A New Fire Suppression Technology

Introducing fixed-pipe compressed-air foam systems, an important innovation in fire suppression system design.

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For decades, firefighting foams delivered through portable equipment or from fixed-pipe systems have provided effective fire suppression. In some industries, such as the petroleum industry, these systems, which incorporate hose nozzles, aspirating-type fixed nozzles, or blower-type foam generators, are essential.

Despite the widespread use of fixed-pipe foam systems, however, potential limitations have emerged. Foam has trouble sticking to vertical surfaces, for example. It isn't as stable or consistent as is desired for some applications, and its expansion ratios aren't always as high as needed. The air used to generate foam at the nozzle may contaminate the foam with soot during a fire and plug the screens that generate foam. Concentrations of foaming agents are high, thus increasing costs. And the momentum needed to deliver the foam to the fire is reduced when the foam impinges on the nozzle, thus reducing its ability to penetrate the fire plume to the seat of the fire.

In responding to these issues, researchers have come up with an important innovation in foam system design: fixed-pipe compressed-air foam systems. Compressed-air foam (CAF) is generated by injecting air under pressure into a foam-solution stream. If the process is done correctly, the solution-and-air mixture moves through the hose or piping, forming compressed-air foam created by the combined momentum of the foam-solution and air-injection streams in the hose or piping.

Mobile compressed-air foam systems mounted on fire service vehicles are already used to fight both wildland and structural fires, delivering CAF through manually operated, smooth-bore-type nozzles that release a "rope" of foam with high forward momentum.[1] This type of system has several advantages. For example, the increased momentum allows the foam to penetrate fire plumes and reach the seat of the fire, enabling firefighters to project the foam a considerable distance. And they use water efficiently.

Given these and other benefits, researchers pondered using CAF in a fixed-pipe system. Such a system hadn't previously been developed due to difficulties in producing and delivering the expanded foam. Not until researchers proved that CAF can be delivered through a fixed pipe did a fixed-pipe system become a real possibility.

Background research

In 1988, researchers at the National Institute of Standards and Technology reported that the ignition-delaying capability of CAF was twice that of water and that its initial retention efficiency was approximately 20 times that of water.[2] Retention efficiency is the ratio of the foam remaining on a sprayed sample compared to water sprayed on an identical sample. Later, they found that the mass-retention effectiveness of CAF was 1.5 to 2 times greater than a spray solution with the same agent.[3] They also reported encouraging results in using CAF hose lines to suppress rubber tire fires, but these weren't conclusive.

By 1995, researchers at the National Research Council (NRC) of Canada had developed a fixed-pipe CAF system and demonstrated that such a system would provide effective fire suppression for Class A and B fires when compared to water mist systems and automatic sprinkler systems.[4,5] The researchers made a number of important advances in CAF fixed-piping system technology, the most important of which was to develop a fixed-pipe system that would actually deliver compressed-air foam. Until then, no one had been able to generate CAF consistently in a fixed-pipe system. Generally, the result was a pulsating, soapy water stream, rather than a solution with the consistency of shaving cream.

Through this work, NRC researchers identified a number of parameters that determine the potential quality of foam, including the air injection and the mixing process, the length of the mixing zone, the number of bends in the piping, and the type of nozzle used. Having resolved these issues, NRC researchers could consistently generate foam with an expansion ratio of 4:1 to 20:1, although, for firefighting purposes, the range of 4:1 to 10:1 was used. Expansion ratio is the final volume of foam compared to the original volume of foam solution.

In the early experimental program at NRC, researchers tested CAF in open spaces and in compartments because these spaces have different extinguishment regimes. Three fuels—heptane and diesel liquid fuels, and wood cribs—were evaluated, as were Class A and B (AFFF) foams. Concentrations of the foam to water were 0.3 percent for Class A foam and 1 to 3 percent for Class B foam, which was less than half

Spill Fire Experiments

TABLE 1

TEST 1 Description:
- Free burn test with 3 gallons (12 liters) heptane spilled at 1 gallon/minute (4 liters/minute) on water in a 10-by-12-foot (3-by-3.65-meter) room.

