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Evaluation of Effects from Mixing Fluorine-Free Foam Concentrates

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16. Abstract

The objective of this test series was to identify changes in extinguishing performance of combinations of Fluorine-Free Foam (F3) concentrates and/or Aqueous Film-Forming Foam (AFFF) concentrates when mixed together. Four types of tests were chosen to examine the effects of mixing in different use cases: Mixed Immediate Use, Mixed Short-Term Stability, Mixed Medium-Term Stability, and Dual Application.

The performance of mixtures between foam concentrates did not always have predictable results. The performance of mixtures between AFFF and F3s tended to be close to the performance of AFFF alone or between the performance of the individual foams. F3 mixtures were more varied, with most showing performance better than the individual foams, one showing performance between the performance of the component foams, and one showing a severe reduction in performance. Given the amount of variation in foams both in performance and chemical makeup in the F3 market, it is important to not mix concentrates without more testing to ensure compatibility.

The Dual Application tests showed much more predictable performance than the mixed concentrate tests. Extinguishment and burnback times were close to or between the baseline values of the component foams in all tests. Based on this result, use of two different foams (e.g., dispensed from two different Aircraft Rescue and Fire Fighting [ARFF] response vehicles) in the response to a fire may not have any significant impact on firefighting performance.

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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 was generated to capture as broad a data set as possible on the capabilities of the commercially available foam products selected for this report. In the majority of the cases, the products were tested to a higher performance standard than what they have been developed for or certified to. Passage or failure of the product tests contained within this report do not necessarily reflect the quality of the product being tested. 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
ARFF	Aircraft Rescue and Fire Fighting
DNE	Did not extinguish
F3	Fluorine-free foam
FLIR	Forward-looking infrared
gpm	Gallons per minute
HRR	Heat release rate
NFPA	National Fire Protection Association
SCBA	Self-contained breathing apparatus
WJHTC	William J. Hughes Technical Center

EXECUTIVE SUMMARY

This test series was performed to identify incompatibilities or decreases in effectiveness and extinguishing performance of combinations of Fluorine-Free Foam (F3) concentrates and/or Aqueous Film-Forming Foam (AFFF) concentrates when mixed together. Four types of tests were designed and conducted to examine the effects of mixing in different use cases: Mixed Immediate Use, Mixed Short-Term Stability, Mixed Medium-Term Stability, and Dual Application. These four types of tests are meant to simulate different types of mixtures of foams. The Mixed Immediate Use, Mixed Short-Term Stability, and Mixed Medium-Term Stability represent concentrates mixed in the tank of a firefighting apparatus prior to discharge and kept for various amounts of time, while the Dual Application represents the application of two different discharged foams from separate firefighting apparatus.

Fire tests were performed at the Aircraft Rescue and Fire Fighting (ARFF) Research Facility at the William J. Hughes Technical Center (WJHTC).

The performance of mixtures between foam concentrates was not always predictable. For mixtures between AFFF and F3s, performance tended to be close to the performance of AFFF alone or between the performance of the individual foams. F3 mixtures were more varied, with most showing performance better than the individual foams, one showing performance between the performance of the component foams, and one showing an incredibly severe reduction in performance. Given the amount of variation in foams both in performance and chemical makeup in the F3 market, it is important to not mix different concentrates. Without more testing to ensure compatibility, it is very possible that some combinations of concentrates may still have adverse reactions, potentially leading to decreases in firefighting performance, or other unforeseen effects. However, this testing shows that under some circumstances, mixing of different foam concentrates does not lead to significant negative effects on performance. More testing is required to be able to make a more definitive conclusion on the effects of mixing F3 concentrates.

The Dual Application tests showed much more predictable performance than the mixed concentrate tests. Extinguishment times were between the baseline values for the individual foams in all tests. This suggests that after being discharged, the foams are not reacting or significantly impacting the firefighting performance of the other foam. Burnback showed similar results, being between or better than the values for the individual foams in all tests. Based on this result, use of two different foams (e.g., dispensed from two different ARFF response vehicles) in response to a fire may not have any significant impact on firefighting performance of the individual foams. While not ideal, during an emergency response firefighters should not allow the presence of different firefighting foams prevent the use of any apparatus, as long as the performance of the individual foams meet the required specifications for their use.

OBJECTIVE

The objective of this test series was to identify incompatibilities or decreases in effectiveness and extinguishing performance of combinations of Fluorine-Free Foam (F3) concentrates and/or Aqueous Film-Forming Foam (AFFF) concentrates when mixed together. Due to the large differences between chemical formulations of F3 concentrates, there are concerns that mixing these materials could lead to negative performance impacts. It would be possible for this mixing to happen in some situations, such as refilling a foam concentrate tank without proper cleaning or removal of leftover material, or different responding fire apparatus dispensing different foams on a fire during an incident response. Four types of tests were chosen to examine the effects of mixing in different use cases: Mixed Immediate Use, Mixed Short-Term Stability, Mixed Medium-Term Stability. and Dual Application. These four types of tests are meant to simulate different types of mixtures of foams. The Mixed Immediate Use, Mixed Short-Term Stability, and Mixed Medium-Term Stability represent concentrates mixed in the tank of a firefighting apparatus prior to discharge and kept for various amounts of time, while the Dual Application represents the application of two different discharged foams from separate firefighting apparatus, such as from the main Aircraft Rescue and Fire Fighting (ARFF) response vehicle and a support vehicle from an outside fire department that may use a different foam concentrate. If mixing the different foam concentrates causes an adverse effect on the material properties or fire extinguishment performance, the test series should identify some of the properties and mixtures that are affected.

TEST FACILITY AND EQUIPMENT

Fire tests were performed at the ARFF Research Facility at the William J. Hughes Technical Center (WHJTC). The exterior of this facility is shown in Figure 1, and the interior is shown in Figure 2. Conducting live fire tests within this facility significantly reduces the effects of environmental conditions on the testing procedures and results.

Figure 1. Exterior of Fire Test Facility

Figure 2. Interior of Fire Test Facility

The facility is a 50-ft-wide by 50-ft-long by 50-ft-tall building with a hood calorimeter. The building was designed for fires of up to 15 megawatts in size, with combustion gases exhausted through a hood calorimeter. The building features a dedicated instrumentation system, thermal and color cameras, a waste containment system, auxiliary power connections, internal water supply connections, and an air supply system for instrumentation cooling and pneumatic tools.

Housed within the facility are test articles for conducting the fire tests described later in this report. These include two circular fire pans (28 sq ft and 50 sq ft), a burnback pot, and foam extinguishers. The fire pans are sized for conducting the MIL-PRF-32725 (Naval Sea Systems Command, 2023) fire tests. The 28-sq-ft MIL-PRF-32725 fire pan is shown in Figure 3, and the 50-sq-ft MIL-PRF-32725 fire pan is shown in Figure 4. A burnback pot was used for conducting the 25% burnback evaluation and was created to the specifications outlined in MIL-PRF-32725. The burnback pot is shown in Figure 5.

Figure 3. MIL-PRF-32725 28-sq-ft Fire Pan

Figure 4. MIL-PRF-32725 50-sq-ft Fire Pan

Figure 5. Mil-Spec Burnback Pot

A modified foam extinguisher (Figure 6) was located within the building during each evaluation. This extinguisher is a 33-gallon foam extinguisher, model Amerex 630, that has been modified for use in the evaluations. The modifications to the extinguisher include a pressure transducer for measuring tank pressure, an Endress + Hauser Picomag flow meter, a regulator for controlling and maintaining the tank pressure supplied by a nitrogen bottle, test nozzles with adapters, and tank and hose heaters to maintain the proper foam solution temperatures when necessary.

