COMPRESSED AIR FOAM SYSTEMS: LIVE FIRE APPLICATION AND CORRESPONDING TEMPERATURE DEGRADATION

EXECUTIVE LEADERSHIP

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Appendices Not Included. Please visit the Learning Resource Center on the Web at http://www.lrc.dhs.gov/ to learn how to obtain this report in its entirety through Interlibrary Loan.

ABSTRACT

This research project examined the cooling effect of Compressed Air Foam Systems (CAFS) in structural fire fighting. During live fire training exercises conducted by the Flower Mound, Texas, Fire Department (FMFD) interior temperature measurements were taken on test fires. The problem this research addressed was overcoming limited understanding of CAFS as applied to structural firefighting, limited experience of FMFD personnel with CAFS, and identifying the impact CAFS has on the interior temperature of the structural firefighting environment. Temperature measurements on live training fires were carried out with equipment and the cooperation of personnel from the Bureau of Alcohol, Tobacco and Firearms (ATF).

The purpose of this research project was to investigate CAFS technology and tactical application in structural firefighting, and develop empirical data to demonstrate the impact CAFS has on the temperature curve of the fire environment. The results will be used as part of a decision making process for possibly changing current suppression tactics and future procurement of additional CAFS units.

This research project used descriptive research methodology in the form of a literature review to identify advantages and disadvantages of CAFS application in structural fire fighting. Evaluative research methodology was used in live fire testing of CAFS during training exercises to evaluate the effect of CAFS application on the temperature gradient and to develop empirical data for departmental purposes.

The research questions were:

1. What are the published advantages and disadvantages of CAFS in structural firefighting?

2. Do CAFS reduce stress and fatigue of firefighters?

3. Can use of CAFS increase the effectiveness and safety of fire suppression personnel?

4. Should the FMFD retrofit additional units with CAFS, or include CAFS in future apparatus specifications?

5. What impact does CAFS have on the temperature gradient of a fire?

The procedure started with a literature review of the reported advantages, disadvantages, and field test results of CAFS. Tactical applications of CAFS were tested in live fire exercises, during the FMFD annual training school, conducted April 11, 12 and 13, 2002, at Fort Wolters in Mineral Wells, Texas.

CAFS was found to provide increased suppression capability, reduced firefighter exertion and stress and was effective in reducing the interior temperatures in structural fires. The resulting recommendations include CAFS specifications for future apparatus purchases, continued training of personnel on CAFS tactical applications and further live fire testing of CAFS extinguishing capabilities. Further research in comparative analysis of CAFS verses water as an extinguishing agent, its impact on the temperature gradient, and tactical fireground application is warranted.

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INTRODUCTION

The Flower Mound, Texas, Fire Department (FMFD) is a professional fire suppression, emergency medical, public education, fire prevention and emergency management organization. The Town of Flower Mound is located in the Dallas, Fort Worth, and Denton triplex area. The department provides emergency services for a population of approximately 53,000 and is housed in three stations. The work force is comprised of three platoons of 17 shift firefighters (total of 51) supported by 7 administrative personnel. Minimum staffing is 14 personnel. Full staffing is 6/5/6 for stations 1, 2 and 3 respectively. An engine and ambulance respond from each station.

The problem this research addressed is overcoming limited understanding of CAFS as applied to structural firefighting, limited experience of FMFD personnel with CAFS, and identifying the impact CAFS has on the interior temperature of the structural firefighting environment. Recently, the FMFD retrofitted a front line engine with CAFS for ISO rating purposes as well as increasing the department’s suppression capabilities. However, the new equipment has had limited use because of circumstances in deployment, call volume, limited training opportunities and few fires.

The purpose of this research project is to determine if CAFS technology and tactical application can increase the effectiveness and the safety of personnel in fire suppression operations and develop empirical data to demonstrate the impact CAFS has on the temperature curve of the fire environment.

This research project uses descriptive research methodology in the form of a literature review to identify advantages and disadvantages of CAFS. Evaluative research methodology is used while testing CAFS on live fire training exercises.

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BACKGROUND AND SIGNIFICANCE

The Town of Flower Mound, Texas, Fire Department (FMFD) is a career Fire/EMS department. Fifty-one duty personnel provide a full range of emergency services including: fire suppression, fire prevention, advanced cardiac life support ambulance service, public education and emergency management. Seven administrative staff personnel support operations.

The department provides services to an estimated population of 53,000 in a community that sprawls over 50+ square miles. The community is rural/suburban. The Flower Mound Chamber of Commerce reports, the average household income is $75,074 and 72% of adult population has had post-secondary education. Annually, more than 1,100 building permits are issued for new single-family homes. Existing housing is available from the $100s to over $2.3 million. The average price of pre-owned homes is $183,960 and the average value of all new construction homes is $234,000. The estimated number of single-family housing units in 2001 was 15,499 and the number of multi-family units was 660 (Flower Mound Chamber Commerce, 2002).

The department staffs and operates three engine companies and three MICU ambulance transport units each shift from three stations. Full staffing is 17 personnel per shift. Minimum staffing is 14. The department augments these staffing levels with aggressive mutual aid requests during fire suppression operations. However, all too often, first due companies are challenged to accomplish too many tactical operations during the initial suppression activities. Research abounds relative to the negative effect understaffing has on personnel and fire suppression outcomes. Taylor (1997) conducted research to see if CAFS could positively affect safety and efficiency of understaffed suppression crews. He made a point that stretching resources to the limit is unsafe and disproportionately increases the risk firefighters face. FMFD personnel are exposed to resource stretching routinely. For FMFD crews this situation is compounded when the fire involves large residential structures (LRS) many in excess of 6000 square feet. There are many of these types of structures in Flower Mound. Several gated communities boast residencies priced from $850,000 to 2+ million dollars. One house under construction in town is in excess of 27,000 square feet and over $7.5 million.

Lacking initial response personnel to carry out fire suppression tactics, property seclusion, difficulty in aggress/egress, mutual aid resources too distant, and firefighters challenged to do too much with too little, compound normal risk factors firefighters face. Even though response times of first due companies usually meets requirements, second and third due companies can be as far as 15 minutes away. Mutual aid companies can take as much as 25 minutes to arrive from the time of the initial call. Initial companies need as much tactical advantage as possible for interior attack operations. Does CAFS offer fire suppression crews an advantage?

As part of an aggressive program to increase FMFD's Insurance Services Office (ISO) rating a decision was made to retrofit a front line apparatus with CAFS. It is a 1250 gpm 1998 Pierce Saber pumper. It was retrofitted in February 2001 with a 200 cfm (cubic feet minute) compressor Hercules CAFS. Limited experience of FMFD personnel with CAFS and a limited understanding of its potential benefits in fire suppression are obstacles in the way of its use. The retro-fitting program was featured in the March 2002, *FireRescue Magazine*. Scott Cook (2002) writes, "…members of the FMFD found a section in the ISO Texas Exception that states if a CAFS equipped engine responds to all structure fires, the department earns 1.5 points. FMFD could solve its point problem with a one-time cost of $35,000—the cost to retrofit one of its existing apparatus with CAFS" (p.58).

