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Establishing a Safety Factor for the Distribution Density Of Compressed-Air Foam and Evaluating CAF's Extinguishing Performance on Free-flowing Spill Fires

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Abstract

Compressed-air foam (CAF) has been proven to be an effective fire suppression material for both class A and B fires. Comparison testing between CAF and standard foam water sprinklers had been conducted previously to quantify the amount of CAF required to outperform a foam water sprinkler system in extinguishing a liquid fuel pan fire and provide superior burn-back protection as specified in the UL162 Foam Equipment and Liquid Concentrates standard. Concerns about variations in the delivered CAF density due to fluctuating water supply pressures and its performance on actual spill fires have been raised in the industry.

This paper describes a series of full-scale Class B fire tests designed to address these concerns. Tests were conducted, using the fire test method described in the UL162 Foam Equipment and Liquid Concentrates standard, to establish minimum and maximum delivered densities of CAF by varying the water supply pressures. A safety factor could then be associated with the normal design application density. Tests were also conducted on a 6 m by 6 m poured concrete slab to compare CAF and standard foam water sprinklers in extinguishing free flowing heptane spill fires with and without shielded areas. These fires ranged in size from 4.65 m^2 to 13 m^2.

1.0 Introduction

1.1 Background

Foam-water sprinkler systems have been designed with a safety factor of 1.6 when used in protection against flammable liquid fires as specified in UL 162 Foam Equipment and Liquid Concentrates standard. CAF (compressed-air foam) using ¼ of the water has been tested successfully and outperforms foam-water sprinklers operating with this safety factor. It was assumed that CAF would have a sufficient safety factor associated with its delivered density because of its superior performance. A number of reduced scale tests have been conducted that substantiate this assumption but questions concerning larger fires and variations in water supply pressures have been raised in the industry.

Concerns were also raised about CAF's ability to extinguish a more realistic fire scenario involving free-flowing spill fires. These fires are especially difficult to extinguish when they are shielded from the direct delivery of foam from the nozzle. This would be the case in hangers where large floor areas would be shielded by aircraft or other service vehicles.

1.2 Project Description

This report describes a series of 5 full-scale Class B fire tests designed to compare low and high water flow conditions with the normal CAF design flow condition and a standard foam water suppression system at the full delivered density of 6.5 L/min/m^2 (1.6 USgal/min/ft^2). The fire condition, suppression grid spacing and the method for determining burn-back protection are taken from the UL162 Foam Equipment and Liquid Concentrates standard.

An additional 9 tests were conducted comparing the extinguishing performance of CAF and foam-water sprinklers on free-flowing heptane spill fires with and without shielding. This fire ranged in size from 4.65 m^2 to 13 m^2.

2.0 Test Details

2.1 Test Facility

A complete description of the test facility, the foam apparatus and the instrumentation can be found in the complete reports # 180 and #174 (http://irc.nrc-cnrc.gc.ca/fulltext/rr180/ and http://irc.nrc-cnrc.gc.ca/fulltext/rr174/). The fire test pan was square, straight-sided, with an area of 4.65 m^2, and was constructed as required by UL-162. The test fire was a heptane pool fire using commercial grade heptane fuel. For the spill fire tests the pan was removed and fuel was delivered to the slab through a 25.4 mm diameter steel pipe fed by a control valve located away from the fire zone.

A grid of 4 CAF nozzles were positioned 10.7 m above the target area at a 3.73 m by 3.73 m spacing in a balanced "H" design fed by a 38 mm supply pipe. The test set-up is shown in Figure 1 below.

