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5100—Fire Management

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Engineering Analysis of Threshold Compressed Air Foam Systems (CAFS)

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SCOPE AND ABSTRACT

This engineering analysis of compressed air foam systems (CAFS) deals only with methods of producing expanded water (foam) and delivering it to the end of a hose, and not with the effect of the expanded water on a wildfire nor with foaming agents themselves.

The Texas Forest Service developed the concept of water expansion using "soap skim" as a foaming agent, positive displacement pumps to pressurize the water-foaming agent solution, and air compressors to supply gas for the water expansion. This concept is in wide use within the State of Texas. Water expansion has been further developed by the USDI Bureau of Land Management (BLM) and the USDA Forest Service through the use of improved foaming agents and centrifugal pumps. CAFS are a brute force method of producing foam; therefore, almost any foaming agent can be used.

It is widely reported that CAFS units are cost-effective since, under some circumstances, they can provide a significant extension of the water carried by a fire engine. If CAFS units were to be used by the Forest Service, there would be added costs for the engine, additional fire crew training, and new procurement documentation. However, the use of CAFS may extend and enhance the water carried by an engine—hopefully to the extent that the added costs and problems associated with the use of additional equipment are offset by the benefits gained. Equipping fire engines with aspirating nozzles may also increase the potential of foaming agents.

If CAFS are adapted to Forest Service equipment, the following guidelines—developed by the Forest Service Washington Office, Fire and Aviation Management Staff, and the San Dimas Equipment Development Center (SDEDC)—should be used:

- With the CAFS in place, there should be no deterioration of the water handling capability or reliability of the engine.
- With the CAFS, the engine should be able to make a moving attack.
- Operation of the engine equipped with CAFS should be easy and simple.

This engineering analysis reviews approaches to, and equipment for, generating expanded water, and grades these on how well they meet the guidelines.

The use of centrifugal pumps for CAFS units has been demonstrated, and a demonstration/validation hydrostatic power take off (pto)-driven CAFS unit has been fabricated. This unit meets the CAFS guidelines for Forest Service fire equipment—no deterioration of water handling ability, can make a moving attack, and easy to use. Less costly centrifugal CAFS units than this can be fabricated; however, they would fall short of meeting the guidelines.

The major advantages of CAFS are the extension of the water carried by an engine and its ability to produce foam at low cost. Other advantages are that the foaming agent may serve as a wetting agent; and the foam is highly visible during and after application, clings to all surfaces, and lasts longer than water. Also, when using foam, attack hose lines are lighter than when filled with water and, with the CAFS, less foam concentrate is used than with other foam-generating methods.

INTRODUCTION

Compressed air foam systems (CAFS), sometimes known as the "Texas Snow Job," were perfected and put into service by the Texas Forest Service in 1977. CAFS units feature the injection of compressed air (or other pressurized gas) into water that contains a foaming agent. With CAFS, significantly less agent is added to obtain the required firefighting foam, so the approach is affordable. CAFS are a brute force method of producing foam; therefore almost any foaming agent will "work." Injection of air takes place at the engine, generally at operating pressures of 80 to 100 psi. Higher or lower pressures are also used—depending on hose size and length.

When flowing in the hose, and upon discharge from the hose, the compressed air expands the water-foaming agent solution giving it a wet, snow-like appearance. Air is generally injected into the water-foaming agent solution at a ratio of 10 to 50 parts by volume of free air (atmospheric pressure) to one part by volume of water-foaming agent solution. This results in a 200-gal tank of water being expanded to 2,000 to 10,000 gal of foam (expanded water).

Earlier foam-producing units, known as Water Expansion Systems (WES), used pressurized tanks to carry the water-foaming agent solution. The WES units were heavy and bulky in size because of the pressure tanks used. A pump was added to raise the pressure of the water-foaming agent solution and to pump directly into the hose line; thus eliminating the need for a heavy, bulky pressurized tank.

Pumping rates of 4 to 5 gpm of water-foaming agent solution with 20-plus cfm of air through 100 to 200 ft of 1-in ID hose is considered the lower threshold range of operation. Higher water-foaming agent solution flow rates, higher air flow rates, and/or longer and larger size hose are possible upgrades that are being used. There are also units in service with lower rates than the threshold range.

The major advantages of a CAFS unit are reported to be the extension and better utilization of the water carried by an engine and the ability to produce foam at low cost. Other advantages are the foaming agent serves as a wetting agent and has high visibility during and after application. The foam clings to vertical surfaces and lasts longer than water. When using foam, fire attack hose lines are lighter than when filled with water, and with CAFS less foam concentrate is used than with other foam generating methods.

One of the low-cost foaming agents which has been used is called "soap skim." Soap skim is a residue from the paper-making process, skimmed off draft paper liquor. Soap skim "crude" comes from paper mills as a dark-brown, viscous material (much like axle grease). The mills sell it for $20 (maximum) per 55-gal drum. It must be diluted half-and-half with water so it can be poured; the diluted mix is called "concentrate."

The concentrate is added to the fire truck water tank to produce an approximately 3 percent water-foaming agent solution. After passing selected health and safety tests, soap skim has been approved for Forest Service use. (See Forest Service Chief's letter of August 21, 1984.) Other low-cost foaming agents that are being used are commercial detergents (such as Dawn, Ivory, and Joy), wetting agents, and high-expansion foaming agents. Some of these are used at ½ to 1 percent solution; others are used at less than ½ percent.

The Forest Service, which evaluates fire chemical products before approving them for operational use, has issued "Interim Requirements for Foam, for Wildland Fires, Aircraft or Ground Application." Major items addressed include health and safety, corrosion, and storage. A copy of these requirements is included as appendix 1 in the San Dimas Equipment Development Center (SDEDC) August 1986 Special Report No. 8651 1803, "Interim Requirements and Manufacturer Submission Procedures for Wildland Fire Foam."

This report outlines in detail the steps to be followed by a supplier to have a foam product evaluated in order to obtain interim approval for operational use by Forest Service field units. As of mid-September 1987, three foams that have been submitted under this procedure have received such interim approval. They are Silv-Ex by Ansul/Wormald; Phos-Chek WD 861 by Monsanto Co.; and Fire-Trol Fire Foam 103B by Chemonics Industries.

The present CAFS units used by the Texas Forest Service have a positive-displacement gear pump to supply the water-foaming solution at up to 100 psi, and an air compressor to supply the air (also at up to 100 psi) to the mix point. The air and water blend at the mix point, and the air/water solution then moves through the fire hose. Usually, no nozzle is used at the end of the hose.

CAFS are in very wide use by the Texas Forest Service and are also being used by the Bureau of Land Management (BLM) and some Forest Service units. It is widely reported that CAFS are cost-effective since, under some circumstances, a significant extension and greater use of the water carried by a fire engine may occur. If this potential is realized, CAFS would have a significant impact on Forest Service fire engine equipment. There would be added costs for the fire truck and also added training for the fire crew; but it may allow an extension of the water carried by an engine in some situations. Equipping fire engines with aspirating nozzles may also increase the potential of foaming agents.

Also, more detailed specific technical data packages and added contract administration would be required when procuring fire trucks. These added costs and complications would hopefully be more than offset by enhanced effectiveness of the fire engine and its crew. If CAFS are adapted to Forest Service equipment, the following guidelines—developed by the Forest Service Washington Office, Fire and Aviation Management Staff, and SDEDC—should be used:

- With the CAFS in place, there should be no deterioration of the water handling capability or reliability of the engine.
- With the CAFS, the engine should be able to make a moving attack.
- Operation of the engine equipped with CAFS should be easy and simple.

