PROPERTIES OF COMPRESSED AIR FOAM

EXECUTIVE LEADERSHIP

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ABSTRACT

In 2000, the San Juan Island Fire Department implemented equipment capable of producing compressed air foam for fighting wildland and structural fires. The problem was that the San Juan Island Fire Department did not have a standard operating policy for compressed air foam pump operations.

The purpose of this applied research project was to assemble information needed to develop a standard operating procedure for compressed air foam pump operations. Evaluative research was used through a search of appropriate literature and field tests of certain properties of compressed air foam. Action research was used to develop a standard operating procedure for the use of compressed air foam. The research was performed to determine answers to the following research questions:

1. What is the appropriate ratio of foam solution-to-air for various types of compressed air foam at 0.3% solution?
2. What is the head pressure of compressed air foam for various types of compressed air foam at 0.3% solution?

A literature search was conducted of any materials relevant to the research questions. While the literature search produced some statements regarding the first question, discrepancies indicated that field tests were required to verify the ratios in field tests. There was limited information available regarding the second question.

Field tests were conducted to measure the properties of compressed air foam. The results were compared to the estimated figures derived from the literature search for question 1 and to theoretical figures developed from laws of physics for question 2.

Consistent figures were developed from the field tests that indicated that wet compressed air foam requires a foam solution-to-air ratio greater than 0.75gpm/cfm; medium or fluid compressed air foam requires a foam solution-to-air ratio between 0.5gpm/cfm and 0.75gpm/cfm; and dry compressed air foam requires a foam solution-to-air ratio below 0.5gpm/cfm.

A formula for head pressure of compressed air foam was derived from the Ideal Gas Law. This formula is presented as:

$$V_F/V_F + (V_A \times 14.7/P_G) \times 0.434 \times H = P_H$$

Where:

V_F = Volume of foam solution

V_A = Volume of air

P_G = Pressure at gauge (absolute)

H = Height above pump

P_H = Head pressure

The theoretical figures produced by this formula were compared to the data generated by the field tests and those generated by an earlier test by other researchers, which both compared favorably. The information generated by this applied research project was incorporated into a standard operating procedure for compressed air foam use and a corresponding pump operations manual.

Recommendations included adoption of the proposed standard operating procedure and pump operations manual. The results also indicate that compressed air foam use can improve the ability to deliver extinguishing agent when elevation changes might inhibit the ability to use water or foam solution. Further recommendations include additional field-testing to analyze foam properties under a wider variety of circumstances. Research is also needed to determine friction loss of foam solution and compressed air foam, and effective nozzle pressure for compressed air foam.

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INTRODUCTION

In 2000, San Juan Island Fire Department purchased two new type 2 engines equipped with compressed air foam systems. Prior to then the fire department had never used compressed air foam. While the department had operational manuals for the existing fleet of type 1 engines, these engines were designed for the use of water and class B foam solution only. The department had standard operating procedures for pump operations using water but not for pump operations using compressed air foam.

The problem was that the San Juan Island Fire Department did not have a standard operating policy for compressed air foam pump operations. Many aspects of the operation of the system were addressed by the instructional information provided by the manufacturer of the fire department's new fire engines. Certain questions remained unanswered by the information provided.

The purpose of this applied research project was to assemble information needed to develop a standard operating procedure for compressed air foam pump operations, and subsequently to produce that standard operating procedure. Evaluative research was used through a search of appropriate literature and field tests of certain properties of compressed air foam. Action research was used to develop a standard operating procedure for the use of compressed air foam. The research was performed to determine answers to the following research questions:

1. What is the appropriate ratio of foam solution-to-air for various types of compressed air foam at 0.3% solution?
2. What is the head pressure of compressed air foam for various types of compressed air foam at 0.3% solution?

BACKGROUND AND SIGNIFICANCE

San Juan Fire District #3 consists of three islands in the San Juan archipelago of Washington State. The Fire District totals 55 square miles of land area. Approximately 4,200 persons lived in the fire district in 1995, with an annual growth rate of 4.5%. The assessed value of property within the fire district increased 60% from 1995 to 1999. This population boom consists almost exclusively of single-family residences being built in the interface. The community was identified as one of the communities at risk from wildland fires on federal lands, and closely resembles the definition of a Category 2 community (intermix community), where structures are scattered throughout the wildland areas (USFS, 2000). A survey by the fire department in 1998 classified 93% of the fire district as “wildland-urban interface” and 7% of the fire district as “wildland”.

The department responds to structure fires within the district and provides mutual aid to surrounding departments. The department also responds to wildland fires on district-protected lands and to wildland fires on state-protected lands under a contract to the Washington department of Natural Resources. During 1998, the department responded to 198 fire calls, of which 29 were wildland fires. The department responded to seventeen other fires during 1998. Two structures were lost to wildland fires during that season, and several others were damaged. The department has experienced an 8% annual increase in incidents over the past decade. The number of structures threatened by wildland-interface fires has increased at an even faster rate.

As of January 1, 2000, the department operated eleven engines. Six of these engines were Type 1 engines designed for structural firefighting. Each of these had a

1000gpm midship pump, with a 750-gallon water tank. Each carried structural firefighting equipment, but did not carry wildland firefighting equipment. The engines were not equipped with class A foam. The department operated one Type 3 heavy brush engine, with a 500-gallon tank and a 250gpm PTO pump. This engine was equipped with a class A foam system plumbed to one 1.5” discharge. The engine was on a two-wheel drive chassis, and was not capable of mobile firefighting.

