Compressed Air Foam

Foreword

The “Leistungsbuch Druckluftschaum” publication has been created by the VFDB CAFS Working Group in order to develop a common and constantly updated database to support CAFS users. This translation is supposed to make the information available to Fire Services outside Germany in order to share the experience and knowledge gathered from research and real world firefighting situations.

It is not a word by word translation as some subjects may be specific to the German Fire Service and not so relevant for Fire Services in other countries. Some additional explanations may have been added for other countries as well.

The front page does show some scenarios, one a restaurant fire in a 7 story apartment building which was about to develop into the upper floors and efficiently stopped from that by the use of CAFS. Another scenario is an attic fire in a multi-story building, at first tried to extinguish with plain water and little success. The decision to use CAFS flipped the switch and knocked down the fire in very few minutes.

How does CAFS work and why is it so much more efficient? These questions are frequently discussed within the Fire Service. The aim of this publication is to give an answer to these questions. Even if used in Europe since 1997, in some areas more than in others, the available information is still not complete and considerably. Some facts are proven by scientific research by now, another subject this publication is supposed to inform about.

Chapters of this publication are:

- Basics / Technology
- Tactics / Operations
- Training
- FAQ’s

This publication must not be static, the readers are welcome to join the discussion with their comments and experiences in order to enhance and improve the information.

This publication makes many references to EN Standards as it has been developed in Europe. The authors acknowledge that there may be other local or regional standards which the reader may need to consider.

Various standards over the world contain similar key statements. As an example the development of EN 16327 avoided any contradictions with the relevant NFPA 1901 chapters. Most principles of firefighting do not change depending on where the fire occurs on our planet.

The working-group would like to express their special thanks to the English Auditors, having worked on the correction of the translated draft in terms of grammar and Fire Service Terminology.

- Merseyside, Fire&Rescue Service
- Andy Roe, Godiva Ltd.

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I. Properties of Compressed Air Foam

Remarks:

The term "solution" will be present in many places within this publication. Where mentioned, it refers to the mixture of water and foam-agent which is used in firefighting operations. Any values given in conjunction with the term "solution" refer to liquid only, not considering the amount of air which is used to create the finished foam.
The abbreviation "NAFS" stands for "Nozzle aspirated Foam System". A foam-nozzle uses the venturi principle to induct air into the solution and create the foam-bubbles. Such nozzles are usually physically large and remove energy from the stream.
The abbreviation "CAFS" stands for "Compressed Air Foam System". Pressurized air is used to create the bubbles inside the system, in most cases at the fire-truck. The compressed air adds energy to the stream.

Water as an extinguishing agent provides a huge capacity to absorb heat once completely evaporated (2.26 MJ/L at 100°C). Heating up the water from 15°C to 100°C (average fireground conditions) will absorb another 0.36 MJ/L.
Theoretically that means that the Fire Service should be able to compensate 2.62 MW per second by evaporating each liter of water. However, unfortunately, in reality less than 100% of the water being applied can be evaporated. The relationship between the mass of the agent applied and its surface has a significant influence on the degree of evaporation and can be considered as the efficiency of the application. One way of increasing the surface of the applied mass is creating smaller droplets. As they expose a larger surface per liter applied, the heat transfer of such bubbles is better than that from large droplets [1].
There are several drawbacks from small droplets as well, as a homogenous spray pattern is difficult to achieve but critical to success. Small droplets lose their kinetic energy quite fast, so the reach may be insufficient, meaning the attack team may need to be close to the fire, exposed to additional heat. Besides not being able to reach the seat of the fire, a spray pattern with small droplets will not be able to provide a mechanical impact onto the combustible material. Especially on larger fires, distance is critical for the safety of the firefighter, streams are being changed from fog to solid to overcome the distance. Excessive application of solid streams can lead to water damage.

By experience and research, like from Karlsruhe University in Germany, the water-spray from average nozzles may be considered to be 20 to 44% efficient [2,7].

Another way of increasing the efficiency of the water application is adding surfactants like Class A Foam. Injection rates in the rage of 0.3 to 0.5% do decrease the surface tension of the water significantly, enabling a nozzle to create droplets which are approximately 40% smaller in size [3]. One of the reasons why the application of Class A foam has spread over the last years with positive effect on the firefighting results.
In case of a fully involved fire in a confined space, there are the following main tasks the droplets need to fulfill [1,2,4]:

- Absorbing energy through evaporation while hitting hot surfaces. Kinetic energy is critical to transport the droplets through the hot gasses. Droplets must reach hot surfaces while still in the liquid stage.

- Gas cooling. In most cases the droplets will be applied under the room´s ceiling, absorbing energy during evaporation and diluting the combustible gases in conjunction with cooling them down.

Only the liquid content of the applied foam can be considered in the calculation of the extinguishing capabilities on Class A Fires while the air is supposed to turn the droplets into bubbles, exposing a larger surface to the heat.

Compared to Nozzle Aspirated Foam, Compressed Air Foam provide a very homogenous bubble structure of approximately 0.1 mm. This bubble structure can be applied as a solid stream which allows the agent to be transported through the flame zone with almost no losses, reaching hot surfaces and cooling them down efficiently by total evaporation. The bubbles reaching the hot surfaces do expand from heat until they burst and completely evaporate their liquid content [5]. The bubbles reaching already cooled down sections of the combustible material do show as white surfaces. Due to the surfactant the released water will penetrate the combustible material, reducing temperatures even further and avoiding re-ignition [5,6]. The cover from the bubble structure will reduce the release of combustible gasses.

Research undertaken at Karlsruhe University in Germany proves that the efficiency of the water application can reach up to 88% when using CAFS [7]. Attack teams have reported better visibility during the attack as well as an immediate flame knockdown in many cases [5,8,9]. Re-ignition was avoided or at least significantly delayed. Inertisation by steam was observed under certain conditions while the attack-teams have never reported excessive discomfort from steam during their stay inside the buildings.

CAFS has proven to be efficient if applied as straight stream and as fog stream in similar ways.

Another experience gained was that appropriate training, especially of the nozzlemen has significant influence on the firefighting results, with CAFS no different than any other firefighting agent.

II. Basics / Technology

1. A compressed air foam system consists of the following:

a) Fire-Pump

A Fire-Pump is required to provide water with the required flow at the required pressure. Requirements to the Fire-Pump are defined in existing standards, EN 1028 in Europe for example.

b) Foam Proportioning System

Also described as Positive Pressure Foam Proportioning System (PPPS). PPPS injects foam agent into the designated plumbing on the discharge side of the Fire-Pump, proportional to the flow-rate. Flow metering systems used in most cases to control the foam injection pump, taking the foam agent from a tank installed with the system. Water Foam Solution is leaving the PPPS and is provided to the downstream installation.

