shows an example of the foam blanket following extinguishment using the CAFS discharge versus the standard discharge with Solberg AviGard.

Figure 9. Foam Blanket After Standard (Top) and CAFS (Bottom) Discharges

Dual discharge using dry chemical powder had inconsistent effects on extinguishment performance. For Chemguard C306, extinguishment times decreased by 2.6 seconds on average when compared to the standard discharge, while National Foam Avio F3 Green KHC and Solberg AviGard increased by 13.5 seconds and 4 seconds on average, respectively. BioEx Ecopol A3+ showed a significant decrease in extinguishment time of 16.5 seconds on average, but there are other factors to consider with this result. In addition to the two tests performed with much shorter extinguishment times, there was one additional test performed where the fire was extinguished in 27 seconds, which is closer to the results from the other discharge types. The two significantly shorter tests were taken as the accepted results for this test series, but in this case the outlier should not be ignored when discussing the foam's performance.

While the fire was extinguished in every test, many tests showed decreased extinguishment performance. One very apparent effect of the introduction of dry chemical powder within the foam flow from the nozzle was an almost complete elimination of the foam blanket, in every case. Tables 11 through 13 show results from the tests performed.

Table 11. Dry Chemical Dual Discharge 75% Extinguishment

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:12.0	00:11.5	00:07.5	00:10.5
Test 2	00:08.0	00:14.0	00:07.5	00:14.5
Average	00:10.0	00:12.7	00:07.5	00:12.5
Comparison to Standard Discharge	00:08.8	00:07.5	00:11.7	00:11.3

Table 12. Dry Chemical Dual Discharge Extinguishment

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:24.5	00:48.5	00:15.0	00:43.5
Test 2	00:23.0	00:33.0	00:16.0	00:28.5
Average	00:23.7	00:40.7	00:15.5	00:36.0
Comparison to Standard Discharge	00:26.3	00:27.2	00:32.0	00:32.0

Table 13. Dry Chemical Discharge Post-Extinguishment Fuel Visibility

Foam	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Test 1	00:01.5	00:11.5	00:00.0	00:00.0
Test 2	00:00.0	00:09.0	00:00.0	00:00.0
Average	00:00.7	00:10.3	00:00.0	00:00.0
Comparison to Standard Discharge	00:09.0	00:00.5	00:06.7	00:20.3

Seventy-five percent extinguishment times were generally similar or faster than any of the other discharges, but it was difficult to record an accurate time for this value because the dry chemical created a cloud of powder in the air, obscuring the view of the test pan. While some foams did initially form a blanket, foam in the dry chemical discharge generally degraded very quickly, leading to very quick or almost immediate fuel visibility. The exception is National Foam Avio F3 Green KHC, which did experience degraded foam quality but still formed a very sparse blanket for a short amount of time. Figure 10 shows an example of the normal lack of foam blanket, which is the pan immediately following extinguishment using Solberg AviGard with dry chemical.

Figure 10. Pan Immediately After Extinguishment Using Dry Chemical Discharge

Throw distance between different foams and configurations did not have consistent differences. Generally, throw distance was shorter for higher expansion discharges, and longer on lower expansion discharges. Nozzle pattern also has an effect on throw distance. Throw distance was measured in all of the nozzle configurations: straight stream, fight position (nozzle adjusted to marked position between straight stream and full fog to give some spread to the foam stream while still maintaining sufficient throw distance to fight the fire across the full 30-ft pan), foam tube, CAFS, and dry chemical. Results from the tests performed are in Table 14.

Table 14. Throw Distance (feet)

Configuration	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Fight Position	48.17	57.75	40.25	48.33
Straight Stream	58.17	61.5	44.5	47.66
Foam Tube	47.08	39.33	42.17	45
CAFS	47.75	29	34.33	55.75
Dry Chemical	52	50.75	43.58	56.5

Expansion ratio and drain-down time were clearly affected by the nozzle configuration. Compared to the standard fight position, the foam tube showed the greatest increase in expansion ratio, increasing by approximately 4–5 for every foam tested. The CAFS discharge also showed an increase in expansion ratio, but only by 1–2 for each foam. The use of dry chemical powder caused the expansion ratio to greatly decrease, to the point where after discharge, foam was usually not visible at all. This is shown in Figure 11, where the expansion ratio test for Solberg AviGard using the foam tube shows foam in almost the entire tube while the test using the dry chemical discharge shows no visible foam, only a whitish-purple mixture that is almost entirely liquid.