Three of the remaining engines were Type 6 light brush engines, with 250-gallon tanks and 87gpm pumps. These were on all-wheel-drive crew cab pickups. One additional type 6 engine was used as an initial attack engine. It was equipped with a 250-gallon tank and a 250gpm pump. It was all-wheel-drive, and was capable of mobile firefighting.

A staff report prepared by the operations division personnel in 1999 recommended replacing the type 1 and type 6 engines assigned to two of the stations with type 2 engines. The features that were recommended included short wheelbase, all-wheel drive, mobile attack capability and the ability to flow water, class A foam solution and class A compressed air foam (CAF). The proposed engine would carry both wildland and structural fire equipment.

The benefits of using class A foam and compressed air foam are becoming widely accepted (Carringer, 1999; Colletti, 1993). Compressed air foam has been in use in fighting wildland fires for many years, and is widely popular for protecting structures from wildland fires.

In November 2000, the San Juan Island Fire Department took delivery of two new fire engines equipped with onboard air compressors. The new fire engines were based on the recommendations of the fire department's Operations Division, and were the first engines purchased by the department capable of producing compressed air foam. The department had previously used class A foam in both wildland and structural firefighting, but the foam was nozzle aspirated.

Having never used compressed air foam, the department did not have a standard operating procedure on its use. As the department prepared to place the engines in service, questions arose from the firefighters assigned to operate the engine. Many of those questions related to hydraulic calculations. Other questions were directed at distinguishing foam types and determining appropriate flow and pressure settings for compressed air foam.

Head pressure calculations are taught to all pump operators when learning to operate structural fire engines, wildland fire engines and portable pumps. During structural fire operations within the district, head pressure rarely enters the equation, as no buildings over three stories are allowed within San Juan County. During wildland fires, hoselays may be considerably more complex. During the Mitchell Bay Fire in 1998, a 1 ½" trunk (supply) line, 2200 feet in length supplied up to six 1" lateral lines. The lateral lines were 100 to 300 feet in length, and flowed 1gpm to 15gpm. The hoselay ran up a 120-foot hill. Pressure variations caused several ruptures of the trunk line during initial attack at times, while at other times there was not sufficient pressure to operate nozzles near the head of the fire. The fire was threatening houses at that time.

The department utilizes written standard operating procedures for pump operations and engine evolutions. The existing standard operating procedures did not address compressed air foam operations, and did not answer the questions raised by the firefighters. The need for policies, standard operating procedures and pump operations manuals is well documented (Carringer, 1999; Colletti, 1994; Liebson, 1996).

This research project was initiated in part to satisfy the requirement of the National Fire Academy to complete the Executive Fire Officer Program. In the Executive Leadership course of that program, the roles of the leader are examined. Among the roles is the role of disseminator. As disseminator, the leader of the organization is responsible for ensuring that members of the organization have the information needed to adequately perform their duties. The information developed through this research project was needed by the members of the department to ensure competent operation of the new engines. The ability to operate the new engines effectively and to adopt and use compressed air foam would directly impact the department's ability to protect homes from wildfires.

LITERATURE SEARCH

1. What is the appropriate ratio of foam solution-to-air for various types of compressed air foam at 0.3% solution?

Water flow meters are recommended to indicate foam type (National Wildfire Coordinating Group, 1993). NWCG (1993) recommends a foam solution-to-air ratio of 1.0gpm/cfm, but does not indicate what type foam this would produce. The publication does indicate that changing air/water ratios will change foam characteristics. Colletti (1994) indicated that adjusting the foam solution-to-air ratio allows direct control of foam quality.

Foam types can be designated as "wet", "fluid" and "dry" (NWCG, 1992; (Stern and Routley, 1996). Other sources (IFSTA, 1996; Colletti, 1998) use five "types" of foam. According to IFSTA, those types range from type 1 (dry) to type 5 (wet). Colletti

(1998) uses an opposing scale, with type 1 being wet foam and type 5 being a dry foam. IFSTA groups types 1 and 2 as dry foam, types 3 and 4 as medium foam and type 5 as wet foam. Colletti (1998) groups type 1 as wet foam, types 2 and 3 as dry foam and type 5 as wet foam. According to Colletti (1998), type 4 is reserved for description of high-expansion foam.

Both sources (IFSTA, 1996 and Colletti, 1998) provide physical descriptions of the types of foam, however the descriptions are inexact. For example, in Colletti (1998), the description of type 1 foam is “watery” and “no body”, while the description of type 2 foam is “watery cream” and “has little body” (Colletti, 1998; p100). IFSTA (1996) describes type 3 as “somewhat runny on vertical surfaces” and type 4 as “runny on vertical surfaces (IFSTA, 1996; p 123).

The descriptions given by NWCG (1993) of foam types did not have the same ambiguity. Wet foam is described as “watery”, “lacks body”, and “fast drain times”. Fluid foam is described as “similar to watery shaving cream”, “flows easily”, and “moderate drain times”. Dry foam is described as “similar to shaving cream”, “clings to vertical surfaces” and “slow drain times” (p.3).