CAFS may not be the answer to the FMFD problem for LRS fire suppression operations or understaffed suppression crews, but it is worthy of the investigation. This research paper has been completed to satisfy the applied research project requirement for the Executive Fire Officer program (EFO), Executive Leadership course at the National Fire Academy. The project relates to the Executive Leadership course material, as outlined in the student manual, in the skills/action areas for ability to communicate, ability to negotiate, mediate and promote consensus, ability to perform analysis and exercise judgment, and ability to manage the decision making process. This research project in large part will be the supporting document for future purchasing consideration, staffing levels and operational procedure development. These are the type of decisions Executive Fire Officers deal with daily.

More important than satisfying a requirement of the EFO program, is making CAFS a successfully integrated suppression tool in the FMFD arsenal. Colletti (1998) makes a point that rings true. Training and education are key.

> “The entire membership must learn the expected use, capability, benefits and pitfalls of new firefighting procedures. With Class A foam and CAFS, classroom instruction and live fire training under controlled, safe conditions are vital to success…membership must feel comfortable about them and gain a level of confidence in how they realistically work. Importantly, each must see, firsthand, that their fireground safety is not compromised.”(Colletti, 1998, p.25)

This project, though limited in strict scientific methodology, is firsthand experience, under controlled conditions, live fire training for members of the FMFD. It is a very important part of the education and training of the members and for the overall transition to CAFS as a suppression agent. The United States Fire Administration is committed to reducing the occupational injury and death rates of fire fighters as part of their operational objectives. If CAFS can impact firefighter safety and effectiveness, then this research, and the effort put into its completion will support that goal.

LITERATURE REVIEW

History of CAFS

Compressed Air Foam Systems date back to the 1930's. They were used in maritime firefighting. In 1938, an article in *The Fireman* (a United Kingdom trade journal), explains the workings of the "Pneumasuds" apparatus on a ship named Patricia. It had an electric motor, a double acting reciprocating pump for water, a rotary air compressor, a small rotary pump for foam solution, a venturi apparatus and a foam solution tank. It was capable of 40/50 gpm at 50 psi, 40 cfm of air at 10 psi with a motor speed of 1350 rpms, delivering 200 gallons of foam per minute (Colletti, 1998).

The technology of CAFS advanced and was used by navy firefighters during World War II. High-energy Class-B foam systems were first experimented with by the British and United States navies in the 1940s (IFSTA, 1996 ed). Not until the 1970s did the fire service start looking at CAFS as a means of fire suppression. The Texas Forest Service is credited, (Boston, 1994; Colletti, 1998; IFSTA, 1996 ed; Taylor, 1997) with experimentation and development of CAFS as a wildland fire fighting application in the early 1970s. In the 1990s, the experiences of the forestry officials and their hypothesis that CAFS could enhance structural firefighting capabilities was taking hold and municipal fire departments were becoming interested (Colletti, 1998).

In short, CAFS is not a new technology. However, the fire service being true to its nature is slow to change. Colletti (1998) brings this point to light in his book. He includes excerpts from Deputy Chief Kenneth L. Jones, of the Fairfax County Fire and Rescue Departments, applied research paper on Class A foam and CAFS, which Jones wrote in 1990.

> Colletti citing Jones: …"Radical changes in applied technology are going to be required in order to enable the Chief Fire Officer to deliver the required fire suppression service with a reduced allocation of critical resources.
>
> In an era of significantly more demands on the municipal budget than there are resources available, the standard procedure of utilizing more staff to handle the suppression problem is not a viable option.
>
> Working smarter with fewer resources will be the direction that fire executives will be given in the years ahead. There has not been a major change in the way fires have been extinguished since water was applied to a fire from a motorized apparatus. The agent of choice has been water because it is usually readily available and the cost associated with it has in most cases been within acceptable parameters.

> …The introduction of a new, more effective method to utilize water by decreasing the amount required, while improving the mobility of attack lines and, thus, reducing the associated water and smoke damage to the structure, certainly deserves serious consideration by the chief fire officer.
>
> …The technology [CAFS] has arrived. The big challenge for the fire service is going to be its ability and willingness to accept fundamental change in the way structure fire operations are conducted by utilizing scarce resources in the most cost-effective manner possible." (pp. 6-7).

It is this struggle to provide a more cost-effective service in conjunction with the reduction of resources that fuels this research. Increasing departmental acceptance to CAFS technology has the potential to fill an ever-widening gap between the supply and demand on resources to deliver emergency services.

Advantages of CAFS:

A great deal of literature (Boston, 1994; Colletti, 1998; Cavette, 1999 & 2001; Taylor, 1997) is in agreement regarding CAFS advantages for structural firefighting applications. In a field test report, Compressed Air Foam for Structural Fire Fighting (1994), the Boston Fire Department evaluated 146 fire calls where CAFS was used as the extinguishing agent. The report finds CAFS was more effective than water as an extinguishing agent, the hose line was easier to move, fire attack was initiated quicker, reduced need for overhaul, concealed spaces were extinguished faster, and steam "punch" was less than with water. Murdock (1997) makes a point regarding limited water resources and CAFS capability to expand this resource. Murdock writes, “ CAF systems do offer a mechanism to increase and enhance the effectiveness of water…improving the extinguishing capabilities of limited water resources will prove a major benefit” (p.26).

In his article, The Finer Points of Foam, Cavette (1999) states, “compressed-air foam offers significant advantages in both wildland and structural incidents.” (p. 5). Some of the advantages Cavette listed include:

- Uses less water.
- Uses less foam concentrate.
- Penetrates fuels more effectively.
- Gives a faster knock down.
- Absorbs heat more rapidly to lessen the chance of flashover in structure fires.
- Reduced the potential for rekindle.
- Can be pumped twice as high as water under the same pressure.
- Lowers risk of heat stress during interior attack.
- Reduces the weight of hose lines.
- Reduces the chance of structural collapse from accumulated weight.
- Reduces water and smoke damage.
- Aids fire investigation by lessening disruption of the scene by streams.
- Forms a vapor barrier around fuels to exclude oxygen.

Cavette offers more advantages in another article, Bubbles Beat Water (2001), an account of testing conducted by the Los Angeles County Fire Department, whereby, CAFS was found to have a faster knock down rate over Class-A foam or water, absorbed heat faster, cast a longer stream thus increasing standoff distances, and caused less water damage.

Robert Taylor, in his applied research project for the National Fire Academy, Executive Fire Officer Program, *Compressed Air Foam Systems in Limited Staffing Conditions* (1997), provides extensive citations for advantages of CAFS. The following accounts are taken from his work. Taylor citing, Jeff Stern and J. Gordon Routley's Report 083 of the U.S. Fire Administration's Major Fires Investigation Project (1996), reported advantages of CAFS included:

- Faster fire extinguishing.
- Foam increased efficiency and conservation of water.
- Low cost.
- Protective blanket.
- Foam is visible during application and after.
- Foam clings to most surfaces protecting exposures.
- CAFS attack lines are lighter.
- Foam may preserve evidence.
- Foam can be used on flammable liquids.
- Aids in wildland and urban interface attacks.
- Reduces property damage.
- Firefighter stress and fatigue may be reduced.

