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## **The Comparison of the Fire Suppression Performance of Compressed-Air Foam with Foam Water Sprinklers on Free-Flowing Heptane Spill Fires**

**Crampton, G.; Kim, A.**

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## ***The Comparison of the Fire Suppression Performance of Compressed-Air Foam with Foam Water Sprinklers on Free-Flowing Heptane 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 foam required to extinguish a liquid fuel fire that was contained within the bounds of a pan as specified in the UL162 Foam Equipment and Liquid Concentrates standard. To date only a few smaller scale tests had been conducted using CAF to extinguish free flowing spill fires.

This paper describes a series of full-scale Class B fire tests designed to compare CAF (Compressed-air Foam) and standard foam water sprinklers in extinguishing free flowing spill fires with and without shielded areas.

## Table of Contents

Abstract.....	i
Table of Contents.....	ii
1.0 Introduction.....	1
1.1 Background.....	1
1.2 Project Description.....	1
2.0 Test Details.....	2
2.1 Test Facility.....	2
2.2 Foam Delivery Systems.....	3
2.3 Instrumentation.....	4
2.4 Test Procedure.....	5
3.0 Results.....	5
3.1 Pan and Spill fire Comparison Tests.....	5
3.2 Unshielded Spill Fire Tests.....	9
3.3 Shielded Spill Fire Tests.....	11
3.4 Milspec Shielded Fire Tests.....	13
4.0 Conclusions.....	15
5.0 Acknowledgements.....	16
6.0 Bibliography.....	16

## 1.0 Introduction

### 1.1 Background

Pan fires are an excellent, reproducible way to evaluate and compare extinguishing systems. Pans are used in many standard test methods and CAF has proven to have superior performance when compared to conventional foam water sprinkler systems in these tests. Concerns in the industry have arisen 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.

In order to address these concerns a series of spill fire tests were designed to evaluate the performance of CAF on increasing spill fire sizes with and without shielding. Two foam water sprinkler tests would also be conducted for the purpose of comparison.

### 1.2 Project Description

This report describes a series of 9 full-scale Class B fire tests designed to compare CAF and foam water sprinklers in extinguishing free-flowing heptane pool fires, increasing in size from 4.65 m<sup>2</sup> to 14 m<sup>2</sup> on a 6m by 6m flat concrete slab. The flow of fuel would be controlled by a valve removed from the fire location and the fuel would be delivered to the slab through a 25.4 mm diameter steel pipe. In addition to visual observations, radiant heat flux was also measured at a point 1.83 m from the edge of the fuel boundary and 1.5 m off the ground. This would allow a comparison to be made with the previous pan fire tests of the same size. The fuel drum was positioned on weigh scales to monitor the flow of fuel during the tests.

The first 2 tests would confine the spill to a 4.65 m<sup>2</sup> **area** using a bead of silicon caulking. Due to the uneven characteristics of the slab this was necessary to achieve the comparison data. Tests 3 to 9 would have no confinement and the fuel would be allowed to flow freely over the slab. Tests 6 to 9 would have a 1 m by 1 m table positioned over a fuelling outlet preventing the foam from landing directly on the fuel surface under the table. To extinguish this scenario, the foam must be fluid enough to

flow under the table. Tests 8 and 9 would use the standard foam sprinklers in place of the CAF system.

## 2.0 Test Details

### 2.1 Test Facility

The tests were conducted indoors at the Fire Research Program's Fire Laboratory where the burn hall measures 55 m long by 30 m wide by 12 m high. At the time of the experiments the ambient temperature was between 20 and 25 degrees Celsius. The 36 m<sup>2</sup> test area was formed level using fibre reinforced concrete (see figure 1). Concentric circles were painted on the slab at 2.44 m, 3.44 m, 4.21, and 4.87 m in diameter. Each circle represents an increase in area and fire size by factors of 1, 2, 3, and 4 respectively.

A grid of 4 CAF nozzles or sprinkler heads were positioned 10.7 m above the slab at a 3.73 m by 3.73 m spacing. Extinguishment data was taken using a 2 w/cm<sup>2</sup> heat flux meter and Solartron data acquisition system. The heptane fuel was delivered through a preset valve from a 205 litre drum mounted on weigh scales shown in the area on the left in figure 1.



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. This system mixes the correct amount of water, air and foam concentrate so that CAF can be formed in the delivery piping.