This engineering analysis reviews methods of generating expanded water and grades these methods on how well they meet the guidelines. The analysis deals only with the methods and ways of producing foam and delivering it to the end of the hose, and not the effect of the expanded water on a fire nor with water-foaming agents themselves.

METHODS OF GENERATING EXPANDED WATER

Methods (and their associated equipment) of generating foam that have been used, are now in use, or have been demonstrated are:

- Solution under pressure in a pressurized tank—pressure provided by compressed bottled gas
- Solution under pressure in a pressurized tank—pressure provided by an air compressor
- Solution in nonpressurized tank—pressure provided by positive-displacement gear pump and air provided by an air compressor
- Solution in nonpressurized tank—pressure provided by centrifugal pump and air provided by an air compressor

  —Pressure controlled by pressure-reducing valve

  —Pressure controlled by centrifugal pump rpm

  —Pressure controlled by pressure-relief valve.

A vital aspect of generating expanded water is the proportioning of the foaming agents. Two general methods of proportioning foaming agents are (1) batch mixing and (2) direct injection. Under direct injection, three ways have been suggested or demonstrated. They are (1) air-operated injection pump, (2) meter motor and, (3) flow meter driving a proportioning pump. Other methods of proportioning foaming agents (such as using the main water pump vacuum and metering through an orifice into the low-pressure side of the pump) can and are being used.

Solution Under Pressure Using Compressed Bottled Gas

Expanded water can be generated by placing the water-foaming agent solution into a pressure tank and pressurizing this tank with air or nitrogen from a high-pressure cylinder. The compressed gas in the high-pressure cylinder is controlled by a pressure regulator to assure that the water-foaming agent solution pressure tank is not overpressurized. The compressed gas not only pressurizes the tank to make the water-foaming agent solution flow out of the tank, but also supplies the gas for the WES (figs. 1 and 2). Operation of this system is very simple; all the operator has to do is turn on a valve.

The pressurized-tank WES units are carried on tractors, and serve as protection for the tractor operator and tractor. This type of unit could also be carried on a logging skidder to control belly pan fires. These systems are commercially available in a number of sizes ranging from 2½ to 50 gal and larger. The pressurized tank is generally a one-shot unit. Referring to the stated Forest Service guidelines, the pressurized-tank units are:

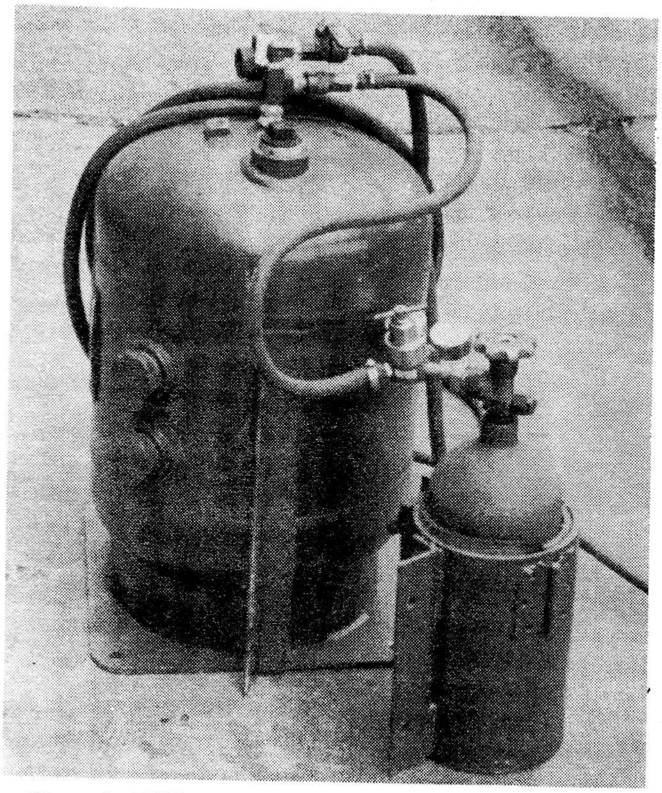

Figure 1. WES unit using a pressurized tank (100 psi) for the water-foaming agent solution and a high-pressure tank (2,000 psi) for the compressed gas to drive the system.

- A one-shot unit with no water handling capability

- Since the unit features a stand-alone design, requiring no outside power, a moving attack can be made

- Operation is very easy and simple.

Solution Under Pressure Using an Air Compressor

The large-size WES design first used by the Texas Forest Service (figs. 3 and 4) had a pressurized tank. This tank was pressurized by an air compressor that also furnished the air for the foam. The pressurized tanks were heavy, bulky, expensive, and also were potentially dangerous. The Texas Forest Service no longer has any of these units in service; they have been replaced with CAFS units having a positive-displacement pump. Referring to the guidelines developed for project guidance, these pressurized-tank units are:

- Capable of limited water discharge and limited drafting, since drafting can only be done with a venturi using air supplied by the air compressor

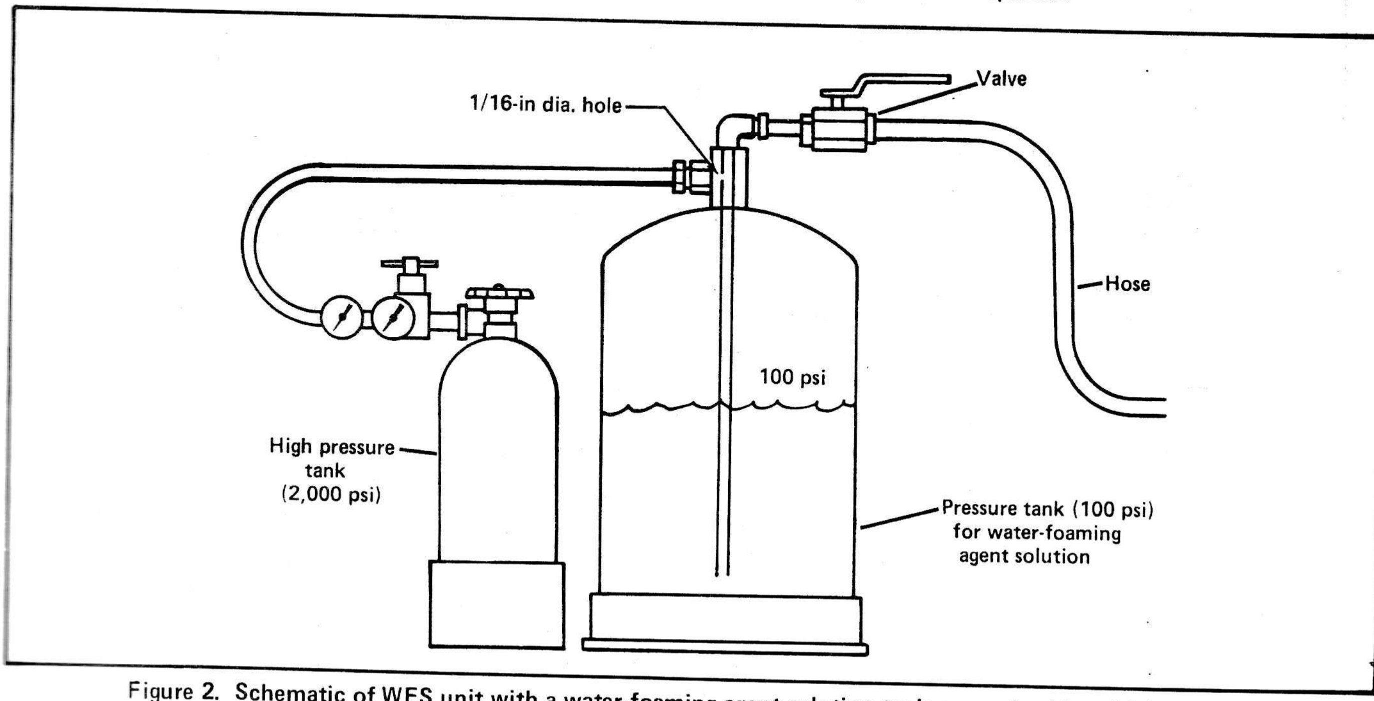

Figure 2. Schematic of WES unit with a water-foaming agent solution tank pressurized by a high-pressure gas cylinder that also supplies the gas for the foam.

