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Fire Tests of Fluorine Free Foams with Compressed Air Foam Systems

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1 Introduction

Aqueous Film-Forming Foams (AFFFs) are high-performance firefighting foams suitable for rapid knockdown of flammable liquid fires with outstanding film-forming capability owing to their key ingredient of fluorinated surfactants. However, the fluorinated surfactants used in AFFFs have negative impacts on the environment and health due to their low biodegradability and ecotoxicity. As such, a range of fluorine-free foams (FFFs) has been commercially developed using other chemicals, including synthetic fluorine-free ether-based surfactants.

It is critical to evaluate the fire suppression performance of FFFs since their performances vary depending on products, fuel types, concentrations, foam qualities/aspiration, and application methods. It is reported that some products require an increase in discharge rate to demonstrate the fire suppression effectiveness equivalent to the AFFFs.

In general, the fire suppression performance is examined by carrying out standard fire tests. Several standard fire test methods are available, each having different objectives and testing scope[1]. Each standard requires to test the foam against a pool fire and evaluate the fire suppression performance based on fire extinguishment time, foam blanket sealability test (Torch test), and burnback resistance time. While heptane is used as fuel for pool fire for IMO[2] 1312 (Revised guidelines for the performance of foam concentrates), EN[3] 1568 (Fire extinguishing media-Foam concentrates) and UL[4] 162 (Standard for Foam Equipment and Liquid Concentrates), gasoline and Jet-A fuel are required by MIL-PRF[5]2485 (Performance specification - Fire extinguishing agent, aqueous film-forming foam (AFFF) liquid concentrate for fresh and sea water) and ICAO[6] (Airport Services Manual Doc 9137-AN/898 Part1-Rescue and Firefighting Fourth Edition), respectively. The required extinguishment time varies with the objectives of each standard. The MIL-PRF2485 requires extremely rapid knockdown of fire within 30 or 50 seconds because the objectives are to minimize thermal damage to costly weapons and maximize the rescue opportunities for the occupants, especially from the flight deck of an aircraft carrier. Concerning airport fires where fast responses are critical, ICAO requires fire suppression with minute flame within 60 seconds and complete extinguishment within 120 seconds for a Jet-A pool fire. FM[7] 5130 (Examination standard for foam extinguishing systems) requires fire extinguishment within 5 minutes from the start of low expansion foam application using water sprinkler and Compressed Air Foam (CAF) nozzles only for hydrocarbon fuel; and only CAF for polar solvent fuel fires.

Following the FM 5130 standard test methods, where possible, a series of fire suppression tests was conducted by the National Research Council Canada (NRC) Fire Safety Unit in collaboration with Fireflex, and the Ottawa International Airport Authority (OIAA) to investigate the performance of FFFs.

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[1] For more detailed comparisons of these standard test methods and surveys of FFF products, please see the NRC Report: Hassan, Rokib, Elsagan, Nour, and Ko, Yoon. 2020. “Assessment of Non-Fluorinated Firefighting Foams: Foam Performance and Ecotoxicity, NRC Report A1-016047.1.(https://publications.gc.ca/collections/collection_2021/cnrc-nrc/NR24-49-2020-eng.pdf)
[2] International Maritime Organization
[3] European Standards
[4] Underwriters' Laboratories
[5] Military Performance Specification
[6] International Civil Aviation Organization
[7] Factory Mutual

1.1 Objectives

The purpose of this collaborative study has been to evaluate the performance of selected FFFs for the following parameters:

- Various types of FFFs and their concentrations
- Various fuels
- Different application methods (CAF/air aspirating foam via sprinkler system, manual CAF, and premixed hose applications)
- Different spray densities (various flow rates and spray duration)
- Torch tests and burnback tests.

2 Test Set-up

A series of pool fire tests were conducted using selected FFFs in the outdoor testing site at the Ottawa International Airport Authority (OIAA).