Requirements to the PPPS are described in standards like EN 16327 [10] for Europe for example and in NFPA 1901 in USA. PPPS are mostly designed to dose high concentrate foam agents at 0.5 to 1% and shall cover the range of flows requested by the application.

Table of systems per EN 16327

PPPS 200	200 l/min nominal solution flow
PPPS 400	400 l/min nominal solution flow
PPPS 800	800 l/min nominal solution flow
PPPS 1600	1600 l/min nominal solution flow
PPPS 2400	2400 l/min nominal solution flow

The number is giving reference to the nominal flow rate of the PPPS at 1% injection rate. That means that a PPPS 800 has to provide at least 800 l/min solution at 1% injection-rate. The ratings of the standard are minimum requirements which can be exceeded.

c) CAFS

Within the CAFS portion of the installed system the compressed air is being added to the solution created by the PPPS inside a mixing chamber. A compressor is mostly used as the air source to allow for continual operation. The mixing chamber can be adjustable to create a range of ratios between foam solution and air. The finished bubble structure leaves the mixing chamber under pressure.

CAFS are also described by existing standards like EN 16327 in Europe and NFPA 1901 in USA.

Today´s compressors are mostly screw-type and driven by the vehicle´s engine via PTO at least in common municipal fire trucks. The specific drive design may vary between manufacturers and models. Screw Compressors need oil injection for cooling and lubrication. Oil is separated from the air inside a so called “Separator Unit”, an oil-cooler is used to maintain compressor oil temperature. Separator unit and cooler may be integrated with the compressor or installed as separate items. There are several concepts to drive the compressor from the vehicles PTO available like:

- Drive in conjunction with the Fire-Pump by gearbox and /or belts
- Hydrostatic drive comprising an hydraulic oil-pump on the PTO and an hydraulic oil-motor at the compressor
- Using a 2nd PTO available from the chassis
- Installing a belt-drive within the driveline between PTO and Fire-Pump

Systems may comprise one or multiple mixing chambers to control the mixture between solution and air. The ratio (solution / air) may be fixed or variable and the control (if variable) may be mechanical or electronic.

EN 16327 qualifies CAFS as follows:

CAFS 200	200 l/min nominal solution flow + min. 600 l/min of air
CAFS 400	400 l/min nominal solution flow + min. 1200 l/min of air
CAFS 800	800 l/min nominal solution flow + min. 2400 l/min of air
CAFS 1600	1600 l/min nominal solution flow + min. 4800 l/min of air

The number again refers to the amount of solution which can be discharged and is a minimum requirement which can be exceeded.

The ratios between liquid and air are defined as 1:3 to 1:10 for wet foam and 1:10 to 1:20 for dry foam.

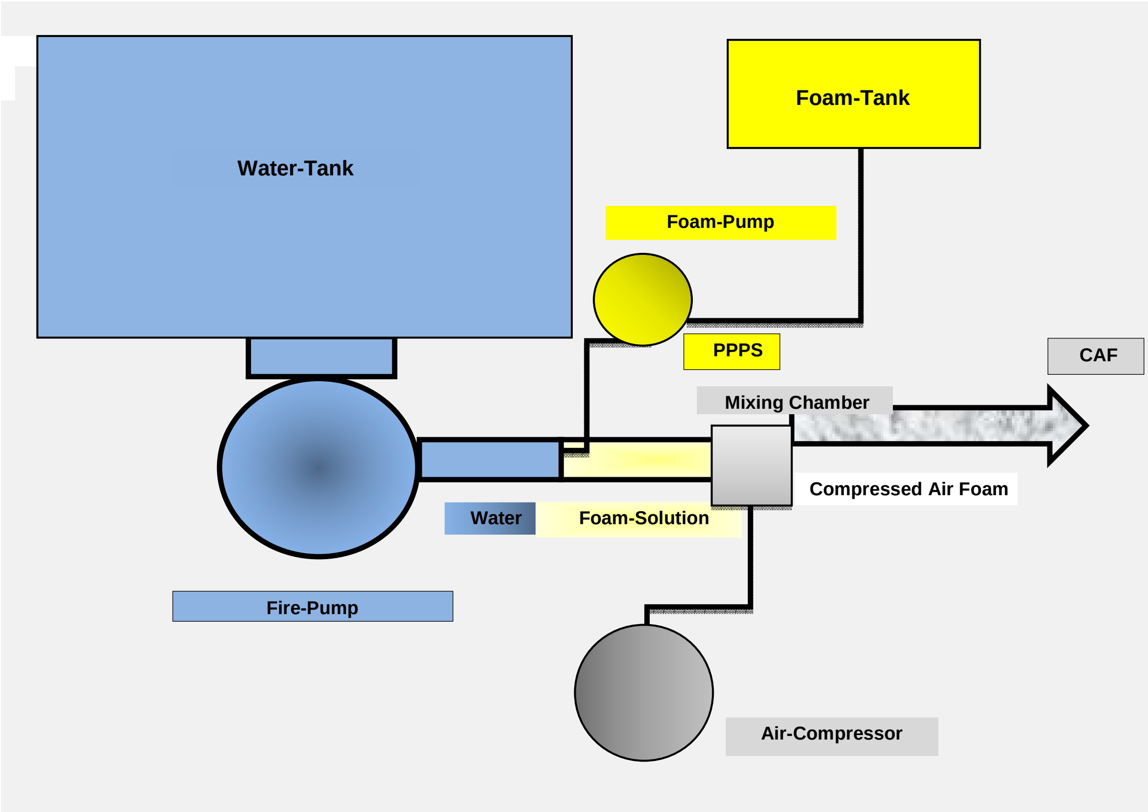
This determination is leading to a required compressor performance:

A CAFS 800 for example must be able to flow at least 800 l/min of solution. As the wettest ratio is 1:3, the compressor needs to provide at least 2400 l/min of air. Compressor performance is defined as the amount of air under atmosphere pressure (expanded volume, not the compressed one).

A CAFS requires safety interlocks for safe operation, air and water alone for example do not mix, so the presence of foam injection must be monitored. Situations like air being injected without the presence of liquid must be avoided.

CAFS operation pressures may range from 5 to 10 bar depending on fireground needs. Most common operation pressure is 7 bar (100 psi).