Figure 3. Texas Forest Service large pressurized-tank WES unit (which is no longer in service) with pressure supplied by an air compressor.

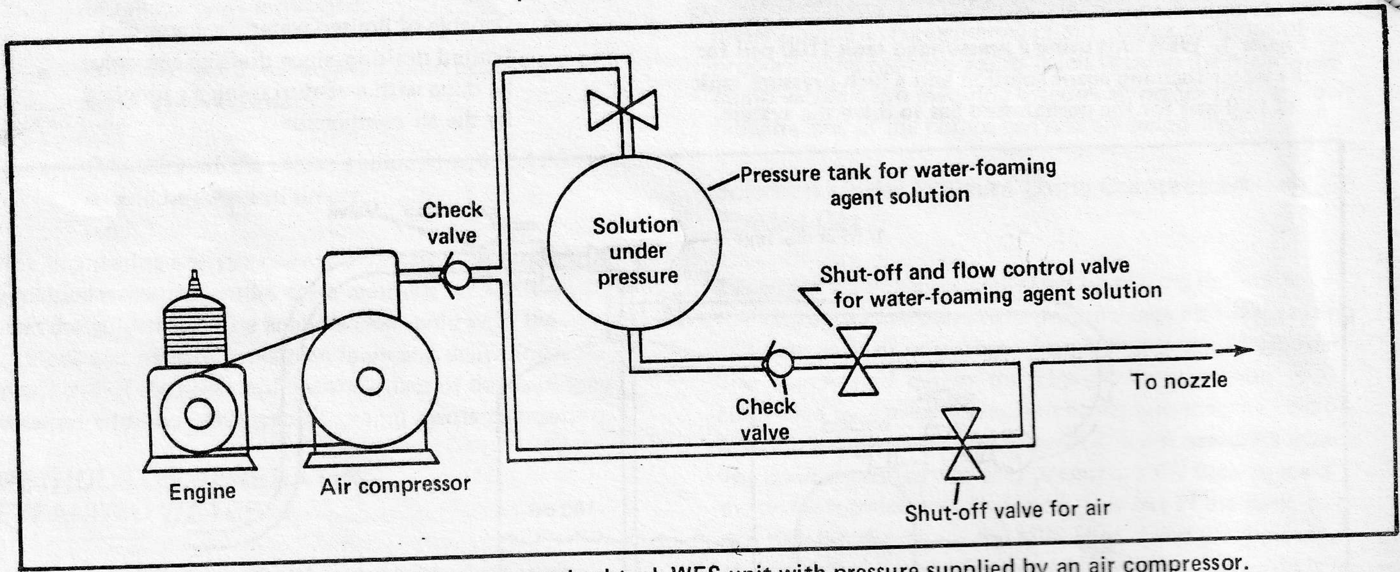

Figure 4. Schematic of large pressurized-tank WES unit with pressure supplied by an air compressor.

- Since the unit has its own air compressor to supply power, a moving attack can be made
- Operation is easy and simple.

While the large pressurized-tank unit does well in meeting the operational guidelines; its heaviness, bulkiness, and high expense, plus the potential danger of its design, have resulted in its discontinued use in favor of nonpressurized tanks.

Solution Pressure Provided by a Positive-Displacement Gear Pump and Air Provided by an Air Compressor

The Texas Forest Service realized the disadvantages of

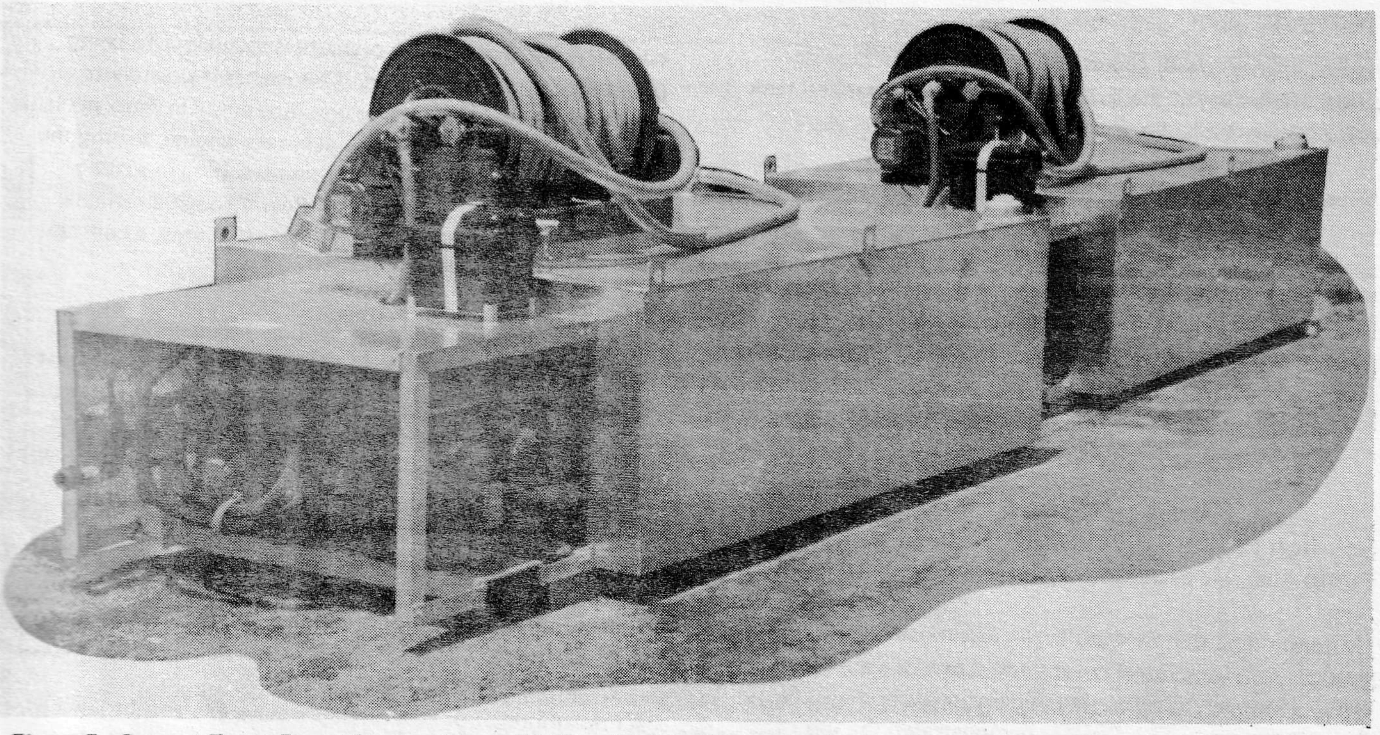

Figure 5. Current Texas Forest Service slip-on CAFS unit with a nonpressurized tank and a positive-displacement gear pump.

