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Publisher's version / Version de l'éditeur:

<https://doi.org/10.1007/s10694-009-0119-3>

Fire Technology, 48, 3, pp. 549-564, 2012-06-01

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NRCC-55250

A version of this document is published in : Fire Technology, 48, (3), pp. 549-564, DOI: [10.1007/s10694-009-0119-3](https://doi.org/10.1007/s10694-009-0119-3)

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Evaluation of the Fire Suppression Effectiveness of Manually Applied Compressed-Air-Foam (CAF) System

Abstract

Mobile CAF systems represent a new type of fire suppression system, which is gaining popularity among fire services. Properly engineered CAF systems produce superior quality foam with high momentum. However, until now, there has not been a study to systematically evaluate the fire suppression effectiveness of mobile CAF systems.

NRC has carried out a project to evaluate the effectiveness of a mobile CAF system in suppressing fully developed compartment fires. Several full-scale compartment fire tests were conducted to compare the fire suppression performance of a manually-applied CAF system with that of hose stream application using water alone and using water-foam solution, under similar conditions.

The study showed that a CAF system is much more effective in suppressing the compartment fire compared to hose stream application with water only or with foam-water solution. A CAF system with a 95 L/min (25 GPM) water flow rate suppressed the test fire better than the hose-stream application with water only or with foam-solution using 360 L/min (95 GPM).

The CAF system suppressed the fire and cooled down the fire compartment (to 200°C) much quicker than the water alone or foam-solution. Also, the total amount of water used to control the test fire was much less with the CAF system than with the water alone or foam-solution.

Key Words: Fire suppression, Compressed-air-foam (CAF) system, Full-scale testing, Compartment fire, Fire fighting.

INTRODUCTION

Current foam systems, which incorporate aspirating-type nozzles have several potential limitations, including poor foam quality due to the use of fire contaminated air for foam generation. Also, since the water flow momentum is used to aspire air at the nozzle to create foam, the hose stream discharge momentum is reduced, which may limit the ability of the foam stream to penetrate fire plumes to reach the seat of the fire.

Recently, several companies have developed mobile compressed-air-foam (CAF) systems for use by fire services. CAF is generated by injecting air under pressure into a foam solution stream. Mobile CAF systems represent a new type of fire suppression system, which is gaining popularity among fire services. Properly engineered CAF

systems produce superior quality foam with high momentum. However, until now, there has not been a study to systematically evaluate the fire suppression effectiveness of the mobile CAF systems. It is necessary to compare the fire suppression effectiveness of the CAF systems with traditional fire suppression systems, such as hose stream application, to truly appreciate the superior fire suppression effectiveness of the CAF approach.

NRC has carried out a project to evaluate the effectiveness of a mobile CAF system in suppressing fully developed compartment fires. The fire suppression effectiveness of the CAF system was compared with that of a hose stream application using water alone and using water-foam solution, under similar conditions.

EXPERIMENTAL SET-UP AND PROCEDURES

Several full-scale compartment fire tests were conducted to compare the fire suppression performance of manually-applied CAF system, hose stream with water, and hose stream with water-foam solution.

Test Compartment

Test compartment was built with wood stud walls and a gypsum wallboard interior. Dimension of the compartment was 4.26 m by 3.65 m with 2.44 m ceiling height. The test compartment had an access door with a dimension of 0.86 m x 2.03 m. There was a short corridor (hallway), measuring 2.3 m wide and 3.65 m long, just outside of the door. This corridor was built as a part of the test compartment to make it more realistic in the arrangement, because in real residential compartments or office spaces, there is usually a corridor outside of the door. This corridor also acted as a target area in measuring the migration of smoke, fire gases and heat from the fire room to other parts of the building, during the fire development and its suppression.

Two test compartments were built on either side of a common corridor, to reduce the turn-around time between the tests and to enhance flexibility in scheduling. A plan view of the test compartment is shown in Figure 1.