EN 16327 as well as NFPA 1901 limits maximum CAFS operation pressures to 10 bar (150 psi). A CAFS shall be capable of producing wet foam with an liquid to air ratio of 1:3 (in liters) at least. The following section will explain the produced foams in detail.



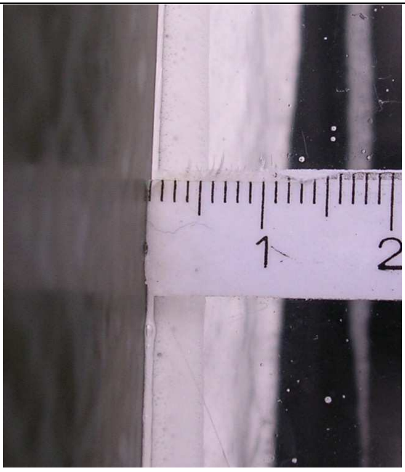
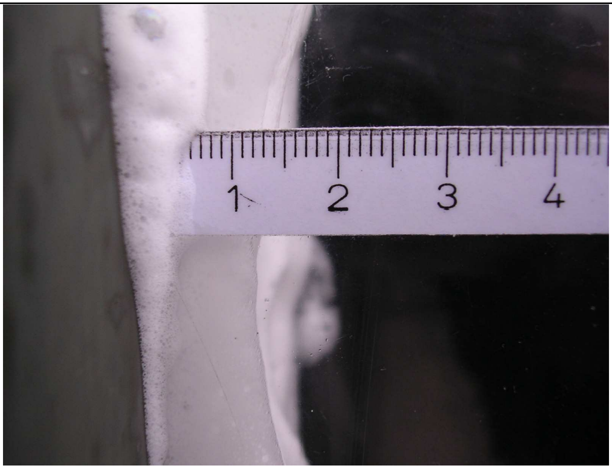
System schematic, Control systems and devices are not shown.

2. Wet & Dry CAFS Foams

Compressed Air Foam can be produced in different consistencies by changing the amount of liquid entering the mixing chamber and being added to the injected air. Less liquid added to the airstream makes a dryer foam, more liquid added to the airstream makes a wetter foam.

The produced foam is not only influenced by the actual System (CAFS) but also by the foam-agent and it´s dosage, as well as by the nozzle used for deployment.

In principle CAFS Foam would only need an orifice like a straight-bore nozzle to be discharged. In fact the fewer obstructions for the finished foam stream, the better the expansion rate of the discharged foam. For the above reason, pistol-grip shut-off valves with a straight bore nozzle shall be used to discharge dry foam. With wet foam such nozzles do provide a good reach and mechanical impact of the stream onto the combustible material. Wet foam may be also discharged by suitable fog-nozzles as explained further down in this publication.

	
Wet foam applied to a wall, thickness approx. 5 mm	*Dry Foam applied to a wall, thickness approx. 15 mm*

3. Safety Devices and Interlocks

- The Fire-Pump and the delivery of plain water shall never be effected by any failure of the PPPS or CAFS
- Air must only be injected once water is flowing and foam agent is being injected
- Operation pressure is limited to 10 bar to avoid excessive forces onto the attached components and severe nozzle reactions
- There must be no pressure peaks and surges effecting the nozzle operator while discharging foam

4. Hoses, nozzles and other equipment

a) Hoses

The minimum hose diameter (ID) for discharging compressed air foam on the fireground shall be 32 mm. Smaller diameter hoses may not be able to flow the required amount of liquid and compressed air at the same time.

Hose-standards, like DIN 14811 [11] or prEN 15886, define certain classes or types of hose in terms of resistance against fireground influences. Independently from the use of foam or CAFS the Fire Service shall determine their specific influences and requirements, then consider related standards to select the appropriate hose for their application.

The use of CAFS does not imply the need for a special hose.

	
Straight bore nozzle 25 mm diameter	*Fog Nozzle adjustable up to 500 l/min*

b) Nozzles

During CAFS operation, the nozzle needs to deploy the amount of liquid, required to compensate the heat generated by the fire, as well as the amount of air, required to produce the bubble structure. The combined flows (liquid and air) require a larger orifice at the discharge than just plain water.

Explanation: Water and foam-agent are non-compressible, 100 liters occupy the same volume, independent from operation pressure. The air is compressible, depending on operation pressure. Theoretically in a static condition (nozzle closed), at 7 bars (100 psi) 700 liter volume of air will occupy 100 liters of space inside the hose line, expanding again to 700 liters once leaving the nozzle. In a dynamic situation (nozzle open) there are additional influences caused by the adjusted ratio and the nozzle used.

By experience the smallest useable nozzle diameter for CAFS operation on the fireground is 19 mm.

The smallest usable fog nozzle must provide a >300 l/min setting and must be adjusted to such a volume to accommodate the CAFS flow.

Automatic nozzles shall not be used with CAFS. Some types allow the “Automatic” function to be turned off and may then be used successfully with CAFS.

c) Special applicators

Such applicators could be useful during certain fireground conditions, for example to apply the agent into hollow spaces, non-accessible areas or into piles of debris or other materials. These applicators had been successfully used to bring the agent (even dry foam) into piles of burning or smoldering materials. Minimal pipe diameter shall be 19 mm.

	
Shut-off valve with probe attached for access into confined spaces	*Detail of the probe shown on left, on the right there is shown a "Mobile Sprinkler Head" which has been used to suppress fires inside confined spaces where it was impossible to enter*

5. Foam Agent

CAFS as such does not require a specific foam-agent. In fact the type of fire makes that determination. In principle any foam-agent capable to produce low expansion foam can be used with CAFS. As a general guideline, the dosing instructions, given by the foam-agent manufacturer shall be observed, especially on Class B fires.

As CAFS is using PPPS style foam-proportioners, highly concentrated foam agents for injection-rates of 1% and less should be used as they offer huge logistical benefits.

There are existing standards, test-procedures and approvals for Class B foam-agents, like EN 1568, which the CAFS user can refer to.

There is an ongoing project to create an ISO standard for Class A Foam Agents. Due to the lack of a relating standard, Class A Foam Agents are being tested and certified against Class B Foam Standards in Germany and other countries for the moment being.

As Class A Foam Agents will not form any film on top of the flammable liquid, extinguishment will depend only on the capabilities of the bubble-structure, similar to a "Non AFFF" synthetic foam-agent. This explains why users were able to suppress smaller Class B fires in the field with CAFS by using Class A Foam agents. Certainly the lack of the film and the missing "lid" against oxygen could increase the risk of re-ignition. Additional testing about the use of CAFS on Class B Fires is planned.