TEST 1 Observations:
- Burn area 5 feet (1.5 meters) in diameter 30 seconds after ignition.
- Flame impinges on ceiling.
- Flame burns out at 3 minutes, 50 seconds.
- Heat release approximately 2.2 MW.

TEST 2 Description:
- FRI SSP2 standard pendant sprinkler 165°F (74°C) quick response at 42 gallons/minute (160 liters/minute).

TEST 2 Observations:
- Sprinkler automatically activates 28 seconds after ignition.
- Fire burns in the open with flame tip impinging heavily on the ceiling.
- Room cooling but no suppression.
- Fire burns out at 3 minutes, 40 seconds—no suppression.
- Total water used was 135 gallons (512 liters).

TEST 3 Description:
- 7G5 mist nozzle at 100 psi, 10 gallons/minute (37 liters/minute).

TEST 3 Observations:
- Mist nozzle manually activated 28 seconds after ignition.
- Fire burns in the open, travelling around surface with flame tip impinging heavily on the ceiling.
- Room cooling but no suppression.
- Fire burns out at 3 minutes, 40 seconds—no suppression.
- Total water used was 31 gallons (118 liters).

TEST 4 Description:
- 0.3 percent Class A, CAF 7 gallons/minute (24 liters/minute) solution and 53 gallons/minute(200 liters/minute) air, expansion 9.5:1.

TEST 4 Observations:
- Foam manually activated 30 seconds after ignition.
- At 1 minute, 10 seconds, flame only under table.
- At 2 minutes, only pilot flame left burning.
- At 2 minutes, 15 seconds, pilot out—suppression achieved.
- Total water used was 11 gallons (42 liters).

Tables/Charts/Figures: ©Christopher McCusker

Spill/Shelf Fire Experiments

TABLE 2

TEST 1 Description:
- Five 1-quart (1-liter) containers of mineral spirits; one on each shelf with 2.8-inch (0.7-meter) diameter heptane pan fire on floor.
- 2.6-gallon (10-liter) fuel as ignition source in pan.
- No suppression system installed.

TEST 1 Observations:
- At 0 seconds, pan fire ignition.
- At 40 seconds, bottom container ignites.
- At 48 seconds, next container up ignites.
- At 56 seconds, next container up ignites.
- At 1 minute, 1 second, next one up ignites.
- At 1 minute, 7 seconds, top container ignites; fire very large; flames fill most of the compartment.
- At 5 minutes, CAF system activated to protect compartment.
- At 6 minutes, 30 seconds, all fires are suppressed.

TEST 2 Description:
- Same fuel arrangement.
- FRI SSP2 standard pendant sprinkler 165°F (74°C) quick response at 42 gallons/minute (160 liters/minute).

TEST 2 Observations:
- At 0 seconds, pan fire ignition.
- At 39 seconds, sprinkler automatically activates.
- At 2 minutes, pan overflows, and flaming fuel travels around enclosure.
- At 40 seconds, bottom container burns; fire large and erratic.
- At 4 minutes, 30 seconds, fire burns throughout compartment.
- At 5 minutes, 30 seconds, fire continues to burn under table.
- At 6 minutes, 30 seconds, fire dies down and at 7 minutes, 10 seconds, burns out. Four containers remain on upper shelves.
- Total water used was 275 gallons (1,042 liters) but no suppression.

TEST 3 Description:
- Same fuel arrangement.
- 7G5 mist nozzle at 100 psi, 10 gallons/minute (37 liters/minute) shelf.

TEST 3 Observations:
- At 0 seconds, pan fire ignition.
- At 38 seconds, manual mist activation.
- At 40 seconds, first container burns.
- At 5 minutes, 23 seconds, next container up burns.
- At 5 minutes, 40 seconds, next container up burns.
- At 6 minutes, next container up burns.
- At 7 minutes, top container burns.
- At 10 minutes, fire continues to burn on the floor and shelves.
- At 11 minutes, 25 seconds, test ends with fires still burning.
- Total water used was 105.6 gallons (400 liters) but suppression not achieved.