As can be seen with most of the advantages listed, they are similar. CAFS has a faster knock down, hose lines are lighter, firefighter stress and fatigue is reduced, all of which make CAFS safer and more effective.

Opinions vary as to how fast CAFS is in knocking down a fire. Taylor (1997) uses a chart to depict how fast CAFS is compared to Class A foam and water. It is a summarization of work by John Liebson.

Chart 1.	Time to Fire Knockdown	Water/Foam/CAFS	
Extinguishing Agent	Time to Knock-down, Minutes	Gallons of Water used	Amount of Foam Agent Used
Plain Water	X	Y	N/A
Class A Foam	.7X	.5Y	Z
Compressed Air Foam	.25X	.3Y	.35Z

The chart indicates CAFS is four times faster at knocking down a fire and uses only 30 percent of the water used in a water only attack. Additional quotes used by Taylor (1997) to qualify/quantify the reduced knock down time of CAFS include:

- ‘The addition of Class A foam and compressed air to a plain water fire stream multiplies the fire-killing power of the stream and the meatware [personnel] using it from 5 to 10 times’ (Davis, 1997b, p.77);

- ‘Class A foam systems and CAFS may knock down up to 10 times more fire with a tenth of the water traditionally used’ (Edwards, 1994, p.66);

- ‘Effectiveness per gallon of water is estimated in the literature as high as 5 to 10 times over plain water for some applications’ (Stern & Routley, 1996, p.13);

- ‘CAFS has a firefighting capability eight to ten times that of plain water.’ (Liebson, 1991, p.23);

- ‘The foam industry is saying it’s ‘three to five times more effective than plain water’…in my experience with CAFS and contrasting flows on structures with Iowa Supply methods, the general range has been a fivefold increase in efficiency…’(Colletti, 1992, p.7-8). (Taylor, 1997, pp. 92-93)

Though the numbers are not exactly the same and the qualifying terminology lacks standardization, it is apparent from the accounts that CAFS is faster on the knock down.

Larry Stevens (1999), in his article, The CAFS Solution, writes that CAFS has a five times faster impact on temperature, the lines are more maneuverable and extinguishes fire with less water. “About five to seven times less water is needed to overhaul a fire. Whatever the figures-a reduction in water used is a reduction in damage done.” (p. 8)

The International Fire Service Training Association (IFSTA) (1996), *Principles of Foam Fire Fighting*, lists tactical advantages of CAFS as:

- The reach of the fire stream is considerably longer than streams from low-energy systems.
- A CAFS produces uniformly sized, small air bubbles that are very durable.

- CAFS produced foam adheres to the fuel surface and resists heat longer than low-energy foam.
- Hoselines containing high-energy foam solutions are lighter than hoselines containing low-energy foam solutions or plain water.
- A CAFS provides a safer fire suppression action that allows effective attack on the fire from a greater distance. (p. 77)

Though written in a way that equates the advantages for application of either wildland or structural fire fighting, IFSTA still makes the same point as others.

Another very noticeable advantage of CAFs is lighter hoseline weight. Common sense alone should tell us that CAFS lines are lighter. They have air in them! Taylor (1997) citing the works of (Colletti, 1994a; Stern & Routley, 1996; Duncan, 1994; and Darley, 1995) makes the case on reduced hoselines weight and how that reduction of weight impacts firefighter safety and fatigue. The following excerpt from Taylor's (1997) applied research paper, *Compressed Air Foam Systems in Limited Staffing Conditions,* makes the case for lighter hoselines and firefighter safety.

> CAFS may reduce the hazards of fire fighting in several ways…a large percentage of firefighter injuries and deaths are related to stress and fatigue. Stern & Routley (1996, p.11) report reduced firefighter fatigue through diminished suppression and overhaul times, causing less exposure to heat and products of combustion. Colletti (1994a) claims: '[CAFS] can reduce flame knockdown times, increase fire stream reach, and provide lighter-weight hoselines, all of which increase fire fighter safety through stress reduction' (p.66). A Federal Emergency

Management Agency (FEMA) study concluded ‘Attack lines that are used to deliver compressed air foam are significantly lighter and easier to handle than plain water hand lines, because the product inside the hose is mostly air. The line weighs approximately half the weight of a regular hose line of the same diameter. The reduced weight and increased maneuverability can reduce firefighter fatigue and stress (Stern & Routley, 1996, p.15). ‘Hose line weight is significantly reduced thus mitigating one of the primary physical stressors of fire fighting’ (Duncan, 1994, p.18). Darley (1995) claims that CAFS can reduce hoseline weight up to one quarter that of plain water, producing less firefighter strain. Colletti (1994b) notes that a CAFS 1.75-inch hoseline weighs about the same as a 1-inch booster line filled with plain water, and that ‘On an interior structural attack the lightweight hoseline can reduce physical exertion and stress of attack team personnel advancing it’ (p. 39).

Disadvantages of CAFS

The first applications of CAFS as a fire suppression tool in municipal fire services was in the wildland environment. Texas Forest Service began using CAFS in the early 1970s (Colletti, 1998; IFSTA, 1996; Taylor, 1997). Because of advancements in technology and the efforts of proponents of CAFS, it is gaining acceptance in structural fire fighting, but not without its disadvantages.

IFSTA (1996) reports a CAFS does have some inherent limitations:

- A CAFS adds expense to a vehicle and can be a high-maintenance item.

- Hose reaction can be erratic with a CAFS if foam solution is not supplied to the hose line in sufficient quantities.
- The compressed air accentuates the hose reaction in the event the hose ruptures.
- Additional training is required for personnel who are expected to make a fire attack using a CAFS or who will operate CAFS equipment. (p. 77)

In the Boston (1994) report company officers and firefighters offered their opinions, few of which were negative. Out of 146 responses to a question about hose kinking 134 responded it was not a problem, 2 responded it was some problem and 10 had no response. In another question, 139 reported no problems with CAFS, 1 reported slippery surfaces, 1 reported strong odor of foam and 5 reported skin irritations. Disadvantages offered by other companies (not Engine 37, the company using the foam agent) and officers were that foam obscures the floor, facepieces get covered with foam, foam could mask or complicate accelerant detection, and some District Chiefs just weren't comfortable with Engine 37 providing back-up with a 1.75 inch hoseline and tank water.

According to Colletti (1996), a problem with CAFS is its use with ordinary fire hose normally used with plain water lines. Colletti (1998) includes an excerpt from a June 15, 1994, Safety Alert Bulletin from the Fire Equipment Manufacturers Association (FEMA).

> …FEMA strongly recommends that no hose be used on a CAF system unless such use is recommended by the manufacturer of the system and the hose

> manufacturer. Use of non-approved hose can be dangerous and may cause a hose or coupling failure, producing property damage, bodily injury or death… (p. 227).