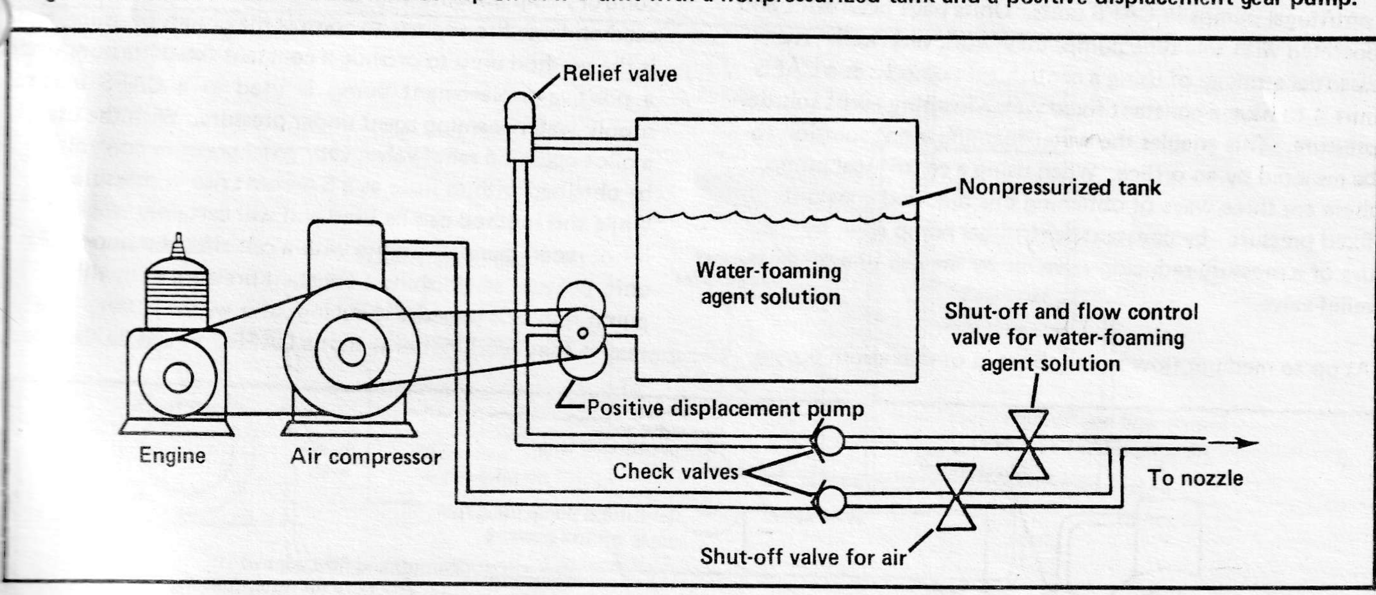

Figure 6. Schematic of CAFS unit with nonpressurized tank and a positive-displacement gear pump.

pressurized-tank systems and developed a nonpressurized tank system. This nonpressurized tank system uses a positive-displacement gear pump to pump the water-foaming agent solution directly into the hose line (figs. 5 and 6). A positive-displacement gear pump was selected for use in nonpressurized tank CAFS for the following reasons—a pressure of only 100 psi is required, low cost, the lower power requirement of a positive-displacement pump as compared to a centrifugal pump, and for metering.

However, the last reason—upon examination—is not correct, as the positive-displacement pump does not do the metering; the flow of the water-foaming agent solution through a ball valve (variable orifice) between two set pressures does. The water flow rates and pressures of the positive-displacement pumps generally used on CAFS units are low and cannot be increased. Direct drafting is slow; thus, a venturi—driven by the compressed air from the unit—is used and the tank fills very rapidly. Advantages of the unit are its low cost and integral engine, which allows the unit to make a moving attack. Referring to the guidelines, the nonpressurized tank with positive-displacement pump units are:

- Capable of limited water discharge (because of limited water flow and pressure of the positive-displacement gear pump) and limited or special drafting
- Since the unit has its own engine, a moving attack can be made
- Operation is very simple and generally easy to operate.

Solution Pressure Provided by a Centrifugal Pump and Air Provided by an Air Compressor

Up to the time that SDEDC began investigating CAFS, it was thought that centrifugal pumps could not be used in CAFS units. However, SDEDC—in cooperation with the BLM, Boise Interagency Fire Center—demonstrated the use of centrifugal pumps in CAFS units. Units have been built and operated with this type pump; they work very well. The essential strategy of using a centrifugal pump with a CAFS unit is to have a constant fixed water-foaming agent solution pressure. This enables the water-foaming agent solution to be metered by an orifice. When using a centrifugal pump, there are three ways of obtaining this required constant fixed pressure—by constant centrifugal pump rpm, by the use of a pressure-reducing valve, or by the use of a pressure-relief valve.

At up to medium flow rates (about ½ of maximum pump output), centrifugal pump pressure is very close to being proportional to rpm squared. This makes it possible to control pressure by controlling pump rpm. On most portable pumps that are driven by a separate engine, setting the throttle is really setting engine rpm—resulting in setting pump pressure. By metering the flow through a variable orifice (ball valve) into a constant pressure area, a constant flow rate is obtained (fig. 7).

A pressure-reducing valve will reduce the possible high, varying pressure of a centrifugal pump to a lower constant outlet pressure (say, 150 psi). This lower constant pressure can then be metered by a variable orifice (ball valve) into another constant pressure area to produce a constant flow (fig. 8). When one engine, with a direct mechanical drive, is used to power both the centrifugal pump and the air compressor, the pressure-reducing valve method of obtaining a constant pressure should be used, since engine rpm—when driving both a centrifugal pump and an air compressor—may vary.

A pressure-relief or back-pressure valve can also be used to control pump pressure (fig. 9). This is the method often used on large fire engines to control maximum pressure, and is the method used to provide a constant fixed pressure when a positive-displacement pump is used in a CAFS unit to supply water-foaming agent under pressure. With the use of a pilot-operated relief valve, very good pressure control can be obtained with as little as a 5 percent rise in pressure. While this method can be used and will certainly work, it is not recommended for use with a centrifugal pump CAFS unit, because establishing a constant pressure with either pump rpm or a pressure-reducing valve works better. The reason they work better is that a CAFS unit can be designed

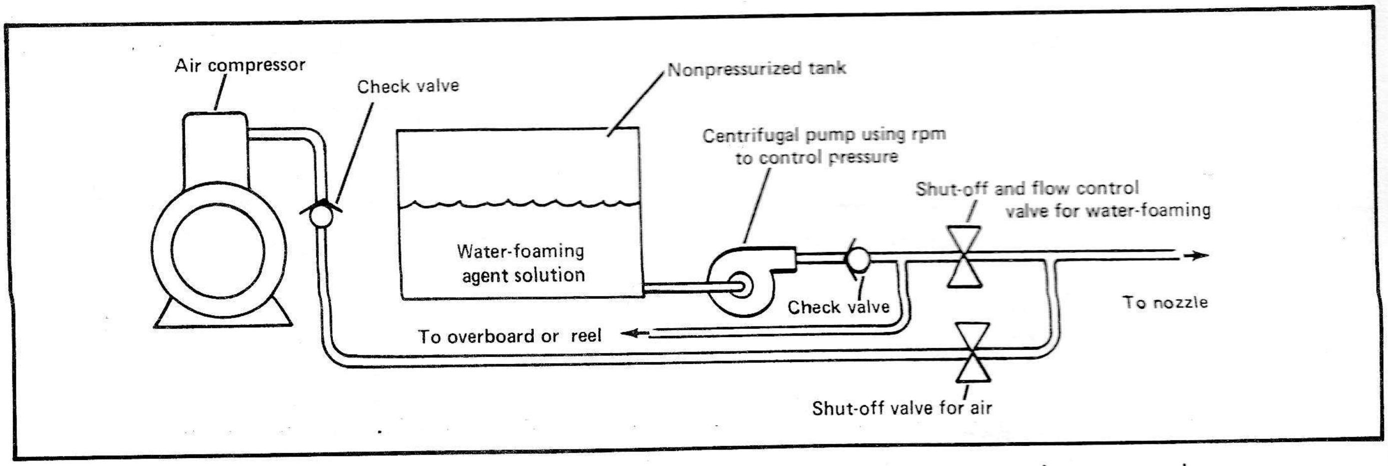

Figure 7. Schematic of centrifugal pump CAFS unit using pump rpm to control pressure and a ball valve to meter water-foaming agent solution into the hose line.