Important information about the foam agent used can be obtained from the manufacturers. They will provide reference for best use and approvals in their Product Data Sheets. *An extract from a Product Data Sheet for a typical Class A Foam Agent is shown on the right.* *The Material Safety Data Sheet (MSDS) holds specific information about the potential risks while storing, handling and using certain Foam Agents. They also provide information about appropriate countermeasures in case of a spill or other incident.*	**Approval** *STHAMEX®-class A Classic 1% F-15 #9144* is approved as fire extinguishing agent for fires of class A and B according to the following standards: DIN EN 1568 Certificate No.: KB-239/14 Part 3 (Heptane): IIIC/IIIC Part 1: Medium ex. DIN EN 3 27A

Operational Assessment

Foam Concentrates for CAFS application:

Synthetic Foam Concentrates	Class A Foam	Foam Concentrate (NN)	AFFF + AFFF Alcohol Resistant
Injection Rate	< 1%	1 - 3%	1 - 6%
Structure - Fires	yes	yes	no (potential pollution)
Wildland - Fires	yes	yes	no (potential pollution)
Class B Spill - Fires	medium sizes (<100m²)	medium sizes (<100m²)	large sizes (>100m²)
Approved according EN 1568 for Class B Fires	yes	yes	yes
Not critical for Sewage Treatment Plant [27]	yes	yes	critical
Bio-degradable	yes	yes	persistent

- Synthetic Foam Concentrates like Class A Foam are considered “oleophilic”, seeking contact and mixture with hydrocarbons, this also explains why Class A Foam Solution penetrates better into combustible materials.
- AFFF is considered “oleophobic”, avoiding contact and mixture with hydrocarbons, this is required to form the film on top of a flammable liquid.

CAFS has been successfully used with AFFF and AFFF-ATC concentrates. One of the goals is to catch a Class B incident at the earliest stage possible and as efficient as ever possible, preventing the escalation into a huge Class B incident.

Technically a Fire-Truck can be equipped with a Dual-Tank system where the PPPS shall automatically select the pre-adjusted injection-rate for each foam-agent carried. This will allow carrying the appropriate foam-agent for Class A and Class B incidents. The decision if a Single- or Dual-Tank system is getting installed shall be based on evaluation of the potential risks which are supposed to be covered with a specific Fire-Truck.

As an example: If the Fire-Truck is used to cover risks caused by the production, handling, transportation or storage of Class B Flammable Liquids, a Dual Tank System shall be considered.

6. Types of Finished Foam and ways to test them

EN 16327 describes a pre-delivery test for CAFS installed into Fire-Trucks. The relevant numbers for each system will be determined during such a test and shall be kept on record. The test procedure may be applied also during other tests which may become necessary over the lifespan of the system, numbers can be compared.

a) Expansion Rate

Simply speaking, air is being used to blow up the solution droplets to a multiple of their original volume. The factor increasing the volume is called “Expansion Rate”. As an example, an expansion rate of 5 means that the addition of 4 liters of air to 1 liter of liquid does result in 5 liters of finished foam. Further details concerning the expansion rate and their testing can be found in standards like EN 1568 [12]. There are other internationally existing standards, like NFPA 11, describing the same test method.

EN 1568 Test Tray

The foam stream shall smoothly rain down onto the tray, the finished foam is collected in the container below. The tare is being deducted from the weight of the full container and divided by the volume of the container. The result is the expansion rate per EN 1568 or equivalent standards.

Discharge-Pressure FP [bar]	8	8	8
Compressed Air Flow [l/min]	100	150	175
Foam-Solution [l/min]	200	300	350
Air (Decompressed) [l/min]	800	1.200	1.400
Foam [l/min]	1.000	1.500	1.750
Expansion-Rate	5	5	5
Water-Content / Foam	20%	20%	20%

The table shows the expansion rate and the relationship between the finished foam and the amounts of liquid and air used by a system.

Influences on the expansion rate

The expansion-rate achieved during EN 1568 testing will mainly depend on the following factors:

- Adjusted ratio at the system. This determines how much solution is being added to the air within the mixing chamber. The achieved expansion-rate shall rise if the ratio is switched from “wet” to “dry”.

- Injection-Rate. The injection-rate, given by the Foam-Agent manufacturer should be used during tests.
- Nozzle, for reference the expansion-rate shall be tested with a 25 mm straight bore nozzle, then continued with any other nozzles or nozzle adjustment the user may wish to test.

There will be additional influences from the hose-set up (length, diameter), additional equipment, wind and ambient temperature. These influences may not be significant for basic tests to ensure system function. However if results shall be compared, conditions need to maintained the same.

Nozzle-Type	**Fog**	**Straight bore**	**Straight bore**
Adjusted ratio	**Wet**	**Wet**	**Dry**
Foam-Solution	**225 l/min**	**225 l/min**	**70 l/min**
Injection-Rate	**0.5 %**	**0.5 %**	**1.0 %**
Discharge-Pressure	**7 bar (100 PSI)**	**7 bar (100 PSI)**	**7 bar (100 PSI)**
Expansion-Rate	**4**	**7**	**24**

The table shows some typical expansion rates achieved under certain conditions.