TEST 4 Description:
- Same fuel arrangement.
- 0.3 percent Class A, CAF. Six gallons/minute (24 liters/minute) solution and 53 gallons/minute (200 liters/minute) air, expansion 9.5:1.

TEST 4 Observations:
- At 0 seconds, pan fire ignition.
- At 35 seconds, CAF system manually activated.
- At 45 seconds, bottom container ignites.
- At 2 minutes, small fire left burning on bottom shelf; at 4 minutes, 40 seconds, all fires suppressed. The four remaining containers are intact.
- Total water used was 26 gallons (98 liters); suppression achieved.

that needed for air-aspirated systems. Both single-nozzle and two-nozzle systems were successfully tested. The performance of the CAF system was also compared to those of water mist and standard sprinkler systems for the same fuels.

For the scenario evaluated, some results showed that both Class A and B CAF fixed-pipe systems could extinguish the heptane fires more efficiently and effectively than standard sprinklers or water mist in both open spaces and compartments, although Class A foam performed slightly better (see Figure 1). The two agents performed the same way in extinguishing diesel pool fires. The wood crib fires were extinguished, and the effect of expansion ratios was demonstrated, with a 4:1 ratio performing better than a 10:1 ratio.

Surprisingly, Class A CAF performed better on the liquid pool fires than on the wood crib fires. The tests also demonstrated the importance of uniform foam distribution, which means that nozzle placement in multiple-nozzle systems is an important issue. Enclo-