2.1 Fluorine-Free Foams

Two different FFFs were tested:

- Dafo FOMTEC/VIKING Enviro ARK
- BioEx Ecopol A

Dafo FOMTEC/VIKING Enviro ARK is free from fluorinated surfactants, polymers and other organohalogens, and they are 100% biodegradable. Dafo FOMTEC/VIKING Enviro ARK is intended for use on Class B hydrocarbon fuel and polar solvent fires as well as Class A fires (as per the manufacturer's technical data sheet). Dafo FOMTEC/VIKING Enviro ARK are low expansion foam concentrate with the FM approval for use with sprinklers (i.e., FM 5130[8]). Average expansion is 7:1, average ¼ drainage time is 25 minutes using a UNI 86 test nozzle.

BioEx Ecopol A is fluorine-free and silicone-free as well as completely biodegradable. BioEx Ecopol A is efficient on hydrocarbon fires. BioEx Ecopol A is certified according to the standard ICAO: Level B[9]. Average expansion is 9:1, average ¼ drainage times are 3 minutes, which however varies depending on the equipment.

In the tests, foam solutions were prepared by mixing the specified amount of concentrate with water either in a premixed solutions or continuously by use of suitable proportioning equipment and/or selected CAF systems. Where possible, foam properties (e.g., expansion ratio, drainage time) were measured.

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[8] FM 5130 requires fire extinguishment by the end of low expansion foam application using sprinkler and CAF nozzles of 5 minute for hydrocarbon and polar solvent fuel fires.
[9] Concerning airport fires where fast responses are critical, ICAO requires fire suppression with minute flame within 60 seconds and complete extinguishment within 120 seconds for a Jet-A pool fire. ICAO requires test pan areas of 2.5, 4.8 and 7.32 m^2 for Level A, B and C, respectively.

2.2 Fuels

The FFFs were tested against the different Class B fires of hydrocarbon fuels and polar solvents. Following fuels were tested. In each test ½ barrel of the fuel was used.

- Hydrocarbon (Class B)
  - Heptane: 143.79 kg/barrel, Flash point < -7°C, Boiling point 82-83°C
  - Jet A / Kerosene: 162.0 kg/barrel, Flash point 40°C, Boiling point 125-292°C
- Polar solvent (Alcohols and Acetone (Class B)
  - IPA (Isopropyl alcohol): 161.02 kg/barrel, Flash point 12°C, Boiling point 82-83°C
  - MEK (Methyl-ethyl-ketone): 166.01 kg/barrel, Flash point -9~-4°C, Boiling point 88-100°C

2.3 Test pan

A square pan made of steel is used with the dimensions as per FM 5130, which is 2.16 m X 2.16 m (4.7 m^2), Min. 305 mm deep. The pan was placed on the cement boards on the testing concrete pad. No backboard over the pan was used in the tests.

2.4 Foam Application Methods

Two different application methods were tested:

- The topside application using the Fireflex ICAF system
- Handheld application using a firehose as per OIAA practices with or without the OIAA CAF system

For the ICAF system, pipelines were built as shown in Figure 1. The pipelines were designed for four nozzles, with one on each side of the pan, yet in each test only two nozzles were selected and operated depending on the wind direction. The nozzles were installed at height of 0.9 m (3 ft) for the design spray density of 0.04 or 0.025 USGPM/ft^2 (1.0 LPM/m^2) for hydrocarbon fuel fires and 0.06 USGPM/ft^2 (2.4 LPM/m^2) for polar solvent fires. In supplying air in the ICAF system, a bank of eight cylinders (11BC615 with the volume of approximately 80 L each) were used, and a concentrate tank (with the volume of 25 gallons) supplied the system with foam concentrate. The pipelines for the aspirated foam mixture by the ICAF system was manually opened and closed during the tests. Also, a water line for a sprinkler nozzle (with a K-factor of 5.6 GPM/$psi^{1/2}$ (80 LPM/$bar^{1/2}$)) was also built to be used in testing of the ICAF system for the hydrocarbon fuel fire tests. The design density of the sprinkler nozzle was 0.3 USGPM/ft^2 (12.2 LPM/m^2).

For the handheld application, firefighters held a firehose and manually directed the spray over the fire area. Figure 2 shows the handheld application using a firehose. Figure 3 shows the nozzles used in the tests: a Fireflex nozzles for the ICAF system, a manual hose for the OIAA CAF system and a manual hose for the pre-mixed foam application.