Boston Fire Department (1994) classified compressed air foam as “wet” or “dry”. Wet foam was identified as having a water/air ration of 1.3gpm/cfm to 1.4gpm/cfm. Dry foam was identified as having a water/air ratio of 0.7gpm/cfm to 0.8gpm/cfm. The method used to arrive at these ratios was not identified.

According to IFSTA (1996), the expansion ratios for the types of foam are as follows: type 1(dry)- 44:1; type 2(dry) – 22:1; type 3 (medium) – 15:1; type 4 (medium)

– 11:1; type 5 (wet) – 8:1. With 7.48 gallons per cubic foot, these ratios expressed in gpm/cfm are type 1 – 0.17; type 2 – 0.34; type 3 - 0.49; type 4 - 0.68 and type 5 – 0.93.

NWCG (1993) ranged foam types by expansion ratios of 1:1 for foam solution to 20:1 for dry foam. A 1:1 expansion would not have compressed air entrained. A 20:1 expansion would equate to 0.37gpm/cfm.

Colletti (1994, p.63) graphed foam solution-to-air ratios. According to Colletti, type 5 (wet) foam would have a foam solution-to-air ratio of 1.0gpm/cfm. Type 4 (medium) foam would have a foam solution-to-air ratio of 0.75gpm/cfm. Type 3 (medium) foam would have a foam solution-to-air ratio of 0.5gpm/cfm. Type 2 (dry) foam would have an foam solution-to-air ratio of 0.25gpm/cfm. Type 1 (dry) foam would have an foam solution-to-air ratio of 0.13gpm/cfm.

NFPA (1999) States that wet foams have expansion ratios of up to 5:1, providing a foam solution-to-air ratio of 1.49gpm/cfm. Fluid foams are identified as having expansion ratios of 6:1 to 10:1 (1.24 to 0.75gpm/cfm) and dry foams are identified as having expansion ratios greater than 10:1 (less than 0.75gpm/cfm). Table 1 shows the foam solution-to-air ratios in gpm/cfm of each of the reported expansion ratios.

	Wet	Medium	Dry
IFSTA	0.93	0.49-0.68	0.17-0.34
Colletti	1.0	0.5-0.75	0.13-0.25
NWCG			0.37
NFPA	1.49	0.75-1.24	<0.75
Boston	1.3-1.4		0.7-0.8

Table 1: Foam types by foam solution-to-air ratios.

IFSTA (1996), Colletti (1998) and NWCG (1993) were in general agreement regarding foam solution-to-air ratios. NFPA (1999) and Boston Fire Department (1994) described considerably wetter ratios. A simple ratio series based on the results of the literature search was established as the preliminary ratios to test with a standard preconnected hoseline. Due to the variance of the NFPA (1999) and Boston Fire Department (1994) figures, field tests were conducted to verify the ratios.

2. What is the head pressure of compressed air foam for various types of compressed air foam at 0.3% solution?

Colletti (1996) describes elevation loss or gain as being less than water, but goes on to state that the exact values have not been determined. Colletti does describe the effects of Boyle's Law on hoseline weight. The Ideal Gas Law, which was developed in part from Boyle's law, was used to determine theoretical values for head pressure of compressed air foam, which were later field tested for verification. Lafferty and Grady (1990) tested head pressure in compressed air foam to determine the maximum height to which foam could be pumped. Three tests were made with a 1.0gpm/cfm ratio. The authors determined that under the conditions tested, the head pressure was 22psi/100feet. This was compared with the theoretical and field test reports obtained through this research project.

PROCEDURES

The research procedure used in this applied research project began with a literature search conducted at the Learning Resource Center of the National Emergency Training Center in Emmitsburg, Maryland. This was augmented by a review of materials present in the San Juan Fire Island Fire Department library, and a search of material available on the internet.

Considerable study had been made of various properties of class A foam solution and compressed air foam. The question of foam solution-to-air ratio was answered in the literature, but not definitively, as the reported data varied from source to source. Head pressure not adequately reported or documented in the literature. Thus field tests were developed to measure those properties under simulated conditions.

Definition of Terms

Class A foam – A firefighting foam designed specifically for use on class A combustibles. Produced by entraining air into a mixture of foam concentrate and water.

Compressed air foam – Class A foam produced by injecting air into a class A foam stream at the point of production.

CFM – Cubic feet per minute. A measure of flow of gases. Unless otherwise specified, standard cubic feet per minute are used.

GPM – Gallons per minute. A measure of flow of liquids.

Head pressure – The force exerted by the weight of a column of fluid.

PSIA – Pounds per square inch, absolute.

PSIG – Pounds per square inch, as measured on a gauge. Unless otherwise specified, all pressure readings and calculations are assumed to be sea level (14.7psia)

SCFM – Standard cubic feet per minute. The equivalent at a given pressure and temperature of one cubic foot per minute at 14.7psia at 60^{o}F.

Type – Throughout this paper, type of foam refers to the identifiable physical properties of finished compressed air foam. Where typing is referred to for resources, standard National Interagency Incident Management System (NIIMS) typing is used.

Research Methodology

This research was evaluative in that various properties of foam were analyzed, either through the reports of others or through field tests. Several tests were conducted.