Several ventilation openings were provided in the test compartment to ensure adequate supply of fresh air for the fire development in the room. Three ventilation openings of 0.229 m by 0.406 m were made on each of the three exterior walls, near the floor level. A simulated window was provided in the test compartment. The window dimension was 0.406 m by 0.48 m. This window was closed during the fire development in the room, but was manually opened at the beginning of fire suppression, simulating window breakage during the fire attack by fire fighters.

Fire Load

Fire load in the test compartment consisted of two wood cribs, a mock-up sofa, and several Oriented Strand Board (OSB) boards, that were used to line the lower half of the compartment walls. Each wood crib was constructed with 48 pieces of 0.038 m x

0.09 m x 0.8 m pine studs, which would produce an approximately 1 MW fire. The mock-up sofa was built with metal frame, and 11 mm (7/16") thick OSB board was used as a seat and back of the mock-up sofa. The sizes of the OSB board for the seat and back were 0.77 m by 1.83 m and 0.61 m by 1.83 m, respectively. The surface of the mock-up sofa was covered with a 100% polyester blanket.

The lower portion of the compartment walls were covered with 11 mm (7/16") thick OSB board. The bottom half of the walls and the floor of the compartment was covered with OSB board. Also, the two wood cribs were covered with 1.22 m by 2.44 m (4 ft by 8 ft) OSB board to enhance the growth of a deep-seated fire within the wood crib. Figure 2 shows the two wood cribs with an OSB board on top, as well as the lower portion of the wall and floor covered with OSB boards.

The total number of 11 mm thick OSB board, which measured 1.22 m by 2.44 m, was twelve, including the ones used on the compartment wall, sofa, and on top of wood cribs. Estimated heat release rate of 12 OSB board was 3.6 MW. Therefore, the total heat release rate in the test compartment at the time of fire suppression was approximately 5.6 MW.

Instrumentation

Thermocouple trees, consisting of five 24-gauge type-K thermocouples spaced 0.5 m apart starting at the ceiling, were located in the fire room and the hallway. In the fire room, the thermocouple tree was located 0.6 m from each adjacent wall in the corner closest to the hallway, so it would not be inline with the hand-line attack. The hallway thermocouple tree was located in the center of the hallway, 1.5 m from the back wall. A heat flux meter was placed in the fire room near the centre of the back wall (Figure 1), and one type-K, 24-gauge thermocouple was located at the top center of the doorway.

A gas sampling tube was placed at the center of the back wall in the hallway, 1.5 m from the floor. The sampling tube was connected to a smoke meter and gas analyzers, to measure the smoke obscuration and concentrations of O₂, CO₂ and CO in the hallway.

Two digital video cameras were set up outside the test compartment to obtain visual records of fire ignition and development in the test compartment, and its suppression during the experiment.

Suppression Systems

Two fire suppression systems were used in this test series.

Initially, it was planned to use a WATEROUS CAF system for all tests. The CAF system was CAFSYSTEMS 100-50-DS, which was constructed to discharge water, foam solution or compressed-air-foam. The unit was designed to produce 300 L/min of water at 8.6 bar (80 GPM @ 125 psig) and 1.13 m³/min of air at 8.6 bar (40 cfm @ 125 psig).

The system included a 757 L (200 gallon) water tank and 38 L (10 gallon) foam concentrate tank.

The WATEROUS CAF system was used in Tests # 1 – #4. However, it was noted during the tests that the unit was not functioning properly. The flow meters in the unit were not registering proper flow rates, and the unit was not producing adequate quality foam. The CAF produced by the unit was found to be very poor quality foam with short drainage time. Therefore, it was decided that a new unit should be used for the remainder of the tests.

The CAF unit, which was used in Tests # 5 – #10, was a HERCULES 140 CFM, hydraulically driven compressed air foam system, which has the capability to discharge foam solution or CAF. This unit contained an oil-flooded rotary screw compressor rated at 65 L/s (140 cfm) @ 1034 kPa (150 psi). The unit also included a Pierce Husky 12 foam proportioner. The unit was mounted in a large Fire Pumper, which had a 500 hp engine and Hale 1500 GPM (gallons per minute) single stage pump. The truck also had a 1890 L (500 gallon) polypropylene water tank, which included 114 L (30 gallon) foam cell containing foam concentrate.