Figure 6. Modified Foam Extinguisher

Two additional smaller extinguishers (Figure 7) were also used for tests that required multiple simultaneous discharge sources, made from 5-gallon stainless steel pressure vessels. Similar to the larger extinguisher, each of these smaller extinguishers was equipped with pressure regulators, pressure gauges, pressure transducers, and a flow meter (each of them using an IFM 7004 magnetic flow meter, which has similar performance characteristics to the Endress + Hauser Picomag flow meter). These smaller extinguishers were pressurized with compressed air rather than nitrogen to simplify the testing setup. The small extinguishers did not have heaters, as they were only able to be used for a single test each and therefore did not need assistance maintaining the foam mixture temperature between tests.

Figure 7. Pressure Control (Left) and Small Extinguisher (Right) for Dual Extinguisher Tests

The test nozzles are the nozzle specified by MIL-PRF-32725 (Naval Sea Systems Command, 2023), referred to as the Mil-Spec nozzle (Figure 8). This nozzle is an air-aspirated foam nozzle designed to flow at either 2 or 3 gallons per minute (gpm) at 100 lb/sq in., depending on the test being performed (Naval Sea Systems Command, 2023), by swapping out the internal orifice plate and jet. An additional 1.5 gpm version of the nozzle jet and orifice was created using 3D printing for use in the dual extinguisher testing (Figure 9). The flow rate of the nozzle was confirmed using the flow meter on the extinguisher before each test. The flow meters have onboard screens for displaying measurements and were integrated into the data collection system for monitoring and recording of the foam discharge flow rate during evaluations.

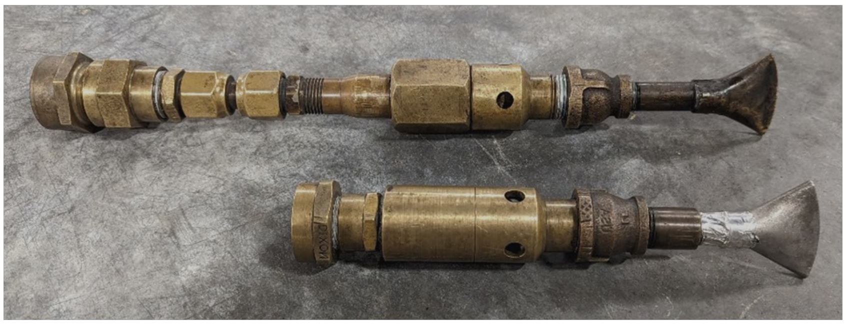

Figure 8. Mil-Spec Test Nozzles

Figure 9. A 3D-Printed, 1.5-gpm Orifice for Mil-Spec Nozzle

To perform the short-term stability evaluations, the methods described in section 4.5.9 of MIL-PRF-32725 (Naval Sea Systems Command, 2023) were followed. This required the use of an incubator (Figure 10), where the samples would be stored for a set period. The procedure for aging following this method will be discussed in more detail later in the Test Procedures section.

Figure 10. Temperature-Controlled Incubator

Other equipment used for the tests were: 1000ml beakers for measuring concentrate, 1000ml Erlenmeyer flasks for the short-term aged tests, and 1-gallon glass jugs for the medium-term aged tests. A 1-gallon jug and Erlenmeyer flask are shown in Figure 11.

Figure 11. Erlenmeyer Flask and 1-gallon Jug

The equipment required to measure foamability included a foam sample collector as described in National Fire Protection Association (NFPA) 412 (National Fire Protection Association, 2020), shown in Figure 12, and an Ohaus Navigator Benchtop Scale (Figure 13). A 1000ml beaker cut down to the 1000ml mark (1000ml beakers often have extra height to allow for easier use in measuring liquids) was used for sample collection.

Figure 12. Foam Sample Collector

Figure 13. Benchtop Scale

DATA AND INSTRUMENTATION

This section discusses the instrumentation used and data collected from each test. Each subsection describes the importance of the type of data and how that data was collected. While not all the data collected was used for the analysis presented in this report, it has been stored for potential later analysis as part of other test efforts.

VIDEO MONITORING

Many evaluations require visual confirmation to determine the performance metrics. The entirety of each fire test was recorded from multiple vantage points. The video was primarily used for real time monitoring of each evaluation and post-evaluation confirmation of fire extinguishment and burnback time. Video of each fire evaluation was instrumental in both objective and subjective assessment of the foam's performance.

Video of each fire evaluation was captured from multiple sources throughout each evaluation. The primary source of video was from the building's two permanently mounted color cameras (Figure 14). These cameras were mounted in opposing corners of the building at a 12-ft height and networked into the building's instrumentation system. A third camera was positioned on the floor to give an additional view of the fire and firefighters. All three cameras were connected to a network video recorder and the remote workstation. The video was recorded during each evaluation while a remote workstation (Figure 15) was used to monitor the cameras in real time.

Figure 14. Mounted Color Camera

Figure 15. Remote Workstation

The secondary source of video was from cameras worn by personnel inside of the building. Personnel wore Fire Cam Onyx helmet-mounted cameras (Figure 16) to provide a first-person perspective of each evaluation. The personnel wearing each camera initiated the recording manually and the footage was stored on the camera locally. After each evaluation, the video files recorded by the cameras were transferred to the workstation.

Figure 16. Helmet-Mounted Camera

THERMAL IMAGING VIDEO

Thermal imaging cameras allow observers to have a better view of the fire in the pan during extinguishment and burnback, as it tends to be difficult to identify details from color camera video due to the light given off by the fire itself. Inside the building are two thermal imaging cameras mounted in opposing corners 12 feet above the floor. The opposing vantage points and elevation reduce data loss from personnel obstruction and ensure thermal imaging data is not obstructed by the pan's edges. The cameras are forward-looking infrared (FLIR) A320 cameras inside air-cooled enclosures (Figure 17). Both cameras are connected to the building's instrumentation system. The remote workstation uses FLIR Research Studio to continuously monitor and record the video captured by each camera.

Figure 17. Thermal Imaging Camera in Enclosure

MANUAL TIME RECORDING

Observers controlled timings for the tests, such as when to begin and end discharge and when to place the burnback pot in the pan, using radio communication between the remote workstation and the firefighters. Observers then used the video feeds during the test to watch the test progress and manually mark important events outlined in MIL-PRF-32725 (Naval Sea Systems Command, 2023). These events are:

1. Dispensing of fuel
2. Fuel ignition
3. Beginning of pre-burn period
4. Beginning of discharge
5. 75% extinguishment
6. Full extinguishment
7. End of discharge
8. Insertion of burnback pot
9. 25% burnback

One observer used a stopwatch to communicate timings to firefighters over the radio and recorded times in a notebook, while the other observer recorded times using buttons on the data collection program on the workstation. This was to give two independent sources of recorded data, allowing comparison and to help identify potential errors in the tests. While the 25% burnback time was recorded manually here, this was only used as a backup for the automatic calculation performed using the heat release rate (HRR) value, outlined in the following section.

<u>OXYGEN CALORIMETRY</u>

Oxygen calorimetry is a method of determining the energy released from a fire based on the reduction of oxygen in the combustion gases. In the fire test building, the hood calorimeter is used for oxygen calorimetry analysis of the fire's behavior. The interior hood is the intake for the combustion gases from the fire, which are pulled through the ductwork to the fan and then exhausted. A section of the ductwork (called the "instrumentation section") is penetrated with multiple sensors to analyze the flow, characteristics, and composition of combustion gases. The sensors consist of three bidirectional probes, two thermocouple profile probes, and a gas sampling probe, in addition to some probes mounted externally to collect data on outside environmental conditions. The type and location of each sensor in the instrumentation section, and the methods used to calculate the fire's HRR, are based on ASTM E2067-12, *Standard Practice for Full-Scale Oxygen Consumption Calorimetry Fire Tests* (ASTM International, 2012).

The bidirectional probes measure volumetric airflow through the duct by calculating pressure drop across the two ends of the probe. The design of these probes is based on the design from *A Robust Bidirectional Low-Velocity Probe for Flame and Fire Application* (McCaffery & Heskestad, 1976). The thermocouple probes measure air temperature in the duct. These measurements are used as part of the HRR calculation.