Figure 1 Fireflex ICAF system for the topside application

Figure 2 Handheld application using a firehose as per OIAA practices with the OIAA CAF system

a) FireFlex nozzle TAR225

b) OIAA CAF nozzle

c) OIAA nozzle

Figure 3 Nozzles used in the tests

2.5 Test matrix

A total of 8 tests were conducted, and Table 1 shows the weather conditions, fuel, discharge method, and foam concentration used in each test.

Table 1 Test Matrix

Test #	Date	Weather	Application	Discharge Method	Fuel	Polar or Hydrocarbon	Foam
1	Oct.14, 2022	14.5°C, 19 km/hr	Fireflex ICAF	topside / 2 Nozzles	Heptane	Hydrocarbon	VIKING Enviro ARK
2	Oct.14, 2022	16.6°C, 24 km/hr	Fireflex ICAF	topside / 2 Nozzles	IPA	Polar	VIKING Enviro ARK
3	Oct. 18, 2022	9.6°C, 12 km/hr	Fireflex ICAF	topside / 2 Nozzles	MEK	Polar	VIKING Enviro ARK
4	Oct. 18, 2022	9.7°C, 13 km/hr	Fireflex ICAF	topside / 2 Nozzles	Heptane	Hydrocarbon	VIKING Enviro ARK
5	Oct. 18, 2022	8.8°C, 14 km/hr	Fireflex ICAF	topside / 2 Nozzles	Jet Fuel	Hydrocarbon	EcopoleA
6	Nov.14, 2022	0.0°C, 23 km/hr	OIAA CAF	manual hose	Jet Fuel	Hydrocarbon	EcopoleA
7	Nov.14, 2022	0.7°C, 18 km/hr	OIAA CAF	manual hose	Jet Fuel	Hydrocarbon	EcopoleA
8	Nov.14, 2022	0.3°C, 24 km/hr	OIAA without CAF	manual hose	Jet Fuel	Hydrocarbon	EcopoleA

3 Test results

The 8 tests were conducted, and in each test fire extinguishment time was recorded. Also, the results of torch tests and burnback flame resistance tests were recorded. Appendix A provides photos taken during the 8 tests.

3.1 The topside application using the Fireflex ICAF system for hydrocarbon fuel and polar solvent fires

The topside application using the Fireflex ICAF system for hydrocarbon fuel fires

Hydrocarbon fuel (heptane or Jet A) of approximately 105 liters (55 USgallons) was poured in the pan filled with water (0.5-inch-thick water substrate). After the pan was ignited, the hydrocarbon fuel fire was allowed to free-burn for a period of approximately 15 seconds, which is consistent with the free-burn time required for sprinkler or CAF nozzles by FM 5130, Foam Extinguishing Systems. Then, the pipeline was manually opened to apply the foam solution at the prescribed rate of 45 LPM of water and 3LPM of 6% foam concentrate for polar solvents or 1 LPM of 2% foam concentrate for hydrocarbon fuels. The duration of spray was 5 minutes. It should be noted that approximately 50% of the sprayed foam solution applied outside the test pan as per the designed nozzle layout. Following the end of foam application, the water sprinkler nozzle was open and operated for 5 minutes, which is consistent with the test requirement for sprinkler and CAF nozzles test for a hydrocarbon fuel fire in FM 5130. The intent of this water sprinkler operation is to evaluate any degradation of the foam blanket by the water spray. After one minute from the end of water sprinkler operation, a first torch test was conducted by passing a

flaming torch above the foam blanket (approximately two inches above), which is to confirm the foam blanket's ability to seal the fuel vapors. A second torch test was performed after 6 minutes from the end of the first torch test. In 1 minute after the second torch test, a stove pipe was placed in a corner of the pan, and the foam in the stove pipe was removed. The fuel in the stove pipe was ignited and allowed to burn for about one minute, and then the stove pipe was removed. The burnback test result was observed, and the time of failure when the fire spread over an area of 10 ft^2 was recorded.