Foam solution-to-air ratios were compared for foam type production by application to a horizontal surface. Fifteen tests were conducted. Ten tests used a 200’ hoselay of 100’ sections of 11.75” double-jacket elastomer-lined polyester hose. The hoselay was selected as it is the standard preconnected attack line used on the department’s fire engines. Three different nozzles were tested. In five tests, the hoseline was operated with a shutoff operated in the fully open position. The shutoff has an internal diameter of 1.375”, presenting the least restriction available from the department’s equipment. In four tests, a smooth bore nozzle 0.9375” in diameter was used. In three tests, a 0.5” smooth bore nozzle was used. Five additional tests were conducted using 100’ of 1” hose, equipped with a 1.5” shutoff and 0.9375” smooth bore nozzle, for a total of fifteen tests.

The hoses were operated at full flow for a minimum of 30 seconds to allow the foam ratios in the hoseline to stabilize. The nozzle was then directed into the test area for fifteen seconds. Four observers then examined the foam on the horizontal surface to determine finished foam type. Stalks of woody vegetation were used to determine ability to cling to vertical surfaces.

Foam type was compared to the descriptions of foam type provided by NWCG (1992). This was made as a subjective decision by the observers. The observers were given the foam descriptions and asked to select either “wet”, “fluid” or “dry” as the description.

The fire engine used for the test was new, with few hours on the pumping system. Water flow and airflow were read from the installed gauges on the pump panel. The fire engine was equipped with a cross-mount auxiliary engine, electronic foam proportioning system, 500gpm pump and 200cfm air compressor. The foam, water flow and airflow were all factory calibrated immediately prior to delivery of the fire engine. The tests were conducted before the fire engine was placed into service.

Analysis of head pressure was made by use of a 1.5” diameter hose lay on a hill. A fire engine was parked at the base of the hill, and 1000’ of hose was laid up the hill. A line gauge was placed 100’ from the end of the hose, and the end of the hose was equipped with a ball valve shutoff. The hose used was single-jacket elastomer-lined polyester forestry hose.

The altitude of the engine and the altitude of the line gauge were analyzed on a USGS (United States Geological Survey) 7.5 minute series topographic map with a contour interval of 20 feet. The altitude was then taken with an altimeter at both locations. The height difference between gauges was 100 feet.

The hose was charged with compressed air foam at various pressures and air-to-foam solution ratios. The nozzle was opened long for a minimum of one minute between readings to allow the compressed air foam to completely recharge the hose. The nozzle was then shut down and the pressure allowed to stabilize for 15 seconds. Readings of the static pressure were then taken on both the engine gauge and the line gauge simultaneously by two independent observers.

The same test was repeated with plain water to compare to known values for head pressure of water.

Limitations

None of the testing equipment used included documentation of accuracy. It can be assumed that the analog pressure gauges were no more accurate than plus or minus 5psi, which is the minimum index on the gauge. The line gauges and pump pressure gauges were compared to each other for relative calibration. The digital water flow and foam flow meters were compared with actual water and foam concentrate used. There was less than 2% variation between the recorded flow and the measured flow, however, this does not ensure that the flow rate measurements were accurate to 2%.

While the overall accuracy of the tests cannot be determined, the purpose for this department was to establish appropriate settings for incident use with the actual equipment used in testing.

The parameters of the tests done for this project where designed to address the fire department's direct needs. Other fire departments may have different needs in compressed air foam use, and might consider measuring these properties in a wider variety of conditions.

RESULTS

1. What is the appropriate ratio of air-to-foam solution for various types of compressed air foam at 0.3% solution?

Analysis of the fifteen tests conducted provided data that was consistent and useful. Appendix A lists the data that was obtained from the tests. While there was some variation in the foam type produced under the various test conditions, the results all fell into a consistent pattern. Foam solution-to-air ratios of 1.0gpm/cfm or higher produced wet foam. Foam solution-to-air ratios higher than 0.5gpm/cfm and lower than 1.0gpm/cfm produced fluid or medium foam. Foam solution-to-air ratios of 0.5 or lower produced foam that was characterized as dry.

One unexpected result of this field test was the variation in foam type caused by distance to the target. Foam that was discharged onto the ground near the nozzle tended to be wetter than foam that was discharged further out. Apparently, the wet foam was dropping out of the fire stream, while the dry foam carried further. In addition, some foam bubbles were lofted out of the fire stream, and dispersed by the wind. This effect was most noticeable when the 0.5” smooth bore nozzle was used. The observers analyzed the foam in the distant half of the discharge stream only.

2. What is the head pressure of compressed air foam for various types of compressed air foam at 0.3% solution?

A theoretical value for head pressure of compressed air foam can be calculated by applying the Ideal Gas Law to the air component of the compressed air foam. The ratio of compressed air to foam solution is calculated, and the weight of the water in a column can then be calculated.

Water, which is non-compressible, will have a head pressure based solely on the height of the water column. Head pressure for water is 0.434psi per foot (Casey, 1970).

Compressed air foam, however, will have a head pressure that varies with pressure, air-to-foam solution ratio and even temperature.

It is possible to ignore the weight of air, as it is a negligible quantity. The specific gravity of the foam concentrate can also be ignored, as it will also have a negligible effect on the head pressure.