Foam concentrate used in the tests was Hi-Combat Class A foam concentrate. This foam concentrate was designed for use in Class A/B foam systems, and it can also be used in CAF systems. This foam concentrate is claimed to be biodegradable. This concentrate is typically used at 0.3% - 1.0% concentration range, and for CAF systems, a 0.1% to 0.5% concentration range is recommended.

Experimental Procedures

The same experimental procedure was used for all experiments to minimize the introduction of unforeseen variables that could affect the results. The experimental procedure used before the start of the test was as follows:

- The gas analyzers and smoke meters were calibrated and the instrumentation was checked.
- The wood cribs were weighed and placed in the room. (2 sets of cribs).
- 4 pans, containing 150 mL of methyl hydrate, were placed under each of the cribs at the quarter points.

During the tests, the following test procedure was followed:

1. Data system was activated at time zero.
2. At 45 s after the data system activation, two wood cribs were ignited using four small pans containing methyl hydrate, located underneath the cribs. As the fire grew in the crib, eventually flashover occurred in the compartment and the mock-up sofa and lower wall and floor of the compartment caught fire. Flashover in the compartment was reached in approximately 3 min from the ignition of the wood

- crib. At this point, flames were coming out of the compartment through the upper portion of the doorway.
3. Approximately 2 min was given beyond the flashover point to have a deep seated wood crib fire and an intense fire in the compartment, before fire attack was attempted by the fire fighter with either CAF or hose-stream application.
 4. When knock down of the fire in the compartment was achieved, the fire fighters sounded a horn, and the amount of water used to that point was recorded.
 5. When complete fire extinguishment was achieved, the total amount of water used for fire suppression was recorded and the data system was turned off.

EXPERIMENTAL RESULTS

A total of ten full-scale fire suppression experiments were conducted in the test compartment using CAF or hose stream application with water or foam solution. Fire control time, the amount of water used and the temperature data in the fire room and in the hallway, as well as the smoke density and gas concentrations in the hallway were measured.

Fire control or knock down of the fire was determined by the fire fighter. He would use his subjective judgement to determine when the room fire was suppressed enough so that there is no large fires in the compartment.

For the water flow rate and the amount of water used, flow rate was set at a fixed value, but during the fire fighting, the nozzle was not always fully open. Depending on the fire-fighting tactic used, fire fighter would use partially open nozzle or intermittent water spray.

Table 1 summarizes the test results. Detailed test results for each test are given in the following section.

Results of Test #1

This was a CAF test. The flow rate was set at 360 L/min (95 GPM) in the WATEROUS CAF system, and the foam concentrate injector was set at 0.5%. The water flow pipe was also connected to NRC flow meter. The flow rate, which was set at 360 L/min in the CAF system, showed 291 L/min (77 GPM) in the NRC flow meter.

A 44.5 mm (1 ¾ inch) hose line was used for this series of tests. The hose line was fitted with a 28.6 mm (1 ⅛ inch) inside diameter connector, which was too small for the flow of the expanded CAF. During the test, the flow rate was reduced because of restriction on the hose capacity, and decreased the water flow rate to 250 L/min (66 GPM), according to the CAF system flow meter.

Fire fighters controlled and extinguished the fire in the test compartment in a short period of time (46 s). The total amount of water used in the test was 159 L (42 US gallons), according to the CAF unit's water consumption meter.

Results of Test #2

The test fire was suppressed using hose stream with water only. The flow rate was set at 360 L/min (95 GPM). The 44.5 mm (1 ¾ inch) hose and nozzle, which was used in Test #1, was too big for the flow, because the hose stream out of the nozzle did not have much momentum. It was changed to a 38.1 mm (1 ½ inch) hose and nozzle.