- Two different foam products of VIKING Environ ARK and EcopoleA were tested for a heptane fire in Test #4 and a Jet A fire in Test #5. The two products were prepared at the concentration of approximately 3%, which is the manufacture's design concentration for hydrocarbon fuel fires. The expansion ratios of the two foam solutions were measured, and a similar value of approximately 11 was obtained for both solutions. However, their measured 25% drainage times were quite different as EcopoleA resulted in a much shorter drainage time than the other foam (see Table 2). Generally, the drainage time gives indication on how fast the foam solution is released from the bubble mass and loses its foam stability.
- The hydrocarbon fuel fires were extinguished in 1 minute 30 seconds in Test #4 and in 1 minute in Test #5 from the foam application. Also, in Test #4 and #5, they passed the torch tests, which demonstrated the fuel shedding ability of the foam blankets to block fuel diffusion through the fuel blankets. It should be noted that the torch test results also demonstrated the stability of the foam blankets with no significant degradation by the water only sprinkler operation (5 minutes) following the foam application (5 minutes).
- In Test #4 and #5, the burnback tests were conducted after a while (i.e., the time of removing the stove pipe was in 15 minutes from the end of foam application) to afford potential foam drainage/collapse making the foam more susceptible to burnback. In Test #4 and #5, the flame in the hole in the foam blanket made by the burnback stove pipe self-extinguished quickly since the surrounding foam blankets were able to expand and cover the flame/hole area before the flame affected/burned the surrounding foam and fuel in the test pan.
- When the same foam (the VIKING Enviro ARK) was tested at a concentration of 2%, lower than the manufacturer's design concentration for a hydrocarbon fuel fire, as in Test #1, fire was extinguished, and the foam blanket passed the torch tests. However, the foam blanket failed to resist the burnback flame as the flame spread out fast and burned the surrounding foam blanket and fuel.

Table 2 Test results from the topside application using the ICAF system for hydrocarbon fuel fires

Test #	**1**	**4**	**5**
Application	Fireflex CAF	Fireflex CAF	Fireflex CAF
Discharge Method	topside / 2 Nozzles	topside / 2 Nozzles	topside / 2 Nozzles
Fuel	Heptane	Heptane	Jet Fuel
Polar or Hydrocarbon	Hydrocarbon	Hydrocarbon	Hydrocarbon
pressure (PSI)	100	100	100
flow rate (LPM)	45	45	45
Sprinkler water flow rate	not measured	130 LPM (1 sprinkler nozzle)	121 LPM (1 sprinkler nozzle)
Foam	VIKING Enviro ARK	VIKING Enviro ARK	EcopoleA
Foam concentration	2%	3.5%	3.62%
Foam expansion ratio	11.83	11.17	11.24

25% Foam drain time	15 minute 26 second	27 minute 14 second	23 minute 56 second
Preburn time	15 second	20 second	23 second
Spray duration	5 minute	5 minute	4 minute 52 second
Fire extinguishment time	1 minute 45 second from foam application	1 minute 30 second from foam application	1 minute from foam application
Water spray duration (minute)	5	5	5
Torch Test 1st	pass @1 minute after water ends	pass @1 minute after water ends	pass @1 minute after water ends
Torch Test 2nd	pass @6 minute after 1st torch test	pass @6 minute after 1st torch test	pass @6 minute after 1st torch test
Pipe in and out	In in 1 minute after 2nd torch, out in 2 minute	In in 1 minute after 2nd torch, out in 2 minute	In in 1 minute after 2nd torch, out in 2 minute
Burnback test	Failed @ 3 minute after the pipe out (foam blanket was washout from water discharge)	Pass (self extinguish)	Pass (self extinguish)

The topside application using the Fireflex ICAF system for polar solvent fires

Polar solvent fire tests followed the similar procedure of the hydrocarbon fuel fire test, yet the water sprinkler nozzle was not operated as FM 5130 does not require it for polar solvent fires.

Polar solvents of IPA or MEK with a volume of approximately 105 liters (55 USgallons) was poured in the pan with no water substrate. After the pan was ignited, the polar solvent fire was allowed to free-burn for a period of approximately 10-17 seconds, which is again consistent with the 15 seconds of free-burn time required for sprinkler or CAF nozzles by FM 5130. Then, the pipeline was manually opened to apply the foam solution at the prescribed rate of 45 LPM and for the duration of approximately 5 minutes. It should be noted that approximately 50% of the sprayed foam solution applied outside the test pan as per the designed nozzle layout. After one minute from the end of foam application, a first torch test was conducted by passing a flaming torch above the foam blanket (approximately two inches above), and a second torch test was performed after a while (approximately 11 minutes) from the end of the first torch test. In 1 minute after the second torch test, a stove pipe was placed in a corner of the pan, and the foam in the stove pipe was removed. The fuel in the stove pipe was ignited and allowed to burn for about 1 minute, and then the stove pipe was removed. The burnback test result was observed.