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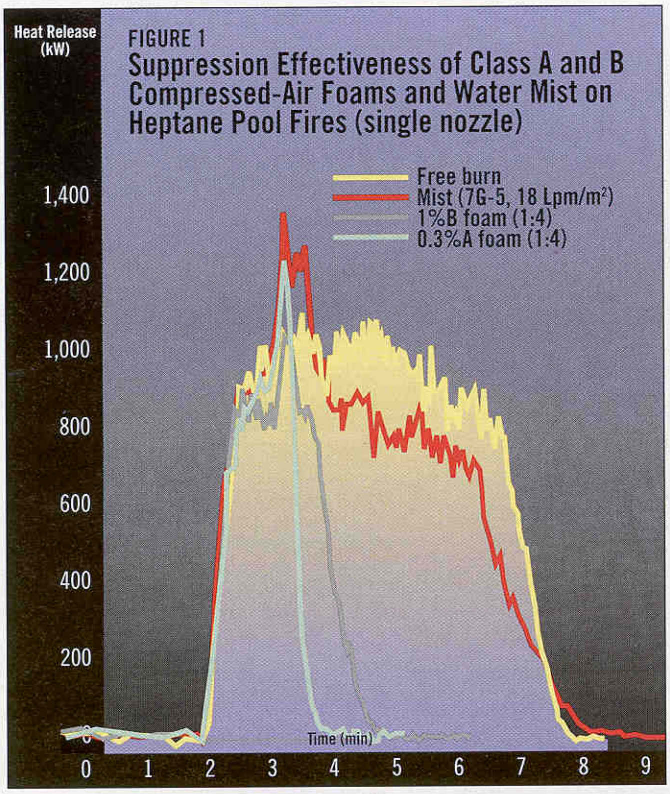
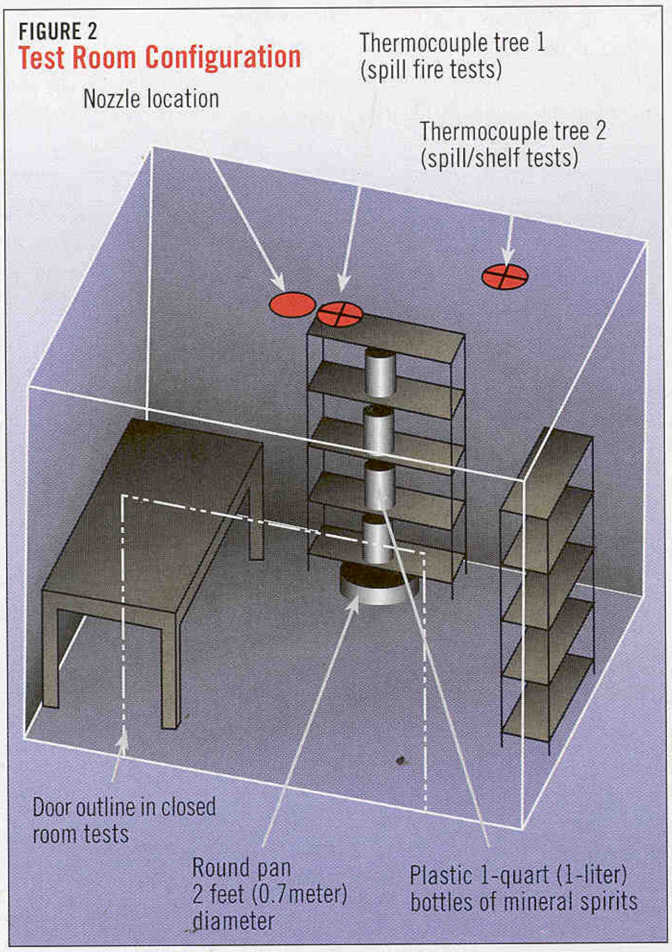
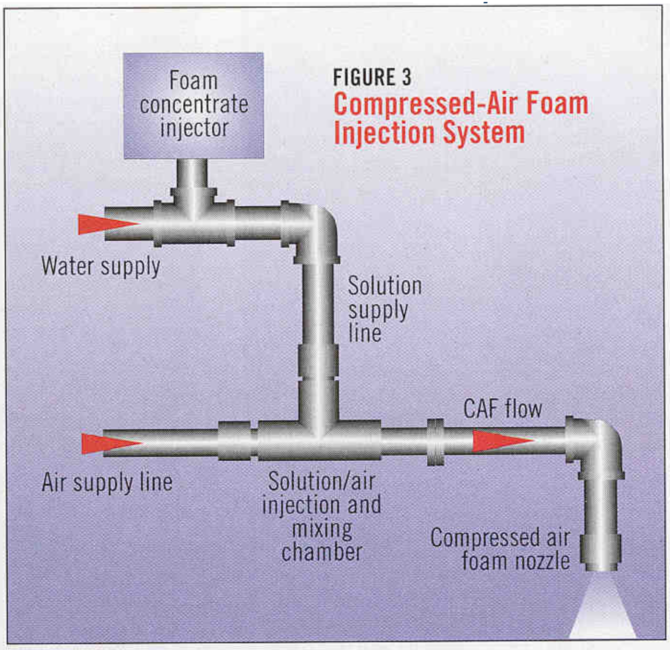






sures have no positive effect on the performance of CAF, as they do with water mist systems. In fact, CAF is equally effective with or without an enclosing compartment. However, CAF did adhere well to the enclosure walls and other vertical surfaces, providing them with an effective ignition-retarding barrier.

This background research clearly demonstrated the viability of fixed-pipe CAF systems and the positive effect CAF systems can have on fire suppression. It showed that CAF could extinguish pool and crib fires in both open and closed compartments using less than half the foam concentrate and considerably less water than air-aspirated systems. This provided a basis for further examination and offered future users the potential for an effective new fire suppression tool.