However, Ron Rochna (1997), International Manager of Foam Education, Hypro Corporation, refutes the FEMA alert. Supported by a citation of an article in *Foam Applications for Wildland and Urban Fire Management*, Volume 7, No.2, September 1995, authored by Lois P. Sicking, titled ‘CAFS Rated Hose: Yes or NO?’ the author, Sicking, makes the point that “pressure is pressure” whether created by liquid or by gas. Hose tested to 450 psi could withstand 450 psi from CAFS or plain water. If a hose is to fail, the pressure is the factor not the product under pressure. Typical hose pressures for CAFS run from 75 to 150 psi and pose no greater threat for rupture. Rochna states,

> “Colletti’s statement regarding the minimum design requirements for a CAFS used in structure and wildland interface fires and its fire hose incompatibility must be restated to say: Fire hose used with a CAFS must not be subjected to pressures exceeding its designed rating. Pressure is pressure—be hydraulic or pneumatic. If the hose is rated to 250 psi, it will perform no better or worse with CAFS. Of all the departments using CAFS, none have reported hose failures.” (p.1)

Slug flow and chatter are other unwanted hose line conditions that can occur. Slug flow occurs when foam concentrate is not introduced. Since water and air do not mix, slugs of water and air pulsate through the hose causing rapid pulsations “slugging” at the nozzle. Chatter on the other hand occurs in the first section of hose coming off the apparatus CAFS discharge. Chatter is due to most CAFS not having a motionless discharge mixing chamber (Colletti, 1998).

Cavette (1999) is in agreement with the disadvantages of CAFS. Cavette includes, expense and maintenance, creation of slippery surfaces, and nozzle reaction as primary disadvantages. Additionally, Cavette points out that because CAFS is such a fast acting extinguishing agent, that it may encourage departments to use smaller lines or flow rates, but warns against this tactic. “Compressed-air foam still requires appropriately sized lines and flow rates, it just extinguishes the fire faster.” (p.6) Cavettes’ opinion mirrors that of Taylor (1997), who writes,

> …literature reports many test fires promptly extinguished with less than 1/10 of the minimum gallonage required by the Iowa State Formula, or even the more demanding National Fire Academy required flow method. This reduced flow can indeed be delivered by smaller, lighter, more maneuverable lines. However, other sources (Colletti, 1992; Fornell, 1991; International Fire Service Training Association 1996; Liebson, 1992, 1996) hold that when using CAFS, the foam solution must equal the minimum required flow of plain water. This school of thought advocates exploiting the extinguishment “premium” of CAFS in the form of quicker fire knockdown, rather than smaller, lighter, and less fatiguing hoselines [delivering reduced flow rates]. (p. 105)

CAFS Field Tests

Holger de Vries (1999) reports on The Tremonia trials, a CAFS field test, conducted in Germany in 1998. In the Tremonia trails, test fires are ignited under control testing conditions and extinguished using three agents; plain water, Class A foam, and sodium polyacrylic additive. Results of these trial showed Class A foam required 40% less gallonage as compared to plain water and required less “extinguishment effort”.

The Los Angeles Fire Department (LAFD) compressed-air foam tests (Cavette, 2001) consisted of live fire extinguishment (controlled conditions) using comparative measures for CAFS and plain water. Similar to other studies the LAFD fires consisted of Class A combustibles, single room and content fires. Extinguishment of LAFD fires started after the fire reached a temperature between 550F and 850F and then were allowed to free burn for a short time. Fire attack commenced from a distance of 35 feet to simulate a curbside distances. The LAFD tests measured knockdown time, gallons of agent applied, and temperature degradation related to time. LAFD test results found CAFS was superior to plain water in all cases. The report noted the following,

> …it took only 25 seconds to knock down the fire with Class A foam/water solution, compared to the 50 seconds it tool with water. Using CAF cut that figure by more than half to 11 seconds, making CAF roughly four times more effective than water…(p. 4).

Cavette continues citing the results for gallons used.

> …foam also out scored water in terms of gallons used. The attack team used 44 gallons of Class A foam/water solution to knock down the fire versus 75 gallons

> of plain water. The CAF test produced even more dramatic results. It took only 16 gallons of CAF to knock down the fire…Again…roughly four times more effective than water in terms of gallons required for knockdown. (p. 4)

Finally, LAFD reported results on test data more inline with this research project. Temperature measurements were taken on the LAFD test fires allowing conclusions to be made on the heat-absorbing property of CAF and demonstrating the impact on temperature relative to time. Cavette again details the findings.

> …the heat absorbing properties of foam reduced the average interior temperatures significantly faster than water. With Class A foam/water solution, it took 1:45 minutes for the average interior temperature to drop from 600F to 200F, compared to 6:03 minutes with water. CAF produced slightly better results with a time of 1:28 minutes.
>
> A plot of interior temperatures versus times reveals that not only did the foam cool the interior in less time, it started to work more quickly. This was especially true of CAF, which produced an almost immediate reduction of temperatures. By contrast, there was an extended period of high temperature before the cooling effect kicked in when using water. In fact, CAF cooled the interior from 600F to 200 F about four times faster and with a significantly larger initial temperature drop (Cavette, 2001, p.5).

The Boston Fire Department (1994) participated in a test program to evaluate the feasibility of CAFS as a firefighting agent in an urban setting. The tests undertaking had similar parameters as this research project. Results would be used to make decisions on retrofitting apparatus and/or whether or not to include CAFS in specifications of future purchases. A single engine company (Engine 37) retrofitted with a CAFS unit participated in this lengthy study. During 1992 and 1993, Engine 37 responded to 146 calls requiring the use of CAF as an extinguishing agent. In addition, three controlled test fires were conducted. The findings in these test fires are consistent with other studies. Boston reports CAFS is faster on the knockdown. Crew reports of actual firefighting and timed measurements in controlled fire tests support the claim. Crews also reported less water use and most fires could be fought with tank water alone. Test fire observations found a reduction of water use as well. Controlled fire experiment # 1 was extinguished using 69 gallons of water, but only 30 gallons of foam. Experiment # 2 used 100 gallons of water and only 36 gallons of foam.

Literature Review Summary

Compressed-air foam systems have been utilized for fire suppression reportedly as far back as 1938 (Colletti, 1998; Taylor, 1997). United States and British navies used the technology during shipboard firefighting in World War II. Technological advances continued during the 1940s and 1950s with CAFS development in flammable liquid fire suppression. Still it was primarily a tool used by armed forces and the petrochemical industry.

The birth of CAFS in the municipal fire service is credited to the Texas Forest Service with their development of wildland firefighting units in the early 1970s (Boston, 1994; IFSTA, 1996; Colletti, 1998; Taylor, 1997). Advances in technology and applications continued, until the early 1990s when forestry officials convinced their hypothesis that effectiveness of CAFS as a wildland suppression tool could crossover to structural firefighting as well (Colletti, 1998).

CAFS offers many advantages to suppression operations. The literature reviewed provided similar lists with some idiosyncratic references to specific findings. However, authors agree (Colletti, 1996 & 1998; Cavette, 1999 & 1002, Boston, 1994; Cook, 2002; IFSTA, 1996 ed.; Stevens, 1999; and Taylor 1997) that CAFS is faster and more efficient at killing a fire, offers firefighters a greater safety margin by increasing the stand-off distance, uses less water, reduces rekindle, makes overhaul easier, and is no more complicated to deploy than water lines. Advantages considered, why wouldn't a department entertain the idea of CAFS fire suppression? Is it in the disadvantages?