- VIKING Enviro ARK (alcohol resistant foam) was tested for an IPA fire in Test #2 and a MEK fire in Test #3. The foam solution was prepared for the concentration of approximately 6%, which is the manufacture's design concentration for polar solvent fires. It should be noted that EcopoleA is not alcohol resistant and cannot be applied to polar solvent fires. The measured expansion ratio of the foam solution was approximately 11, and the measured 25% drainage time was approximately 46 minutes, which is much longer than that of the same foam solution at 3%.
- The IPA fuel fire was extinguished in 3 minutes 52 seconds from foam application in Test #2, but the MEK fire was not extinguished in Test #3 as the tested FFF solution dissolved in the fuel.
- Thus, torch tests were conducted only in Test #2, and it passed the torch tests, demonstrating the fuel shedding ability of the foam blankets to fuel diffusion.

- In Test # 2, the burnback test was conducted in approximately 15 minutes from the end of foam application, and the surrounding foam blanket quickly spread and covered the hole made by the burnback stove pipe and extinguished the flame.

Table 3 Test results from the topside application using the ICAF system for polar solvent fires

Test #	**2**	**3**
Application	Fireflex CAF	Fireflex CAF
Discharge Method	topside / 2 Nozzles TAR225	topside / 2 Nozzles TAR225
Fuel	IPA	MEK
Polar or Hydrocarbon	Polar	Polar
pressure (PSI)	100	100
flow rate (LPM)	45	45
Sprinkler water flow rate	n/a	n/a
Foam	VIKING Enviro ARK	VIKING Enviro ARK
Foam concentration	6%	6%
Foam expansion ratio	10.92	not measured
25% Foam drain time	45 minute 48 second	not measured
Preburn time	17 second	10 second
Spray duration	4 minute 58 second	5 minute
Fire extinguishment time	3 minute 52 second from foam application	failed
Water spray duration (minute)	n/a	n/a
Torch Test 1st	pass @1 minute after foam ends	n/a
Torch Test 2nd	pass @11 minute after 1st torch test	n/a
Pipe in and out	In in 1 minute after 2nd torch, out in 2 minute	n/a
Burnback test	Pass (self extinguish)	n/a

3.2 The manual hose application for hydrocarbon fuel fires

The manual hose application for hydrocarbon fires

The manual hose application tests were conducted with and without the OIAA CAF system. Hydrocarbon Jet A fuel of approximately 105 liter (55 USgallons) was poured in the pan filled with water (0.5 ~1 inch-thick water substrate). After the pan was ignited, the hydrocarbon fuel fire was allowed to free-burn for a period of approximately 60 seconds, which is consistent with the free burn time required by the ICAO tests. Then,

firefighters manually applied the foam solution using the hose line at the prescribed pressure of 116 psi for the OIAA CAF system or 140 psi for OIAA system without CAF. The duration of application was 1-2 minutes. It should be noted that 50±10% of the sprayed foam solution applied outside the test pan. After one minute from the end of foam application, a first torch test was conducted by passing a flaming torch above the foam blanket, and a second torch test was performed after 6-7 minutes from the end of the first torch test. In 1 minute after the second torch test, a stove pipe was placed in a corner of the pan, and the foam in the stove pipe was removed to ignite the fuel underneath. Then, the stove pipe was removed, and the burnback test result was observed.

