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# *The Determination of a Safety Factor for the Application Density of Compressed-Air Foam on Flammable Liquid Fires*

Research Report 180

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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 UL162 "Foam Equipment and Liquid Concentrates". Concerns about variations in the delivered CAF density due to fluctuating water supply pressures have been raised in the industry.

This paper describes a series of full-scale Class B fire tests designed to establish minimum and maximum delivered densities of CAF by varying the water supply pressures. A safety factor could then be associated with normal design application density.

## Table of Contents

## 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.

### 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. The extinguishing performance and burn-back time from these adverse condition tests must meet the criteria set out in the standard and should come close to the performance of a standard foam water suppression system at its full delivered density.

## 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 18 and 22 degrees Celsius. The fire test pan was square, straight-sided, with an area of 4.65 $m^2$, and was made of 6.4 mm thick steel plate as required by UL-162. The height of the pan was 305 mm with a continuous horizontal lip 38 mm wide projecting outwards on the top edge of all sides. The test fire was a heptane pool fire using commercial grade heptane fuel. The fire test pan was placed on the floor, centred below the piping grid that was positioned 10.7 m above.

The test pan contained a water layer not less than 25.4 mm deep, with 100 L of heptane poured over the water. With the rapid fire suppression by the CAF, it was found that there was excessive unburned fuel left over when 205 litres were used for a fire suppression test, thus creating an environmental problem. The fuel quantity was reduced to 100 litres however, the 203 mm distance form the top of the pan to the liquid surface, as required in UL-162, was maintained by adding additional water.

A grid of 4 CAF nozzles were positioned 10.7 m above the pan 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.

