A NEW COMPRESSED-AIR-FOAM TECHNOLOGY

Andrew Kim and George Crampton
National Research Council of Canada

INTRODUCTION

There is a major thrust to find an appropriate fire suppression agent to replace halon because of its ozone-depleting potential. Efforts so far show that there may not be one halon replacement agent but that several alternative fire suppression technologies may be suitable to replace halon, depending on the application.

Because of its inexpensive cost and superior fire suppression performance, halon has been the agent of choice and has been used widely, including in applications where halon is not necessarily the only option. This prevented development of other fire suppression technologies that have good potential. With the restriction on the use of halons, it may be wise to look at some of the other fire suppression technologies as a basis for further development to substitute for halon.

One such technology is foam system. For decades, firefighting foams delivered from fixed-pipe systems have provided effective fire suppression for such applications as chemical and petroleum industries and military installations. Despite the widespread use of fixed pipe foam systems, issues about their potential limitations have emerged. Such issues, which limit the overall effectiveness of fixed pipe foam systems and provide opportunities for potential improvements, include the following:

- Foam is not as stable and consistent, and expansion ratios are not as high as would he desired for some applications.
- Air to generate foam at the nozzle. which comes from the fire environment, contaminates the foam with soot and plugs screens that generate foam.
- Concentrations of foaming agents are quite high thus increasing costs.
- The momentum to deliver the foam to the fire is reduced by the action of impinging on the nozzle, thus reducing its ability to penetrate to the seat of the fire through the fire plume.

To help address some of these issues, an important innovation in foam system design has emerged; the introduction of fixed compressed air foam systems. Such systems expand the potential applications of foam tire suppression technology and offer significant benefits to users.

Compressed-air foam (CAF) is generated by injecting air under pressure into a foam solution stream. The process of moving the solution and air mixture through the hose or piping. if done correctly, forms compressed-air foam. The energy for the CAF comes from the combined momentum of the foam solution and air injection streams in the hose or piping. One significant advantage of such CAF systems is the increased momentum of the foam, enabling it to penetrate fire plumes and reach the seat of the fire, Also, compressed air foams distributed from a fixed system possess better stability with respect to drainage than aspirated foams, since CAF is characterized by a narrow distribution of bubble sizes.

This paper describes the successful implementation of CAF technology in a fixed piping system and provides a comprehensive set of results showing the effectiveness of overhead CAF systems.

GENERATION OF COMPRESSED-AIR FOAM

An effective CAF system produces foam consisting of similar-in-size bubbles, delivers the foam to nozzles without changes in foam properties, and provides a means of uniformly distributing foams over a prescribed area. **A** CAF system consists of three zones:

1. Air injection zone: Air is injected through a small orifice into a larger diameter stream of water, ensuring that the air pressure can be maintained higher than the water pressure, so that water does not back up into the air line. This eliminates the pulsations occurring in a large diameter pipe if air and water pressures are not balanced.
2. Development zone: After injection of air into the stream of foam solution in the mixer, foam flows through a segment of flexible tubing, which acts as a foam improver. After passing through the tubing, the foam is directed to the distribution piping. Abrupt bends in the piping as well as flow contractions and manifolds promote redistribution of foam into separate gas and liquid phases. The present system can produce uniform foams with expansion ratios ranging from 1:4 to 1:20. Foam solutions with expansion ratios in excess of 1:10 were found to be too dry to suppress fires effectively.
3. Discharge zone: A special nozzle was designed to permit the smooth discharge of foam. This nozzle consists of three orifices spaced at 120-deg intervals. The jet reaction of the discharging foam rotates the nozzle distributing the foam in a continuous arc to uniformly cover a circular area about 2 m in diameter. The CAF nozzles have no sharp bends and contain no impact points, which are normally present in sprinklers and fixed aspirated nozzles.