The gas-sampling probe is the intake for the gas analyzer, which is remotely located. The gas analyzer measures the concentrations of oxygen, carbon monoxide, and carbon dioxide in the air flowing through the duct. The sample from the gas-sampling probe is filtered through a filter bank located on the platform next to the instrumentation section, then is transported through tubing to a conditioning system located by the remote workstation. The conditioning system prepares the sample to be measured by the gas analyzer by cooling it and removing any remaining moisture. The sample is then measured by the gas analyzer and exhausted into the environment. The gas analyzer used for measurement is a Rosemount MLT-4 (Figure 18). Due to the length of tubing used to transport the gas sample, the time at which the sample is measured is delayed from the time it is pulled from the duct. The LabVIEW software has been configured to account for this delay when calculating the calorimetry data.

Figure 18. Gas Analyzers

Additional data needed for oxygen calorimetry comes from measurement of ambient environmental conditions. Ambient temperature, relative humidity, pressure, and atmospheric air composition are measured by sensors located near the instrumentation section platform. A gas-sampling probe and a pressure transducer are mounted just outside the instrumentation enclosure on the instrumentation section platform. This gas-sampling probe is connected to another Rosemount MLT-4 gas analyzer for atmospheric composition measurement, and atmospheric pressure is measured with an Omega PX119-030AI pressure transducer.

All of the duct sensors are connected to the instrumentation system on the platform, then monitored and recorded from the remote workstation. The fire's HRR is calculated from the data measured by all these sensors. This is a continuous measurement throughout each fire evaluation. As foam is applied to the fire, the energy released by the fire diminishes until the fire is extinguished.

The HRR data was used in the burnback portion of each evaluation for the final determination of the 25% burnback time based on the measured HRR of the growing fire. This method of burnback time determination removes any bias the observer has and is a repeatable and quantified point to ensure all burnback times are at the same point of fire growth.

TEST MATRIX

Four foams were chosen to be tested as two-part mixtures: one AFFF (Chemguard C306) and three F3s (National Foam Avio F3 Green KHC, BioEx Ecopol A3+, and Solberg Avigard). The F3s chosen were the highest-performing foam concentrates from testing performed previously as part of the F3 Testing report published by the FAA (FAA, 2022).

For this portion of the research, 56 fire tests were conducted. This consisted of two fires per mixture per test type. An additional foamability evaluation was conducted for each mixture per test series. Table 1 shows the total amount of fires for each mixture of foam concentrate. Table 2 shows the fires for each mixture per test series (a total of 12 per series) plus eight additional fires to establish a baseline in the dual extinguisher tests for each foam.

Table 1. Total Fires Conducted per Mixture

Foam Type	Chemguard C306	National Foam Avio F3 Green KHC	BioEx EcoPol A3+	Solberg Avigard
Chemguard C306	2			
National Foam Avio F3 Green KHC	8	2		
BioEx Ecopol A3+	8	8	2	
Solberg Avigard	8	8	8	2

Table 2. Fires per Test Type

Foam Type	Chemguard C306	National Foam Avio F3 Green KHC	BioEx EcoPol A3+	Solberg Avigard
Chemguard C306	0 (2 for dual application)			
National Foam Avio F3 Green KHC	2	0 (2 for dual application)		
BioEx Ecopol A3+	2	2	0 (2 for dual application)	
Solberg Avigard	2	2	2	0 (2 for dual application)

FIRE TEST PROCEDURES

This section details each test series and preparation of the mixtures of foam concentrate.

SAMPLE PREPARATION

For the mixed concentrate tests, the sample mixtures were prepared at the same time. Each mixture was an even mixture of two parts, 1L (0.264 gallons) of each concentrate for a total of 2L (0.528 gallons). The Mixed Immediate Use tests used 1L each of two different concentrates, added directly to the 33-gallon extinguisher with 17.2 gallons of water (for a 3% solution) and mixed thoroughly. The mixing process was to partially fill the extinguisher with water, then add in the prescribed amount for the concentration of interest. The containers in which the concentrate was transported to the extinguisher were then rinsed with water and poured into the extinguisher, accounting for the rinse water in the solution and ensuring the concentrate was all out of the container. After the containers were rinsed, the extinguisher was filled with the amount of water necessary to achieve the final solution volume and concentration. The solution was then mechanically agitated/mixed with a handheld drill and mixer attachment. This ensured that all of the concentrate had gone into the solution evenly and homogenously. The extinguisher was then sealed and pressurized to be ready for discharge. Immediately prior to performing the tests the temperature of the discharged foam was measured by placing a thermocouple in the discharge stream prior to collecting the sample. The temperature of the discharged foam must be 73.4 °F ±9 °F (23 °C ±5 °C).

The Mixed Short-Term Stability tests used the aging method of MIL-PRF-32725 (Naval Sea Systems Command, 2023). The two different concentrates were mixed together evenly and placed in lightly stoppered Erlenmeyer flasks. Immediately after mixing, the mixed samples were stored in the incubator at a temperature of 149 °F for 10 days. The samples were removed from the incubator and used to fire test within one day of removal. The mixed samples were inspected for precipitation, stratification, or other signs of visually identifiable interactions. Two liters of the mixed concentrates were then added to the 33-gallon extinguisher with 17.2 gallons of water (for a 3% solution) and mixed thoroughly. The filling and mixing process followed that of the Mixed Immediate Use tests.

The Mixed Medium-Term Stability tests used a 30-day aging period. After the samples were mixed, they were stored in 1-gallon glass jugs at room temperature in a chemical storage cabinet. After the aging period elapsed, the samples were removed from the cabinet and used within five days of completing the aging period. These samples were inspected for precipitation, stratification, or other signs of visually identifiable interactions. Two liters of the mixed concentrates were then added to the 33-gallon extinguisher with 17.2 gallons of water (for a 3% solution) and mixed thoroughly. The filling and mixing process followed that of the Mixed Immediate Use tests.

For the dual extinguisher tests, 0.124 gallons (470ml) of concentrate was added directly to each of the 5-gallon modified extinguishers along with four gallons of water and thoroughly mixed, with each extinguisher getting a different type of foam concentrate (except for baseline tests, where each extinguisher was filled with the same material). The two foams for this test were mixed as finished foam when discharged into the pan, rather than in the extinguisher. In each iteration of the two fire tests for each combination of foam concentrates, the component foams were discharged from the alternate extinguisher to compensate for potential effects from the different foamability characteristics seen with the different nozzles.

FIRE TESTS IN A 28-SQUARE-FOOT PAN

The Mixed Immediate Use, Mixed Short-Term Stability, and Mixed Medium-Term Stability tests all used the procedures from section 4.5.11.1 in MIL-PRF-32725 (Naval Sea Systems Command, 2023), performing the gasoline fire test in the 28-sq ft pan. The differences for these three test types were based on the concentrate used, and how it had been aged as outlined in the previous section. The standard procedure used for these tests was as follows:

1. Check water, fuel, and foam temperatures to be sure readings are within range (73.4 °F ±9 °F [23 °C ±5 °C])
2. Check that foam flow rate through nozzle is 2gpm using attached flow meter; adjust pressure if necessary to reach desired flow rate