The total amount of water used in the test was 170 L (45 US gallons), according to the CAF unit's water consumption meter. Comparison of the results from Tests #1 and #2 showed little difference. The total amount of water used in Test #2 was larger than in Test #1, but the difference was not significant. The temperature drop in the fire room and target area showed similar results in Test #1 and in Test #2.

Results Of Test #3

This was a CAF test with reduced flow rate of 182 L/min, however, the CAF unit was not operating properly.

It took approximately 90 s to control the fire in the test compartment. The total water used, according to the CAF unit's accumulated flow meter, was 367 L. But, when the amount of water used in the tank was measured, the actual amount of water used was 273 L. This indicated that the unit's flow meter was not functioning properly.

Assuming that the difference between the total water consumption shown by the meter on the CAF system and the actual amount of water used applies to other tests, then the total amount of water used in Test #1 was 117 L, and 125 L in Test #2.

Results Of Test #4

This test was a repeat test of Test #3, because the CAF unit was not functioning properly in Test #3. The flow rate was set at 189 L/min (50 GPM), according to the CAF unit's flow meter. Water was supplied by the NRC's fire pump, and NRC flow meter showed 151 L/min (40 US GPM), which showed questionable accuracy of the CAF unit's flow meter. The foam concentrate injector unit in the CAF system was set at 0.5 % concentration.

The CAF unit did not operate properly. It took 76 s to control the fire in the test compartment, and the total amount of water used in the test was more than 265 L.

After Test #4, several investigative tests were conducted with the WATEROUS CAF unit. The foam produced by the unit was observed to be of poor quality. Visual inspection of the foam showed that it was watery and did not seem to be properly expanded. The foam produced by the WATEROUS unit was different than normal CAF, which looks like a creamy foam and sticks to vertical walls. It was also found that the foam injector was not functioning properly. Even though the foam injector was set to

inject the concentrate to produce 0.5% foam solution, the unit was injecting much more concentrate, producing close to a 5% foam solution.

It was determined that the test series with the WATEROUS CAF unit was not producing meaningful data. Therefore, it was decided to discard the test results of Tests #1 to #4, and to continue the test series with a new CAF unit.

Results of Test #5

HERCULES 140 CAF unit was used in this test as well as in the remainder of the test series. In order to eliminate any further calibration discrepancies, it was decided to conduct all of the remaining tests using a calibrated 416 L (110 US gallon) reservoir. All water and premixed solutions would be drawn from this tank making comparison of the water consumption very accurate. Test #5 was a hose stream test with water only. The flow rate was set at 360 L/min (95 GPM) on the HERCULES 140 CAF unit flow meter. The flow meter reading of the HERCULES unit matched with the reading of the NRC flow meter.

The test fire was knocked down in 35 s, and the amount of water used until that time was 148 L. The total amount of water used to extinguish all fires in the test compartment was 151 L.

Figures 3 and 4 shows the temperatures in the fire room and hallway, respectively. The graphs show the temperatures measured at the thermocouple tree and the average temperature of the thermocouples. Figure 5 shows heat flux values measured in the fire room near the two wood cribs during the test. It shows a sharp drop in the heat flux as soon as the fire attack started.

Results of Test #6

This was a repeat test of Test #5. The flow rate was set at 360 L/min.

The test fire was knocked down in 40 s, and the amount of water used until that time was 87 L. The total amount of water used to extinguish all fires in the test compartment was 95 L.

This test showed that the fire fighter was able to extinguish the fire using less water in the second test. It seems that the fire fighter was gaining experience from his first try, because the fire condition was exactly the same. He was able to anticipate a certain reaction from his attack and used optimum water spray.

Figure 6 shows the smoke obscuration measured in the hallway. The result shows the smoke density drop with hose stream attack, but it goes up again after a while. This is probably due to wet smoke produced by the hose stream attack, which sticks to the surface of the optical density smoke meter.