EXPERIMENTS

Experiments were conducted in a mobile test unit measuring 3.5 by 3.1 by 3.3 m. The chamber's walls were constructed from perforated steel to break up the convective air currents without limiting the ventilation rate. The chamber simulated open-space condition with unlimited ventilation. A thermocouple tree, containing 6 thermocouples at 0.3-m intervals, was placed above the centre of the fuel with the lowest thermocouple 1.5 m above the floor. The thermocouples provided an indication of fire control for experiments in which full flame extinction was not achieved. To estimate the mitigating effect of fire suppression systems on the thermal radiation hazards, three heat flux meters were placed around the enclosure.

FUEL TYPE

Three types of fires were used in the tests: heptane pool, diesel pool, and wood crib fires. A 0.9-m diameter pan with a lip height of 100 mm was used for the pool fires. Wood cribs weighed 9.5 kg, had outside dimensions of 0.6 by 0.6 by 0.3 m, and were constructed from 40 by 40-mm pine sticks. Pans and cribs were placed either on the floor or on the top of a 0.7 m high support platform in the open space fire tests. The nozzles were located 3 m above the floor.

For the crib and the diesel pool fire tests, the fires were allowed to bum for approximately 2 min before activation of the suppression system, to allow the fire to reach the fully developed stage. This was verified by the heat release rate data. For the heptane pool fires, a 1-min prebum was selected since the heptane pool fire reached steady burning conditions more rapidly than diesel fuel and wood cribs.

FOAM CONCENTRATES

The effectiveness of the fixed-piping CAF system was investigated in conjunction with Class A and B foams. A Silvex solution* manufactured to be diluted at 1% in air-aspirated systems, was selected for the Class A foam. This type of foam is primarily applied against fires involving Class A combustibles and is made from hydrocarbon-based surfactants. It lacks film-forming properties, but possesses excellent wetting capacity. In the present experimental program, the Silvex foam concentrate was mixed with water at 0.3% concentration.

The Class **B** foam was an aqueous film-forming foam (AFFF) concentrate. recommended for application at 6% concentration in air-aspirated systems, for use in suppressing flammable liquid fires. AFFF is made from fluorocarbon-based surfactants and has strong film-forming characteristics. The quantity of AFFF concentrate used in the present experimental program was between 1% and 3% of the water flow rate.

TEST RESULTS AND DISCUSSION

Table I provides a summary of the experimental conditions and results. The experiments were designed to provide performance comparisons, and to address the following questions:

1. How do Class A and Class B foaming agents compare in a CAF system?
2. What foam expansion ratios are most effective, and most practical?
3. How does increased flux density and foam concentration affect suppression ability?
4. How docs the performance of a CAF system differ in mitigating pool fires and crib fires'?
5. How do fixed CAF systems compare to water mist and sprinkler systems?

HEPTANE POOL FIRES

Class A and B Foams: The experimental results with a single foam nozzle. located directly above the fuel. showed that a CAF system, using Class A foam, suppressed a 0.9-m diameter heptane pool fire within 1 min of the activation of the system. Class B foam, however, was not as effective as the Class A foam. The CAF with 1% Class **B** foam solution. having an expansion ratio of 1:4, suppressed the heptane pool fire in 1 min *35* s, whereas 0.3% Class A CAF, with an expansion ratio of 1:4, extinguished the heptane pool fire in less than 40 s.

The difference in the performance of the two foams (Class A and **B)** is probably due to the concentrations used in our tests. The Class B foam concentrate (AFFF) was designed for application at a concentration of 6% in an air-aspirated nozzle system and the Class A foam was designed for use at 1% concentration. This means that, in our study, Class A foam concentrate was used at approximately 30% strength and Class **B** foam was used at less than 20% strength. However, in the CAF system, both foam concentrates performed well even at such low concentrations.

---

* Certain commercial products are identified in this paper to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the NEC, nor does it imply that the product or material identified is the best available for the purpose.

TABLE I. SUMMARY OF RESULTS OBTAINED IN OPEN-SPACE EXPERIMENTS.