As with any new idea/technology, change is hard. That "change" by far, is a major disadvantage to overcome with CAFS (Colletti, 1998). Other disadvantages include, cost to retro-fit existing apparatus, increased cost for foam and for maintenance, specialized training for personnel assigned to CAFS units, nozzle reaction, creates slippery surfaces, complicates investigations, and resistance of members to embrace new ideas (Boston, 1994; Cavette, 2001; Colletti, 1996; Roche, 2001; Rochna, 1997; IFSTA, 1996 ed.; and Taylor, 1997). Disadvantages can be overcome. Increasingly, the advantages outweigh the disadvantages of CAFS. Change is occurring in the fire service and CAFS is gaining hold as a new and useful extinguishing agent for structural fire suppression. However, the historical stronghold plain water has on fire suppression will not be easy to conquer, nor must it be. CAFS is just another tool.

PROCEDURES

The literature review started in October 2001 with an investigation of resource material available at the Learning Resource Center (LRC), National Fire Academy, in Emmitsburg, Maryland. Several documents were secured from the LRC through the Interlibrary Loan Program. Other printed resources from the Lewisville, Texas City Library and fire service organizations were also included. Additionally, information obtained through Internet searches for CAFS articles was included. The literature primarily focused on advantages and disadvantages of CAFS in structural fire fighting and the effects those have on firefighter safety and efficiency.

Live fire exercises conducted on April 11, 12, and 13, 2002 in Mineral Wells, Texas, on a decommissioned military base (Fort Wolters), as part of FMFD's annual live fire-training requirements provided the opportunity to conduct interior temperature measurements on actual fires. All burn exercises complied with NFPA 1403 guidelines. Temperature readings collected by thermo-couplers placed in the burn rooms downloaded to a recording device. Personnel from the Bureau of Alcohol Tobacco and Firearms (ATF) administered the data collection. Complete measurements and graphs are included in the Appendix A.

Several (circa 1950s) wood frame houses were secured as burn buildings. These were duplex, single story built up roof structures. Rooms were shored up with sheetrock by covering openings in the walls, ceilings, doors, and plywood placed over window openings. The rooms were preloaded with fuel loads consistent with normal Class A combustibles. Fires were ignited without the use of accelerants. Thermo-couplers were installed in the burn rooms to measure temperature. The thermo-couplers were placed in the fire room and spaced at ceiling, floor and mid-level. Temperature readings were reported and recorded at 15 seconds intervals.

NFPA 1403 guidelines were adhered to during the live fire exercises. Command controlled evolution sequences, deployment, water supply and data collection. The Fire Boss controlled fuel loads, fire ignition and was designated interior safety officer during burns. A Safety Officer was assigned to exterior oversight and deployment of backup lines and RIT teams. The Safety Officer had authority to terminate any evolution independent of Command. Suppression teams attacked the test fires using 1 ¾ inch CAFS hand lines. Suppression teams utilized TFT combination nozzles. Fires were attacked with short burst (2-3 seconds) of foam agent.

Opinions of FMFD personnel and comments regarding CAFS and the live fire training evolutions were solicited via e-mail. Responses to the request were tabulated and the results used to answer research questions. Tabulations are included in Appendix B.

Definition of Terms

Fire Boss: Interior fire crew leader assigned to fire ignition, fuel loading, interior crew safety and building integrity.

Command: Officer assigned to monitor temperature readings; coordinate suppression activities, back-up safety line assignments and water supply.

Safety Officer: Exterior officer assigned to monitor operations and overall fire-ground safety aspects.

AFT: Officer(s) from the Bureau of Alcohol Tobacco and Firearms assigned to set up and administer monitoring equipment for data collection.

Thermo-coupler: Temperature sensor for reading heat levels inside fire rooms.

Coupling Tree: A set of thermo-couplers configured in a continuous string measuring temperatures at ceiling level, midlevel, floor-level and attached to the ceiling and floor with wood screws and wire.

Ceiling Level: Temperature reading 12 inches from the ceiling.

Midlevel: Temperature reading 4 feet above the floor.

Floor level: Temperature reading 12 inches above the floor.

Compressed Air Foam System (CAFS): A mechanical system designed to mix water, foam and compressed air.

Class A Foam: Foam used on ordinary combustible fires (wood, paper, furniture). Foam derived from hydrocarbons possessing a high surfactant property.

Cubic feet minute (Cfm): Measure of airflow comparable to gallons per minute for water.

Gallons per minute (Gpm): Measure of water flow.

Assumptions and Limitations

The live fire testing of CAFS is subject to numerous limitations. Weather conditions though similar from day to day could not be controlled. The houses used as burn buildings were similar in most respect, built in the same time period, construction materials, room configuration and attic spaces, however, hidden flaws and inconsistencies are assumed limitations to the accuracy and duplication effort. As much as possible the fuel loads used to simulate normal room configurations consisted of like materials (i.e., mattresses, chairs, couches). Suppression crews were instructed to make objective reports of their suppression activities, however some limitation must be placed on reporting accuracy. The assumption is that no one intentionally made false reports and was objective in their assessments. Finally, in as much as the same size hose line, flow rates and pumping pressures were consistent in all tests, the accuracy is limited by the mechanics of the equipment, its actual performance, objective reporting of agent application and method of application.

RESULTS

Research Question #1

What are the advantages and disadvantages of CAFS in structural firefighting? Supported by the literature review, advantages offered by CAFS in structural firefighting include:

- Faster knockdown power
- Reduction in water used, thus, increasing longevity of limited water supplies
- Increased stand-off distance, allowing agent application to begin faster

- Lighter more maneuverable hoselines
- Increased saturation of fuel loads
- Decreased incidents of rekindle
- Reduction in collateral damage (water/salvage)
- Immediate reduction of heat

These advantages are not without offsetting considerations, or disadvantages. Some disadvantages found through the literature review of CAFS include:

- Cost to purchase or retrofit apparatus
- Maintenance costs for equipment
- Increased training requirements
- More complicated pumping procedures
- Decision making-when to use CAFS and when not to
- Slippery Surfaces
- Complicates investigative efforts

Research Questions 2 and 3 were answered in part by the literature review and from answers to questions on a survey e-mailed to FMFD personnel after the live fire training exercises.

Research Question #2

Do CAFS reduce stress and fatigue of firefighters? The literature review supports the position that CAFS can reduce firefighter stress and fatigue primarily due to the reduced time required to extinguish the fire, increased stand-off distances, and improved effectiveness of overhaul operations, reduction in hose weight and corresponding maneuverability, and the increase to firefighter safety derived from a combination of all the advantages. Responses to the survey questions by FMFD personnel also support the literature findings. When asked if CAFS makes your fire suppression job easier (Survey Q8), 89% (33 of 37) responded; Yes. When asked specifically if CAFS reduces stress and strain on firefighters (Survey Q9), 78% (29 of 37) responded; Yes.