3. Have firefighters don all gear and get in position
4. Begin recording with FLIR cameras and LabVIEW
5. Confirm all firefighters are ready (have them signal through the cameras by raising a hand), have helmet cameras on, and ensure Self-Contained Breathing Apparatus (SCBA) is working
6. Give permission to start when they are ready
7. Begin timing when fuel is dispensed into pan (10 gallons of gasoline must be fully dumped within 30 seconds)
8. Mark fuel ignition when fire from ignition torch touches fuel (must be ignited within 30 seconds of fuel dispensing)
9. Begin 10-second pre-burn countdown (and mark time for beginning of pre-burn period) once pan is fully involved
10. Begin discharge (and mark time for beginning of discharge) at end of countdown
11. Mark time for 75% extinguishment
12. Mark time for full extinguishment
13. After 80 seconds, give 10-second countdown to end of discharge (start at 80 seconds, or 1:20 after start of discharge)
14. End discharge at 90 seconds (and mark time for end of discharge)
15. Wait 15 seconds
16. Ignite burnback pot
17. Give 15-second countdown to burnback pan insertion
18. Place burnback pot in center of 28-sq ft pan (and mark time for insertion of burnback pot)
19. Once firefighters have determined that fire is established outside the burnback pot, remove burnback pot
20. Mark time for 25% burnback
21. Wait for fire to become fully involved
22. Extinguish fire in pan using either backup extinguishers or remaining foam from test extinguisher
23. End FLIR recording as soon as fire is extinguished
24. Have firefighters exit building
25. End LabVIEW recording one minute after fire is extinguished to allow data to filter through
26. Allow smoke and fumes to clear the building before re-entering for cleanup

During the 25% burnback evaluation, the fire was allowed to burn to full involvement to ensure the data collection system has recorded the correct value. Because a visual estimation of 25% involvement in real time can be inconsistent between individuals, 25% burnback was determined by measuring the HRR from the fire. For this test series, 25% burnback was taken as the time after the insertion of the burnback pot to when the measured HRR value was equal to the theoretical energy output of a fire 25% of the area of the pan.

DUAL APPLICATION

This test type used two 5-gallon extinguishers, each filled with a different foam solution (or both filled with the same for the baseline tests). Procedures followed that of MIL-PRF-32725 using the Jet-A fire test in the 50-sq ft pan (section 4.5.11.2 in that document [Naval Sea Systems Command, 2023]) but using two firefighters, each using a Mil-Spec Test Nozzle that has been modified using a new orifice plate to give a flow rate of 1.5 gpm for a total foam flow rate of 3 gpm through both nozzles (matching the original test procedure's flow rate). Two fires were conducted with each combination, and for each set of baseline evaluations. Each foam also had a foamability evaluation performed. As with the procedures outlined in the 28-Square Foot Fire Tests section above, during the 25% burnback evaluation the fire was allowed to burn to full involvement. The test procedure for the Dual Application tests was as follows:

1. Check water, fuel, and foam temperatures to be sure they are within range (73.4 °F ±9 °F [23 °C ±5 °C])
2. Check that foam flow rate through each nozzle is 1.5 gpm using attached flow meter; adjust pressure if necessary to reach desired flow rate
3. Have firefighters get all gear on and get in position
4. Begin recording with FLIR cameras and LabVIEW
5. Confirm all firefighters are ready (have them signal through the cameras by raising a hand), have helmet cameras on, and SCBA is working
6. Give them permission to start when they are ready
7. Begin timing when fuel is dispensed into pan (15 gallons of Jet-A must be fully dumped within 30 seconds)
8. Mark ignition when fire from ignition torch touches fuel (must be ignited within 30 seconds of fuel dispensing)
9. Begin 60-second pre-burn period countdown (and mark time for beginning of pre-burn period) once pan is fully involved
10. Begin discharge (and mark time for beginning of discharge) at end of countdown
11. Mark time for 75% extinguishment
12. Mark time for full extinguishment
13. After 80 seconds, give 10-second countdown to end of discharge (start at 80 seconds, or 1:20 after start of discharge)
14. End discharge at 90 seconds (and mark time for end of discharge)
15. Wait 15 seconds
16. Ignite burnback pot
17. Give 15-second countdown to burnback pan insertion
18. Place burnback pot in center of 50-sq ft pan (and mark time for insertion of burnback pot)
19. Once firefighters have determined that fire is established outside the burnback pot, remove burnback pot
20. Mark time for 25% burnback
21. Wait for fire to become fully involved
22. Extinguish fire in pan using either backup extinguishers or remaining foam from test extinguisher

23. End FLIR recording as soon as fire is extinguished
24. Have firefighters exit building
25. End LabVIEW recording one minute after fire is extinguished to allow data to filter through
26. Allow smoke and fumes to clear the building before re-entering for cleanup

FOAMABILITY

Foamability is determined by two characteristics of the foam solution: expansion ratio and drainage time. The expansion ratio of the foam solution is the volumetric ratio between the non-aspirated liquid solution and the aspirated foam. Drainage time is the duration of time the aspirated foam takes to return to its liquid, non-aspirated state. In this case, the drainage time is quantified by the amount of time 25% of the solution takes to return to its liquid state. Both the expansion ratio and drainage time were measured during a single test using the same discharge sample. The evaluation procedures and analysis of these characteristics are based on the procedures detailed in NFPA 412, *Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment* (NFPA, 2020).

The solution temperature of the discharged foam must be 73.4 °F ±9 °F (23 °C ±5 °C). This temperature was measured by placing a thermocouple in the discharge stream prior to collecting the sample. Correction factors for both expansion ratio and drainage time were applied based on the solution temperature. If the solution temperature was above 70 °F (21 °C), there was no expansion ratio correction factor and drainage time was corrected by adding 0.1 minute for each 3 °F (1.7 °C) above 70 °F (21 °C). If the solution temperature was below 70 °F (21 °C), 0.1 unit of expansion was added to the expansion ratio and 0.1 minute was subtracted from drainage time for each 3 °F (1.7 °C) below 70 °F (21 °C) (National Fire Protection Association, 2020).

To conduct this evaluation, the following materials were required:

- Foam sample collector
- 1,000-ml graduated cylinder cut to fit in foam sample collector
- Benchtop scale
- Stopwatch
- Striker (Straightedge)
- Thermocouple for solution temperature
- Absorbent wipes

The procedure for performing the foamability tests was as follows:

1. Weigh empty 1,000-ml graduated cylinder for test
2. Record weight
3. Gather graduated cylinder, gloves, and paper towels
4. Set up Foam Sample Collector
5. Place graduated cylinder in Foam Sample Collector
6. Prepare striker (straightedge)
7. Spray foam off to side, measuring temperature

8. Once temperature stabilizes, record temperature and move foam discharge onto backboard. Discharge from 4–5 ft from backboard in slow sweeping motions
9. Discharge until container is filled with foam
10. Stop discharge
11. Start stopwatch for drainage test at end of discharge
12. Remove graduated cylinders from holder
13. Record liquid level in bottom of container every 30 seconds
14. Strike excess foam from top of container using striker
15. Clean off foam from outside of container while bringing container into measurement area
16. Once the container is inside and fully cleaned of foam, weigh container and record result
17. Calculate 25% drainage by multiplying the difference in weights for the empty and full container by 0.25, which will give the volume in ml (this assumes a density of 1,000g/ml)
    a. Expansion ratio is calculated by dividing 1,000 by the difference in weights for the empty and full container
18. Continue recording liquid level until 25% of the foam has drained (and for one to two readings after if possible)
19. Once 25% drainage is reached, measure liquid temperature using probe, and record temperature

RESULTS

The Tables 3 through 10 show the results from the mixed material fire testing. To simplify the presentation of the data, the analysis section uses averaged values for each test and foam combination; however, all results are included in the tables below. Tests where the fire was not extinguished are marked as "Did Not Extinguish" (DNE).