According to the Ideal Gas Law PV=nRT where V=volume; n=molar mass of gas; R=universal gas constant; T=temperature; and P=pressure. Thus, for a fixed mass of gas, an increase in gas pressure will result in a decrease in gas volume, given a constant temperature. An increase in temperature will result in an increase in gas volume, given a constant pressure.

A standard cubic foot or air per minute (scfm) is equal to one cubic foot per minute at 14.7psia at 60^{o}F. Compressed air foam at a ratio of 1.0gpm/cfm at 0psig (14.7psia) will have a volumetric ratio of 7.48 gallons of air to 1.0 gallon of foam solution at 60^{o}F.

Hence the theoretical head pressure would be 0.05psi per foot. An increase in pressure will directly reduce the volume. At 14.7psig (29.4psia), the head pressure would double as the volume of air is reduced by 50%. Thus the head pressure would be 0.10psi per foot. At 102.9psia (88.2psig), the head pressure would increase to 0.22psi per foot.

Continuing this theory, head pressure would also depend on foam solution to air ratios. The lower the ratio, the drier the foam, and the less air it contains. Compressed air at a ratio of 0.25gpm/cfm would have a head pressure at 0psig of 0.01psi per foot. At 102.9psia, the head pressure would be 0.06psi per foot.

The effects of temperature on a compressed gas require conversion to absolute temperature. 60^{o}F is 519.4^{oF} above absolute zero. Increasing the temperature of the gas to 100^{o}F, which is 559.4^{o}F above absolute zero, yields an increase in volume of 7.7%. Decreasing the temperature to 0^{o}F decreases volume by 12.6%. The effect on head pressure is therefore less significant than the effects of mix ratio and pressure. To simplify the calculations, a constant temperature of 60^{o}F is assumed.

Thus, a formula for head pressure in compressed air foam at 60^{o}F is:

$$V_F/V_F + (V_A \times 14.7/P_G) \times 0.434 \times H = P_H$$

Where:

V_F = Volume of foam solution

V_A = Volume of air

P_G = Pressure at gauge (absolute)

H = Height above pump

P_H = Head pressure

	0 psig	**80 psig**	**100 psig**	**120 psig**	**140 psig**
1.0gpm/cfm	0.05psi/ft	0.20 psi/ft	0.22 psi/ft	0.23 psi/ft	0.25 psi/ft
0.75gpm/cfm	0.03 psi/ft	0.17 psi/ft	0.19 psi/ft	0.21 psi/ft	0.22 psi/ft
0.5gpm/cfm	0.03 psi/ft	0.13 psi/ft	0.15 psi/ft	0.16 psi/ft	0.18 psi/ft
0.25gpm/cfm	0.01 psi/ft	0.07 psi/ft	0.09 psi/ft	0.10 psi/ft	0.11 psi/ft

Table 2: Theoretical head pressure of compressed air foam given in psi/foot at various ratios and pressures.

The field tests of head pressure provided results that were consistent with the theoretical results provided by the formula developed herein, within the limits of tolerance of the testing equipment used. The results are tabulated in Appendix B.

A Standard Operating Procedure and Pump Operator’s Manual were developed based on the information generated by this research project in conjunction with the informational materials provided by the manufacturer and the Standard Operating Procedures and Pump Operations Manuals used in the past by the fire department. The documents were tested for usefulness as part of the initial training program for pump operators on the new fire engines.

DISCUSSION

The foam solution-to-air ratios reported in the various literature sources varied in description, definition and mathematical ratio. All of the sources described wet foam in ratios consistent with the results of the field tests. NFPA (1999) and Boston Fire Department (1994) ratios for dry foam were wetter than those identified in the field tests, as was the NFPA ratio for medium foam. All of the remaining ratios were consistent with the results of the field tests.

The lack of clarity between the five “types” of foam presented by Colletti (1993) and IFSTA (1996) ruled against their use by pump operators within San Juan Island Fire Department. The use of the terms “wet”, “fluid” and “dry” were in general agreement between NWCG and NFPA. The terms are simple and definable by appearance of the finished product. More specific definition could be made by comparison of drain times in conjunction with expansion, however the department does not have the ability to measure drain times. Adoption of the three types as described by NWCG was adopted as the standard for describing foam type within the department.

The lack of consistent characterization of foam solution-to-air ratio in the literature presented a potential challenge to pump operators. The use of expansion ratios by NFPA (1999), NWCG (1993) and IFSTA (1996) provided usable guidelines for pump operators only after conversion to foam solution-to-air ratios. Airflow and water flow can be read directly from the instrumentation provided on the fire engines.

Colletti (1996) was correct in stating that head pressure was lower for compressed air foam than water. This is an intuitive assumption as well in that air is lighter than water or foam solution. This was confirmed theoretically and in the field tests. Lafferty and Grady (1990) found head pressure for compressed air foam at 1.0gpm/cfm to be 22psi/100feet over an elevation change of 820 feet with a base pressure of 180psi. This measurement agrees with the theoretical head pressure. While the head pressure at 180psi would be higher than that reported by Lafferty and Grady, the gradual decrease in hoseline pressure over the length of the hoseline would equate to a decrease in head pressure as the foam expanded. Thus the head pressure would be approximately .27psi/foot at the base. At 400 feet of elevation about the base, the head pressure would have dropped to .20psi/foot and at the top the head pressure would drop to .05psi/foot.