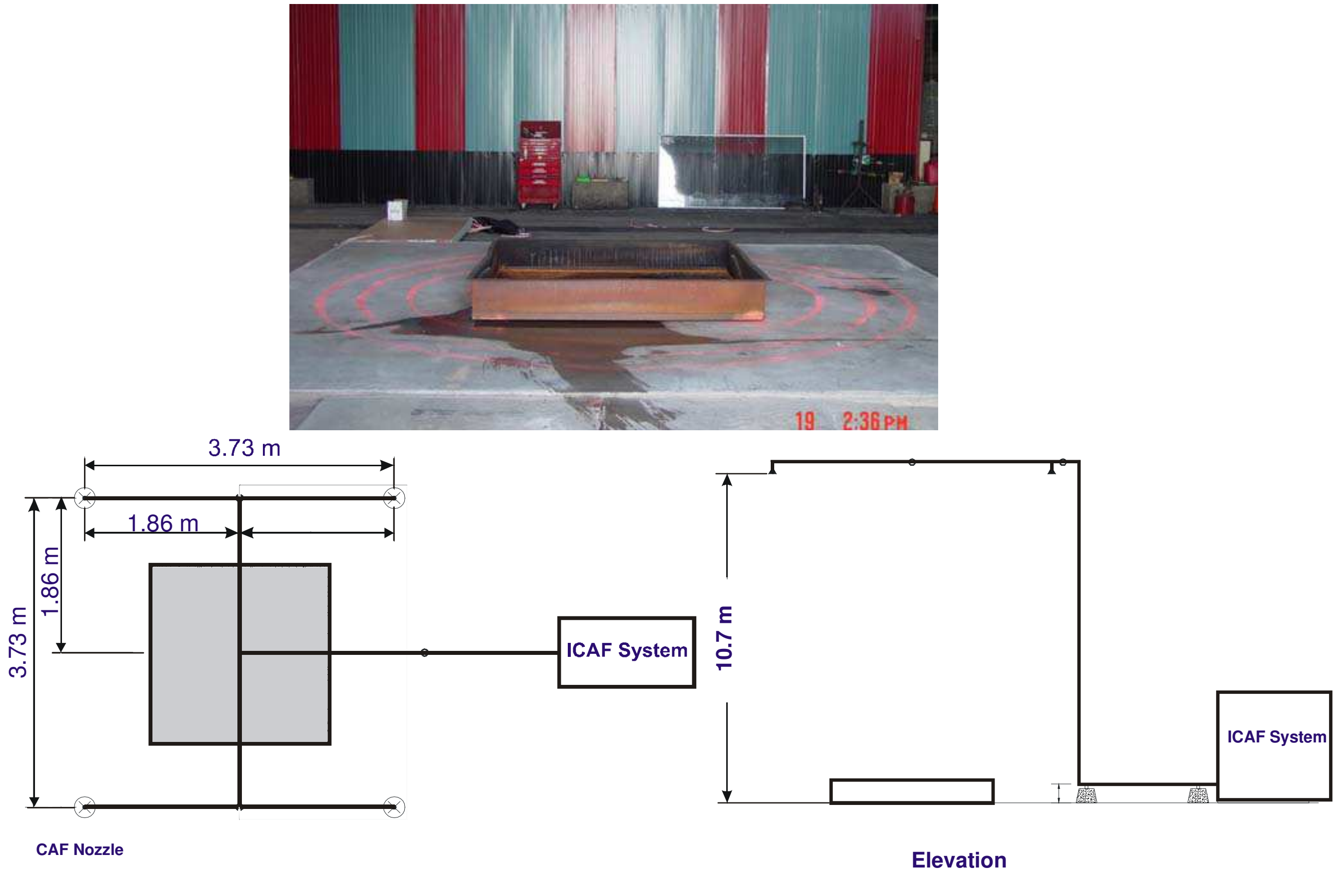


Figure 1. Fire test facility.

2.2 Foam Delivery Systems

The foam delivery system was supplied by FireFlex Systems Inc. and is shown in Figure 2.

Figure 2. Foam delivery apparatus.

This system mixes the correct amount of water, air and foam concentrate so that CAF can be formed in the delivery piping. The CAF is then distributed over the target area through 4 CAF rotary nozzles shown in Figure 3.

Figure 3. CAF delivery nozzle

2.3 Test Procedure

Water is added to the pan to cover the bottom to a depth of approximately 50mm. Heptane fuel (100 litres) is poured over the water. This is enough fuel for a free burn of 5 minutes 30 seconds and produces a lip height in the pan of 200 mm. The cameras are started and the fuel is ignited. The foam system is activated and the foam is delivered 15 seconds after ignition. The time to extinguishment is recorded and the foam system remains active for a total of 5 minutes. At 6 minutes from ignition a propane torch is passed over the surface of the foam blanket for a period of 1 minute. This stage is repeated at 14 minutes 15 seconds from ignition. At 16 minutes from ignition a stovepipe, 300 mm in diameter by 360 mm long, is placed in the pan 600 mm from each adjacent side in the corner where the fire extinguished last. The foam inside the pipe is removed and the fuel surface is ignited using the torch at 17 minutes. The pipe is removed at 18 minutes and the time to burn back 0.93 m^2 is recorded.

To be considered to pass the system must extinguish the fire within the 5 minutes of foam application and provide at least 5 minutes of burn-back protection after the stovepipe is removed. At no time during either of the 2 torch tests can sustained burning occur, should an area of the surface ignite. Some “ghost flames” are permitted during the burn-back portion however they must self extinguish within 30 seconds.

In the spill fire tests the pan is removed and the fuel valve is opened, spilling fuel on the centre of the slab for 45 seconds before ignition. The foam is applied 15 seconds later and is turned off when all flames are extinguished or a maximum time of 5 minutes has elapsed. A 1 metre square table was added for tests 11-14 to provide a shielded area.