Test no.	Fuel	Nozzle type	Nozzle no.	Nozzle height (m)	Additive	Fire reduced	Extinguishment time (min:s)
T01	Heptane	Water mist	2	3	None	No	No
T02	Diesel	Water mist	2	3	None	Yes	1:09
T06	Crib	Water mist	2	2.3	None	Yes	No
T11	Heptane	Foam	2	3	0.3% A*	Yes	025
T12	Heptane	Foam	2	3	0.3% A t	Yes	0:30
T13	Crib	Foam	2	2.3	0.3% A t	Yes	1:42
T14	Crib	Foam	2	2.3	0.3% A*	Yes	0:37
T15	Heptane	Foam	2	3	1% B*	Yes	1:11
T16	Heptane	Foam	2	3	1% B t	Yes	2:45
T17	Heptane	Sprinkler	2	3	None	No	No
T18	Diesel	Sprinkler	2	3	None	Yes	3:30
T20	Crib	Sprinkler	2	2.3	None	Yes	4:35
T22	Heptane	Water mist	1	3	None	Yes	No
T38	Heptane	Foam	1	3	0.3% A t	Yes	0:49
T39	Heptane	Foam	1	2.3	0.3% A t	Yes	0:44
T40	Crib	Foam	1	2.3	0.3% A t	Yes	5:22
T41	Heptane	Foam	1	2.3	1% B†	Yes	2:55
T42	Heptane	Foam	I	2.3	1% B*	Yes	1:35
T43	Heptane	Foam	1	3	1% B*	Yes	1:33
T44	Heptane	Foam	1	3	0.3% A*	Yes	0:30
T45	Heptane	Foam	1	2.3	0.3% A*	Yes	0:38
T48	Crib	Foam	1	2.3	0.3% A*	Yes	3:10
T70	Diesel	Foam	2	3	0.3% A t	Yes	0:35
T71	Diesel	Foam	2	3	0.3% A*	Yes	0:28

* Foam expansion ratio **of** 1:4.

† Foam expansion ratio of 1:10.

***Foam* Expansion Ratio:** Different expansion ratios for Class A and B foams were compared to determine the impact on the suppressibility of heptane pool fires. Test results showed that a lower expansion ratio foam (1:4) extinguished the fire a little quicker than the higher expansion ratio foam (1:10). A Class A foam with an expansion ratio of 1:4 extinguished the heptane pool fire in **38** s, compared to 44 s with an expansion ratio of 1:10. For the Class B foam, the difference was somewhat larger; a foam with a 1:4 expansion ratio extinguished the fire in 1 min 35 s, compared to 2 min *55 s* with a 1:10 expansion ratio foam. This does not necessarily mean that a lower expansion ratio foam is more effective than a higher expansion ratio foam. The difference in extinguishment times between the two foam expansion ratios was small, and one should consider that the 1:4 expansion ratio foam required 2.5 times more foam solution than the 1:10 expansion ratio foam. In fact, considering the water requirement, a higher expansion ratio foam may be more efficient in extinguishing a liquid fuel pool fire. If the expansion ratio is too high (above 1:10), however, the foam may be too dry and too light to be able to penetrate the buoyant plume and reach the fuel surface to suppress the fire.

DIESEL POOL FIRES

Using two foam nozzles, the Class A CAF, with an expansion ratio of 1:10, extinguished a 0.9-m diameter diesel pool fire within 35 s. Foam, with an expansion ratio of 1:4, extinguished the fire in 28 s. The CAF was equally effective in suppressing the diesel (high flashpoint liquid) and heptane (low flashpoint liquid) pool fires.