While the generation of a set of three simple ratios for foam type production has quantified and simplified the role of the pump operator in setting air and water flows for best effect, the results of the head pressure analysis have not been as advantageous. It is, however possible to narrow the head pressure series to a few, commonly used pressure settings to reduce calculation by the pump operator. For the drier foams, it should be possible to ignore head pressure entirely on small elevation changes. At 100psi a 0.25gpm/cfm foam loses only 9psi per 100 feet, compared to a loss of 43psi for water.

To simplify matters for pump operators, a standard operating procedure has been proposed that adopts a single value for head pressure for compressed air foam. Using 0.2psi/foot in the range of 100psi to 150psi approximates the values projected. The estimated head pressure for wet foam (1.0gpm/cfm) at 150psi would be understated by 5psi per 100feet elevation gain, which is within the limit of the tolerances of the pump gauges. The estimated head pressure for a dry foam (0.5gpm/cfm) at 100psi would be overstated by 5psi per 100-foot elevation gain, again within the tolerances of the departments' ability to accurately set pump pressures.

The implications for effectiveness in large elevation changes is, however quite positive. Dry foam could be pumped to the upper floors of a high-rise or a tall hill with only a fraction of the head pressure generated by a water column. High-pressure pumps, booster pumps and pressure reducing valves could become unnecessary.

Considering the length of time that compressed air foam has been is use and considering the number of apparatus that are being delivered with compressed air foam capability, it is remarkable that research on properties of compressed air foam have not kept pace. A number of properties have not been documented including fire flow values for controlling fires in structures; appropriate flow rates for wet line production in various fuel types; friction loss and effective nozzle pressures.

In its initial plan, this applied research project also included calculation of friction loss for compressed air foam in 1.5" and 1.75" hose. An exhaustive literature search found no data on friction loss of compressed air foam. Field tests of friction loss were conducted in conjunction with this research project, however the results were inconclusive. It appears that compressed air foam decompresses to some degree before exiting the hose at the nozzle. Hoses containing compressed air foam are less rigid close to the nozzle than at the pump. While data was obtained on the pressure difference between the pump and a line gauge placed in the hose lay, it is not possible to state whether the pressure loss was caused by friction or by decompression.

Knowing the friction loss in a compressed air foam hose will not suffice without knowing what constitutes an effective nozzle pressure. An analysis of foam fire streams for nozzle pressure, reach, penetration and stream disruption are needed.

RECOMMENDATIONS

Recommendations included adoption of the proposed standard operating procedure and pump operations manual. While not all properties of compressed air foam have been measured or analyzed, the advantages of using compressed air foam are definite, especially when protecting structures. Simple operating procedures and clear instructions can minimize the need for trial and error application. Consistent identification of foam types and foam solution-to-air ratios should improve the pump operators ability to deliver the desired foam type.

The results also indicate that compressed air foam use can improve the ability to deliver extinguishing agent when elevation changes might inhibit the ability to use water or foam solution. In scenarios where these effects can have a serious impact on firefighting capabilities, such as the Mitchell Bay Fire, compressed air foam should be used.

Field-testing is needed to analyze foam properties under a wider variety of circumstances. Additional research should address foam solution-to-air ratio measurement for application at low flow rates and high flow rates, and application at lower and higher pressures. The parameters of the tests done for this project where designed to address the fire department's direct needs. Other fire departments may have different needs in compressed air foam use.

A correlation between foam type and effectiveness is various situations was anecdotally available in the literature and assumed in the standard operating procedures. Specific tests to determine the actual effectiveness of various foam types could lead to an increased efficiency in firefighting capability.

Research is also needed to determine friction loss and effective discharge pressure of foam solution and compressed air foam. Pump operator training routinely includes an understanding of friction loss and nozzle pressures. Neither should be ignored for compressed air foam.

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APPENDIX A: Results of foam type analysis.

Test	Hose	Nozzle	Solution	Air	Ratio	Description
1	1.75	1.375	90	46	1.96	wet
2	1	0.9375	36	26	1.38	wet
3	1.75	0.9375	56	60	0.93	wet
4	1.75	1.375	82	82	1.00	wet
5	1	0.9375	30	30	1.00	wet
6	1.75	0.5	28	33	0.85	fluid
7	1	0.9375	26	33	0.79	fluid
8	1.75	1.375	70	90	0.78	fluid
9	1.75	0.5	30	45	0.67	fluid
10	1	0.9375	24	38	0.63	fluid
11	1	0.9375	18	36	0.50	dry
12	1.75	1.375	60	120	0.50	dry
13	1.75	0.5	22	64	0.34	dry
14	1.75	1.375	40	120	0.33	dry
15	1.75	0.5	15	60	0.25	dry

APPENDIX B: Results of Head Pressure Tests

FS/Air Ratio	Base elevation	Top elevation	Base pressure	Top pressure	Head
Water only	30	130	140	96	44
2.00	30	130	115	91	24
1	30	130	100	81	19
0.75	30	130	100	82	18
0.5	30	130	100	86	14
0.25	30	130	112	100	12

APPENDIX C: Standard Operating Procedure for Compressed Air Foam Use

706 USE OF COMPRESSED AIR FOAM AND CLASS A FOAM

POLICY:

1. The use of class A foam and compressed air foam shall be at the discretion of the company officer, unless specifically directed not to use compressed air foam by their immediate supervisor or the commanding officer.
2. All personnel must be certified as Driver/Operator 1 and have completed the CAF Operator course before operating the compressed air foam systems.