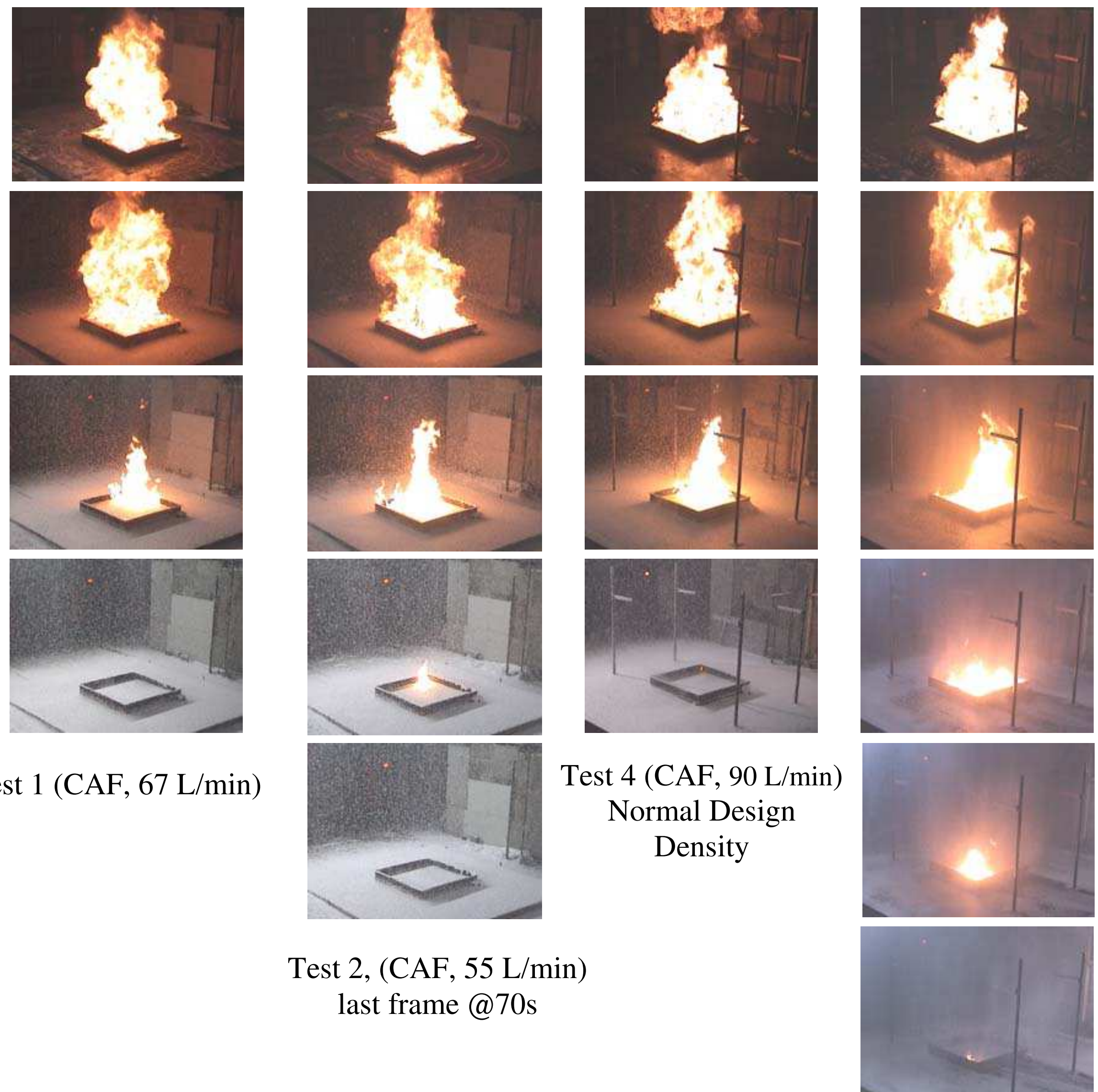
3.0 Results

3.1 Reduced Water Flow Tests

Tests 1 and 2 were reduced water flow tests. The normal design condition flow for the system is 90 L/min with 2% Class B foam concentration and an expansion of 10:1. This yields a distribution density of 1.63 $L/min/m^2$. Test 1 had a water flow of 67 L/min, which is reduced by a factor of 1.33 from the normal condition. The concentration of the Class B foam solution increased to 2.7% since the concentrate injection is independent of water flow and assumes the normal flow condition is achieved. This yields a distribution density of 1.22 L/min/m^2. Test 2 had a water flow of 55 L/min, which is reduced by a factor of 1.64 from the normal condition. The concentration of the Class B foam solution increased to 3.3 %. This yields a distribution density of 1.0 L/min/m^2.