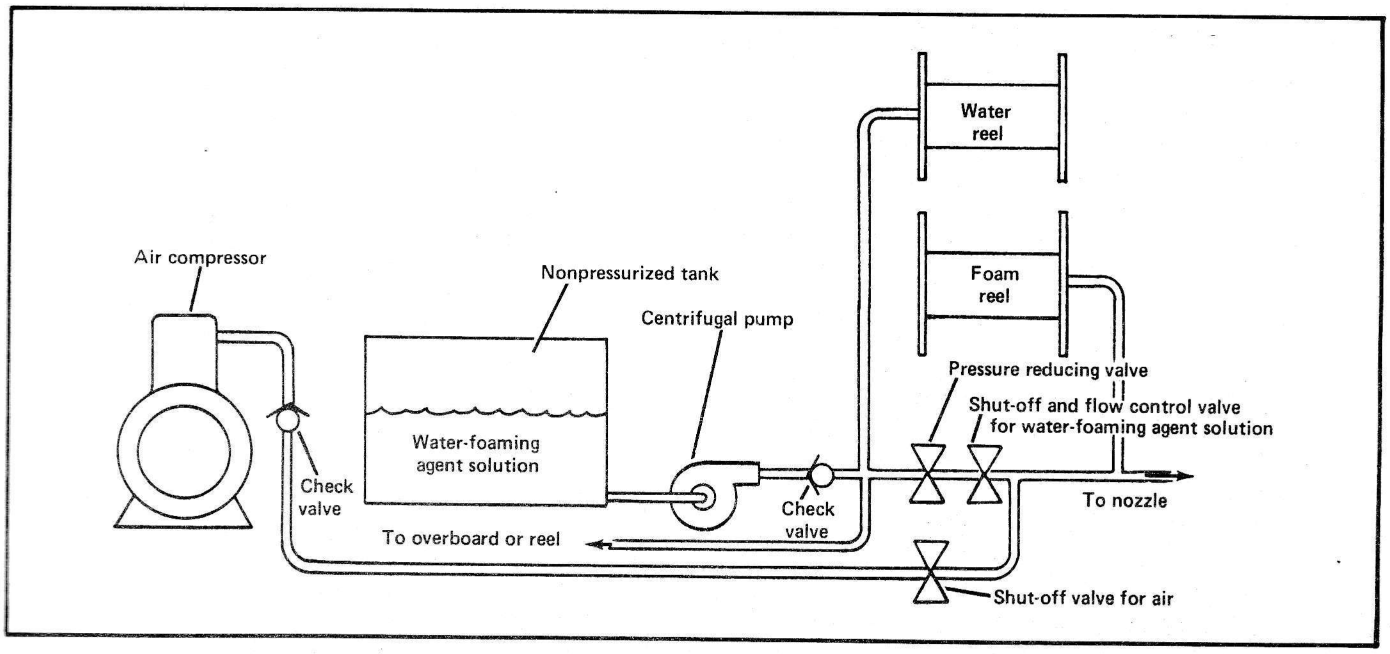

Figure 8. Schematic of centrifugal pump CAFS unit using a pressure-reducing valve to control pressure and a ball valve to meter water-foaming agent solution into the hose line.

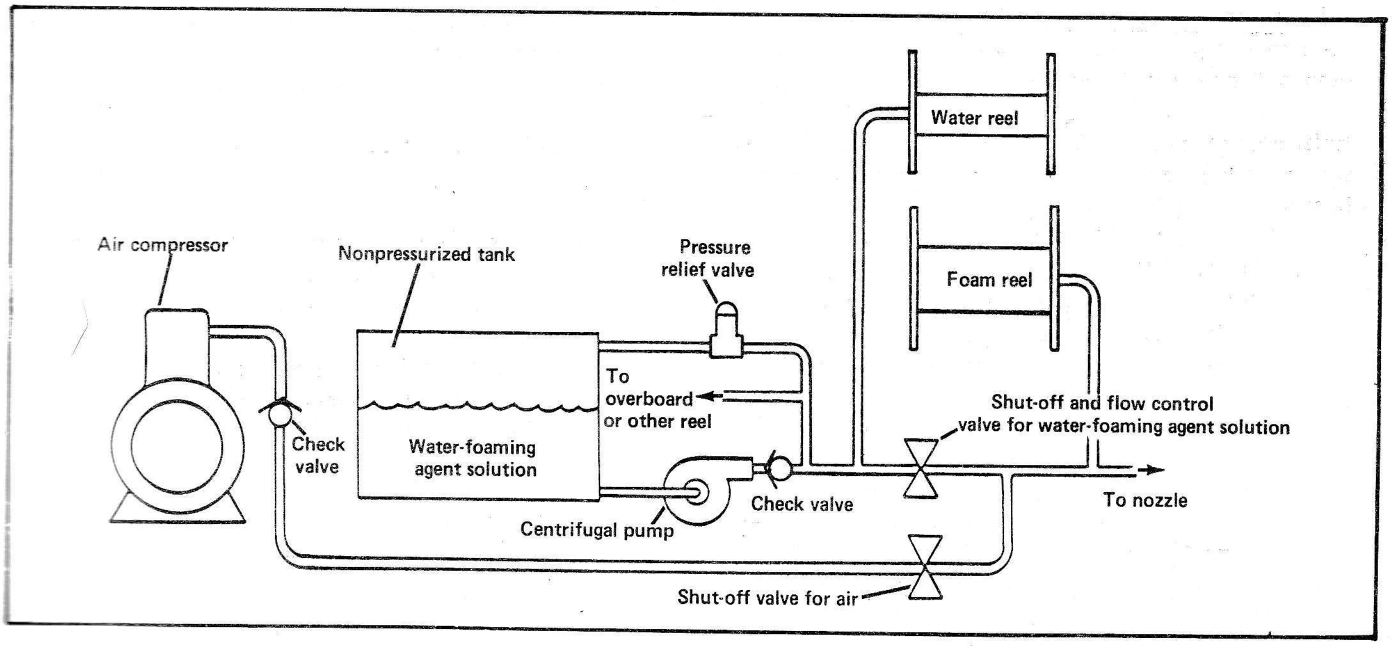

Figure 9. Schematic of centrifugal pump CAFS unit using a pressure-relief valve to control pressure and a ball valve to meter water-foaming agent solution into the hose line.

with a smaller engine when pump rpm or a pressure-reducing valve is used to establish the needed constant pressure.