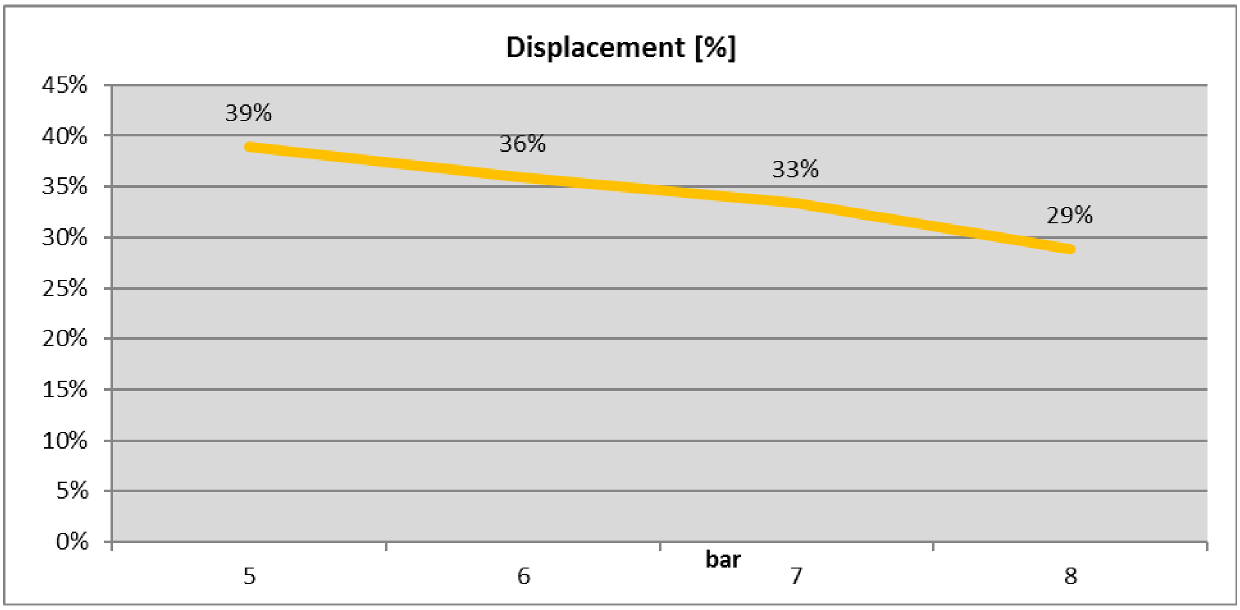
EN 16327 determinations

- Wet Foam = Ratios (solution / air) from 1:3 ranging up to 1:10, Expansion-rates ranging from 4 to 10
- Dry Foam = Ratios from 1:10 ranging up to 1:20, Expansion-rates >10

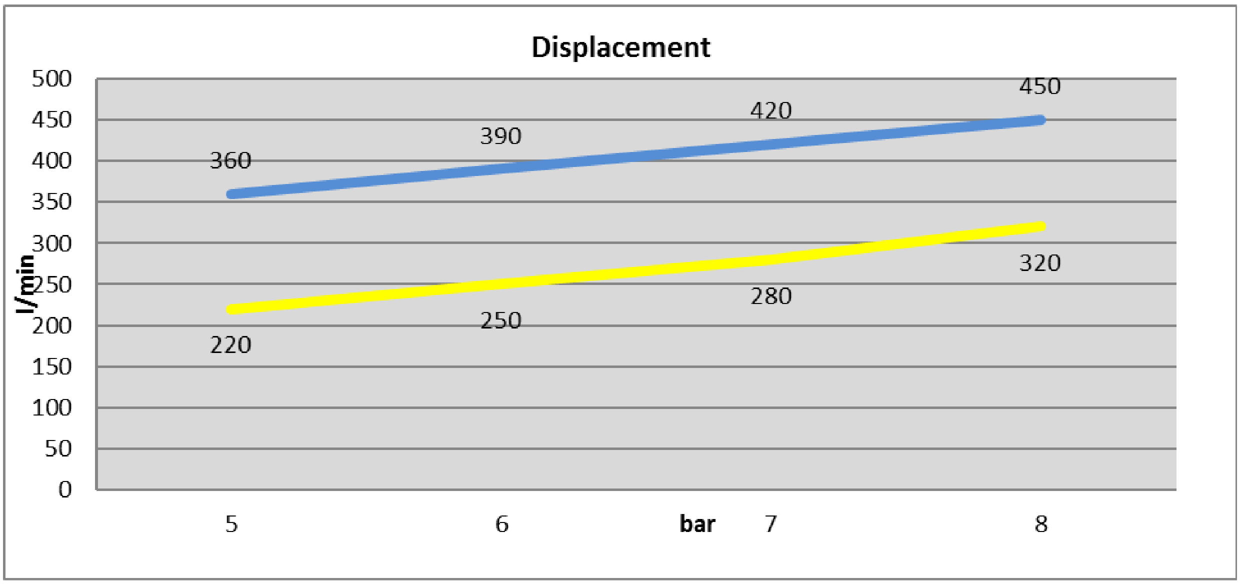
Note that the Ratio is an adjustment of the system used for operational purpose to accommodate specific fireground conditions. The expansion-rate is the actually produced foam at such adjustments, influenced by the factors explained in the previous sections.

b) Displacement

Once leaving the mixing chamber the plumbing and the attached hoses are filled with the mixture of solution and air under pressure. The static situation (nozzles closed) is dictated by Boyle´s law. The dynamic situation (nozzles open) will be influenced by the system capabilities and ratio adjustments. In any case a certain portion of the liquid normally filling the hose-volume is replaced by the compressed air. When discharging wet foam the displacement is in the area of 30% [13]. When discharging dry foam the displacement will be higher. Depending on the ratio, set at the mixing chamber, the displacement may reach up to 80%.



The graph was determined through a test of a system while using the hose- and nozzle arrangement from a common fireground condition. It shows the displacement of liquid by compressed air in the hose line under dynamic conditions.



This graph determines the flow from a nozzle using plain water as the blue line. The yellow line shows the flow under the same pressure while discharging compressed air foam. The difference in flow between the two lines can be described as displacement.

How to determine displacement in the field

One way to determine the displacement is to measure the flow while discharging water only (air turned off) across a range of pressures like shown on the previous graphs. Then the same test is being repeated while discharging compressed air foam (air turned on). At the same pressure, the flow will be lower. The difference in flow reading is the displacement of liquid caused by air.
Another way to determine the displacement (or the amount of air within a hose line) is by weigh of a certain length of hose. For this test a short piece of hose (approx. 3 m) shall be equipped with cou-

plings and shut-off valves on both ends. This test-hose must be coupled into the hose line between the system and the discharge device. Once filled with the desired media, both shut-offs shall be closed and the test-hose can be detached from the hose line and being hung up on a fish scale. To begin with the weight of the hose filled with water shall be determined. The CAFS Samples will weigh less. The loss of weight allows to calculate the displacement or the air content of the sample. For realistic results foam shall be discharged over approx. 30 seconds to allow the system to stabilize, then the valves shall be shut at the same time. If the dynamic pressure (hose line pressure while discharging) is taken as well, the air content of the sample can be calculated.

Equipment required for the above test:

- T or Y with shut-offs upstream from the sample, this shall allow shut-off and pressure-relief
- One hose length between vehicle and T or Y
- Sample hose, approx. 3 m with shut-offs on both ends
- Nozzle to discharge finished foam
- One hose length between sample and nozzle
- Scale, a "fish scale" type may work well

Pressure	Water	CAF Wet	Displacement	%
5 bar	9.1 Kg	6.7 Kg	2.4 Kg	26

The table shows one typical example for the determination of the displacement.

7. Guidelines for a CAFS Purchase

The following example is based on a typical EN 1846 Municipal Pumper in the 14 to 18 ton range for example per the German HLF 20 Specification. As most countries have similar truck specifications in principle, the general requirements can be adopted into any local specifications.