- EcopoleA was tested for a Jet A fire in Test #6, #7 and #8. The foam solution was prepared for the concentration of approximately 3%, which is the manufacture's design concentration for hydrocarbon fuel fires. In Test #6 and #7, the 3% foam solution was aspirated using the OIAA CAF system equipped in their firefighting truck, and in Test #8, the CAF system was not used, and the premixed foam was applied.
- In Test #6, #7 and #8, the Jet A fire was extinguished in 46 seconds, 40 seconds, and 25 seconds from the start of foam application, respectively. The shortest extinguishment time resulted from Test #8 is attributed to the higher spray pressure/flow rate used in the manual nozzle.
- The duration of foam application was 1 minute 46 second, 2 minutes, and 1 minute 25 second in Test #6, #7 and #8, respectively. It should be noted that the spray duration is not proportional to the amount of the foam applied to the test pan, yet the thickness of the foam blanket was thicker in Test #7 than Test #6.
- Both foam solutions applied with and without the CAF passed the torch tests, demonstrating the fuel shedding ability of the foam blankets to fuel diffusion. It should be noted that the boiling point of Jet A fuel is higher than that of heptane.
- In Test #6, #7 and #8, the burnback tests were conducted after a while (i.e., the time of removing the stove pipe was approximately 11-13 minutes from the end of foam application). The foam blanket failed on the burnback flame resistance test in Test #6, unlike in Test #7, which is attributed to the longer spray duration and relatively thick foam blanket formed in Test #7. In Test #8, where no CAF was used, the flame in the hole over the foam blanket made by the burnback stove pipe self-extinguished quickly by the surrounding foam blankets closing the flame/hole area.

Table 4 Test results from the manual hose application for a hydrocarbon fuel fire

Test #	**6**	**7**	**8**
Application	OIAA CAF	OIAA CAF	OIAA without CAF
Discharge Method	manual hose	manual hose	manual hose
Fuel	Jet Fuel	Jet Fuel	Jet Fuel
Polar or Hydrocarbon	Hydrocarbon	Hydrocarbon	Hydrocarbon
pressure (PSI)	approx. 116	approx. 116	approx. 140
flow rate (LPM)	Not known	Not known	Not known
Sprinkler water flow rate	n/a	n/a	n/a
Foam	EcopoleA	EcopoleA	EcopoleA
Foam concentration	3%	3%	3%
Foam expansion ratio	not measured	not measured	not measured

25% Foam drain time	not measured	not measured	not measured
Preburn time	60 second	60 second	60 second
Spray duration	1 minute 46 second	2 minute	1 minute 25 second
Fire extinguishment time	46 second from foam application	40 second from foam application	25 second from foam application
Water spray duration (minute)	n/a	n/a	n/a
Torch Test 1st	pass @1 minute after foam ends	pass @1 minute after foam ends	pass @1 minute after foam ends
Torch Test 2nd	pass @7 minute after 1st torch test	pass @7 minute after 1st torch test	pass @7 minute after 1st torch test
Pipe in and out	In in 1 minute after 2nd torch, out in 2 minute	In in 1 minute after 2nd torch, out in 2 minute	In in 1 minute after 2nd torch, out in 2 minute
Burnback test	failed	Pass (self extinguish)	Pass (self extinguish)

4 Conclusions

- The performance of selected FFFs were tested for various foam concentrations, fuels (including hydrocarbon fuels and polar solvents), application methods (CAF/air aspirating foam via sprinkler system, manual CAF, and premixed hose applications) as well as various flow rates and spray durations. The tests were conducted using a pan with an area of 4.7 m^2.
- The test results ensured that the concentration of the foam solution should follow the manufacturers' design concentration to achieve timely fire extinguishment, and effective burnback flame resistance. Also, the foam solution was not able to resist the burnback flame when the spray duration was relatively short, and the foam blanket over the fuel surface was not thick enough.
- The tested FFFs applied via the FireFlex ICAF system extinguished the hydrocarbon fuel fires (e.g., Heptane, Jet A) in approximately 1-2 minutes and the polar solvent IPA fire in approximately 4 minutes from the start of foam application. It should be noted that a polar solvent MEK fire was not extinguished as the tested FFF solution dissolved in the fuel. However, no other foam concentrate, even a C8/C6 foam has been reported to pass the test. Thus, it is important to test FFFs for fuels, fire sizes and application methods of interest to define the extent of their performance.
- The tested FFF applied using the manual firefighting hose with the OIAA CAF system extinguished the Jet A fire in 40-46 seconds from the start of foam application. When applied without the CAF, the Jet A fire was extinguished rapidly within 25 seconds from the start of foam application. It should be noted that the tested FFF demonstrated rapid fire extinguishment in the tests because the tested fire size was relatively too small for the pressure of the tested manual hose application.