Figure 7 shows CO, CO₂ and O₂ concentrations measured in the hallway. The results show immediate changes in the gas concentrations with the fire attack.

Results of Test #7

This was a foam water solution test with 0.5% foam concentration. The flow rate was set at 360 L/min (95 GPM).

The test fire was knocked down in 32 s, and the amount of water used until that time was 53 L. However, it took sometime to extinguish all fires in the test compartment, and the total amount of water used to extinguish all fires in the test compartment was 238 L.

Results of Test #8

This was a repeat test of Test #7, but with 0.3% foam concentration instead of 0.5% foam concentration. The flow rate was again set at 360 L/min.

Since this was a second try with the same flow of foam water solution, the fire fighter was able to improve his fire fighting technique from his first try, which consumed a large amount of water. The test fire was knocked down in 13 s, and the amount of water used until that time was 57 L. The total amount of water used to extinguish all fires in the test compartment was 96 L.

Results of Test #9

This was a CAF test with 0.3% foam concentration. The flow rate was set at 95 L/min (25 GPM).

The test fire was knocked down in 15 s, and the amount of water used until that time was 23 L. The total amount of water used to extinguish all fires in the test compartment was 91 L.

Figures 8 and 9 show the temperatures measured in the fire room and hallway, respectively. The graph shows temperatures measured at the thermocouple tree and the average temperature measured by the thermocouples.

Results of Test #10

This was a repeat test of Test #9.

The test fire was knocked down in 15 s, and the amount of water used until that time was 23 L. The total amount of water used to extinguish all fires in the test compartment was 87 L. The results of Test #9 and #10 are almost the same, indicating good repeatability with CAF.

DISCUSSION

An experimental study was carried out to evaluate the effectiveness of mobile CAF system in suppressing fully developed compartment fires. In the first four tests, WATEROUS CAF system was used. However, the CAF system did not function properly, so the test results were not useful for the project. It was not possible to

compare the fire suppression performances of CAF and hose stream with water alone based on those test results.

In the subsequent tests, HERCULES 140 CAF system was used, which produced proper CAF. In the tests, the fire compartment was instrumented with a thermocouple tree and heat flux meter. The hallway outside of the fire compartment was instrumented with a thermocouple tree, as well as to measure smoke obscuration and gas concentrations. These instrumentations were installed to measure parameters, which could possibly show the difference in fire suppression effectiveness of CAF and hose stream with water only and with water-foam solution. However, reviewing the test results showed that smoke obscuration and gas concentration data in the hallway and heat flux measurement in the fire room did not provide results which could be used to determine the fire suppression effectiveness of CAF and water. These values change so dramatically soon after the fire fighter applies water or CAF to start the fire suppression, there is no clear distinction between the water, foam-water and CAF applications.

The test results showed that the most useful data for this purpose was the temperature measurements in the fire room and the total amount of water used to control the compartment fire.

Temperature data and the water consumption rate showed that CAF is much more effective in suppressing a compartment fire than hose stream with water only or with foam-water solution.

Figure 10 shows the average temperatures in the fire compartment for Tests #6, #8 and #10. Test #6 was with water only, and Test #8 was with foam-water solution, while Test #10 was with CAF. The graph shows that, at the time of fire attack by fire fighters, the average temperature in the fire room was almost equal in the three tests. However, after the fire attack, the average room temperature dropped much quicker with CAF than with foam-water solution or with water alone. If we take 200°C as the critical temperature in the fire room, it took 35 s for the average room temperature drop to the critical temperature when CAF was used (in Test #10) compared to 45 s for foam-water solution (in Test #8) and 60 s for water alone (in Test #6). CAF was able to control the fire and reduce the room temperature much quicker with much less water flow (95 L/min) compared with the foam-water solution and water alone, both of which used 360 L/min (95 GPM) flow rate.

The amount of water used to control (knock down) the compartment fire was also much less with CAF than with foam-water solution or water alone. It required approximately 118 L of water to control the fire with water alone, and approximately 55 L with a foam-water solution. With CAF, it required only 23 L of water to control the fire.