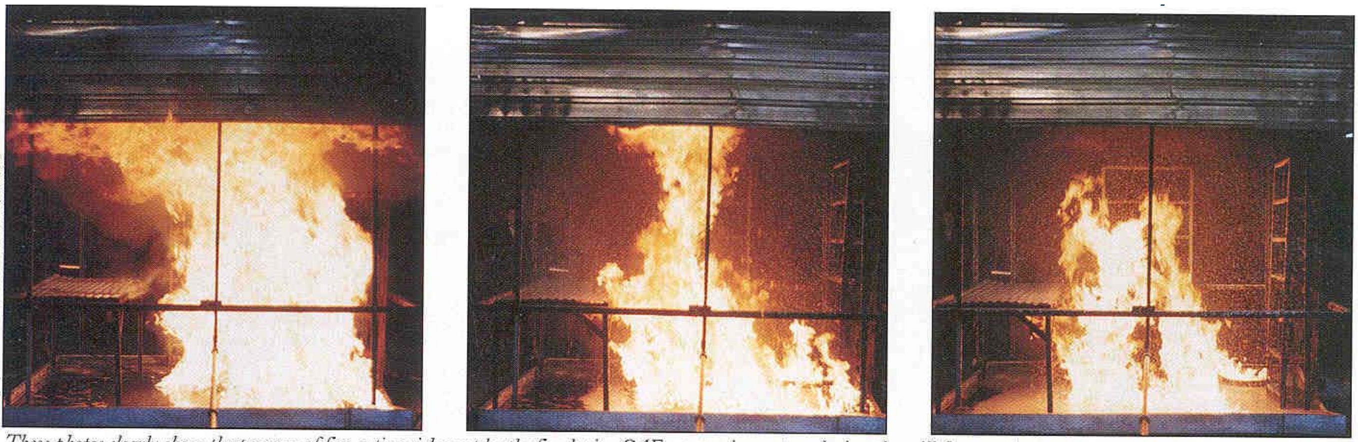
Real-life fire scenarios

If CAF fixed-pipe systems were to be used in real-life applications, NRC researchers realized, they'd have to demonstrate the systems' performance in fire scenarios that could occur in real life. To that end, they identified a pool fire and a spill fire, combined with packaged flammable liquids on shelving, as two typical scenarios against which they could demonstrate the CAF fixed-pipe systems' performance. Both these scenarios resemble arrangements found in hardware stores, paint stores, and building supply stores, as well as flammable liquids storage rooms in a number of occupancies.

As shown in Figure 2, the experiments were conducted in a high open and closed room with a ceiling. The room measured 9.8 feet by 11.9 feet by 9.8 feet (3 meters by 3.65 meters by 3 meters). The structure itself was constructed of welded steel tubing with a 26-gauge steel sheeting ceiling. The floor of the test area had curbs 7.9 inches (200 millimeters) high to contain spills. For the open space tests, the sides of the test room, other than the curbs, were open to the burn hall.

The test room contained a steel table 7.5 feet long, 3.2 feet wide, and 3.2 feet high (2.3 meters by 1 meter by 1 meter) and two steel shelving units 3.2 feet long, 0.9 feet wide, and 7.5 feet high (1 meter

Photographs: ©National Research Council/Canada



These photos clearly show the progress of fire extinguishment by the fixed-pipe CAF suppression system during the spill fire experiments.

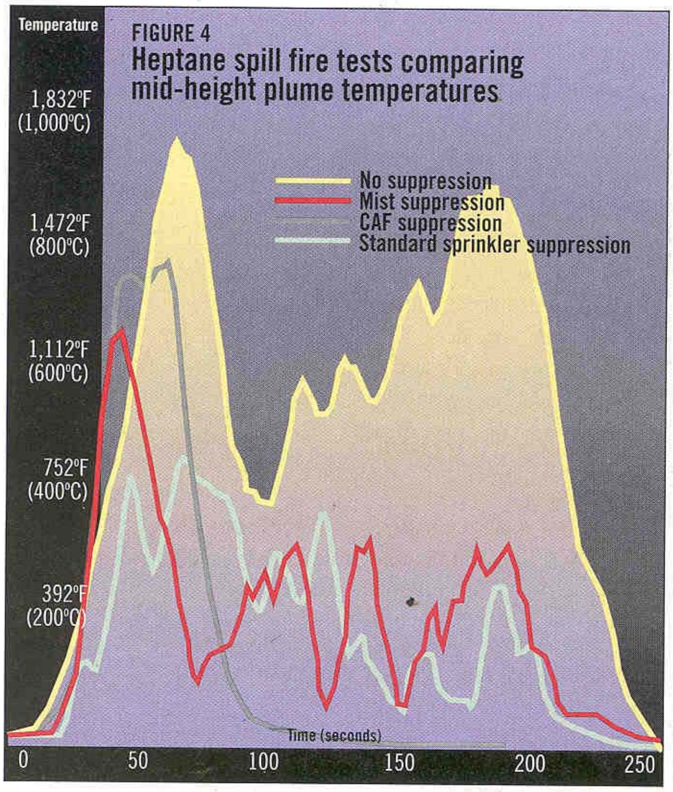
by 0.3 meters by 2.3 meters), containing seven equally spaced shelves.