Table 3. Mixed Immediate-Use Fire Test Results

Foam 1	Foam 2	Test	75% Extinguishment Time	Full Extinguishment Time	25% Burnback
Chemguard C306	National Foam Avio F3 Green KHC	Mixed Immediate Use	00:27.5	00:40.0	05:27.6
			00:26.0	00:36.5	06:23.5
Chemguard C306	BioEx Ecopol A3+	Mixed Immediate Use	00:17.0	00:28.0	06:58.5
			00:19.5	00:31.0	07:10.0
Chemguard C306	Solberg Avigard	Mixed Immediate Use	00:19.0	00:31.5	07:52.5
			00:22.0	00:35.0	08:21.5
National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Mixed Immediate Use	00:26.0	00:36.5	05:21.5
			00:26.5	00:39.0	06:00.5
National Foam Avio F3 Green KHC	Solberg Avigard	Mixed Immediate Use	00:23.0	00:33.0	06:00.0
			00:25.0	00:36.5	06:19.0
BioEx Ecopol A3+	Solberg Avigard	Mixed Immediate Use	00:24.0	00:37.5	05:23.5
			00:21.5	00:35.5	06:08.0

Table 4. Mixed Short-Term Stability Fire Test Results

Foam 1	Foam 2	Test	75% Extinguishment Time	Full Extinguishment Time	25% Burnback
Chemguard C306	National Foam Avio F3 Green KHC	Mixed Short-Term Stability	00:25.0	00:36.5	05:06.1
			00:26.0	00:39.0	05:12.1
Chemguard C306	BioEx Ecopol A3+	Mixed Short-Term Stability	00:18.5	00:27.0	08:11.0
			00:19.5	00:26.0	07:33.1
Chemguard C306	Solberg Avigard	Mixed Short-Term Stability	00:20.0	00:33.5	06:52.5
			00:20.0	00:33.5	07:48.2
National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Mixed Short-Term Stability	00:19.5	00:36.0	05:21.5
			00:24.0	00:36.0	05:13.0
National Foam Avio F3 Green KHC	Solberg Avigard	Mixed Short-Term Stability	DNE	DNE	DNE
			DNE	DNE	DNE
BioEx Ecopol A3+	Solberg Avigard	Mixed Short-Term Stability	00:31.5	00:50.0	04:56.5
			00:23.5	00:55.0	04:36.5

Table 5. Mixed Medium-Term Stability Fire Test Results

Foam 1	Foam 2	Test	75% Extinguishment Time	Full Extinguishment Time	25% Burnback
Chemguard C306	National Foam Avio F3 Green KHC	Mixed Medium-Term Stability	00:23.5	00:36.0	05:40.1
			00:23.0	00:37.0	06:01.0
Chemguard C306	BioEx Ecopol A3+	Mixed Medium-Term Stability	00:19.0	00:38.5	08:33.1
			00:16.5	00:30.5	08:07.2
Chemguard C306	Solberg Avigard	Mixed Medium-Term Stability	00:17.0	00:38.0	08:40.0
			00:19.0	00:29.5	07:31.0
National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Mixed Medium-Term Stability	00:24.0	00:34.0	05:56.0
			00:19.5	00:36.5	06:29.5
National Foam Avio F3 Green KHC	Solberg Avigard	Mixed Medium-Term Stability	00:22.0	00:34.0	06:43.0
			00:19.5	00:34.5	06:47.1
BioEx Ecopol A3+	Solberg Avigard	Mixed Medium-Term Stability	00:18.0	00:36.0	06:11.5
			00:22.0	00:35.5	06:03.0

Table 6. Dual Application Fire Test Results

Foam 1	Foam 2	Test	75% Extinguishment Time	Full Extinguishment Time	25% Burnback
Chemguard C306	Chemguard C306	Dual Application	00:15.0	00:32.5	08:51.1
			00:16.0	00:31.0	08:58.5
National Foam Avio F3 Green KHC	National Foam Avio F3 Green KHC	Dual Application	00:32.0	00:56.5	04:49.5
			00:26.0	00:47.5	05:14.6
BioEx Ecopol A3+	BioEx Ecopol A3+	Dual Application	00:35.0	00:48.0	05:05.5
			00:26.5	00:43.5	04:55.0
Solberg Avigard	Solberg Avigard	Dual Application	00:20.5	00:40.0	05:29.0
			00:21.0	00:42.0	06:47.6
Chemguard C306	National Foam Avio F3 Green KHC	Dual Application	00:17.5	00:33.5	08:05.5
			00:17.0	00:37.0	06:47.6
Chemguard C306	BioEx Ecopol A3+	Dual Application	00:18.0	00:34.5	06:27.0
			00:21.0	00:33.5	06:01.0
Chemguard C306	Solberg Avigard	Dual Application	00:21.5	00:37.5	07:27.6
			00:17.0	00:39.5	08:10.1
National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Dual Application	00:27.5	00:50.5	05:07.5
			00:26.5	00:50.0	05:08.5
National Foam Avio F3 Green KHC	Solberg Avigard	Dual Application	00:26.0	00:47.5	06:03.0
			00:25.5	00:45.0	05:56.1
BioEx Ecopol A3+	Solberg Avigard	Dual Application	00:27.0	00:47.0	05:23.0
			00:21.5	00:37.5	06:02.5

Table 7. Mixed Immediate Use Foamability Test Results

Foam 1	Foam 2	Test	Expansion Ratio	25% Drainage Time
Chemguard C306	National Foam Avio F3 Green KHC	Mixed Immediate Use	10.28	05:03.2
Chemguard C306	BioEx Ecopol A3+	Mixed Immediate Use	10.47	04:03.7
Chemguard C306	Solberg Avigard	Mixed Immediate Use	10.60	04:27.7
National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Mixed Immediate Use	10.68	11:58.9
National Foam Avio F3 Green KHC	Solberg Avigard	Mixed Immediate Use	10.71	11:54.3
BioEx Ecopol A3+	Solberg Avigard	Mixed Immediate Use	10.16	09:25.9

Table 8. Mixed Short-Term Stability Foamability Test Results

Foam 1	Foam 2	Test	Expansion Ratio	25% Drainage Time
Chemguard C306	National Foam Avio F3 Green KHC	Mixed Short-Term Stability	9.44	04:58.2
Chemguard C306	BioEx Ecopol A3+	Mixed Short-Term Stability	10.42	04:29.9
Chemguard C306	Solberg Avigard	Mixed Short-Term Stability	10.12	04:24.7
National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Mixed Short-Term Stability	10.59	11:43.1
National Foam Avio F3 Green KHC	Solberg Avigard	Mixed Short-Term Stability	1.70	Instant
BioEx Ecopol A3+	Solberg Avigard	Mixed Short-Term Stability	9.02	06:28.2

Table 9. Mixed Medium-Term Stability Foamability Test Results

Foam 1	Foam 2	Test	Expansion Ratio	25% Drainage Time
Chemguard C306	National Foam Avio F3 Green KHC	Mixed Medium-Term Stability	10.53	04:13.8
Chemguard C306	BioEx Ecopol A3+	Mixed Medium-Term Stability	10.50	04:32.3
Chemguard C306	Solberg Avigard	Mixed Medium-Term Stability	10.56	04:57.7
National Foam Avio F3 Green KHC	BioEx Ecopol A3+	Mixed Medium-Term Stability	10.46	12:09.9
National Foam Avio F3 Green KHC	Solberg Avigard	Mixed Medium-Term Stability	10.41	13:41.8
BioEx Ecopol A3+	Solberg Avigard	Mixed Medium-Term Stability	10.15	11:08.8

Table 10. Dual Application Foamability Test Results

Foam 1	Test	Expansion Ratio	25% Drainage Time
Chemguard C306	Dual Application, Extinguisher 1	9.18	03:29.6
	Dual Application, Extinguisher 2	11.02	03:29.0
National Foam Avio F3 Green KHC	Dual Application, Extinguisher 1	8.64	10:07.5
	Dual Application, Extinguisher 2	10.96	09:37.5
BioEx Ecopol A3+	Dual Application, Extinguisher 1	9.02	06:05.7
	Dual Application, Extinguisher 2	10.77	07:15.8
Solberg Avigard	Dual Application, Extinguisher 1	8.85	03:27.6
	Dual Application, Extinguisher 2	10.66	05:43.4
	Dual Application, Extinguisher 1	8.61	09:07.6

For the foamability results for Solberg Avigard, the results from Extinguisher 1 were inconsistent. Because of the large difference in 25% drainage times between Extinguisher 1 and Extinguisher 2, the foamability test using Extinguisher 1 was repeated. While the expansion ratio was similar, the 25% drainage time was significantly longer. For the purposes of this report, the first two values will be used, but all results are included in Table 10 for future reference. Foam solutions used for the dual extinguisher foamability tests were not used in the fire tests. For the fire tests, each solution was discharged from the alternate extinguisher for the second test, in an effort to compensate for different expansion ratios between the nozzles.