Another way of obtaining a known rate of water flow from a centrifugal pump (when it is used to supply water-foaming agent to a CAFS unit), is by the use of a special automatic flow-rate control valve. This valve is available from the Kates Company, 2101 Waukegan Road, Deerfield, IL, 60015, (312) 945-0950. It allows flow at a preset rate, regardless of upstream or downstream pressure—provided the pressures are within the operating window of the valve. The valve would work very well in controlling the flow rate of water-foaming agent in a CAFS unit, but is not recommended for two reasons. First, even with the use of this valve the maximum water pressure to the CAFS hose line should be limited, or equal, to the maximum air pressure from the air compressor which would require the use of a pressure-reducing valve or the use of pump rpm to control maximum water pressure and, second, this is an expensive valve.

If two auxiliary engines or two power sources are used in a CAFS unit (one to power the centrifugal pump and one to power the air compressor), controlling pump pressure by pump rpm usually will work very well, and should be used. In general, centrifugal pumps are preferred over positive-displacement pumps because of higher and more flexible capacity and better reliability. A disadvantage of the centrifugal pump, when used on a threshold CAFS unit (4 to 5 gpm, 20-plus cfm air, and 200 ft of 1-in hose), is that it requires more power to drive the centrifugal pump than a positive-displacement pump. In fact, a 18-hp engine will carry the load on a threshold CAFS unit when a positive-displacement pump is used; but when a centrifugal pump is used, a 25-hp engine is required.

Referring to the guidelines, when CAFS units are equipped with centrifugal pumps the following general statements can be made:

- With CAFS equipment in place—provided there is adequate power available and good design is used—no deterioration of the water handling capability or reliability should result

- When auxiliary engines are used to power a CAFS unit, a moving attack can be made; when the standard truck pto system is used to power the CAFS unit, a moving attack cannot be made; and, finally, when a hydrostatic pto drive is used, a moving attack can be made—provided it is designed correctly

- In general, with a well-designed CAFS unit, well-trained operators, and correct use of the unit, the operation of a centrifugal pump CAFS unit should be relatively simple.

PROPORTIONING FOAMING AGENTS

Batch Mixing

Adding the foaming agent directly (batch mixing) to the fire engine main water tank is the method generally used to proportion the foaming agent. This batch mixing method is certainly the simplest approach and is the lowest equipment cost method of proportioning foaming agents. When a fire engine water tank has been charged with a foaming agent, and water only is desired, the water-foaming agent solution can be used just as water is used; since, without the compressed air being added, the solution will not produce foam. Also, if a low-cost ($1 to $10 per 100 gal of water) foaming agent is used, the cost of throwing the foaming agent away is a relatively minor expense.

Direct Injection

The foaming agent can also be injected directly into the water stream on the discharge side of the pump at the proper rates to give the desired proportion. The advantages of directly injecting the foaming agent into the water stream on the high-pressure side of the pump are:

- No chemicals are added to the fire engine water tank, run through the pump, or circulated back to the tank by way of the tank fill valve or pump bleed line

- The proportion can be changed when operating

- When refilling a partially used tank of water, dip sticking or gauging is not required, because the foaming agent is not added to the tank

- The fire engine equipped with a direct injection system can draw water directly from a nurse tanker or hydrant to make expanded water.

Also, when using the direct injection method of proportioning, the foaming agent is only used at the rate desired and the amount needed; none is thrown away when water only is desired. Three systems have been suggested or demonstrated to do this—(1) an air-operated injection pump, (2) a meter motor, and (3) a flow meter driving a proportioning pump.

Air-Operated Injection Pump with Orifice Metering—In the air-operated injection pump system, the foaming agent is injected directly into the water stream on the discharge, or high-pressure, side of the water pump at the rate that provides the desired percentage of foaming agent in the water. The rate of injection is controlled by the air pressure and size of the injection orifice, which is adjustable. The pressure of the air to operate the air pump is controlled by the flow rate of the water. Water flow rate and the proportion (percentage) of foaming agent can be adjusted while operating.

A demonstration/validation CAFS unit using this sytem has been fabricated and operated by the Deschutes National Forest, Bend, OR. This unit operated extremely well; however, some modification should be made to the injection pump controller so it would be more proportional over a wider range. On the Deschutes National Forest unit, the injection pump is also used to inject fire retardants up to a 15 percent solution with a water flow of 20 gpm. The injection pump can also be used as a high-pressure (up to 500 psi), low-volume pump and, therefore, makes a very good hose tester.

Meter Motor—In the meter motor proportioning system, a positive-displacement triplex plunger pump pumps the foaming agent directly into the discharge, or high-pressure, side of the pump. A working demonstration/validation model has not been completed; but experiments indicate that the meter motor method should work well.

Proportioning Pump with Flow Meter—A proportioning pump driven by a flow meter can also be used to meter-in the foaming agent. By using the meter to drive the proportioning pump, the correct proportion of foaming agent can be injected into the high-pressure side of the pump.

The major advantages of the direct injection method of proportioning the foaming agent are that no chemicals are added to the fire engine water tank, the percentage of mix can be changed while operating, and an outside water source can be used.

Other methods of proportioning foaming agents (such as using the pump vacuum and an orifice) are in use. *Fire Service Hydraulics*, second edition, edied by James F. Casey, 1970 (Technical Publishing Co., Div. of Dun-Donnelley, New York) discusses six foam proportioning systems—the nozzle eductor, in-line eductor, around-the-pump proportioner, foam concentrate pump proportioners, pressure-proportioning tank, and water-motor proportioner. Some of these foam proportioning systems use the low pressure of the suction side of the water pump and eductors or ejectors which, because of the low pressures involved, can be very touchy and extremely situation specific. Because of this, it may be best to avoid these types of proportioning systems.

MAJOR COMPONENTS OF CAFS UNIT

The three major components of a CAFS unit are (1) the power source, (2) water pump, and (3) air compressor.

Power Sources

The power source can be one or two auxiliary engines or the truck engine driving through a pto. Each has its advantages and disadvantages, depending on use and power required. Small auxiliary engines (5 to 10 hp) tend to be low cost, very easy to set up and install in a short time, and can easily make a moving attack. Truck engine pto-driven systems tend to be much lower in cost for high-power requirements, weigh less, require less maintenance, and are more reliable—but require advance planning and engineering to ensure good design and installation. Straight mechanical pto's generally do not make moving attacks well; however, with the use of a hydrostatic pto, a moving attack can be easily made. But, with a hydrostatic pto, there is a marked increase in cost. (The cost of a hydrostatic pto drive for a threshold CAFS unit is in the range of $4,000 to $6,500.)

The previously mentioned (under ***"Air-Operated Injection Pump with Orifice Metering")*** demonstration/validation Deschutes National Forest CAFS unit has two truck engine hydrostatic pto drive systems; one hydrostatic drive powers a centrifugal pump and the other a 25-cfm air compressor. Better design, along with better component selection and placement, would reduce the size, weight, and cost of this CAFS unit.

Water Pumps

The two types of water pumps used on firefighting equipment are centrifugal and positive displacement. As stated earlier, the centrifugal pump is the preferred pump for wildland firefighting equipment; however, the centrifugal pump does require more power to operate than the positive-displacement pump when used in a CAFS unit. To illustrate this, a threshold unit (4 to 5 gpm, 20-plus cfm air, and 200 ft of 1-in hose) equipped with a positive-displacement pump will operate well with an 18-hp engine, while a threshold unit equipped with a centrifugal pump would require a 25-hp engine. Nevertheless, there are major advantages to the CAFS unit equipped with a centrifugal pump as there is no deterioration of the water handling performance nor of the reliability of the fire engine related to water handling.