**Figure 2.** Foam delivery apparatus.

The CAF is then distributed over the target area through 4 CAF rotary nozzles shown in figure 3. When the foam water sprinkler system is installed the same piping is used and the foam water is delivered at the same outlet locations. The delivered density for the CAF system is  $1.63 \text{ l/min/m}^2$  while the foam water sprinkler system delivers  $6.5 \text{ l/min/m}^2$ . The total water flow for the 4 CAF nozzles is  $90 \text{ l/min}$  and the flow for the foam water sprinkler system is  $360 \text{ l/min}$ . The expansion of the CAF system is 10:1 with a drain time of 5 min 20 seconds and a solution concentration of 2% Class B foam for tests 1 to 6 and 2% milSpec Class B for test 7. The foam water sprinkler system had a 3:1

expansion with a drain time < 1 min and a solution concentration of 3% Class B foam for test 8 and 3% milSpec Class B for test 9.



**Figure 3.** CAF Delivery Nozzle

### **2.3 Instrumentation**

The solution flow was monitored using a calibrated Krohne model Ecoflux 1010 Magnetic flow-meter and the airflow was measured using a Brooks Model 1112A09G3B1A rotometer. Pressures were measured using calibrated pressure gauges, and foam expansions and drain times were determined by weight using a Mettler PC4400 calibrated balance. Radiant heat flux measurements were taken using a Medtherm Heat flux transducer Model 64-02-14 Serial # 57496 and recorded on a Solartron model 3595 IMP data acquisition system. The tests were recorded on a the Sony Model DCR-TRV340, 8 mm digital video tape and still photos were taken using a Sony Model DSC-F707 digital camera.



## 2.4 Test Procedure

The tests were initiated by pre-spilling the fuel for a period of 45 seconds. This was done using a pre-set valve for the flow rate and a separate valve to turn the flow on or off. The fuel forms a pool that extends to the boundary of the fire area in the 45 second pre-fill time. This is true for all flow rates and fire sizes. The data system is then activated and the fire is ignited from the edge with a propane torch. At 15 seconds from ignition the foam is applied and the test continues until the fire is completely extinguished or 5 minutes has elapsed. The first 3 tests were fuelled from a single point in the centre of the slab. Due to slight unevenness in the slab surface it was decided to deliver the fuel from 4 outlets to cover the area of interest more accurately. This 4 outlet fuel delivery system was used for the remaining 6 tests. A table was added for tests 6-9 to provide a shielded area and this set up is shown in figure 4.