Additionally, FMFD personnel responded to questions on extinguishment, hoseline movement, hoseline kinking and overall suppression rating (Survey Q1, Q2, Q3, and Q4). FMFD personnel found that CAFS was more effective than water (Survey Q1) as an extinguishing agent with 86% responding it was more effective than water, 11% responding it was as effective as water, and 3% (1) responding that it was less effective than water. FMFD personnel expressed the same opinions on the extinguishing characteristics of CAFS as were found in the literature.

Responses to (Survey Q2) whether the hoseline was more maneuverable, upheld the literature review findings again. All FMFD personnel, 100%, 37 out of 37, answered CAFS hoselines were easier to move than water. This was also demonstrated during live fire training with exterior fire suppressions activities.

Research Question #3

Can use of CAFS increase the effectiveness and safety of fire suppression personnel? The answer is predominately based on literature review and indirectly supported by answers from FMFD personnel. The survey responses provided by FMFD personnel make inferences to the effectiveness and safety, but do not specifically point to that aspect.

Reasonable deductions can be made that due to the increased knockdown power of CAFS, the increased stand-off distance and the greater amount of fire CAFS can extinguish with comparative flow rates, firefighter effectiveness and safety are increased. Firefighters are able to initiate fire attack from greater distances, fires are knocked down (blacked out) faster and CAFS can extinguish larger fires than plain water at the same flow rates. Increasing firefighter effectiveness equates to a reduction in time exposed to products of combustion, structural collapse hazards, superheated environment, and maximum (peak level) physical exertion. These factors support an increase in firefighter safety. Sprains and strains are the number one cause of firefighter injury. CAFS can potentially reduce the incidents of strains and sprains. Lighter hose, more maneuverable, less effort, less time exposed to firefighting activities are potential factors for reduction of fireground injuries. Heart attacks being the number one cause of fireground deaths (prior to September 11, 2001) are also potentially reduced with CAFS. A reduction in the stress and fatigue imposed on firefighters on the fireground will help reduce heart attacks. Firefighters do not exert themselves as much using CAFS as they do using water fighting fires. 33 (89%) of FMFD personnel responded that CAFS maked the fire suppression job easier. Likewise, 29 (78%) reported that CAFS reduced stress and strain.

Research Question #4

Should FMFD retrofit additional units with CAFS, or include CAFS in future apparatus specifications? This question is answered by the FMFD survey. Though retrofitting apparatus with CAFS is expensive, justification for or against was not sought in the literature review. The intent of this question was to illicit the perceived value FMFD personnel have of CAFS after the live fire training exercises. Of personnel answering 43% (16), rated CAFS overall “Exceptional” as a fire suppression tool, while 51% (19) rated it “Above Average”. When asked if FMFD should retrofit additional apparatus with CAFS (survey Q6) responses were split, 41% (15) said, Yes, and 54% (20) responded, No. On the contrary, when asked if new apparatus should have CAFS specifications included, 86% (32) responded, Yes and only 5% (2) responded, No.

Research Question #5

What impact does CAFS have on the temperature gradient of a fire? Single room content test fires were conducted and temperature measurements recorded. Complete graphs and tables of temperature measurements are included in the appendices for each test fire conducted. CAFS has an immediate impact on the temperature of a fire. Minimum agent applications from CAFS handlines eliminate extreme heat in confined space fires. Tests demonstrated CAFS impact on reducing temperatures from a low of 30% to as high as a 61% decrease in temperatures. These results were achieved with short (2 or 3 sec.) burst of CAF agent. All temperature measurements and degrees reported are Fahrenheit. Appendix A provides data on all fires measured.

Test Fire #1

The first test fire conducted involved a single room measuring 12' x 14' with 2 open closets one measuring 2'x 6' and another measuring 3'x 7'. A thermo-coupler temperature tree was secured to the floor and ceiling in the opening to the 3'x 7' closet. Temperature sensors at the ceiling, floor and mid-level measured and downloaded data to a recording device every 15 seconds. This allowed a temperature signature of the fire from initiation to extinguishment. The test only looks at the immediate impact CAFS has on temperature. Fire knockdown and extinguishment though reporting in some cases was not observed for findings purposes. Fuel loads consisted of Class A combustible material. Table 1 shows the temperatures measured and impact CAFS had on temperature.

Table 1. CAFS Effect on Temperature (Measured in Degrees Fahrenheit) Test Fire #1

Time	Ceiling	Mid-level	Floor	
10:59:49	120	90	66	Fire Ignited
11:08:49	674	458	124	Flashover Imminent
11:09:04	1061	647	170	Flashover
11:10:04	1313	953	219	Max Temp/CAFS
11:10:19	520	394	225	
Percent Drop	61%	58%	(2%)Temp Increase	

Test Fire #2

Test fire #1 was allowed to rekindle and became test fire #2. The temperature signature of test fire #2 gives evidence to the reported reduction in rekindle effect CAFS has on fuel. An elapsed time of 8 minutes transpired before a loveseat was introduced to the fuel load and some kindling was done to promote propagation of heat and fire. The Fire Boss stated he couldn't make it burn again. As shown in Table 2 the temperature never reached that of test fire #1. Where test fire #1 took 9 minutes to reach flashover and went from 378 degrees to 1061 degrees in 30 seconds once flashover occurred; test fire #2 took 10 minutes and 26 seconds to reach 865 degrees. The temperature signature (see Appendix A) shows the fire could not overcome the moisture soaked fuel. British Thermal Units (BTUs) were absorbed as moisture from the fuel streamed off. Firefighters on the suppression crew (seasoned veterans) observed ceiling collapse and flames extending into the attic, therefore test fire #2 was extinguished and the room abandoned.

Table 2. CAFS Effects on Rekindle (Measured in Degrees Fahrenheit) Test Fire #2

Time	Ceiling	Mid-Level	Floor	
11:18:39	303	230	116	Rekindle Allowed
11:22:39	344	234	119	
11:24:05	428	391	164	Equipment Check
11:29:05	865	575	291	Attic Extension/CAFS
11:29:20	596	413	255	
Percent Drop	31%	28%	12%	

Test Fire #3

Data from test fire #3 is corrupt and can not be included in the findings; however it is included in the appendices. A slight over estimation of the fuel load caused the fire to burn too hot and too close to the couplers causing the thermo-coupler tree to malfunction.

The experiment was abandoned and the structure allowed to burn. Defensive fire attacks and exposure protection evolutions ensued. Defensive operations provided opportunities to observe hose maneuverability and exterior CAFS knockdown power.

Test Fire #4

FMFD returned to Mineral Wells, Texas on April 12, 2002 to the abandoned military base called Fort Wolters, to conduct more test fires. Test fire #4 involved a room measuring 14'x 11' with a 4'x 3' open closet. The coupling tree was secured in the opening of the closet. The room was fueled with a mattress, loveseat and a chair. The mattress was raised off the floor with bricks and a pallet to approximate a bed frame. The ignition of test fire #4 began in the middle of the room and was allowed to propagate to other fuel sources on its own. No accelerants were used in any fires.