Air Compressors

There are several types of positive-displacement air compressors—piston, rotary van, rotary helical screw, and rotary lobe. The piston type is by far the lowest cost and simplest and is, therefore, the type which should be used in a CAFS unit. A single-stage piston air compressor will meet the pressure requirements for a CAFS unit of 130 psi required to flow the expanded water from the engine to the nozzle. Higher pressure, two-stage compressors can be used, but there appears to be little need for pressures over 130 psi if adequate size fire hose is used. With 130-psi air pressure, foam can be moved through up to 800 ft of 1-in hose and over 2,000 ft of 1½-in hose at threshold CAFS flow rates. Longer lines can be pumped, but the problem is that it takes too long for the expanded water to reach the end of the hose.

In a test using 4,000 ft of 1½-in hose, it took over 15 min for expanded water to reach the hose end. Also, single-stage air compressors generally weigh less and cost less than two-stage air compressors. However, two-stage air compressors with good intercooling require 10 to 15 percent less power than single-stage compressors, when operating at the same pressure. Because of the need for only 130 psi (or less) and the lighter weight and lower cost, the single-stage air compressor is recommended for CAFS units.

CAFS UNIT DESIGN

After reviewing the guidelines for CAFS units, CAFS unit designs, and major components of CAFS units; a CAFS threshold unit design chart was developed (fig. 10). The five design approaches used in the chart were as follows:

- Hydrostatic pto-driven systems for centrifugal pump and air compressor
- Centrifugal pump driven by side-mounted transmission pto and a underhood, belt-driven air compressor
- Slip-on centrifugal pump unit and an underhood, belt-driven air compressor
- Two auxiliary engines; one to drive centrifugal pump, the other to drive the air compressor
- One auxiliary engine; driving both the centrifugal pump and the air compressor.

In applying the guidelines and considering other pertinent information, the ideal threshold CAFS unit should have a centrifugal pump and both the pump and air compressor should be hydrostatically pto-driven. This will result in no deterioration of the water-handling performance or reliability of the engine as related to water handling, and will also allow the engine to make a moving attack. The ideal engine should be simple and very easy to operate. This quality is almost entirely dependent on the ability and diligence of the designer. The reason for desiring a centrifugal pump is the centrifugal pump is the preferred type of pump for wildland fire fighting.

Disadvantages of a hydrostatically pto-driven CAFS unit are that the pto-driven system in the threshold CAFS unit power size (20 hp) will have a high initial cost and requires advanced planning and good engineering. However, the advantages of smaller size, somewhat less weight, and less maintenance will help offset the higher initial cost. A low-cost, pto-powered CAFS unit can be fabricated—if the requirement for a moving attack is lifted. This can be done by powering a centrifugal pump by a side-mounted transmission pto and providing an underhood, belt-driven air compressor. In this system, because only one engine is used, a pressure-reducing valve must be used to establish a constant water pressure. Cost of this drive system would be approximately $1,200.

If a slip-on pumper unit with a centrifugal pump is already in service, or if the requirement for a moving attack with water only would be satisfactory, a threshold CAFS unit can be fabricated using the auxiliary engine-driven centrifugal pump and an underhood, fan belt-driven air compressor. A pressure-reducing valve would not be required, because pressure can be controlled by pump rpm's. Installation cost of the underhood, belt-driven air compressor drive system would be approximately $450, not including the air compressor. The air compressor would cost approximately $1,900; other materials plus installation costs would bring the total cost up to approximately $3,400. If the total drive system costs and component costs are added (an engine to drive the slip-on pumper and a belt drive to power the air compressor), the cost would approach $5,200.

The guidelines can also be met by using either one or two auxiliary engines. For a two-engine threshold CAFS unit, two 11-hp engines would be adequate (at a cost of approximately $800 each, or $1,600.) For a one-engine threshold

Design type	Pressure control	Performance	Power required (hp)	ESTIMATES: can vary greatly Drive cost ($)	System cost ($)	Weight (lb)	Volume (cu ft)	Advantages	Disadvantages
Hydrostatic pto-driven system for centrifugal pump & air compressor	Pump rpm or pressure-reducing valve	Pump 53 gpm @ 300 psi 94 gpm @ 100 psi Compressor 25 cfm @ 100 psi	20	6,500	10.800	470	4.7	Good water handling; can make running attack; uses only truck engine; small size; less weight	High cost; advance design and planning required
Side-mounted pto-driven centrifugal pump & underhood, belt-driven air compressor	Pressure-reducing valve or pump rpm	Pump 70 gpm @ 200 psi 110 gpm @ 100 psi Compressor 25 cfm @ 100 psi	30	1,200	4,500	280	2.2	Good water handling. can make limited running attack with water only; uses only truck engine small size less weight; low cost	Advanced design & planning required; no running attack possible with CAFS
Slip-on centrifugal pump unit & underhood, belt-driven air compressor	Pump rpm	Pump 20 gpm @ 250 psi 58 gpm @ 100 psi Compressor 25 cfm @ 100 psi	11 Pump; Compr., truck engine-driven	950	5,200	280	6.1	Good water handling; can make running attack with water; relatively easy to install; can be installed in the field	Weight of unit; space requirement; slip-on tanker engine to maintain
Two engines: Engine driving centrifugal pump & engine driving air compressor	Pump rpm or pressure-reducing valve	Pump 20 gpm @ 250 psi 58 gpm @ 100 psi Compressor 25 cfm @ 100 psi	11 Pump & Com-pressor	1,600	5,200	330	9.9	Water handling, OK; can make running attack; easy to install in the field	Two engines to maintain; size & space requirements more than that desired
One engine	Pressure-reducing valve	Pump 70 gpm @ 300 psi 100 gpm @ 100 psi Compressor 25 cfm @ 100 psi	25	3,900	7,900	640	9.8	Good water handling; can make running attack; slip-on unit	High cost; high weight; space requirements more than that desired

Figure 10. CAFS threshold unit design chart.

CAFS unit, a 25-hp rated engine is required in conjunction with a pressure-reducing valve. The approximate cost of a 25-hp engine and pressure-reducing valve is $3,900.

CAFS LARGER THAN THRESHOLD UNITS

Up to this point, what may be considered a threshold CAFS unit has been discussed—a unit with a 20-cfm air compressor. Much of what has been discussed can be applied to CAFS units with larger air compressors. This is important because the current thinking is a desire for larger units. To investigate larger units, the senior author assisted BLM personnel at the Boise Interagency Fire Center (BIFC) in December 1986 with a series of CAFS flow tests using air flow rates up to 100 cfm and both 1-in and 1½-in hose. The foaming agent used in these tests was Silv-Ex at a ½ percent concentration. The water and foaming agent were batch mixed in a 500-gal tank, with water pressure supplied by a Wajax BB-4 pump and air supplied by a 150-cfm air compressor.

During the flow tests, hose size and length, cfm of air, gpm of water, pressure (psi) at the mix point, feet of stream throw, and type and appearance of the foam stream were recorded. Then, the ratio of air-to-water and the stream exit velocities in mph were calculated. (Refer to the table in the appendix for a complete listing of these recorded and calculated test results. The last two columns in the table give a classification of the foams produced in the test.)

For 1½-in hose, with an air flow rate of 100 cfm, the observed foam type was plotted against gpm. Type 3 foam (the type reportedly to be the most desired by the field) is produced at a flow of 40 gpm with hose lengths of 25, 50, 100, 150, and 200 ft at 100 cfm air flow. This is an air-to-water ratio of 19 to 1. These flow tests also indicated that, when flowing through 200 feet of hose, up to 40 cfm of air can be used with 1-in hose and up to 100 cfm can be used with 1½-in hose. This is because, when flowing foam at these rates through 200 ft of hose, the mix point pressure is at (or is approaching) 100 psi, which is close to the top working pressure of single-stage air compressors.