Test 1 extinguished the fire in 1minute and had the same extinguishment performance as the normal flow condition test. It provided 15 minutes of burn-back protection compared to 30 minutes 45 seconds for the normal condition. By comparison the foam water sprinkler system at a density of 6.5 L/min/m^2, extinguished the fire 1 minute 40 seconds and provided 17 minutes 9 seconds of burn-back protection. Test 2 extinguished the fire in 1 minute 10 seconds and provided 10 minutes of burn-back protection.

The extinguishment photo sequences for Test 1 and 2 are shown side by side with the normal condition test and the foam-water sprinkler test in Figure 4.



Test 1 (CAF, 67 L/min)

Test 4 (CAF, 90 L/min)
Normal Design
Density

Test 2, (CAF, 55 L/min)
last frame @70s

Figure 4: Extinguishment photo sequences @ 20 second intervals starting from foam system activation.

Test 5, (FWS, 360 L/min)
Normal Design Density

3.2 High Water Flow Test

Test 3 had a water flow rate of 144 L/min, which was increased from the normal condition test by a factor of 1.6. This reduced the solution concentration to 1.2% since the concentrate injection is independent of water flow and assumes the normal flow condition is achieved. Test 3 extinguished the fire in 1 minute 31 seconds and provided 16 minutes 50 seconds of burn-back protection. Figure 5 shows the side by side photo extinguishment sequences for Test 3 compared to the normal condition test and the foam-water sprinkler test.

Test 3, (CAF, 144 L/min) last frame @ 91s

Test 4, (CAF,90 L/min) Normal Design Density

Test 5, (FWS, 360 L/min) Normal Design Density

Figure 5: Extinguishment photo sequences @ 20 second intervals starting from foam system activation.

Table 1. Test Results

Test Description				Foam Distribution; litres/min/m^2 (USgal/min/ft^2)	Extinguishment time (s)	Burn-Back time min:s
Test #	**Foam Type**	**Flow Condition; L/min**	**Foam Condition Conc. (expansion)**			
1	CAF B	reduced; 67	2.7% (14.5:1)	1.21 (.03)	60	15:00
2	CAF B	reduced; 55	3.3% (17.3:1)	1.0 (.024)	70	10:00
3	CAF B	increased; 144	1.2% (6:1)	2.61 (.064)	91	16:50
4	CAF B	normal; 90	2% (10:1)	1.63 (.04)	60	30:50
5	Foam -water Sprinkler	normal; 360	3% (3:1)	6.5 (.16)	100	17:09

4.0 Results

4.1 Unshielded Spill Fire Tests

Tests 6 to 10 were unshielded spill fire tests to establish comparisons with pan fires of the same size. The 8 L/min fuel flow rate required for the 4.65 m^2 fire was increased to 22.5 L/min and produced a fire area over 13 m^2 for all the remaining tests.

Test 10 was an unconfined and unshielded fire with a 22.5 L/min fuel flow rate. The heat flux shown in Figure 6 is significantly higher than the smaller fires from Tests 1 to 4 and the time required to extinguish the fire to the fuelling outlets is approximately 30 seconds longer.