Test fire #4 took 11 minutes to build to flashover. Test fire #4 was ignited at 10:47:53 am. Flashover was imminent at 10:59:38. At 11:00:08 maximum temperature readings recorded and CAFS application was initiated. A 2 to 3 second burst of CAF from a TFT nozzle on a 1.75" line caused a temperature drop of 42% at the ceiling. Table 3 on the following page shows the temperature readings at all levels for test fire #4. The integrity of the burn room remained intact after test fire #4, therefore, test fire #4 was allowed to rekindle with the additional of more Class A combustible fuel loads. The rekindle fires constituted the next data measures; test fire #5.

Table 3. CAFS Effect on Temperature (Measured in Degrees Fahrenheit) Test Fire #4				
Time	Ceiling	Mid-Level	Floor	
10:47:53	159	136	68	Fire Ignition
10:53:53	367	281	76	
10:58:53	442	412	82	
10:59:53	602	501	86	Flashover Imminent
11:00:08	1148	730	155	Flashover/Max temps
11:00:23	1123	823	130	Entry made (cool air injected)
11:00:38	1041	798	115	CAFS Initiated
11:00:53	611	415	141	Temp Drop
Percent Drop	41%	47%	22% (Temp. Increase)	

Test Fire #5

Test fire #5 is a continuation of test fire #4. Temperature monitoring for test fire #5 continued at 11:05:08 (3 minutes and 15 seconds after termination of test fire #4). Two rekindles occurred and were measured in test fire #5. Maximum temperatures measured at ceiling level were 1031 degrees and 1089 degrees respectively. Temperature recordings after CAFS application showed a 310 degrees drop or 30% and a 337 degrees drop or 31%. Complete data and graphic representation is shown in Appendix A. Table 4 shows temperatures measured and the effect of CAFS application.

Table 4. CAFS Effect on Temperature (Rekindles: Test Fire #5)

Time	Ceiling	Mid-Level	Floor	
11:07:08	361	328	117	Rekindle starting
11:09:08	530	473	111	
11:12:08	971	895	574	
11:12:53	1031	968	497	Flashover/ CAFS applied
11:13:08	721	566	271	
Percent Drop	30%	41%	45%	
11:14:08	456	402	169	Rekindle starting
11:15:08	566	527	174	
11:16:08	1015	911	292	Flashover
11:16:23	1089	1021	497	CAFS applied
11:16:38	752	663	443	
Percent Drop	31%	35%	10%	

After the second rekindle, due to questions of structural integrity, the fire was extinguished and the room abandoned for testing purposes. Evolutions moved to an adjacent room for more testing and temperature measurements.

Test Fire #6

Test fire #6 was the final fire monitored. Because of the condition of the structure it was decided that multiple rekindles would be used to get as many peak temperature

CAFS impacts measured as possible before construction integrity was compromised. Table 5 shows the maximum temperatures prior to CAFS application and the corresponding temperature drops for each flashover. The room measures 10’ x 12’ and has a 2’x 2’ open closet. Thermo-couplers on a coupling tree were secured in the opening of the closet. Fire ignition was at 12:55:50. Fire propagation developed for 6 minutes and the first flashover occurred at 13:01:50. Subsequent rekindles were allowed to reach maximum temperatures before CAFS was introduced again.

Table 5. CAFS Effect on Temperature (Test Fire #6 and Rekindles)

Time	Ceiling	Mid-Level	Floor	
12:55:50	182	139	85	Fire Ignited
13:03:05	1311	1309	566	Flashover/CAFS applied
13:03:20	765	630	232	
Percent Drop	42%	51%	59%	
13:04:35	1343	1325	203	2nd Flashover
13:05:05	823	755	212	CAFS applied**
Percent Drop	39%	43%	4% (Temp Increase)	
13:06:35	1399	1427	267	3rd Flashover
13:06:50	705	634	292	CAFS applied
Percent Drop	50%	55%	9% (Temp Increase)	

Table 5.con't. CAFS Effect on Temperature (Test Fire #6 and Rekindles)

Time	Ceiling	Mid-Level	Floor	
13:11:35	1319	1249	380	4^{th} Flashover
13:12:05	780	639	214	CAFS applied**
Percent Drop	41%	48%	43%	

(**) Note. CAFS application specified occurred while a temperature data recording and download sequence was in process. Appreciable temperature drops recorded with the next 15 seconds download.

Additional Observations

At the conclusion of each days test fires, defensive evolutions using 1.75" CAFS hoselines were conducted. Observations during those evolutions also support the claims of others. CAFS hoselines allowed personnel to stand 30 to 40 feet away from a fully involved wood frame structure and effectively initiate an aggressive exterior suppression effort. CAFS foam blankets protected exposures from direct flame impingement, to the surprise of everyone. Flame impingement on a wood sided structure estimated at 3 minutes (protected by a CAFS foam blanket) produced no charring, blistering, or heat build up. This author, walked between the fire building and exposure, approximately a 20 foot separation, (in full PPE) only moments after the flame vortexes subsided and inspected the exposure wall. It was barely warm to the touch. CAFS demonstrated its exceptional exposure protective properties.

DISCUSSION

Literature review of the advantages of CAFS provided many positives reports of its effectiveness as a suppression agent. Faster knockdown of fires, less water use, extended standoff distance, reduced rekindle, more effective overhaul, and increased firefighter safety are major advantages reported by researchers (Cavetti, 1999 & 2001; Colletti, 1998; IFSTA, 1996 ed.; Murdock, 1997; Roche, 2001; and Taylor, 1997). Taylor (1997) cited many references to CAFS's knockdown power with accounts ranging from 5 to 10 times faster and as much as 20 times faster than plain water. Cavette (1999) provided the most extensive list of advantages in his article, The Finer Points of Foam, by listing 27 points in four categories of consideration. His categories were "more effective water", "greater safety, less stress", "less equipment damage", and "less property damage" (p.5-6). During the live fire training, observation of firefighter activity and exertion, coupled with firefighter responses to questions regarding fireground operations and CAFS supported the finds in the literature. FMFD firefighters demonstrated a positive attitude for CAFS, 86% saying it was more effective than water, 100% saying the hose was easier to move, 94 % rated it above average or higher overall as a suppression tool, 89% said it made their firefighting job easier and 78% said it reduced stress and strain.

The reduction in water used by CAFS to extinguish fires was demonstrated in several tests. In a Los Angeles Fire Department (LAFD) test, Cavette (2001) reports tests fires (single story, four room fires) required 75 gallons of plain water, 44 gallons of Class A foam solution, and only 16 gallons of compressed-air foam to knockdown the fires.

The Boston (1994) report shows CAFS effectiveness in terms of time and gallonage in a three fire test experiment. The reports shows, CAFS was either more effective in time to extinguishment or in gallons used, or more effective in both in all three tests. Foam and water usage was not a measured component of the live fire training, however, the apparatus operators made comment on how little foam was being used and how the water supply was lasting much longer.