- Fire-Pump, FPN 10-2000 per EN 1028
- Foam Proportioner, PPPS 800 per EN 16327
- Compressed Air Foam System, CAFS 800 per EN 16327
- Water-Tank, min. 1600 liters
- Foam-Tank, min. 120 liters (will allow to produce 24000 liters of solution at 0.5% injection-rate)

The necessary operation steps on top of starting the Fire-Pump (engage PTO) to start a CAFS Attack shall be limited to:

- Engage System (select CAFS operation)
- Adjust Fire-Pump Pressure
- Open the desired discharge

It is beneficial to have the nominal flow of 800 l/min solution available through one outlet in order to operate portable monitors or aerial devices. The system may still have multiple outlets.

There may be the argument about the fact that a CAFS with less flow could be sufficient for most compartment fires. However a common municipal Fire-Truck shall provide the capacity to fight fires of a larger scale as well as those which are or can become the really critical ones. Such fires will challenge the first truck arriving, including it´s crew to a very large extent.

The firefighting capacity immediately available can make the difference between a successful rescue and loosing the building and it´s occupants. If a fire is about to engage a complete roof, flash across a complete attic, jump onto the next floor or engulf the adjacent building. Aerial devices and portable ground monitors are common tools to put in an efficient stop.

MAR (Minimum Application Rate, explained further down in detail) in such situations can be 800 l/min of solution or even more, system and operation-procedures need to keep up with that demand to be successful.

Example: First truck comprising a CAFS 800 arrives at scene, starting the attack to avoid further spread and prepare for entry. Second truck, also comprising a CAFS 800, arriving as back-up can provide sufficient compressed air foam flow for an aerial or a portable monitor. The performance of the first truck is still sufficient for safe and efficient final extinguishment.

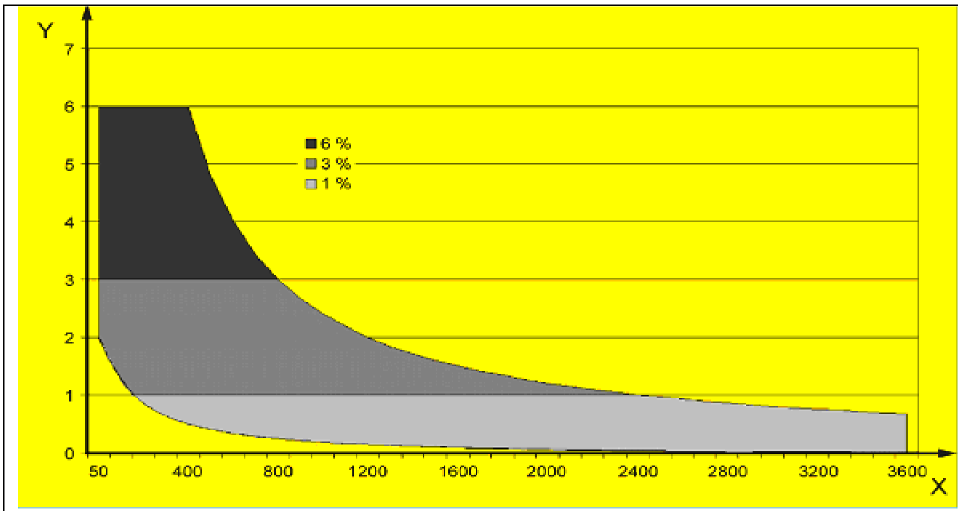
More complicated example, but technically possible, is to join the CAFS Flow from two CAFS 400 together to supply a monitor or aerial device.

The actual solution flow in l/min shall be visible on the pump-panel. It shall be possible to check total water consumption and total foam-agent consumption during an incident. As an option the data may be stored and / or transmitted for further evaluation.

All parts of the system shall be suitable for the foam-agent specified by the end-user. Flushing of Class A Foam shall not be required.

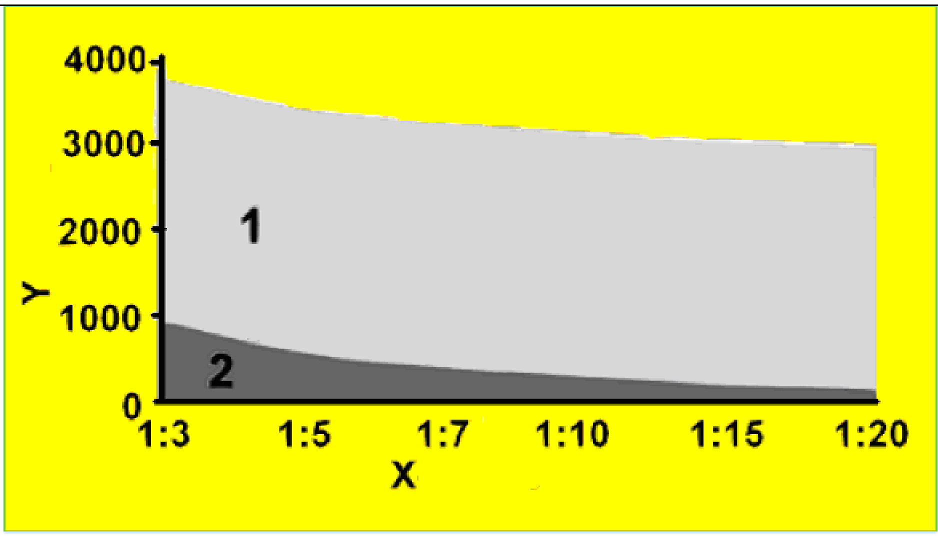
The manufacturer shall provide the following minimum documentation:

- Performance curve of the Fire-Pump per EN 1028
- Working Range Diagram of the PPPS per EN 16327
- Working Range Diagram of the CAFS per EN 16327
- Data of the max. possible flows in terms of solution and air from the system.
- If a system uses multiple mixing chambers, the flow from each single mixing chamber shall be provided.
- Data of the max. possible solution flow during CAFS operation, available from a single outlet.
- Test report on the acceptance test as described in EN 16327.