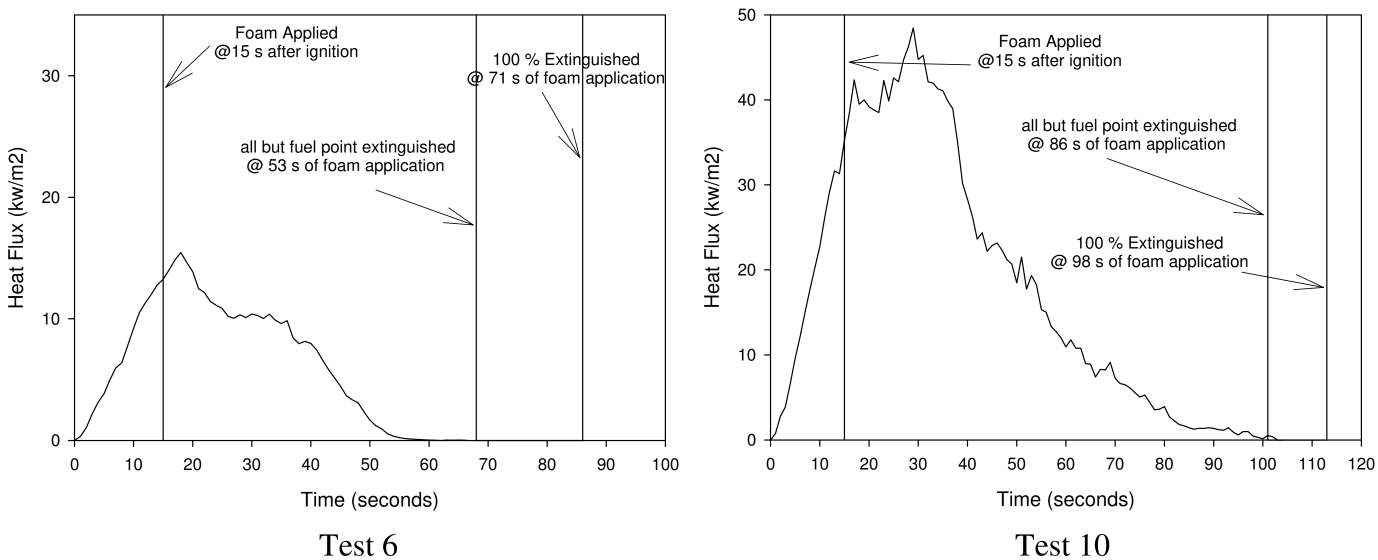


Figure 6. Heat flux from the 4.65 m^2 and the 13 m^2 fire size

Figure 7 shows the photo extinguishing sequence from the smaller fire of Test 8 and the larger fire from Test 10. The time to completely extinguish the larger fire is 16 seconds longer than the smaller fire of Test 8. The photo frames are at 30-second intervals from foam application on the top to the second last frame from the bottom. The last frame shows the exact extinguishment time.

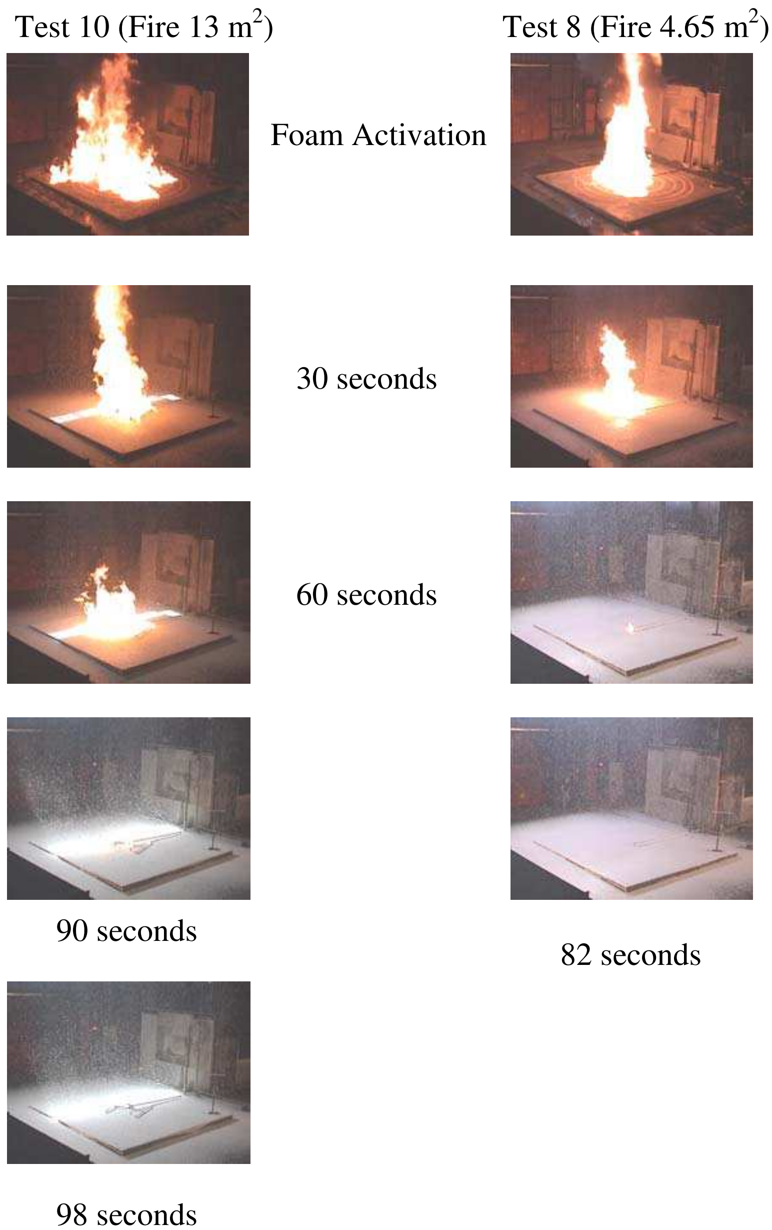


Figure 7. Photo sequence for Test 10 and Test 8.

4.2 Shielded Spill Fire Tests

Tests 11 to 14 were shielded tests incorporating a 1 m by 1 m by 0.8 m high steel table positioned over one of the four fuel outlets. The area of shielding is shown in Figure 8.

Figure 8. Shielded area under table.