PROCEDURES:

706-1 RECOMMENDED FOAM USE

1. Generally, class A foam may be used on any fire of class A combustibles, including wildland fires, structure fires and most vehicle fires.
2. Dry foam is recommended to protect exposures from wildland or structure fires, or to pre-treat vegetation.
3. Fluid or medium foam is recommended for initial attack on structures or for wet line production at wildfires. Fluid foam may be used to bank wildland fuels for later mop-up.
4. Wet foam or foam solution is recommended for overhaul of structure fires.
5. Foam solution is recommended for mop-up of wildland fires.

706-2 WHEN NOT TO USE FOAM

1. Class A foam consists of 99% or more water. When water is inappropriate, so is class A foam.
2. Class A foam should not be used on petrochemical spills, due to its ability to emulsify petrochemicals.

706-3 EQUIPMENT

1. Class A foam or compressed air foam may be used in any hoseline.
2. Foam solution should be applied using ordinary water nozzles.
3. Compressed air foam may be applied using ordinary nozzles or smooth bore shut-offs. Constriction at the nozzle causes the foam to be wetter. Use these as a guideline:
    - 1 ½” shutoffs should be used for pre-treating vegetation or structures.
    - 1” or 15/16” smooth bore nozzles should be used for initial attack of structure fires.
    - Combination fog nozzles should be used for structure fire overhaul.
    - ½” smooth bore nozzles should be used for wet-line production.

706-4 TACTICS

1. Most tactics of water application will not change significantly with class A foam.
2. The use of a straight stream of compressed air foam will have an effect similar to a narrow fog in an indirect attack.
3. Application of compressed air foam to heavily involved spaces in structural fires may cause a more rapid conversion to steam.

706-5 PUMP OPERATIONS

1. Follow the procedures outlined in the attached “Type 2 Pump Operations Manual” when operating the CAF system. All operators should be familiar with the procedures outlined in the manual.
2. A copy of the “Type 2 Pump Operations Manual” should be kept on each Type 2 engine for reference.

APPENDIX D: Pump Operator's Manual

Pierce Hawk - Type 2 Engine

Pump Operator's Manual

Notice: Read and Understand the entire manual before attempting to perform any operations using the Pierce Hawk pump and CAF system.

Introduction

The Pierce Hawks are equipped with two engines. One engine provides power to the drivetrain, and the second engine provides power for the pump system. The pump engine is coupled directly to the water pump. The water pump is rated at 500gpm at 150psi. A PTO can also operate an air compressor for the compressed air foam system. The air compressor is rated at 200cfm at 150psi.

The auxiliary engine operates from the main fuel tanks. The pickup tube is designed to prevent operation when the fuel tank drops below ¼ full. If you attempt to run the engine below ¼ tank, the auxiliary engine may die from fuel starvation. The engine will then require re-priming to run. The auxiliary engine has an alternator that will keep the batteries charged in most cases. It will not be capable of keeping up with all of the emergency lights, scene lights and radio. Reduce loads if operating only from the auxiliary engine.

The pumping system can be operated to provide water, foam solution or compressed air foam.

The engine is equipped with six discharges: Discharges 1 and 2 are 2 ½" discharges and can supply water only. They are located at the pump panel. Preconnects 1 and 2, and the front discharge are 1 ½" discharges and can supply water, foam solution or compressed air foam. When one foam discharge is supplied with foam solution, all foam discharges supply the same foam solution. Air can be selected by individual discharge.

Foam concentrate is injected into a foam discharge manifold. The manifold supplies only the foam discharges, so foam solution cannot be re-circulated into the tank. There is a check valve on the foam manifold that prevents foam solution from flowing back into the pump.

The foam system has a control head that is used to control the foam injection rate. The foam control head also displays water flow, total water flowed, foam concentration rate and total foam concentrate used.

Starting the pump

1. Open tank-to-pump and tank-fill valves.
2. Close all drains.
3. Engage pump master switch.
4. Push pump start switch.

Charging a line with water

1. Start pump.
2. Check that line is clear of bed and nozzle operator is ready.
3. Open discharge for desired line.
4. Close tank-fill valve.
5. Throttle to desired pressure. (Push and hold throttle switch in desired direction).
6. Set pressure relief valve while water is flowing.

Setting pressure relief valve

1. Flow water through desired line.
2. Turn pressure relief valve "on".
3. Turn pressure relief adjustor down until "open" light indicates.
4. Turn pressure relief adjustor up one-quarter turn past when the "closed" light indicates.

Turning on foam solution

1. Press red "foam" button on foam control head. (The red light below the foam button will come on. The light will blink when foam concentrate is flowing.)
2. Open discharge line. (It is best to start foam before opening discharge line to ensure immediate foam injection. Starting foam after line is charged will delay foam solution.)