Additionally, a CAFS does increase firefighter effectiveness and firefighter safety (Boston, 1994; Coletti 1998; Cavette, 2001; Taylor, 1997). FMFD personnel responding to questions on the survey indicated agreement with the literature. Again, 86% feel it is more effective, 100% find it easier to move the lines, 78% say it reduces stress and strain. A conclusion could be made from this that CAFS increases firefighter effectiveness by making the job easier, less stressful (physically demanding) and because it extinguishes fire faster. Firefighter effectiveness is a relative term. It must be considered in context with what the intended outcome of the operation is. CAFS and firefighter effectiveness can only be considered in terms of extinguishing fire, salvage and overhaul, and reduction in collateral damage. In this context it is reasonable to say that CAFS is extremely effective in increasing fire fighter effectiveness.

Another question is the effect CAFS has on firefighter safety. It is reasonable to conclude that decreasing the time spent fighting fire and exposing personnel to the hazards associated with fire suppression activities would have a positive effect on fire fighter safety. However, aggressive interior fire suppression activities are dangerous and will remain dangerous, regardless of the intervention tool used. What CAFS does is allow firefighters to engage the fire from a greater distance, put out bigger fires faster, improve interior conditions by reducing heat, and blankets and permeates fuels, thus reducing the possibility of rekindles. Firefighter safety is the responsibility of the firefighter, company officer, incident commander and ultimately the Fire Chief. There is grave danger in placing undue value in a tool or technology verses training and education of personnel. CAFS can positively effect firefighter safety, but, a more important factor in that equation is education, training, and sound fireground decision making.

The Boston (1994) report along with Colletti (1998), Cavette (1999, 2001), Stevens (1999), and Taylor (1997) mention the ease of maneuverability of CAFS hoselines as major advantages and a significant reduction in firefighter stress and physical exertion. FMFD personnel voiced their agreement in the survey results. Observations at the live fire training revealed larger hoselines using CAFS were as easy to maneuver as smaller plain water lines.

The advantages of CAFS are numerous, however, disadvantages also exist. The literature review revealed that, the cost to purchase, operate and maintain a CAFS, training required to familiarize personnel, nozzle reaction, hoseline incompatibility, skin irritant, slog flow and hose chatter, complexity of pump operations, slip hazard, and complication of investigative efforts were noted disadvantages (Boston, 1994; Cavette, 1999, 2001; Colletti, 1996, 1998; IFSTA, 1996 ed.). These are accurate disadvantages.

Slug flow was an observed problem in the live fire training. While waiting to make interior attacks suppression crews were instructed to discharge their lines outside. The lines discharged a plug of foam solution followed by a plug of air, then water and finally compressed-air and foam. This was repeated several times. The combination of ingredients in the hose; foam solution, water and compressed air, separate in a static CAFS hoseline. It is possible to overcome this disadvantage with training. Nozzle reaction is listed as another disadvantage, however, observations of FMFD personnel in training seem to down play this disadvantage. Granted nozzle noise is considerably louder with CAFS, but, nozzle reaction force in pounds, appeared only slightly greater in CAFS hoselines. Granted the live fire training FMFD conducted did not measure this element, but personnel accounts did not mention nozzle reaction as a significant disadvantage.

Cost of purchasing new CAFS, retrofitting old apparatus, and maintenance costs are the most deterring of all disadvantages. Retrofitting can be expensive. Scott (2002) reports FMFD paid roughly $35,000 to retrofit an engine. At that price, CAFS would not have been an option for FMFD based solely on fire suppression criteria. It was purchased for the reduction it made in the ISO rating. Its suppression application is just now being explored. Whether or not costs are a disadvantage is relative to the economic situation of the community involved. They can be, but then again, increased effectiveness and reductions in collateral damage can offset these costs.

What CAFS demonstrated in this research is its impact on the temperature gradient. Out of all the test fires, the minimum temperature degradation was 31% and the maximum was 61%. Consistently, CAFS reduced the interior temperature (at ceiling level) by an average of 35%. Further research of the temperature gradient in conjunction with full extinguishment of the fire would provide a wider understanding of CAFS application.

In summary, this research found nothing to dispute previous efforts with regard to CAFS as an extinguishing agent, its advantages or disadvantages, or its application in the fire service. The results overwhelming support others findings. Temperature degradation in the FMFD tests was similar to LAFD results. Crew comments were similar to those in the Boston report. In as much as the research questions answered by this project lend to CAFS reported effectiveness and ability to improve firefighter safety, there is more that still needs to be done in FMFD to create corporate confidence in the technology.

RECOMMENDATION

The recommendations of this research stress training and education of FMFD personnel in the tactical advantages, disadvantages and operational considerations of CAFS. FMFD having expended the dollars to retrofit an engine with a CAFS must now embark on an aggressive campaign to train personnel on its use. Prior to conducting the live fire training discussed in this research, all personnel attended a short classroom lesson on CAFS. It lacked depth in scope, explanations of critical physical components, offered little in the way of authoritative data to support CAFS and was perceived as nothing more than a waste of time by many FMFD members.

If FMFD is going to utilize CAFS in its fire suppression arsenal, it must educate and train the personnel expected to use it. Colletti (1998) makes the point well.

> "The entire membership must learn the expected use, capability, benefits and pitfalls of new firefighting procedures. With Class A foam and CAFS, classroom instruction and live fire training under controlled, safe conditions are vital to success…membership must feel comfortable about them and gain a level of confidence in how they realistically work. Importantly, each must see, firsthand, that their fireground safety is not compromised." (Colletti, 1998, p.25)

The live fire training associated with this research project gave FMFD members their first glimpse of CAFS capabilities. Many were involved in only one evolution of actual fire suppression activity. The training was brief and compressed. It falls far short of what is necessary to accomplish, what I term "corporate confidence", whereby every member holds an accepted minimal level of proficiency and experience with CAFS.

Data collected in this project should be used to develop a comprehensive CAFS training program for FMFD. On completion of the training FMFD personnel will be awarded a certificate recognizing their accomplishment. CAFS should be treated as any other specialization. Training on task specific criteria would ensure proficiency, while education on the advantages, disadvantages, history, and field test data would form the basis for confidence building.

Regarding future purchases of CAFS and the retrofitting of additional apparatus, finds of this research do not support any additional retrofitting of current apparatus in the FMFD. This is partly due to the complexity and cost to re-engineer the pump, find space to mount equipment, and the maintenance record of the present retrofitted unit in FMFD. However, the majority opinion of FMFD personnel is to include CAFS in any future apparatus purchases, and as such, having demonstrated the capabilities of CAFS to administrative personnel in the live fire training and through the literature covered in the research it is easy to support the recommendation to include CAFS as a specification on any new purchases.

Finally, more must be done in the way of experimental evaluation of CAFS. Is it really as good as it appears, or is the research biased? Some claims seem unbelievable. Others have been demonstrated. The fire service is a stubborn profession. We are set in our ways and hard to change. The Self Contained Breathing Apparatus (SCBA) took time to catch on. Unfortunately, some firefighters still choose to suck smoke believing it is a heroic demonstration of bravado. I disagree emphatically. CAFS, if it is as good as it is represented to be, it should become the primary extinguishing method of the fire service. Only continued investigative research will prove whether or not this is the case.

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