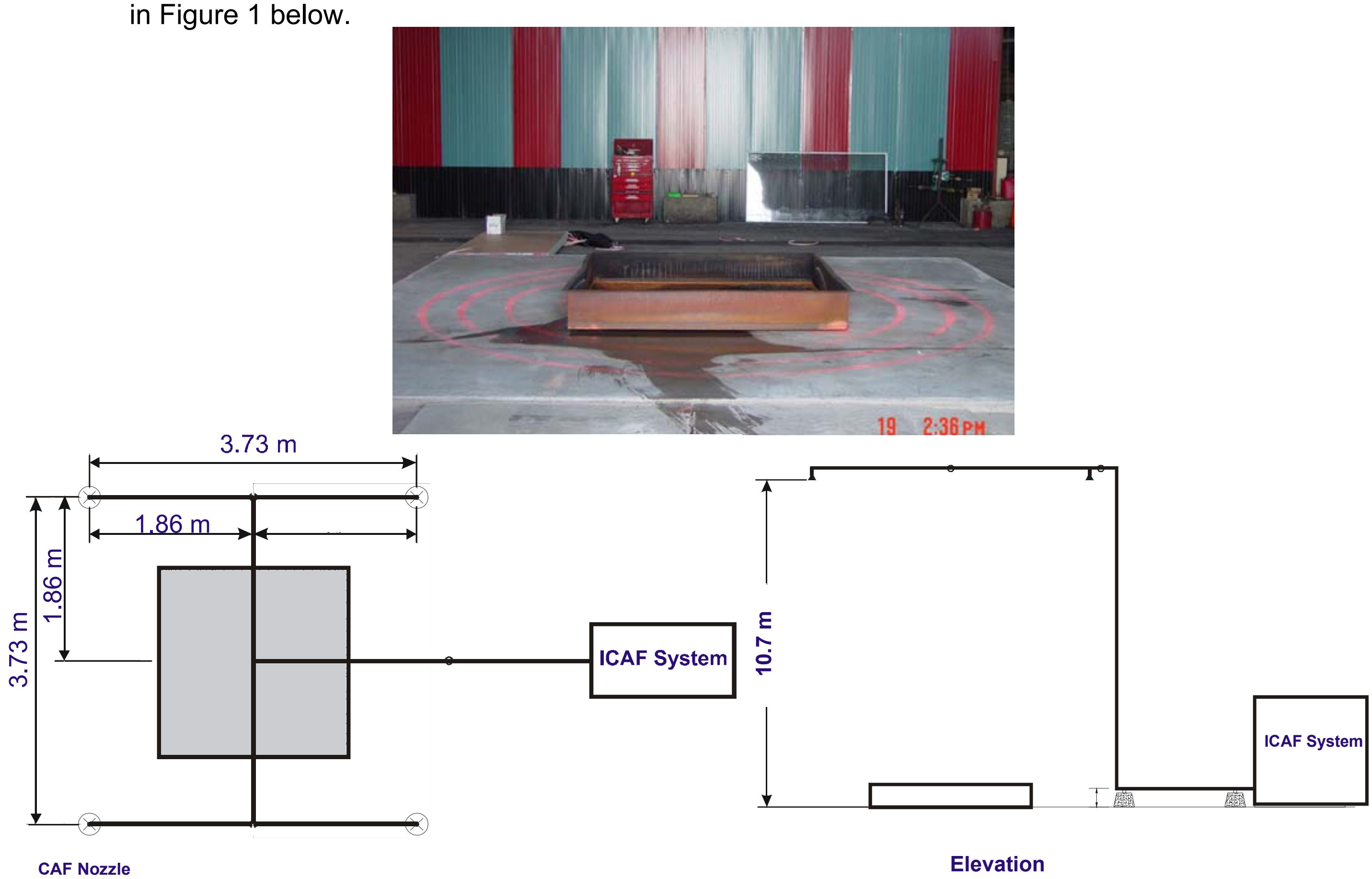


**Figure 1. Fire test facility**

### 2.2 Foam Delivery Systems

The foam delivery system was supplied by FireFlex Systems Inc. and is shown in Figure 2. 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. The delivered density for the CAF system under normal design conditions is 1.63 $l/min/m^2$ while a foam water sprinkler system delivers 6.5 $l/min/m^2$. The total water flow for the 4 CAF nozzles is 90 l/min. The expansion of the foam for the CAF system under normal design conditions is 10:1 with a drain time of 5 min 20 seconds and a solution concentration of 2% Class B foam. The total flow for the 4 foam-water sprinklers is 360 l/min. The expansion of the foam is 3:1 with a drain time of < 1minute and a solution concentration of 3% Class B foam.

**Figure 3.** CAF Delivery Nozzle

The total flow of water was reduced from 90 l/min to 67 l/min in Test 1 and further reduced to 55 l/min in Test 2. This was accomplished by reducing the water supply pressure. The total flow of water for Test 3 was increased to144 l/min. This represents a high water pressure condition and since the amount of concentrate is dependant on the air supply only, the CAF produced would be at a lower concentration than the normal design condition.

### 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. 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.

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### 2.4 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 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.

## 3.0 Results

**Table 1. Test Results**

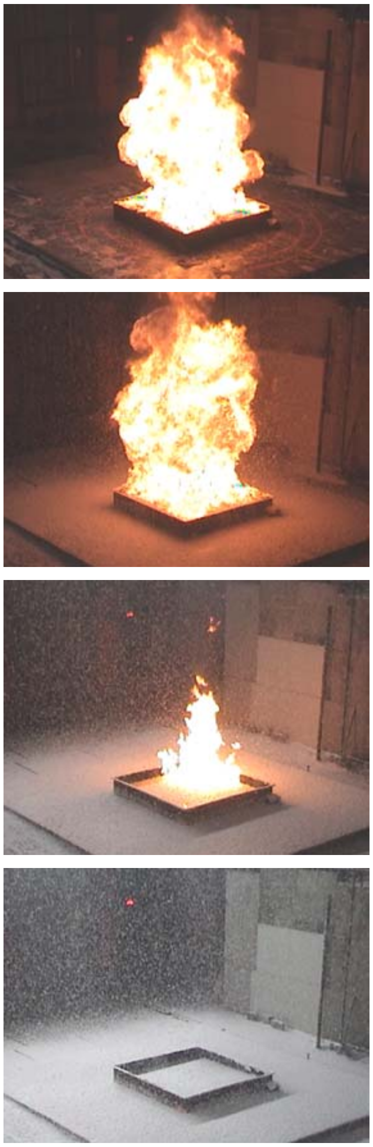
| Test Description | | | | Foam Distribution; litres/min/m2 (USgal/min/ft2) | Extinguishment time (s) | Burn-Back time min:s |
|---|---|---|---|---|---|---|
| Test # | Foam Type | Flow Condition; l/min | Foam Condition Conc. (expansion) | | | |
| 1 | CAF B | reduced; 67 | 2.7% (14.5:1) | 1.21 (.03) | 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 |