The test results clearly show that CAF is much more effective in suppressing compartment fires than with water alone or with foam-water solution.

CAF is a new type of fire suppression system, and it may require different approaches in fire-fighting. There is a need for training fire-fighters in using CAF properly to get the maximum benefit. In this project, the fire-fighter did not have a prior training in using CAF system. Even with no training, CAF had a much better performance than hose stream application with water or foam solution.

There are many commercial CAF systems available these days. However, not all CAF systems perform equally. One needs to check the CAF system to make sure that it has proper foam quality and discharge momentum.

In a previous NRC study [1], performance of fixed-pipe CAF system was compared to that of water mist and water spray with foam concentrates. In the study, it was clear that CAF has a superior fire suppression performance than water mist or foam solution spray. However, in this study, which compares the fire suppression performance of manually applied CAF versus water and foam-solution, it is not that easy to quantify the benefit of the CAF system, because of the human factors involved.

CONCLUSION

A project to evaluate the effectiveness of mobile CAF system in suppressing fully developed compartment fires was carried out. The study showed that a CAF system is much more effective in suppressing compartment fire compared to hose stream application with water only or with foam-water solution.

The tests showed that a much lower water flow rate is required to suppress a compartment fire with CAF compared to water alone or foam-water solution. A CAF system with a 95 L/min water flow rate suppressed the test fire better than the hose-stream application with water only or with foam-solution using 360 L/min (95 GPM).

The CAF system suppressed the fire and cooled down the fire compartment (to 200°C) much quicker (35 s) than the water alone (60 s) or foam-solution (45 s). Also, the total amount of water used to control the test fire was much less with the CAF system (23 L) compared to water alone (118 L) or foam-solution (55 L).

REFERENCES

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Table 1 Summary table of the test results

Test #	Description	Foam concentration	Fire Room	Water Flow Rate	Knock-down Time	Water Used for Knock-down	Total Water Consumption
*1	CAF	0.5%	North	250 L/min (66 GPM)	46 s	< 151 L (40 US gal)	159 L (42 US gal)
*2	Water only	0	South	360 L/min (95 GPM)	32 s	< 132 L (35 US gal)	170 L (45 US gal)
*3	CAF	0.5%	South	182 L/min (48 GPM)	90 s	< 284 L (75 US gal)	367 L (97 US gal)
*4	CAF	0.5%	North	189 L/min (50 GPM)	76 s	< 246 L (65 US gal)	265 L (70 US gal)
5	Water only	0	North	360 L/min (95 GPM)	35 s	148 L (39 US gal)	151 L (40 US gal)
6	Water only	0	South	360 L/min (95 GPM)	40 s	87 L (23 US gal)	95 L (25 US gal)
7	Foam-solution	0.5%	South	360 L/min (95 GPM)	32 s	53 L (14 US gal)	238 L (63 US gal)
8	Foam-solution	0.3%	North	360 L/min (95 GPM)	13 s	57 L (15 US gal)	96 L (25 US gal)
9	CAF	0.3%	North	95 L/min (25 GPM)	15 s	23 L (6 US gal)	91 L (24 US gal)
10	CAF	0.3%	South	95 L/min (25 GPM)	15 s	23 L (6 US gal)	87 L (23 US gal)

* WATEROUS system calibration not accurate.

* Thermocouple location

O Heat Flux meter

Gas and Smoke sampling point

Figure 1: Plan view of test room

Figure 2 Picture of wood cribs with OSB board on top

Figure 4 Temperatures in the hallway (Test # 5)

Figure 5 Heat flux values in the fire room (Test #5)

Figure 6 Smoke density in the hallway (Test #6)

Figure 7 Gas concentrations in the hallway (Test #6)

Figure 8 Temperatures in the fire room (Test # 9)

Figure 9 Temperatures in the hallway (Test # 9)

Figure 10 Average temperature in the fire room (Test #6, #8, #10)