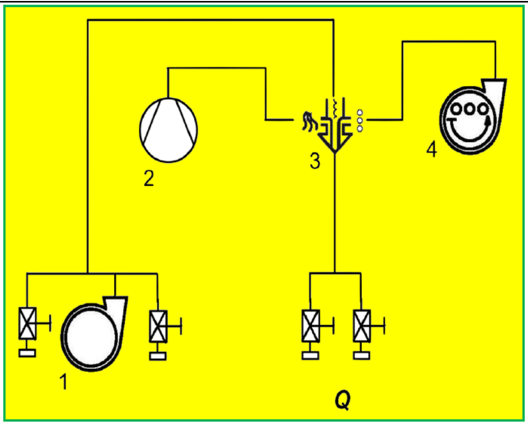
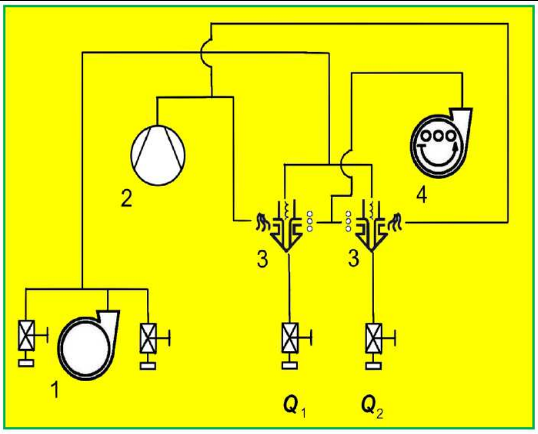
x- axis = achievable solution- flow rate l/min
y- axis = achievable injection- rate %

Sample of a working-range diagram of the PPPS per EN 16327. The x-axis describes the solution-flow in l/min, the y-axis describes the achievable injection-rate. The user can see how much flow is available at a certain percentage during operation.



X- axis = ratio
y- axis = flow- rates l/min

Sample of a working-range diagram of the CAFS per EN 16327. The x-axis shows the ratios which can be selected, the y-axis shows the amounts of solution (2) and air (1), the system can flow at a certain setting.

	
Schematics from EN 16327 explaining potential system layouts: 1 = Fire-Pump, 2 = Compressor, 3 = Mixing Chamber, 4 = Foam Pump. The graph on the left shows a system with a single mixing chamber, the graph on the right a system with dual mixing chambers. The user must know the nominal solution flow (Q) from the system being used.	

III. Tactics / Operations

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<td>The photo shows excessive application and / or the application of plain water and foam into the same area, may lead to situations like the above.

Water may run-off, leaving the foam piling up behind.</td>
<td>The photo shows an incident with consequent and controlled foam application. The foam will stay within the area of application. Cold areas do show as white surfaces. The foam cover will provide longer lasting cooling, the moisture will penetrate into the combustible material or evaporate. There is no run-off of any significance.</td>
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1. Providing sufficient resources

In order to explore the full benefits of CAFS in terms of fastest possible knockdown, most efficient use of resources, least amount of total damage etc.. The concept of implementing CAFS into a department strategy shall comprise as much Fire-Trucks as possible being equipped with CAFS and the CAFS to meet certain performance criteria. The available CAFS capacities shall be used as regular as ever possible to receive the full benefits. Just having one CAFS in a fleet and being able to advance one CAFS nozzle may bring a benefit in some situations, but never the breakthrough into making the department better, safer and more efficient as a whole.
During the stage of not having yet enough CAFS resources in a fleet, the following considerations may help:

- Use the full capacity of the available CAFS first, before starting to apply water only onto the same Fire-Scene. Shut down water application once CAFS resources become sufficient to control the situation.
- Create sections on the scene where only one agent, not a mix of agents is being applied (for example: North Section = CAFS, South Section = water).
- The combined application of CAFS and NAFS onto one scene is still not ideal, but a possible compromise during lack of CAFS resources. Creating sections on the scene shall be considered as well.

Keep in mind that water applied onto foam covers may agitate the solution and re-create bubbles again (see left picture above).

2. How to size a system?

One main focus of this publication is to address the CAFS implementation into the concepts of municipal fire departments. Based on many years of CAFS experience the recommendation is to equip the standard European style municipal Rescue Pumper per EN 1846 with a CAFS meeting EN 16327 CAFS 800 criteria. It is also recommended that the nominal solution-flow of 800 l/min can be discharged through one single outlet. Reasons for the recommendation are:

- The system installed into a full-size municipal Fire-Truck shall be capable to support at least two hand operated nozzles providing sufficient solution flow (cooling capacity).
- Not less than 200 l/min solution per hand operated nozzle is regarded sufficient and can be part of the safety concept. Should a team ever get into a situation where they have to protect themselves quite hard and efficiently, such flow-rates shall be considered. The potential availability of a certain flow-rate does not mean that it has to be applied over the whole time, it shall be available if needed. Note that the full size municipal Fire-Truck shall be able to supply compressed air foam to multiple nozzles.
- A typical ground monitor with a 34 – 40 mm nozzle can be advanced to deploy 800 l/min of solution to stop a larger fire from getting out of control.
- An aerial device can be used to quickly and specifically apply a larger stream in order to stop a fire from further spread by providing a fast and efficient knockdown. Typical aerial monitors do comprise nozzles in the 34 – 40 mm range as well and 800 l/min is a common flow in aerial applications.
- Monitors with lower application rates may not provide the same throwing-range and the stream may break up before actually reaching the target. Weaker streams are also more likely to be effected by wind. Any agent not reaching the target is lost.
- The system shall be able to handle critical fires, likely to become out of control if not stopped quickly and efficiently. The dynamics during situations when a fire spreads across a whole roof, potentially into the attic, over to another section or building, must be considered. These situations hold a huge potential in savings on property damage and justify the investment in CAFS equipped Fire-Trucks.

3. Minimum Application Rates (MAR) with Class A Fires

For Class A Fires fixed determinations about the MAR hardly exist, calculations are indeed complex, especially during the rush while approaching a certain fire-scene. Literature holds some guidelines for estimations, in USA for example, the so called “Iowa Formula”.
Understanding MAR and their potential calculations or estimations is very critical with Class A Fires to be successful, no matter which agent is being used. Physical laws dictate how much energy can be absorbed by total evaporation of a certain amount of liquid. This is why knowledge about the solution flow-rate becomes important. The variable on the fireground, effected by agent, system and application-procedures, is the efficiency of the liquid application, which means how much of the liquid applied, actually evaporates reducing heat. Whatever does not evaporate or soak into the remaining materials, must be considered “run-off” and may even account for water-damage. Research from Karlsruhe University in Germany for example, have determined that the efficiency of compressed air foam application can be 88%, approx. 12% of the applied solution soaked into the remaining materials,

no run-off at all. That means from 100 liter of solution applied, 88 liter are evaporated and 12 liter are soaked up by the remaining combustible material. There was no run-off at all.