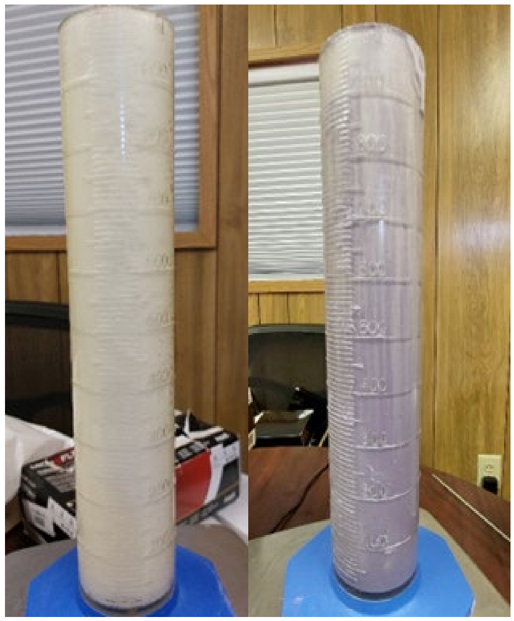

Figure 11. Expansion Ratio Tests for Foam Tube (Left) and Dry Chemical (Right) Discharges

Due to this lack of expansion and that the inclusion of dry chemical powder is technically not factored into the calculations for expansion ratio in NFPA 412, the expansion ratio results from the dry chemical discharge should not be taken as a completely accurate measurement, but only used as a reference to show how little expansion was present. Due to this, these entries are marked with an asterisk in Table 15, which shows results from expansion ratio testing.

Table 15. Expansion Ratio

Configuration	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Fight Position	5.89	6.94	4.74	6.78
Foam Tube	10.71	10.47	8.97	11.04
CAFS	7.47	8.80	5.22	7.61
Dry Chem	N/A*	1.10*	1.89*	1.70*

Drain-down time generally followed changes in expansion ratio, except in the case of the CAFS discharge. For Chemguard C306, 25% drain-down times were short in the standard fight position, with times approximately doubling from 1:59.7 minutes to 3:52.9 minutes with the use of a foam tube and increasing to 6:58.8 minutes, nearly 3.5 times longer, with the use of the CAFS. National Foam Avio F3 Green KHC followed a similar trend for the foam tube discharge, approximately doubling from 2:21.6 minutes to 3:48.3 minutes, but when the CAFS was used, the 25% drain-down time increased to 24:32.3 minutes, approximately 11 times higher than the standard fight position discharge. While beginning from a higher 25% drain-down time, BioEx Ecopol A3+ followed a similar trend as Chemguard C306, initially showing a 25% drain-down time of 7:44.6 minutes in the fight position, then approximately doubling to 13:03.7 minutes with the use of the foam tube and increasing to 22:51.3 minutes, approximately three times the fight position, with the use of the CAFS. Solberg AviGard was slightly different from the rest, beginning with a 25% drain-down time of 4:06.2 minutes and approximately doubling to 11:50.4 minutes with the use of the foam tube; but unlike the other foams, not changing much with the use of the CAFS (25% drain-down was 11:33.8 minutes, actually a slight decrease compared to the foam tube discharge). For all foams, the use of dry chemical powder caused the 25% drain-down time to be instant. Table 16 shows results from the 25% drain-down time testing.

Table 16. 25% Drain-Down Time (minutes)

Configuration	Chemguard C306	National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Solberg AviGard
Fight Position	01:59.7	02:21.6	07:44.6	04:06.2
Foam Tube	03:52.9	03:48.3	13:03.7	11:50.4
CAFS	06:58.8	24:32.3	22:51.3	11:33.8
Dry Chem	Instant	Instant	Instant	Instant

ANALYSIS

In this test series, no matter what configuration was examined, all foams were able to extinguish all fires in all test conditions. While there were differences between the performance of these foams, they were all effective fighting a 30-ft diameter fuel fire using a 40-gpm handline with or without supplemental air injection, air entrainment, or dry chemical entrainment. However, there are notable differences in how the different methods affect different foams.