CHEMGUARD C306 AND NATIONAL FOAM AVIO F3 GREEN KHC

Averaged results from mixed material testing for Chemguard C306 and National Foam Avio F3 Green KHC as well as baseline single-material tests (marked with an asterisk) from the F3 Testing report published by the FAA (FAA, 2022) are shown in Table 11. The baseline tests were performed before measurement of 75% extinguishment was part of the established testing procedure, and thus was not recorded. Foamability information (expansion ratio and 25% draindown) was not included for the non-baseline dual application tests, as the test was not designed to accurately measure a discharge from two separate nozzles.

Table 11. Averaged Fire Test Results for Mixed C306 and Avio Green

Test	75% Extinguishment	Full Extinguishment	25% Burnback	Expansion Ratio	25% Drainage Time
Chemguard C306*		00:27.3	07:54.5	10.14	03:21.7
National Foam Avio F3 Green KHC*		00:56.3	03:23.5	8.85	03:40.6
Mixed Immediate Use	00:26.8	00:38.3	05:55.6	10.28	05:03.2
Chemguard C306 Aged*		00:29.0	09:27.0	8.39	04:03.6
National Foam Avio F3 Green KHC Aged*		00:48.0	03:47.0	8.94	03:37.9
Mixed Short-Term Stability	00:25.5	00:37.8	05:09.1	9.44	04:58.2
Mixed Medium-Term Stability	00:23.3	00:36.5	05:50.5	10.53	04:13.8
Chemguard C306 Dual Application	00:15.5	00:31.8	08:54.8	10.10	03:29.3
National Foam Avio F3 Green KHC Dual Application	00:29.0	00:52.0	05:02.1	9.80	09:52.5
Dual Application	00:17.2	00:35.3	07:26.6		

* Results originally from F3 Testing report (FAA, 2022).

Mixing these foams produced results generally between the performance of the individual foams. The expansion ratio was consistent across all the mixed concentrate tests and did not differ too significantly from the baseline tests. Twenty-five percent drainage was longer for the Mixed Immediate Use and Mixed Short-Term Stability tests, but in the Mixed Medium-Term Stability tests showed similar results as the baseline tests.

Fire performance of the mixture increased slightly after aging. The reason for this is unknown, but a possibility is that some part of the mixture began to break down or come out of solution, allowing the mixture to perform more similarly to pure Chemguard C306. This is because in the 10-day aged samples, a residue (Figure 19) was found on the bottom of the beakers that was not present for any other mixture. This residue did not wash away when simply rinsed with water or other solvents such as alcohol and required scrubbing to remove completely.

Figure 19. Residue in Bottom of Beaker After Short-Term Aging

It is possible this is some component that came out of the solution due to the mixture of these materials, the increased temperature, or a combination of both. A similar process may have occurred with the medium-term aged samples, but since they were stored in mostly opaque bottles, it was not possible to confirm if there was a residue.

Results were also between the performance of the component foams when discharging through the dual extinguishers. The performance was similar to that of the Chemguard C306 Baseline tests.

CHEMGUARD C306 AND BIOEX ECOPOL A3+

Averaged results from mixed material testing for Chemguard C306 and BioEx Ecopol A3+ as well as baseline single material tests (marked with an asterisk) from the F3 Testing report published by the FAA (FAA, 2022) are shown in Table 12. The baseline tests were performed before measurement of 75% extinguishment was part of the established testing procedure, and thus was not recorded. Foamability information (expansion ratio and 25% Drainage) was not included for the non-baseline dual application tests, as the test was not designed to accurately measure a discharge from two separate nozzles.

Table 12. Averaged Fire Test Results for Mixed C306 and Ecopol A3+

Test	75% Extinguishment	Full Extinguishment	25% Burnback	Expansion Ratio	25% Drainage Time
Chemguard C306*		00:27.3	07:54.5	10.14	03:21.7
BioEx Ecopol A3+*		00:47.0	04:46.0	10.02	09:15.8
Mixed Immediate Use	00:18.3	00:29.5	07:04.3	10.47	04:03.7
Chemguard C306 Aged*		00:29.0	09:27.0	8.39	04:03.6

Test	75% Extinguishment	Full Extinguishment	25% Burnback	Expansion Ratio	25% Drainage Time
BioEx Ecopol A3+ Aged*		00:51.0	04:15.0	10.03	08:55.8
Mixed Short-Term Stability	00:19.0	00:26.5	07:52.1	10.42	04:29.9
Mixed Medium-Term Stability	00:17.8	00:34.5	08:20.1	10.50	04:32.3
Chemguard C306 Dual Application	00:15.5	00:31.8	08:54.8	10.10	03:29.3
BioEx Ecopol A3+ Dual Application	00:30.8	00:45.8	05:00.3	9.89	06:40.8
Dual Application	00:19.5	00:34.0	06:14.0		

* Results originally from F3 Testing report (FAA, 2022).

In most tests, mixing these foams produced results closer to that of Chemguard C306 by itself, both in extinguishment time and burnback resistance. In the Mixed Short-Term Stability tests, results were better than those of the component foams. Results were close to those of the un-aged Chemguard C306 baseline results, so it is possible this was a result of variability in the testing results due to the manual fire extinguishment used in the testing method. Foamability (expansion ratio and drainage) was generally closer to BioEx Ecopol A3+ for expansion ratio, and Chemguard C306 for drainage time.

<u>CHEMGUARD C306 AND SOLBERG AVIGARD</u>

Averaged results from mixed material testing for Chemguard C306 and Solberg Avigard as well as baseline single material tests (marked with an asterisk) from the F3 Testing report published by the FAA (FAA, 2022) are shown in Table 13. The baseline tests were performed before measurement of 75% extinguishment was part of the established testing procedure, and thus was not recorded. Foamability information (expansion ratio and 25% draindown) was not included for the non-baseline dual application tests, as the test was not designed to accurately measure a discharge from two separate nozzles.

Table 13. Averaged Fire Test Results for Mixed C306 and Avigard

Test	75% Extinguishment	Full Extinguishment	25% Burnback	Expansion Ratio	25% Drainage Time
Chemguard C306*		00:27.3	07:54.5	10.14	03:21.7
Solberg Avigard*		00:47.0	04:41.0	8.97	03:34.3
Mixed Immediate Use	00:20.5	00:33.3	08:07.0	10.60	04:27.7
Chemguard C306 Aged*		00:29.0	09:27.0	8.39	04:03.6

Test	75% Extinguishment	Full Extinguishment	25% Burnback	Expansion Ratio	25% Drainage Time
Solberg Avigard Aged*		01:03.5	03:37.1	8.90	05:42.6
Mixed Short-Term Stability	00:20.0	00:33.5	07:20.4	10.12	04:24.7
Mixed Medium-Term Stability	00:18.0	00:33.8	08:05.5	10.56	04:57.7
Chemguard C306 Dual Application	00:15.5	00:31.8	08:54.8	10.10	03:29.3
Solberg Avigard Dual Application	00:20.8	00:41.0	06:08.3	9.75	04:35.5
Dual Application	00:19.3	00:38.5	07:48.8		

* Results originally from F3 Testing report (FAA, 2022).

Mixing these foams produced results closer to those of Chemguard C306 by itself, both in extinguishment time and burnback resistance. Foamability (expansion ratio and drainage) does not seem to be too affected by mixing; however, these foams had similar performance in that respect to begin with. The exception was with the aged tests, where foamability increased by 1. While this is not a very large change, it is noticeable, and may have been caused by using different nozzles for the tests in the F3 Testing report and the tests in this series. While both nozzles used were built from the same set of drawings and have identical flow and pressure characteristics, some foams have different results from foamability tests through the nozzles due to small changes in the construction of the nozzles.