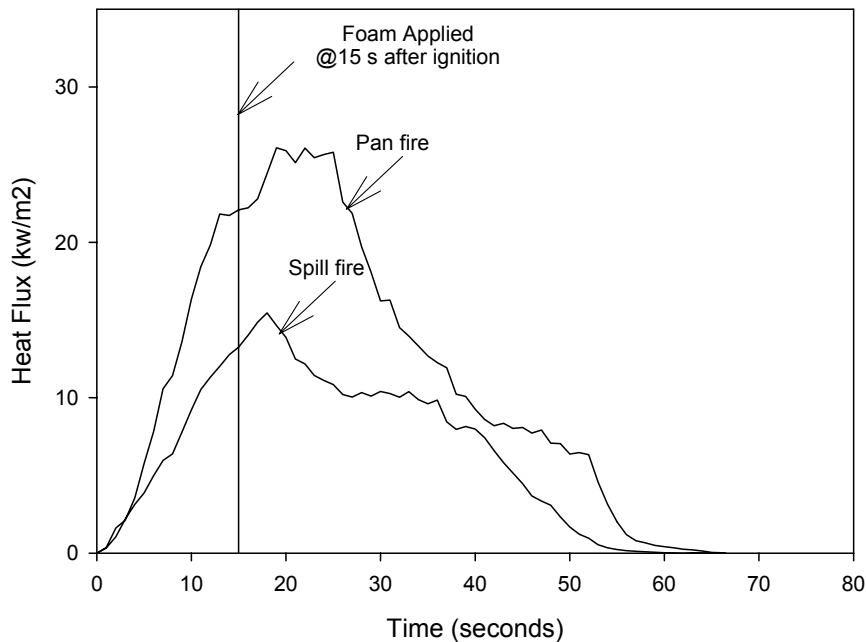
**Figure 4.** Shielded test set-up

## 3.0 Results

### 3.1 Pan and Spill fire Comparison Tests

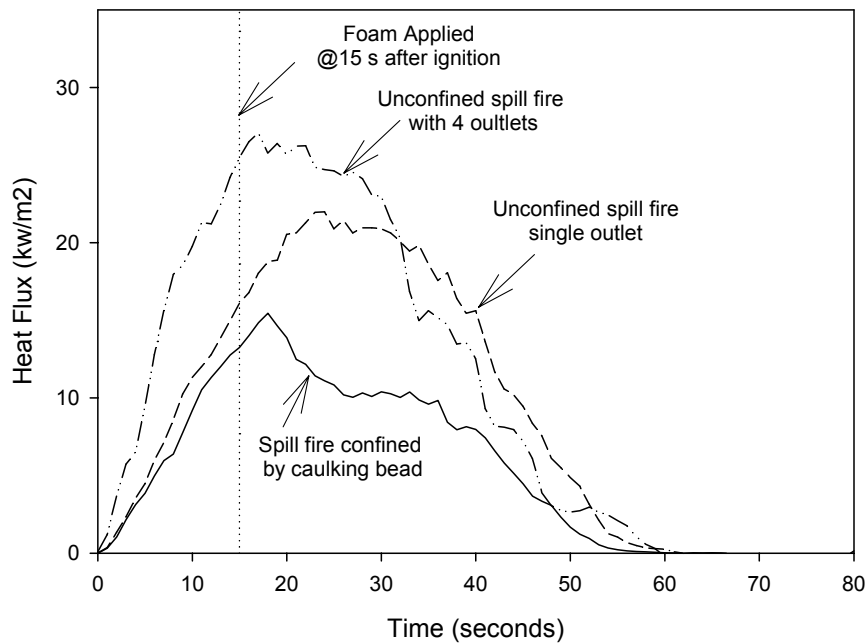
Tests 1 and 2 were spill fire tests confined to 2.44 m diameter with a shallow bead of silicon caulking. A radiant heat flux meter was positioned at a point 1.83 m from the edge of the fuel boundary and 1.5 m off the ground. It was determined from spilling

heptane onto a water base that 8 l/min would be required to sustain a 2.44 m diameter fire. Since the surface of the concrete was rougher than water it was decided to spill 11 l/min. Based on the heat of combustion for heptane this translates to a 6 megawatt fire. It was observed during the test that the fire did extend beyond the caulking boundary before the foam was applied. This indicated that the estimate for the flow rate of the spill was correct at around 8 l/min. The pan fire of the same size consumes 21.3 l/min and has a heat output of 11.5 megawatts. Figure 5 compares the radiant heat flux from the pan and the spill fire and clearly shows that pan fire has a 67% higher heat flux 15 seconds after ignition, at the point when the foam application begins.



**Figure 5.** Radiant heat Flux from a 2.44 m diameter pan and spill fire

Test 3 used the same fuel flow rate (11l/min) as test 1 and 2 except the caulking was removed and the area was no longer confined to 2.44 m in diameter. Figure 6 shows the radiant heat flux of the confined spill compared to the unconfined spill. The fact that the unconfined spill fire is larger confirms that 11 l/min is excessive for the 2.44 m diameter fire and the estimated 8 l/min is the required flow rate to sustain the 2.44 m fire. Test 4 used the same fuel flow rate (11 l/min) but delivered the fuel from 4 points instead of 1 central point. The more uniform distribution of fuel is represented in the higher heat flux shown in figure 6.



**Figure 6.** Confined and unconfined free-flowing spill fire.

This comparison data is supported by the section on Liquid Fuel Fires by Gottuk and White in the SFPE Handbook of Fire Protection Engineering.

Extinguishment times for tests 1 to 4 and the pan fires of the same size are all between 45 and 60 seconds of foam application. The results of all the tests are shown in Table 1.