Dry chemical entrainment reduced expansion ratio to between 1 (no expansion) and 2 in all cases. Drain-down times were essentially instantaneous throughout all foams. This caused no foam blanket to develop in the test pan; however, all fires were still able to be extinguished. This also caused the most varied extinguishment times across all foams and across all test scenarios. Chemguard C306 was more consistent than the other foams that were tested in this series with dry chemical entrainment. It is important to note that while BioEx Ecopol A3+ did have two tests with consistent results using the dry chemical discharge, it also had one outlier test where the fire was extinguished in 27 seconds (as opposed to 15.5 seconds for the other two tests performed). This suggests that it might also experience varied extinguishment performance despite some results being consistent. For the other two F3s, extinguishment time increased compared to the standard fight position discharge. Solberg AviGard on average increased by 4 seconds, while National Foam Avio F3 Green KHC increased by 13.5 seconds on average. So, while some foams are not negatively impacted by the use of dry chemical, others are significantly negatively impacted, at least for initial extinguishment. The other benefits of dry chemical powder could outweigh these negatives depending on the situation, and for most dual discharge systems like those used in our testing it is very easy to start and stop the flow of dry chemical when needed.

Use of a foam tube increased expansion ratio by 4–5 for all foams. The foam tube also increased all drain-down times for all foams, with Chemguard C306 and National Foam Avio F3 Green KHC gaining 1–2 minutes while BioEx Ecopol A3+ and Solberg AviGard both gained over 6 minutes. Extinguishment times were also affected, decreasing compared to the standard fight position discharge by 2.1 seconds for Chemguard C306, 3.7 seconds for BioEx Ecopol A3+, 8 seconds for Solberg AviGard, and 0.2 seconds for National Foam Avio F3 Green KHC.

Similar to the foam tube, the CAFS discharge increased foamability performance. The CAFS discharge increased expansion ratio between 0.5 and 1.8 across the foams tested while drain-down time generally increased. For Chemguard C306, 25% drain-down times increased from 1:59.7 minutes in the standard discharge to 6:58.8 minutes, nearly 3.5 times longer with the use of the CAFS. National Foam Avio F3 Green KHC increased from 2:21.6 minutes with the standard discharge to 24:32.3 minutes, approximately 11 times higher, when using the CAFS. BioEx Ecopol A3+ followed a similar trend to Chemguard C306, initially showing a 25% drain-down time of 7:44.6 minutes in the standard discharge, increasing to 22:51.3 minutes, which is approximately three times the standard discharge with the use of the CAFS. Solberg AviGard was slightly different from the rest, beginning with a 25% drain-down time of 4:06.2 minutes with the standard discharge and more than doubling to 11:33.8 minutes with the use of the CAFS (slightly shorter than the 11:50.4 minutes drain-down time with the use of the foam tube).

Because discharge was ended at time of extinguishment, generally foam blankets were not fully formed in the pan. Foam tube and CAFS application resulted in the most blanket coverage of all discharge types with varying degrees between foams and each method. Discharging foam for a time after extinguishment might have allowed for better fuel coverage and a more stable foam blanket, at least for the non-dry chemical discharges. The lack of any established foam blanket suggests that the addition of dry chemical into the foam stream negatively affects the ability for the foam to form at all, meaning that additional discharge time might not change the final foam blanket significantly.

Changes in firefighting performance due to changes in foam delivery configurations were not consistent across the different foams tested. F3s generally saw slightly increased performance with the higher expansion ratio discharges like the foam tube and CAFS discharges. The dry chemical discharge reduced extinguishment performance for two F3s, Solberg AviGard and National Foam Avio F3 Green KHC. Improved expansion ratio for any foam generally led to more cohesive foam blankets and longer times to fuel visibility following the end of discharge, while the use of dry chemical significantly reduced the expansion ratio of all foams and led to a less well-developed foam blanket.

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