In order to extinguish the fire under the table the foam must build up and flow. This is made more difficult by the dynamics of the flowing stream of fuel exiting the outlet. Under these conditions the CAF system in Test 11 was able to confine the fire to the shielded area in less than 90 seconds and choke the fire to a candle size in less than 2 minutes. The fire continued to candle until the outlet was buried by the CAF blanket and was extinguished at 4 min 58 s. The foam water sprinklers (Test 8) had a faster knock down due to its greater flow characteristics but once a water layer formed on the slab the fuel was floated on the surface and the fire increased in size and spread, flowing flames at times off the slab. At the end of 5 minutes of foam water application the fire was stable and not reducing in size. Figure 9 compares Test 11 (90 L/min CAF at 2% Class B concentration) with the Foam water sprinkler Test 13 (360 L/min at 3% concentration).

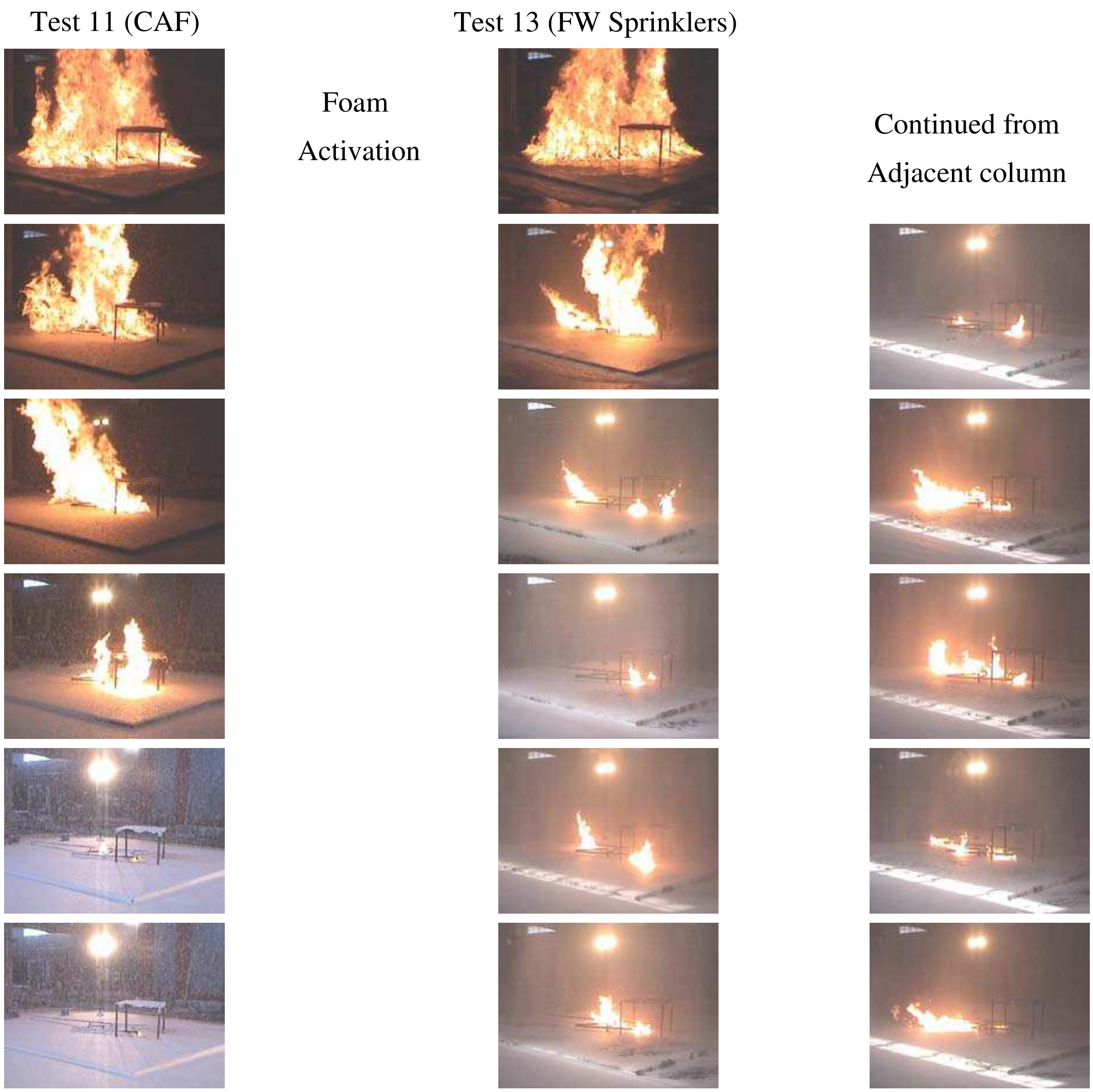


Figure 9. Extinguishment sequences at 30 s intervals

4.3 Milspec Shielded Fire Tests

Test 12 and Test 14 had the same conditions as Tests 11 and 13 except the regular Class B foam was replaced with milspec Class B foam. The milspec foam performed better than the standard foam in both the CAF and foam water sprinkler tests. The greatest difference was the initial knock down time being 20 to 30 seconds faster with the milspec foam. In the case of the foam water sprinklers it also controlled the fire better than the standard foam keeping the flare-ups suppressed and not allowing fire to spread as easily after several minutes of application. At the end of the 5 minute application time it was unable to completely extinguish the fire in the foam water sprinkler test but the fire was small and confined to the shielded area at the fuel outlet. Figure 10 shows the side-by-side photo extinguishment sequences for the milspec foam tests.