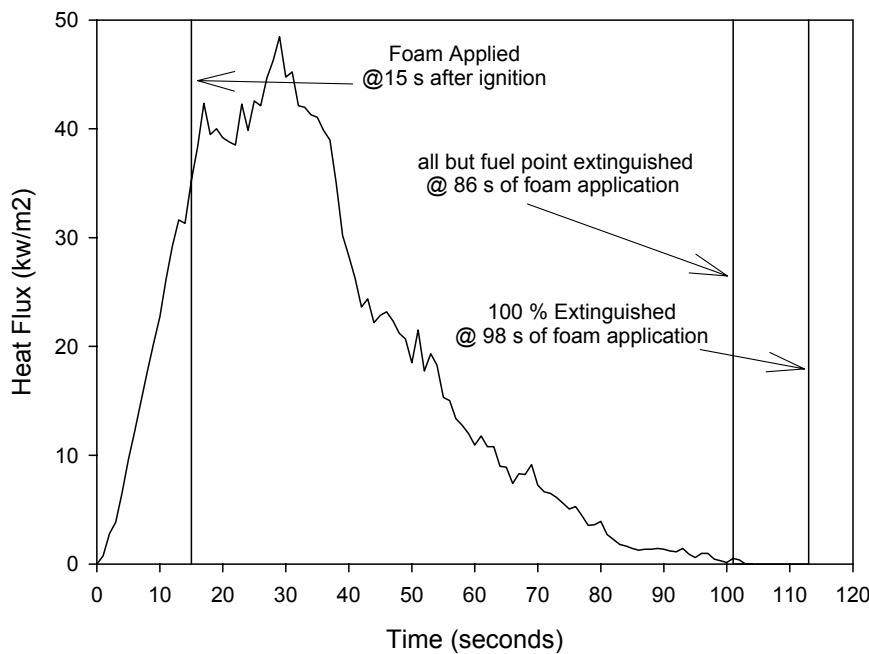
**Table 1. Spill Fire Test Results**

Test Description					Foam Distribution; litres/min/m2	Fire Size Mw	Extinguishment time; min:s	
Test #	Foam Type	Heptane Fuel Flow rate	Shielded Fire	Solution Flow; l/min			99%	100%
1	CAF B, 2%	11 l/ min	no (confined to 4.65m2)	90	1.63	<6	0:53	1:13
2	CAF B, 2%	11 l/ min	no (confined to 4.65m2)	90	1.63	<6	1:00	1:08
3	CAF B, 2%	11 l/ min	no ( unconfined >4.65m2)	90	1.63	6	0:46	1:22
4	CAF B, 2%	11 l/ min	no ( unconfined >4.65m2)	90	1.63	6	1:05	1:28
5	CAF B, 2%	22.5 l/ min	yes ( unconfined >13m2)	90	1.63	11.5	1:26	1:38
6	CAF B, 2%	22.5 l/ min	yes ( unconfined >13m2)	90	1.63	11.5	1:55	4:58
7	CAF Milspec B, 2%	22.5 l/ min	yes ( unconfined >13m2)	90	1.63	11.5	1:45	4:20
8	FWS ClassB, 3%	22.5 l/ min	yes ( unconfined >13m2)	360	6.5	11.5	1:30	not ext.
9	FWS Milspec B, 3%	22.5 l/ min	yes ( unconfined >13m2)	360	6.5	11.5	2:00	not ext.

### 3.2 Unshielded Spill Fire Tests

Tests 1 to 4 were unshielded spill fire tests to establish comparisons with pan fires of the same size. The 8 l/min flow rate required for the 4.65 m<sup>2</sup> fire was increased to 22.5 l/min and produced a fire area over 13 m<sup>2</sup> for all the remaining tests.

Test 5 was an unconfined and unshielded fire with a 22.5 l/min fuel flow rate. The heat flux shown in figure 7 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 7.** Heat flux from the 13 m<sup>2</sup> fire size (Test 5)

Figure 8 shows the photo extinguishing sequence from the smaller fire of test 3 and the larger fire from test 5. The time to completely extinguish the larger fire is 16 seconds longer than the smaller fire of test 3. 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.

Test 5 (Fire 13 m<sup>2</sup>)

Test 3 (Fire 4.65 m<sup>2</sup>)



Foam Activation



30 seconds



60 seconds



90 seconds

82 seconds



98 seconds

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**Figure 8.** Photo Sequence for test 5 and test 3

### 3.3 Shielded Spill Fire Tests

Tests 6 to 9 were shielded tests incorporating a 1m by 1m by 0.8 m high steel table positioned over one of the four fuel outlets. The area of shielding is shown in figure 9.



**Figure 9.** 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 6 was able to confine the fire to the shielded area in under 90 seconds and choke the fire to a candle size in under 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 10 compares test 6 (90 l/min CAF at 2% Class B concentration) with the Foam water sprinkler test 8 (360 l/min at 3% concentration).



Test 6 (CAF)



Foam  
Activation



Test 8 (FW Sprinklers)



Continued from  
Adjacent column



Figure 10. Extinguishment sequences at 30 s intervals



### **3.4 Milspec Shielded Fire Tests**

Test 7 and test 9 had the same conditions as tests 6 and 8 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. The CAF test was able to completely bury the outlet and extinguish the fire in 4 minutes and 20 seconds. Figure 11 shows the side-by-side photo extinguishment sequences for the milspec foam tests.

Test 7 (CAF)



Test 9 (FW Sprinklers)



Foam  
Activation

Continued from  
Adjacent column

Figure 11. Extinguishment sequences at 30 s intervals

## 4.0 Conclusions

The CAF system was able to suppress a 2.44 m diameter free-flowing spill fire as fast as the 2.44 m diameter 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 without 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.

## **5.0 Acknowledgements**

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