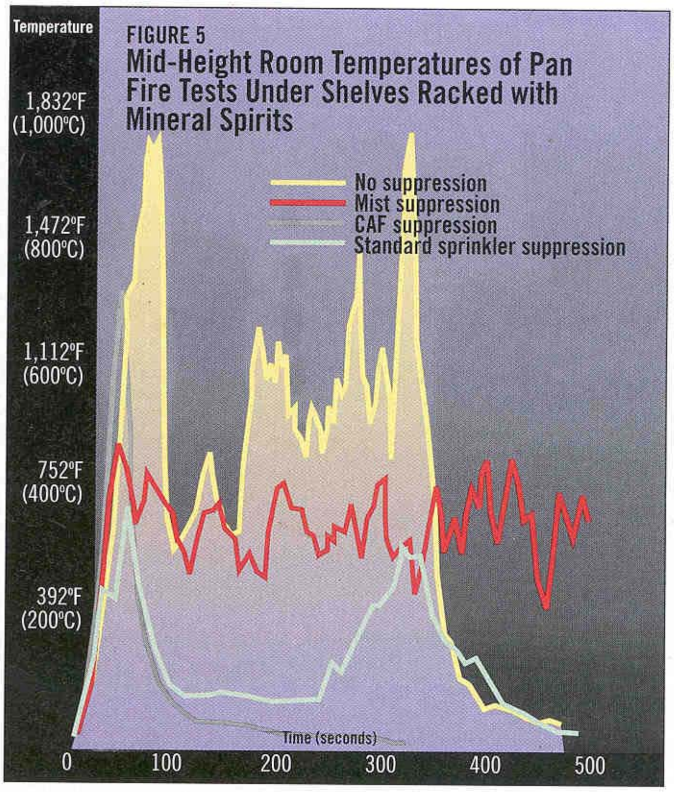
A single foam distribution nozzle was mounted at ceiling level at the center of the room and connected to the CAF system, which consisted of a commercial injector to meter foam concentrate into the water stream and a solution-air injection and mixing chamber (see Figure 3). The CAF was "scrubbed" through 9.8 feet (3 meters) of 1-inch-diameter (25.4-millimeter-diameter) steel pipe before it reached the nozzle. For all the tests, the system flowed 6.3 gallons per minute (24 liters per minute) of 0.3 percent Class A foam solution and 52.8 gallons per minute (200 liters per minute) of air, producing foam at an expansion rate of 9.5:1.

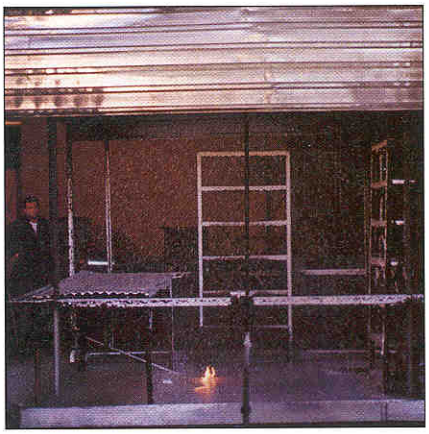
Fire test setup

Preliminary experiments showed that a 1-gallon (4-liter) heptane spill created a pool fire 4.9 feet (1.5 meters) in diameter that lasted approximately 30 seconds. To evaluate the CAF system, the fuel spill simulated three containers holding 1 gallon (4 liters) each, for a total of 3 gallons (12 liters). The pool was created by flowing heptane into the test room at a rate of 1 gallon per minute (4 liters per minute) and igniting the pool after 1 minute. The floor was covered with water 0.9 inches (25 millimeters) deep to ensure that the fuel was properly distributed. This created a fire with a heat release rate of approximately 2.2 MW that lasted approximately 3 minutes.