### 3.1 Reduced Water Flow Tests

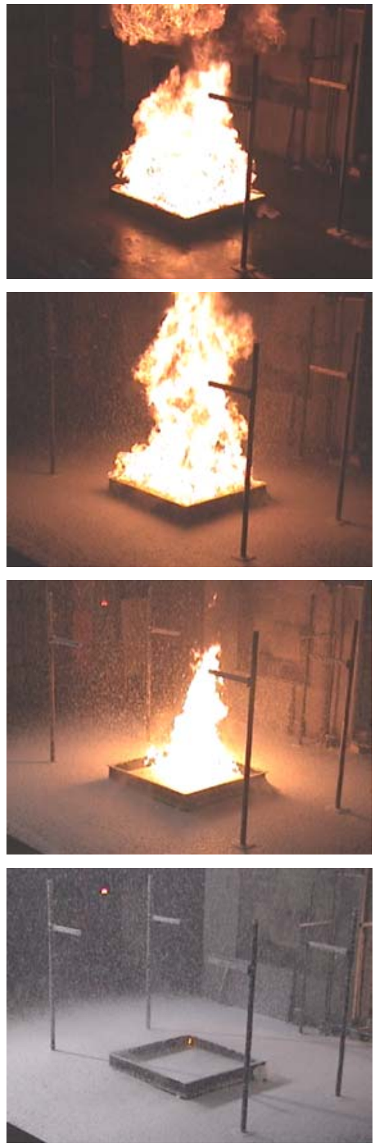
Tests 1 and 2 were reduced water flow tests. The normal design condition flow for the system is 90 l/min with 2% Class B foam concentration and an expansion of 10:1. This yields a distribution density of 1.63 l/min/$m^2$. Test 1 had a water flow of 67 l/min, which is reduced by a factor of 1.33 from 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.

The extinguishment photo sequences for Test 1 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)



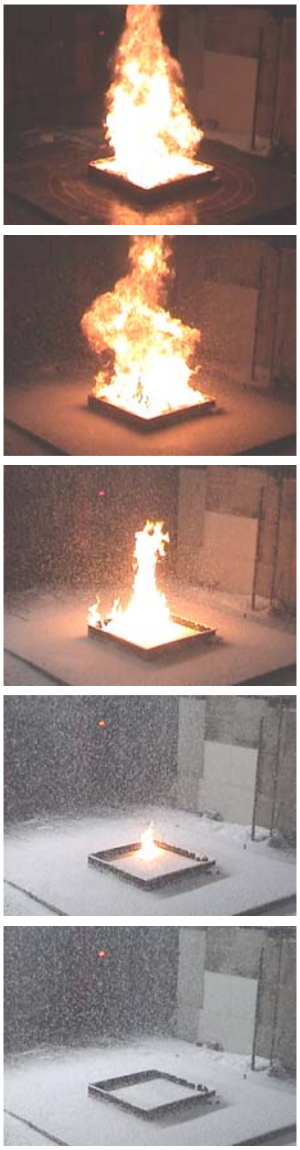
Test 4 (CAF,90 l/min)
Normal Design Density

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

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

Test 2 extinguished the fire in 1 minute 10 seconds and provided 10 minutes of burn-back protection.

The extinguishment photo sequences for Test 2 are shown side by side with the normal condition test and the foam-water sprinkler test in Figure 5.



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

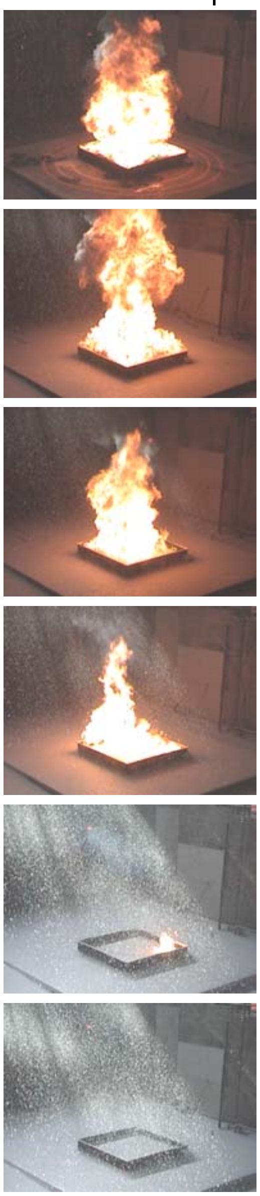
Test 4, (CAF,90 l/min)
Normal Design Density

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

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

### 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 6 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 6:** Extinguishment photo sequences @ 20 second intervals starting from system activation.

## 4.0 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. The area of coverage from the CAF system did not change significantly in these reduced flow tests. The yield of the delivered volume of expanded foam remained the same since the volume of the air did not change and the expansion of the foam solution increased.

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.

## 5.0 Acknowledgements

The author wishes to thank Jean-Pierre Asselin and the staff of FireFlex Systems Inc., Michael Ryan and the staff of the Fire Research Program for their assistance and contributions to this test series.

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