<u>NATIONAL FOAM AVIO F3 GREEN KHC AND BIOEX ECOPOL A3+</u>

Averaged results from mixed material testing for National Foam Avio F3 Green KHC and BioEx Ecopol A3+ as well as baseline single material tests (marked with an asterisk) from the F3 Testing report published by the FAA (FAA, 2022) are shown in Table 14. The baseline tests were performed before measurement of 75% extinguishment was part of the established testing procedure, and thus was not recorded. Foamability information (expansion ratio and 25% draindown) was not included for the non-baseline dual application tests, as the test was not designed to accurately measure a discharge from two separate nozzles.

Table 14. Averaged Fire Test Results for Mixed Avio Green and Ecopol A3+

Test	75% Extinguishment	Full Extinguishment	25% Burnback	Expansion Ratio	25% Drainage Time
National Foam Avio F3 Green KHC*		00:56.3	03:23.5	8.85	03:40.6
BioEx Ecopol A3+*		00:47.0	04:46.0	10.02	09:15.8

Test	75% Extinguishment	Full Extinguishment	25% Burnback	Expansion Ratio	25% Drainage Time
Mixed Immediate Use	00:26.3	00:37.8	05:41.0	10.68	11:58.9
National Foam Avio F3 Green KHC Aged*		00:48.0	03:47.0	8.94	03:37.9
BioEx Ecopol A3+ Aged*		00:51.0	04:15.0	10.03	08:55.8
Mixed Short-Term Stability	00:21.8	00:36.0	05:17.3	10.59	11:43.1
Mixed Medium-Term Stability	00:21.8	00:35.3	06:12.8	10.41	13:41.8
National Foam Avio F3 Green KHC Dual Application	00:29.0	00:52.0	05:02.1	9.80	09:52.5
BioEx Ecopol A3+ Dual Application	00:30.8	00:45.8	05:00.3	9.89	06:40.8
Dual Application	00:27.0	00:50.3	05:08.0		

* Results originally from F3 Testing report (FAA, 2022).

It is unclear why, but mixing these foams appears to provide better performance than that of the component foams across most tests. Mixed Immediate Use, Mixed Short-Term Stability, and Mixed Medium-Term Stability all showed extinguishment times over 10 seconds shorter than the baseline tests for either component foam, and 25% burnback times of more than one minute longer. The mixture was not significantly affected by either aging process, performing similarly in all tests.

When discharging foam through the dual extinguishers, the performance was close to the performance of the component foams.

<u>NATIONAL FOAM AVIO F3 GREEN KHC AND SOLBERG AVIGARD</u>

Averaged results from mixed material testing for National Foam Avio F3 Green KHC and Solberg Avigard as well as baseline single material tests (marked with an asterisk) from the F3 Testing report published by the FAA (FAA, 2022) are shown in Table 15. The baseline tests were performed before measurement of 75% extinguishment was part of the established testing procedure, and thus was not recorded. Foamability information (expansion ratio and 25% draindown) was not included for the non-baseline dual application tests, as the test was not designed to accurately measure a discharge from two separate nozzles.

Table 15. Averaged Fire Test Results for Mixed Avio Green and Avigard

Test	75% Extinguishment	Full Extinguishment	25% Burnback	Expansion Ratio	25% Drainage Time
National Foam Avio F3 Green KHC*		00:56.3	03:23.5	8.85	03:40.6
Solberg Avigard*		00:47.0	04:41.0	8.97	03:34.3
Mixed Immediate Use	00:24.0	00:34.8	06:09.5	10.71	11:54.3
National Foam Avio F3 Green KHC Aged*		00:48.0	03:47.0	8.94	03:37.9
Solberg Avigard Aged*		01:03.5	03:37.1	8.90	05:42.6
Mixed Short-Term Stability	DNE	DNE	DNE	1.70	Instant
Mixed Medium-Term Stability	00:20.8	00:34.3	06:45.0	10.46	12:09.9
National Foam Avio F3 Green KHC Dual Application	00:29.0	00:52.0	05:02.1	9.80	09:52.5
Solberg Avigard Dual Application	00:20.8	00:41.0	06:08.3	9.75	04:35.5
Dual Application	00:25.8	00:46.3	05:59.5		

* Results originally from F3 Testing report (FAA, 2022).

As with the National Foam Avio F3 Green KHC and BioEx Ecopol A3+ mixture, this mixture performed better in the non-aged tests than either of the baseline samples. Extinguishment times for the Mixed Immediate Use and Mixed Medium-Term Stability were over 12 seconds shorter, and 25% burnback times were over one minute longer for the Mixed Immediate Use, and nearly three minutes longer for the Mixed Medium-Term Stability.

However, this performance was not consistent across all tests, as the Mixed Short-Term Stability did not extinguish the fire at all. Foamability was significantly impacted, with 25% drainage happening instantly. Figure 20 shows the short-term aged foam as it was discharged through the Mil-Spec nozzle. Note the lack of a foam blanket forming on the concrete. Figure 21 shows an example of what a more typical foam discharge looks like through the same nozzle. This image is from testing performed prior to this test effort and is only included to provide context for the performance of the mixture of concentrates.

Figure 20. Discharge of Mixed Short-Term Stability National Foam Avio F3 Green KHC and Solberg Avigard

Figure 21. Example of Discharge with Higher Expansion Foam from Same Nozzle

Spraying this foam on the fire did not produce any meaningful reduction in overall fire size, as shown in Figure 22. This test was repeated with a new batch due to the nature of the results and had the exact same outcome. Visual changes observed included a darkening of the concentrate in the beakers, though this was visible on the baseline tests with only Solberg Avigard. Otherwise, there was no other indicator prior to discharge that this would not be an effective foam. This change was not seen in the long-term aged samples, which performed very similarly to the instant mix samples. It is not clear at this point what the cause of this change was (it is suspected that the elevated temperature used in the aging process was a contributing factor), but the results were repeatable.