CONCLUSIONS AND RECOMMENDATIONS

The use of centrifugal pumps for CAFS units has been demonstrated and a demonstration/validation hydrostatic pto-driven CAFS unit has been fabricated that meets the guidelines for CAFS units for Forest Service fire equipment (good water handling, moving attack, and easy to use). Less costly centrifugal CAFS units can be fabricated; however, these fall short of some elements of the guidelines.

SDEDC recommends the following course of action pertaining to CAFS technology:

1. Continue to monitor known CAFS units that are being used within the agency and by its cooperators.

2. Continue with SDEDC efforts in developing and refining the air-operated, direct injection pump proportioning system and also the meter motor system—as there is a high interest by field units in direct injection proportioning systems.

3. Expand CAFS unit design charts to include 40, 60, 80, and 100 cfm size units, since the current trend for CAFS units is a desire for higher flow rates.

4. As indicated by National and Regional support, design and fabricate a SDEDC "model" CAFS unit for demonstration and use in a number of Forest Service Regions. The design of this demonstration unit should make trade-offs between performance, cost, weight, and ease of operation—potentially resulting in the best overall unit for Forest Service use.

5. With successful implementation of recommendation No. 4, and support from National and Regional direction and funding, consideration should be given to the production of technical data packages for CAFS units for use by the Forest Service and its cooperators.

6. Expand hardware development to include air-aspirating nozzles and non-compressed air systems.

7. Continue the development, cooperation, and exchange of information within the Forest Service, with cooperating agencies, and other interested organizations.

APPENDIX--RESULTS OF BLM CAFS FLOW TESTS

A series of CAFS flow tests were conducted using both 1- and 1-1/2-in hose and air flow rates of up to 100 cfm in the 1-1/2-in hose. Silv-Ex at a 1/2 percent concentration was used as the foaming agent. It was batch mixed in a 500-gal water tank; the water pressure was supplied by a Wajax BB-4 pump, air by a 150-cfm air compressor. A horizontal line is used in the table of test results that follows to indicate when a different hose length was used.

TABLE OF FLOW TESTS OF CAFS BY BLM AT BIFC
DECEMBER 1986

Hose		Air	Water	Ratio	Mix	Velocity	Throw	Foam	
Size in	Lgth ft	cfm	gpm	Air/Water	Pres. psi	mph	ft	Type	Appearance
1	200	20	5	30	60	43	25	2	Spotty
"	"	20	10	15	78	44	26	3	Good
"	"	20	15	10	78	46	45	4	Good
"	"	20	20	7.5	85	47	50	4.5	Good
"	"	20	25	6	94	49	55	5	Excellent
"	"	30	7.5	30	88	64	25	2	Spotty
"	"	30	15	15	98	67	55	3	Good
"	"	28	22.5	9.3	109	65	55	4	Strong
"	"	40	5	60	80	85	18	1	Weak
"	"	36	10	27	102	78	25	2	Weak
"	150	40	10	30	100	86			OK
1-1/2	25	40	10	30	10	38	25	2	Flutter, weak
"	"	40	20	15	15	40	50	3	Flutter, OK
"	"	40	25	12	15	40	50	4	
"	"	60	15	30	15	57	45	2	Flutter, OK
"	"	60	30	15	22	59	60	3.5	Flutter, OK

Hose		Air	Water	Ratio	Mix	Velocity	Throw	Foam	
Size	Lgth			Air/Water	Pres.				
in	ft	cfm	gpm		psi	mph	ft	Type	Appearance
1-1/2	25	60	45	10	30	61	75	4	Good
"	"	80	20	30	22	77	60	2	Thin
"	"	80	40	15	30	79	65	3	Good
"	"	80	60	10	40	81	78	4	Strong
"	"	100	25	30	30	96	70	2	Flutter
"	"	100	30	25	35	96	75	2	Flutter, good
"	"	100	35	21	35	97	75	3	Good
"	"	100	40	19	38	98	75	4	Good
"	"	100	50	15	44	99			
"	"	100	60	12	45	100	80	5	Good
"	50	60	15	30	25	57	25	1	Spotty
"	"	60	30	15	35	59	65	2.8	Good
"	"	60	35	13	35	60	70	2.8	Good
"	"	60	45	10	37	61	70	3	Good
"	"	60	60	7.5	42	63	65	4	Good
"	"	80	20	30	35	77	40	2	Flutter
"	"	80	40	15	45	79	65	3	Good
"	"	80	60	10	55	81	75	3	Good
"	"	80	75	8	60	83	75	3.5	Very good
"	"	100	25	30	42	96	60	2.5	Good
"	"	100	30	25	45	96	60	2.5	
"	"	100	35	21	47	97	55	3	Good
"	"	100	40	18	50	98	60	3	Flutter, good
"	"	100	50	15	55	99	65	4	Good

Hose		Air	Water	Ratio	Mix	Velocity	Throw	Foam	
Size	Lgth			Air/Water	Pres.			Type	Appearance
in	ft	cfm	gpm		psi	mph	ft		
1-1/2	50	127	70	14	72	126	70	3	Too strong
"	"	132	45	22	60	128	65	2.5	Good
1 1/2	100	40	10	30	25	38			
"	"	100	25	30	60	96	60	2	Weak
"	"	100	40	19	66	98	70	3	Good
"	"	100	50	15	75	99	75	3.5	Good
"	"	100	75	10	90	102	75	4	Strong
"	150	100	25	30	72	96	60	2	
"	"	100	50	15	80	99	70	3	Good
"	"	100	75	10	90	102	80	4	Strong
"	"	80	78	8	96	83	80	4	Strong
"	200	30	7.5	30	30	29	25	1	Surging
"	"	30	15	15	42	30	30	2	Weak
"	"	30	22.5	10	45	31	50	2.5	Good
"	"	30	25	9	4	31	60	3	Good
"	"	30	30	7.5	45	31	60	4	Good
"	"	40	10	30	50	38	25	2	Spotty
"	"	40	20	15	54	40	45	2.5	Good
"	"	40	25	12	52	40	48	3	Good
"	"	40	30	10	55	41	50	4	Good
"	"	60	15	30	60	57	50	2	Weak
"	"	60	30	15	70	59	65	3	Very good
"	"	60	45	10	75	61	75	3.5	Very good
"	"	60	50	9	75	62	85	4	Strong

Hose		Air	Water	Ratio	Mix	Velocity	Throw	Foam	
Size	Lgth			Air/Water	Pres.			Type	Appearance
in	ft	cfm	gpm		psi	mph	ft		
1 1/2	200	80	20	30	70	77	65	2	Good
"	"	80	40	15	80	79	75	2.5	Very good
"	"	80	50	10	80	80	80	3	Strong
"	"	95	45	16	95	94	75	4	Good
"	"	100	25	30	80	96	70	2	Good
"	"	100	40	19	95	98	78	3	Good
"	"	100	50	15	95	99	75	2.5	Good
"	"	105	35	22	92	102	75	2	Good
"	"	120	22	41	90	114	65	1	Weak

The details of the type-of-foam classification (next to last column in the table) are as follows:

Foam type (on a scale of 1 to 5)	Description of foam	Air-to-water ratio
1	Mostly air; very "dry" and fluffy	40 to 80
2	Like shaving (or whipped) cream; holds peaks; does not immediately run on vertical surfaces	25 to 45
3	Like watery shaving cream; peaks collapse; immediately runs on vertical surfaces	10 to 30
4	Very wet; readily runs off vertical surfaces	7 to 15
5	Mostly water; no "body"	Up to 10