One series of experiments involved only a spill fire. In the second series, one 0.3-gallon (1-liter) plastic container of mineral spirits was placed at the center of each shelf in one shelving unit, and a pan 2.7 inches (0.07 meters) in diameter was centered below the shelves. The pan contained 2.6 gallons (10 liters) of heptane, which was enough to burn







and the shelves. With an ignition-retardation capability twice that of water, this provides an efficient fire control mechanism.

The CAF produced in these experiments was stable and consistent, and provided even coverage. Previous research showed that this was the result of more uniform bubbles in the foam. Furthermore, CAF is produced using air in the vicinity of the compressor, not the fire zone, thus eliminating the potential for soot contamination.

CAF expansion ratios can be as high as 40:1, although the practical range for fire suppression is 4:1 to 10:1. For Class A foam, the concentration used was 0.3 percent, which is significantly less than the concentration needed in air-aspirated applications. For Class B foam, the concentration used in earlier tests was less than that needed in normal applications, although research must still be conducted to determine the optimum concentration of Class B foam for CAF systems.

In addition, CAF could penetrate the plumes of fires larger than 2 MW and extinguish the fire either by direct contact from above or by foam flow to the fire source. CAF also allowed firefighters to see through it to the objects in the room while it was discharging, allowing them to identify the seat of the fire more quickly. This is sometimes difficult to do when sprinkler and water mist systems are discharging.

Clearly, CAF systems have potential that needs to be explored further. For example, they could provide fire suppression in remote areas that have no significant water supplies or in areas where water supplies are poor. Or they might be "packaged" for specific applications, such as cooking range hoods and paint spray booths. CAF systems might also prove more cost-effective than traditional aspirating nozzle foam systems. Although there is still research to be conducted, these tests clearly demonstrate that fixed-pipe CAF systems have a bright future.

for approximately 10 minutes. This simulated a spill from a container pooling on the floor and exposing the containers on the shelves above.

For the spill fires in the first series, four tests were conducted. In one, no suppression was attempted. In the other three, standard sprinklers, water mist nozzles, and CAF nozzles were used. The test compartment was open to the burn hall in all four tests, and four thermocouples were mounted in a vertical array at the center of the room, 2.3 inches (0.06 meters) apart starting at ceiling level (see Table 1).

The experiments in this series showed that the standard sprinkler and water mist systems could cool the space but couldn't suppress the fire until the fuel had completely burned off, while the CAF system could suppress the fire. Figure 4 shows the mid-height room temperatures for each of these four spill fire experiments.

Spill/shelf fire experiments

For the spill/shelf tests, the walls of the test space were enclosed with 26-gauge sheet steel, except for a 6.5- by 7.8-foot-high (2- by 2.4-meter) doorway opening. The four thermocouples were mounted in a vertical array 1.9 feet (0.6 meters) apart, starting at the ceiling, and were 1.9 feet (0.6 meters) from the north and east walls. Again, four tests were conducted using the same conditions used in the first series of spill tests (see Table 2).

Depending on the test, different numbers of 0.3-gallon (1-liter) mineral spirits bottles ignited and spilled their contents, adding to the fire. Again, only the CAF system was able to extinguish the fires. The sprinkler and water mist systems could cool the enclosure but not extinguish the flames. The CAF also adhered effectively to the enclosure walls and shelves. The results of the tests are illustrated in Figure 5, which shows the mid-height room temperatures for these four experiments.

Discussion

Both series of experiments demonstrated the capabilities of fixed-pipe CAF systems in practical applications, and proved that CAF can address those issues previously thought to limit the potential use of fixed-pipe foam systems.

Using Class A foam, the CAF system performed well in both open space and enclosed spaces, controlling and suppressing the fire in approximately 1 minute, 30 seconds, even when the fire was shielded from direct CAF spray. CAF stuck to, and protected, both the walls

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