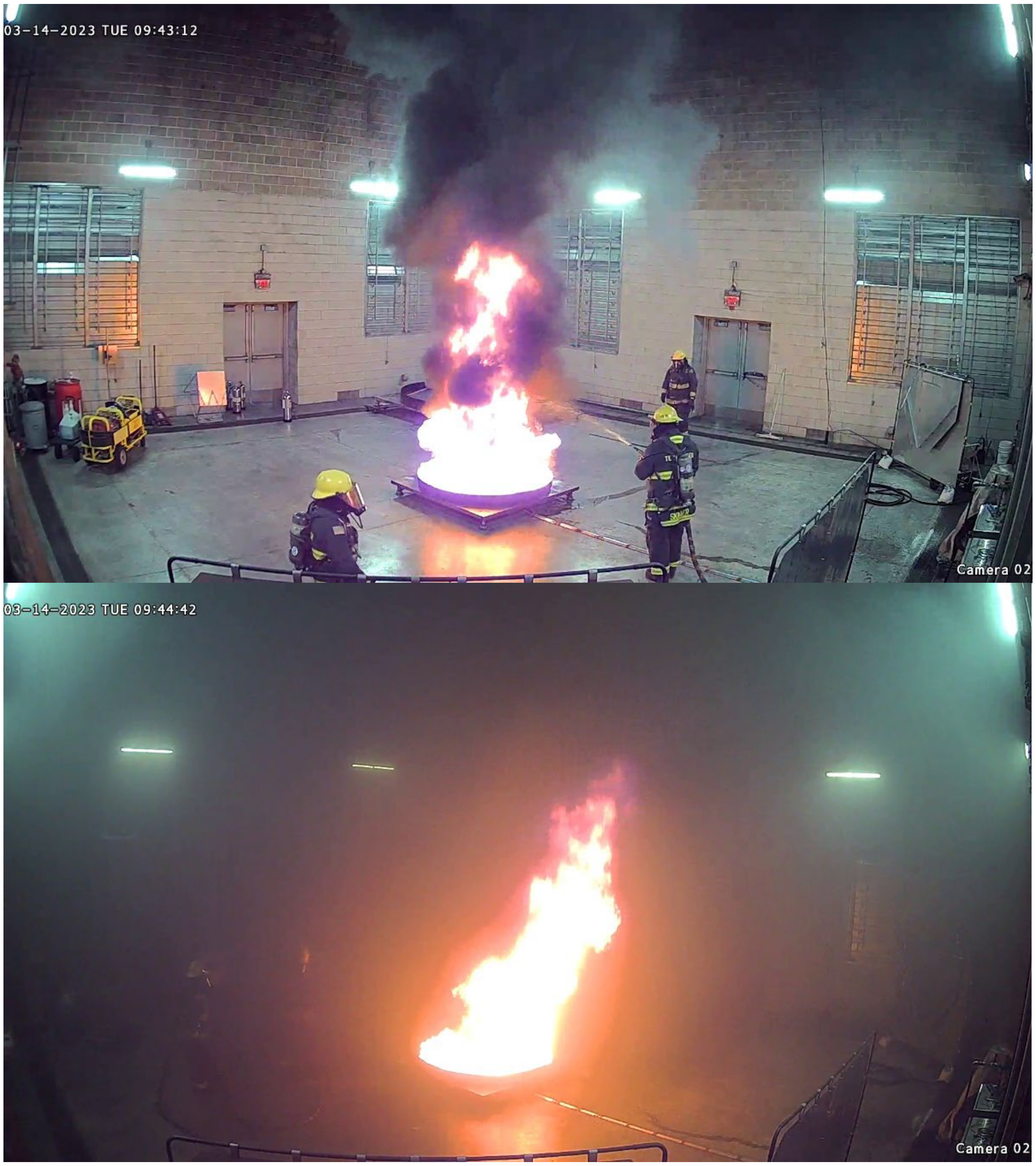

Figure 22. Fire at Beginning (Top) and End (Bottom) of Discharge in Mixed Short-Term Stability with National Foam Avio F3 Green KHC and Solberg Avigard

When foam was discharged through the dual extinguishers, the performance was generally close to the performance of the component foams and did not display the decrease in firefighting performance witnessed in the Mixed Short-Term Stability tests.

BIOEX ECOPOL A3+ AND SOLBERG AVIGARD

Averaged results from mixed material testing for BioEx Ecopol A3+ and Solberg Avigard as well as baseline single material tests (marked with an asterisk) from the F3 Testing report published by the FAA (FAA, 2022) are shown in Table 16. The baseline tests were performed before measurement of 75% extinguishment was part of the established testing procedure, and thus was not recorded. Foamability information (expansion ratio and 25% draindown) was not included for the non-baseline dual application tests, as the test was not designed to accurately measure a discharge from two separate nozzles.

Table 16. Averaged Fire Test Results for Mixed Ecopol A3+ and Avigard

Test	75% Extinguishment	Full Extinguishment	25% Burnback	Expansion Ratio	25% Drainage Time
BioEx Ecopol A3+*		00:47.0	04:46.0	10.02	09:15.8
Solberg Avigard*		00:47.0	04:41.0	8.97	03:34.3
Mixed Immediate Use	00:22.8	00:36.5	05:45.8	10.16	09:25.9
BioEx Ecopol A3+ Aged*		00:51.0	04:15.0	10.03	08:55.8
Solberg Avigard Aged*		01:03.5	03:37.1	8.90	05:42.6
Mixed Short-Term Stability	00:27.5	00:52.5	04:46.5	9.02	06:28.2
Mixed Medium-Term Stability	00:20.0	00:35.8	06:07.3	10.15	11:08.8
BioEx Ecopol A3+ Dual Application	00:30.8	00:45.8	05:00.3	9.89	06:40.8
Solberg Avigard Dual Application	00:20.8	00:41.0	06:08.3	9.75	04:35.5
Dual Application	00:24.3	00:42.3	05:42.8		

* Results originally from F3 Testing report (FAA, 2022).

In fire extinguishment performance, this mixture performed better than the individual baseline tests for the Mixed Immediate Use and Mixed Medium-Term Stability tests, fully extinguishing the fire in over 10 seconds less than the respective baseline tests. Foamability in the Mixed Immediate Use tests were generally similar to that of BioEx Ecopol A3+ on its own. For the Mixed Short-Term Stability tests, performance was between the performance of the two component foams, leaning slightly more towards BioEx Ecopol A3+. For the Mixed Medium-Term Stability tests, performance was noticeably better across all tests except for expansion ratio, which remained in the same range.

When discharging foam through the dual extinguishers, the performance was generally close to the performance of the component foams.

ANALYSIS

Table 17 shows a summary of the results from testing. Yellow represents results between the performance of the component foams, green represents results better than the component foams, and red represents results worse than the component foams.

Table 17. Summary of Extinguishment Results

	Chemguard C306/National Foam Avio F3 Green KHC	Chemguard C306/BioEx Ecopol A3+	Chemguard C306/Solberg Avigard	National Foam Avio F3 Green KHC/BioEx Ecopol A3+	National Foam Avio F3 Green KHC/Solberg Avigard	BioEx Ecopol A3+/Solberg Avigard
Mixed Immediate Use	Yellow	Yellow	Yellow	Green	Green	Green
Mixed Short-Term Stability	Yellow	Green	Yellow	Green	Red	Yellow
Mixed Medium-Term Stability	Yellow	Yellow	Yellow	Green	Green	Green
Dual Application	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow

Table 18. Summary of Burnback Results

	Chemguard C306/National Foam Avio F3 Green KHC	Chemguard C306/BioEx Ecopol A3+	Chemguard C306/Solberg Avigard	National Foam Avio F3 Green KHC/BioEx Ecopol A3+	National Foam Avio F3 Green KHC/Solberg Avigard	BioEx Ecopol A3+/Solberg Avigard
Mixed Immediate Use	Yellow	Yellow	Yellow	Green	Green	Green
Mixed Short-Term Stability	Yellow	Yellow	Yellow	Green	Red	Green
Mixed Medium-Term Stability	Yellow	Yellow	Yellow	Green	Green	Green
Dual Application	Yellow	Yellow	Yellow	Green	Yellow	Yellow

The performance of mixtures between foam concentrates was not always predictable. The performance of mixtures between AFFF and F3s tended to be close to the performance of AFFF alone or between the performance of the individual foams. F3 mixtures were more varied, with most performing better than the component foams. One mixture of only F3 foams achieved results between the performance of the component foams on their own, while another mixture showed a severe reduction in performance. Given the amount of variation in foams both in performance and chemical makeup in the F3 market, it is important to not mix different concentrates. Without more testing to ensure compatibility, it is very possible that some combinations of concentrates may still have adverse reactions, potentially leading to decreases in firefighting performance, or other unforeseen effects. However, this testing shows that under some circumstances, mixing different foam concentrates does not lead to significant negative effects on performance. More testing is required to be able to determine definitive effects of mixing F3 concentrates.

The Dual Application tests showed much more predictable performance than the mixed-concentrate tests. Extinguishment times and foamability results were between the results of the component foams in all tests. This suggests that after being discharged, the foams did not react or significantly impact the firefighting performance of the other foam. Suspected issues with the foam blankets of the individual foams (such as the blankets not combining and forming a seam) were not observed in this this test series. Given the size of the pans, individual foams were likely too thoroughly mixed to form independent blankets. Performance (both extinguishment and burnback) was never worse than the lower-performing component foam. Based on this result, use of two different foams (e.g., dispensed from two different ARFF response vehicles) in response to a fire may not have any significant impact on the firefighting performance of the individual foams. While not ideal, during an emergency response firefighters should not allow the presence of different firefighting foams prevent the use of any apparatus, as long as the performance of the individual foams meet the required specifications for their use.

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