Adjusting foam solution

1. Press either "up" or "down" button on foam control head momentarily to switch the readout to "foam concentrate". A red light will show under "foam concentrate" and the control head will read "PA #" (<u>P</u>ercentage - class <u>A</u> – concentration percentage).
2. Press and hold "up" or "down" button on foam control head until desired concentration achieved.

Foam solution rates

1. Default percentage is 0.5%.
2. Use 0.5% for CAF when using hard water.
3. Use 0.3% for CAF when using soft water.
4. Use 0.5% for foam solution for fire attack.
5. Use 0.1% to 0.2% for foam solution when mopping up.

Setting pressure for water or foam solution using automatic nozzles

1. Automatic nozzles are designed to automatically adjust pressure at the nozzle depending on flow. Use the following engine settings:

200’ Preconnect:

Engine Pressure	**Flow Rate**
80	60
110	100
150	150
190	200

Starting air compressor

1. Pump engine should be at idle. (Do not engage at high engine speeds.)
2. Air selector should be on “CAFS”
3. Engage air compressor switch. (If air compressor is shut down during operation, wait 30 seconds before restarting.)

Turning On Air

1. Start air compressor.
2. Charge line with foam solution.
3. Engage discharge air switch. Do not operate air if out of foam concentrate, or if foam is not on. Slug flow will develop.

Setting Pressure for compressed air foam

1. Initial pressure setting for CAF is 100psi.
2. Lines over 250’ may require higher pressures.
3. Maximum engine pressure for CAF is 150psi.

Note: Friction loss values have not been determined for compressed air foam. Communicate with nozzle operator to establish appropriate nozzle pressure.

Head Pressure

1. For water or foam solution, add 4psi for every 10’ elevation gained (pumping uphill).
2. For water or foam solution, subtract 4psi for every 10’ elevation lost (pumping downhill).
3. For compressed air foam, add 2psi for every 10’ elevation gained (pumping uphill).
4. For compressed air foam, add 2psi for every 10’ elevation gained (pumping downhill).

Adjusting type of foam

1. Charge line with compressed air foam.
2. Decrease foam solution by pushing in discharge valve to make drier foam.
3. Increase foam solution by pulling discharge valve out to make wetter foam.
4. Use the following ratios for foam types:

Foam Type	Ratio
Wet	1gpm to 1cfm
Fluid	2gpm to 3cfm
Dry	1gpm to 2cfm

Drafting

1. Pump engine should be off.
2. Tank-to-pump and tank fill should be closed.
3. All drains should be closed
4. Position engine.
5. Attach hard suction.
6. Start pump engine.
7. Engage primer until pump discharge reads constant pressure and water flows steadily from primer discharge under pump.
8. Open discharge or tank-fill.

Filling the Tank

1. Open tank-fill. (Maximum fill pressure is 100psi. Maximum fill rate is 500gpm. Gate tank-fill when tank nearly full.)

Operating from hydrant (no lines charged)

1. Connect supply line to auxiliary suction port.
2. Open intake port and tank-fill.
3. Start pump.
4. Open discharges as needed.
5. Partly close intake port to maintain intake pressure between 10psi and 30psi. (A pressure differential of 50psi is needed to allow pressure relief valve and air cooler to function correctly.)

Operating from hydrant or supply line (lines charged)

1. Connect supply line to auxiliary suction port.
2. Slowly open intake port until intake pressure reads 10 psi.
3. Close tank-to-pump.
4. Maintain intake pressure between 10psi and 30psi.
5. Refill tank as needed to keep full.

Refilling foam system

1. Refill foam tank when foam control head flashes “Lo Con” or “No Con”, or when level indicator lights show concentrate is low. (Do not mix foam concentrates. Use only the foam concentrate currently in the foam tank.)

Shutting Down

1. Always shut down air first, then foam, then water. Use the procedures outlined below. Always flush foam lines when done pumping.

Shutting down air discharge

1. Idle down pump engine.
2. Shut down air discharges. (Warn nozzle operator when shutting down air discharges when discharge lines are flowing CAF. Sudden change from CAF to foam solution or water may make lines uncontrollable at high discharge rates and pressures.)
3. Shut down air compressor, if no longer needed.

Turning foam system off

1. Idle down pump engine.
2. Shut off foam by depressing red “foam” button on foam control head.
3. Flush all foam lines with water until water appears and feels clean, if done with foam.
4. Refill foam tank.
5. Reset water and foam flow displays, if done with pumping operations.

Shutting down pump engine

1. Idle down engine.
2. Open tank-fill and tank-to-pump.
3. Shut down pressure relief valve.
4. Shut down discharges.
5. Open manifold drain and discharge drains.
6. Depress pump master switch to off position.

Shutting down pressure relief valve

1. Idle down pump engine.
2. Turn pressure relief valve “off”.
3. Turn pressure relief adjustor up two full turns.

Priming foam system

1. Pump engine should be off.
2. Fill foam tank.
3. Turn calibrate/injection valve (at foam pump) to calibrate.
4. Turn on foam control head.
5. Adjust foam concentration up to 2.0%.
6. Enter simulated flow mode by depressing and holding both “up” and “down” buttons simultaneously.
7. Run foam pump until foam runs steadily from calibration dump line.
8. Shut off foam system by depressing red “foam” button.
9. Turn calibration/injection valve to injection.
10. Depress both “up” and “down” buttons momentarily to reset out of simulated flow mode.