Appendix A: Test Photos

		
Preparation	Fire ignition	
		
	Spray foam	Spray foam
		
Fire Suppression by the foam	Spraywater	First torch test
		
First torch test	Second torch test	
		

Figure 4 Day 1 – Test #1

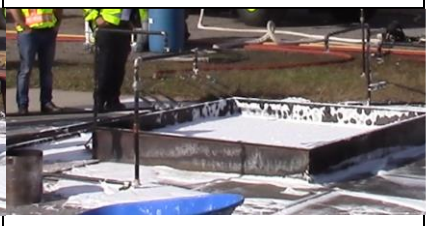
		
Fuel preparation	Ignition	Spray foam
		
Spray foam	Spray foam	Spray foam
		
Fire suppression	Torch test	Add stove pipe
		
Fire in stove pipe	Remove stove pipe	Fire extinguished

Figure 5 Day 1 Test #2

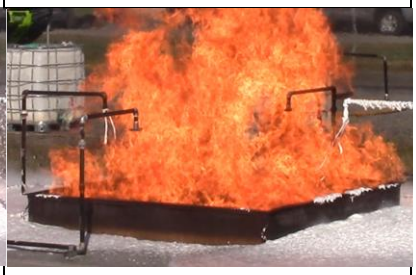
		
Fuel Preparation	Fire ignition	
		
Spray foam	Spray foam	Spray foam
		
		Burned out

Figure 6 Day 2 Test #3

		
Fuel preparation	Fire ignition	
		
Spray foam	Spray foam	Fire suppression by foam
		
Spray water	Torch test	Add stove pipe
		
Ignite stove pipe	Remove stove pipe	
		
Fire suppressed by foam	Cleaning foams	Cleaning for the next test

Figure 7 Day 2, Test #4

		
Preparation of fuel	Fire ignition	Spray foam
		
Fire suppressed by foam	Spray water	First torch test
		
Add stove pipe		Ignite stove pipe
		
Remove stove pipe	Foam suppressed fire	Cleaning

Figure 8 Day 2 Test #5

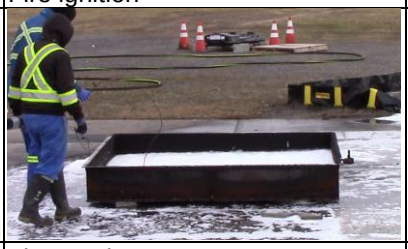
		
Preparation of fuel	Fire ignition	Spray foam
		
Fire suppressed by foam	First torch test	Add stove pipe
		
Ignite stove pipe	Remove stove pipe	
		
Foam didn’t suppress fire	Foam didn’t suppress fire	

Figure 9 Day 3 Test #6


Preparation

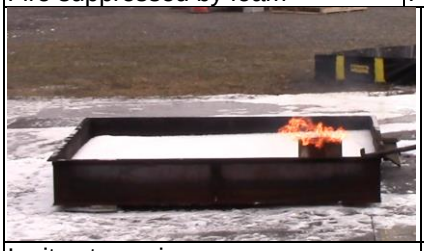

Fire ignition


Spray foam


Fire suppressed by foam


First torch test


Add stove pipe


Ignite stove pipe


Remove stove pipe


Foam suppressed fire


Cleaning

Figure 10 Day 3, Test #7

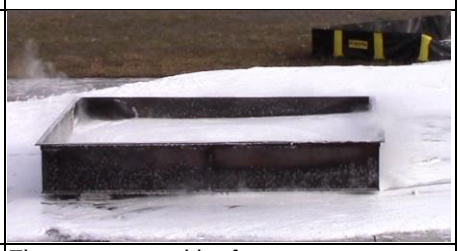
		
Igntion	Fire spread	
		
Spray foam	Spray foam	Fire suppressed by foam
		
First torch test	Second torch test	Add stove pipe
		
Ignite stove pipe	Remove stove pipe	Foam suppressed fire

Figure 11 Day 3 Test #8