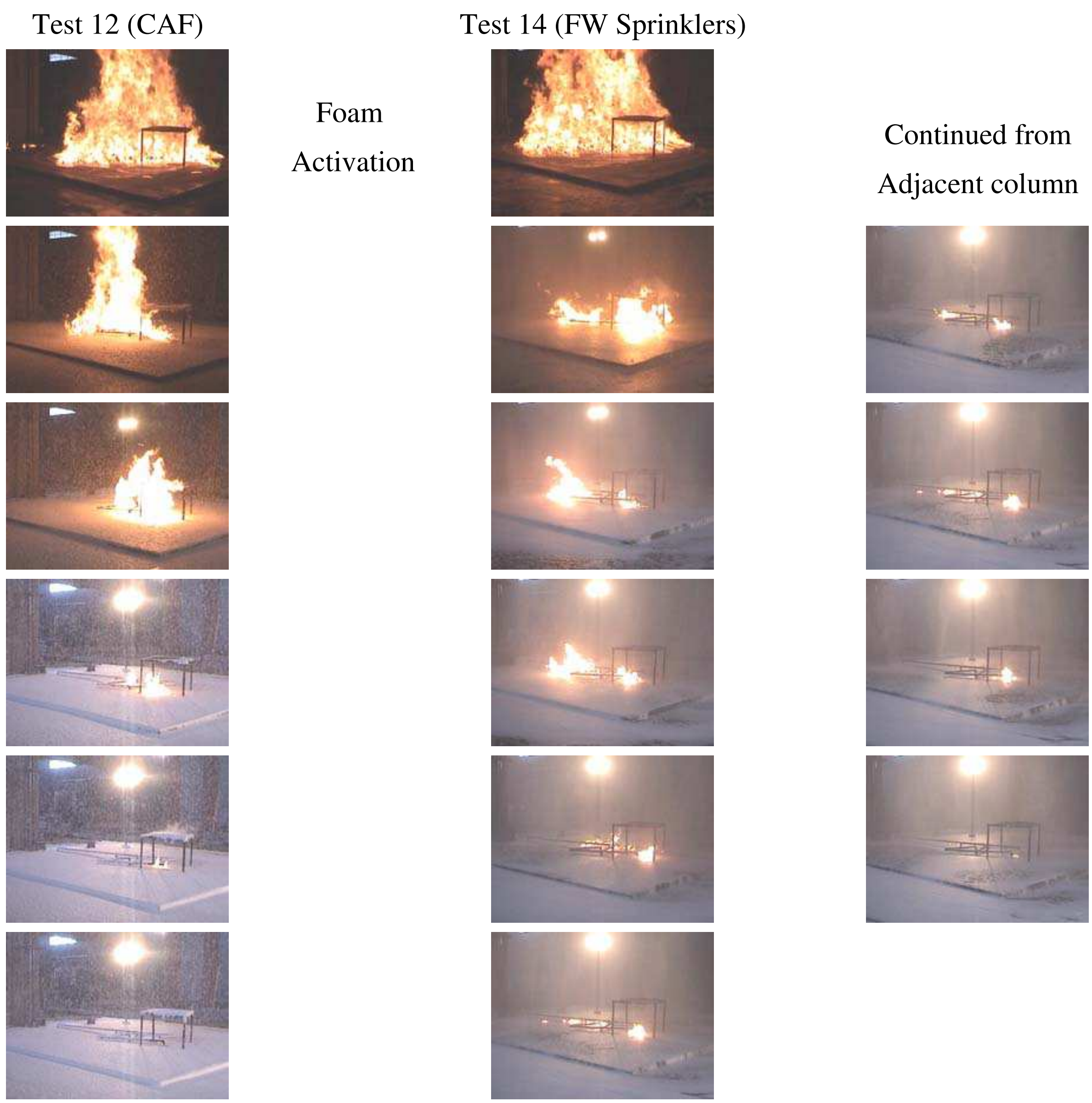


Figure 10. Extinguishment sequences at 30 s intervals

Table 2. Spill Fire Test Results

Test Description					Foam Distribution; litres/min/m^2	Fire Size Mw	Extinguishment time; min:s	
Test #	Foam Type	Heptane Fuel Flow rate	Shielded Fire	Solution Flow; L/min			99%	100%
6	CAF B, 2%	11 L/ min	no (confined to 4.65m^2)	90	1.63	<6	0:53	1:13
7	CAF B, 2%	11 L/ min	no (confined to 4.65m^2)	90	1.63	<6	1:00	1:08
8	CAF B, 2%	11 L/ min	no (unconfined >4.65m^2)	90	1.63	6	0:46	1:22
9	CAF B, 2%	11 L/ min	no (unconfined >4.65m^2)	90	1.63	6	1:05	1:28
10	CAF B, 2%	22.5 L/ min	no (unconfined >13m^2)	90	1.63	11.5	1:26	1:38
11	CAF B, 2%	22.5 L/ min	yes (unconfined >13m^2)	90	1.63	11.5	1:55	4:58
12	CAF Milspec B, 2%	22.5 L/ min	yes (unconfined >13m^2)	90	1.63	11.5	1:45	4:20
13	FWS Class B, 3%	22.5 L/ min	yes (unconfined >13m^2)	360	6.5	11.5	1:30	not ext.
14	FWS Milspec B, 3%	22.5 L/ min	yes (unconfined >13m^2)	360	6.5	11.5	2:00	not ext.

5.0 Conclusions

The extinguishment performance in the reduced flow tests has shown that the normal CAF design density of 1.63 L/min/m^2 (0.04 USgal/min/ft^2) has a safety factor associated with it that is greater than 1.6. Test 2, at 55 L/min flow rate was able to exceed the extinguishment performance of the standard foam-water sprinkler system by 30 seconds. It would appear that the delivered density could be reduced even further, however the burn-back protection drops off more rapidly with the dryer foam than the extinguishment performance. The burn-back protection dropped from over 30 minutes to 10 minutes. This is still a factor of 2 over the required 5 minutes but a further reduction in density would be very close to the minimum acceptable performance. It should be noted that the standard foam-water sprinkler system using 6.5 times more water flow and 6 times more concentrate flow took over 42% longer to extinguish the fire.

The high flow CAF test (144 L/min) had the poorest performance in the CAF series. This was due primarily to the solution concentration being reduced to 1.2% from 2% in the normal condition. Previous testing has shown that CAF will suffer extinguishment performance losses with concentrations less than 1.5% using standard Class B foam. This condition still extinguished the fire 9 seconds faster than the standard foam-water sprinkler system and provided the same burn-back protection (~17 minutes). This condition can be greatly improved by ensuring the concentration does not drop much below 2% when the variable high flow condition is expected. This high flow test also demonstrates that the fire extinguishing performance of the system is not improved by adding more water alone.