A CAF system extinguishes pool fires by providing a foam blanket, which covers the fuel surface and reduces the thermal feedback to the fuel surface. If the foam blanket is applied rapidly. suppression of the evolving volatile fuel vapours is less important [1], although some effects are obviously present. It takes slightly longer to extinguish fires of low flashpoint liquids. Compare, for example, the extinguishment times for 1:10 foams. which were 35 s and 44 s in the case of high and low flashpoint liquids, respectively. Therefore, the flashpoint temperature of the fuel is not as critical as in the case of extinguishment with water mist. The water mist system could extinguish the diesel fires, but could not extinguish the heptane pool fires (Table 1).

WOOD CRIB FIRES

Foam Expansion Ratio: The Class A CAF, delivered from a single nozzle above the fire, was not as effective in extinguishing wood crib fires as in extinguishing the liquid fuel fires. The foam, with an expansion ratio of 1:4, controlled the wood crib fire in less than 1 min and extinguished all flames at 3 min 10 s. The foam blanket covered most of the top surface area of the crib in less than 30 s. however, due to the orientation of the nozzle, the side of the crib was not blanketed by foam. There were persistent flames within the crib which were eventually extinguished as water slowly drained from the foam blanket into the core of the wood crib. With a 1:10 expansion ratio foam, the heat release rate was reduced because the foam blanket partially covered the top surface of the crib. However, even after 4 min of foam application, the foam blanket was not contiguous and flames continued through the top of the crib.

Comparison of crib and liquid fuel fires: Comparing the wood crib results to the liquid fuel results (Table 1) indicates that the Class **A** CAF performed better on liquid fuel fires. With liquid fuel pool fires, the foam expands to completely cover the fuel surface. This blocks the heat transfer from the flame to the fuel surface and decreases the vaporization of the fuel. In the crib fires, foams cannot reach all of the interior burning surfaces, however. the water draining from the foam eventually penetrates the crib and may indeed extinguish the fire.

Foam Distribution: The importance of a uniform distribution of foam was illustrated by the relative performance of the dual nozzle configuration compared to a single nozzle. Two foam nozzles. located ***2.3*** m above the crib and 2 m apart, provided sufficient foam to cover the top and side of the wood crib, resulting in fire extinguishment. The low expansion ratio foam (1:4) suppressed the fire in 37 s. The foam with an expansion ratio of 1:10 extinguished the fire in 1 min 42 s.

In comparison tests, two sprinklers took 4 min 35 s to extinguish the fire, whereas water mist from two nozzles could not extinguish the wood crib fire. The experimental results show that a fixed CAF system is very effective in extinguishing wood crib fires, provided that it is distributed uniformly and is able to cover all surfaces of the crib.

CONCLUSIONS

National Research Council of Canada has developed a means of producing Class **A** and Class B compressed-air foam (CAF) in a fixed pipe system, incorporating a new and innovative foam distribution nozzle. Foam break-up, which prevented the development of this technology in the past, was avoided by the careful engineering design of the nozzle and the piping system.

With the fixed pipe CAF system, it was possible to produce foams with high momentum using less than half the amount of foam concentrate recommended for an aspirated system. Using the CAF system, foams with expansion ratios ranging from 1:3 to 1:20 were produced by controlling the foam solution and air flow rates. Although in wildland and structural firefighting, foams with expansion ratios ranging from 1:2 to 1:100 may be used (as dictated by a specific application), the optimum fire suppression efficiency in the current test setup was obtained using foams with expansion ratios between 1:4 and 1:10. Foams with expansion ratios higher than 1:10 were too dry to penetrate the flame and reach the fuel surface. Foams with expansion ratios lower than 1:4 drained too quickly and were unable to maintain a foam blanket on the fuel surface. Also, the amount of water required for the lower expansion foam was considered to be too great.

The system extinguished heptane and diesel pool fires and wood crib fires quickly, with a small amount of water. This makes it an ideal candidate for applications in areas where water supply is limited.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support from the Canadian Forces Fire Marshal's Office, National Defence Canada.

REFERENCE

1. Nash, **P.,** "The performance of firefighting foams on flammable liquid fires," *Fire Prev Scie and Tech*, *5*, pp. 4-13, 1973.