The CAF system was able to suppress a 4.65 m^2 free-flowing spill fire as fast as the 4.65 m^2 pan fire. It took longer to completely extinguish the spill fire due to the difficulty in covering the fuel flowing from the outlet. When the fire was increased to 3 times the area and heat release, the CAF system took less than 30 seconds longer to suppress the fire and only 16 seconds longer to completely extinguish it. The foam water sprinkler system was able to suppress the spill fire faster than the pan fire due to the addition of the fast flowing foam water on the slab combining with the foam water landing on the fuel surface directly. The pan fire must be extinguished by the latter method only. After only 30 seconds of discharge the depth of foam water on the slab was enough to reduce the benefit of the flowing foam water and allow the fuel to ride on top without a great deal of interaction between the two. In the standard Class B foam tests this gave the fire the opportunity to actually grow in size and free flow off of the slab. This situation is not desirable since the fire could be floated out of the protected zone or be allowed to burn back quickly should the system run out of concentrate or water. After the sprinkler test was over there was no fuel left on the slab to clean up. All of the fuel was deposited into the trenched area which had filled and overflowed. In contrast to this the CAF system was able to build up and completely extinguish the fire. After 30 seconds the CAF had build up on the slab and began to flow. The flow of CAF unlike the flow of foam water was able to cover the surface of the fuel and not flow under it. At the end of the tests most of the fuel remained on the slab in the protected zone and the less dense CAF had covered the fuel surface and overflowed the slab leaving the fuel behind. This could be extremely beneficial in fuel storage areas protected by dykes where the fuel can be contained within the dyke and the CAF can overflow reducing the danger of spreading the fuel.

The CAF system was able to suppress the large free-flowing spill fires using 25% of the water flow and a factor of 6 less concentrate when compared to the foam water sprinkler system. It was able to extinguish the fires completely by covering the fuel outlet while the foam water sprinkler system could not. CAF was able to flow under the shielded area after 30 seconds of discharge. Visibility was well maintained throughout the CAF tests with very low steam production.

6.0 Acknowledgements

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