It is discussed to reduce MAR because of the better efficiency of a CAFS attack. Potentially possible in theory, but may not be regarded good practice to do in the field. Fire Suppression becomes safer and more efficient while not reducing the flow in l/min but to reduce the period of application (close the nozzle once suppression has taken place). This leads to the lowest total water consumption possible while not giving up on the advantages gained from a more efficient extinguishing system. This publication does not suggest using smaller Fire-Trucks or lower flow-rates (below proven MAR calculations) because of CAFS, as this could mean giving up on the gains in enhanced firefighter safety and improved extinguishment capacity again.

Fire Services must understand MAR calculations or estimations and their comparison against the capabilities of the extinguishing systems available, when they establish SOP´s for certain situations.

4. Minimum Application Rates with Class B Fires

The MAR for a Class B fire can be taken from the Foam-Agent Data Sheets as the determination is part of the approval procedure for the foam-agent.
These MAR were determined during NAFS application and do hold a certain safety margin, which is in principle a good thing to be observed. Again, CAFS is the potentially more efficient foam application versus NAFS and NFPA 11 [14] does provide a MAR while using CAFS of 1,63 l/min and m² for non-polar and 2.3 l/min and m² for polar flammable liquids.

Like with Class A Fires, a MAR of 200 l/min per hand-operated nozzle has been proven to be beneficial in the field. Experience also tells that training is critical for a safe and efficient attack on Class B Fires in general. Due to the fact that Class B Fires are rather rare for the average Municipal Department, experience is sometimes missing and enhanced training shall be considered.

The general fact that a foam-stream must never be applied into the flammable liquid spill direct, must be emphasized with CAFS even more as a CAFS Stream holds more energy than a NAFS Stream. Proper and known procedures like “Rain Down”, “Roll on” and “Bank off” should be considered. The CAFS stream does allow to attack a Class B fire from a larger distance.

Example for “Rain Down”	

Example for "Bank down"	

5. Effective Range of a CAFS Stream

The horizontal reach of a stream is defined as the distance from the nozzle to the point when the agent hits the ground. The issue with this definition is that attacks in the field are mostly three-dimensional and the vertical reach of the stream must be considered as well. The effective range of the stream in this publication is defined as the distance from the nozzle to a mark on a wall, 2 m above ground. CAFS does provide an improved three-dimensional stream versus plain water or NAFS as energy in terms of compressed air is added to the stream.

Compressed Air Foam applied from a fog-nozzle. The reach is measured from the nozzle to the point when the stream still hits the 2 m mark on the wall [15].

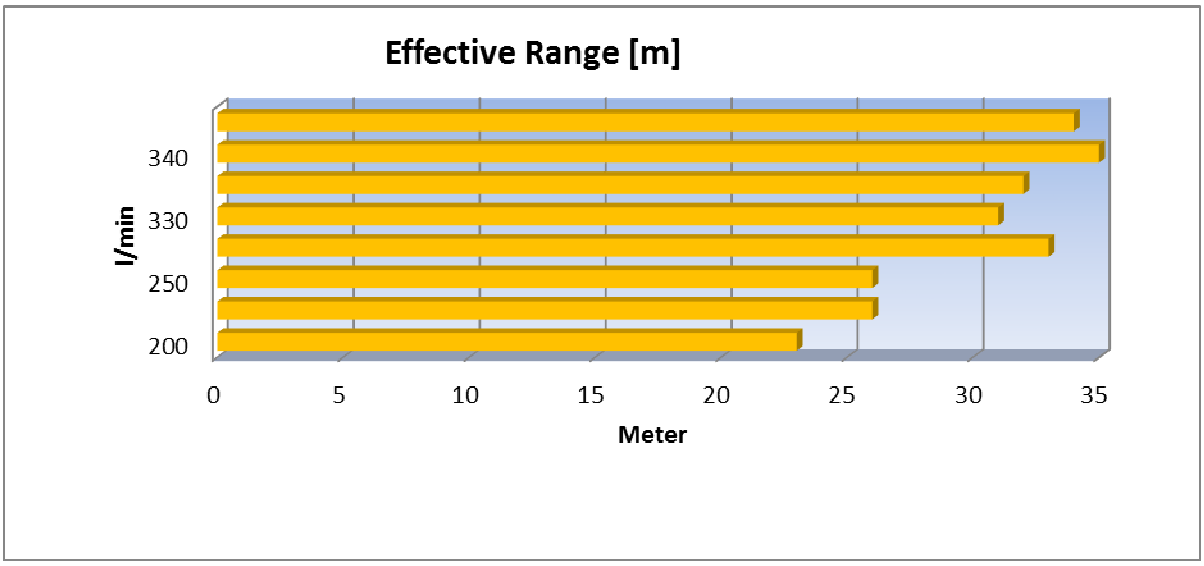


Table shows different effective ranges caused by nozzle-characteristics. The vertical reach of a CAFS stream can be helpful to reach a fire, spreading across the front of a building by immediate application of a nozzle immediately upon scene arrival. Heights up to 25 m can be achieved. Again flow-rates have a significant influence on the height being reached.

	
Vertical reach during a test, 19 m have been achieved as shown with a flow-rate around 200 l/min. Increasing the flow-rate will increase the reach of the stream.	*Aerial devices help once the target can no longer be reached from the ground.*

6. Using CAFS during a Fire Attack

Any attack shall be started with wet foam at first to provide sufficient cooling. Dry foam is used for protective cover when cooling could be a secondary requirement.
Known laws about protection from Gamma Rays apply to the protection from radiated heat as well:

- Twice the distance = one quarter of the radiation
- Half the distance = four times the radiation
- Distance = Safety
- The longer reach and the better effective range of a CAFS stream do provide additional safety and less stress for the firefighter

One key to a successful fire attack is to apply the agent across a wide area of the heated surfaces in such a way that maximum evaporation and cooling can be achieved without having any of the applied agent running-off. Experience of the nozzlemen and how well they will reach and hit their target is critical. Any run-off is useless and will account for water damage.

Spray patterns like TZO have shown to be beneficial with CAFS as well. Foam lasting on a surface indicates temperatures <100°C and shall cause the nozzlemen to re-direct the stream or close the nozzle. The white surface is relatively well and easily recognizable, even under fireground conditions.

The discussion about the best nozzle to be used is an ongoing one:

- Straight bore nozzles provide a good reach and the highest mechanical impact on the combustible material. They may be less beneficial for fighting fires in small confined spaces.
- In confined spaces (interior attack) it has been proved beneficial to use a fog-nozzle and widen up the stream to approx. 20° [16]. It was proved to distribute the agent over a wider surface in a shorter time.
- Setting a fog-nozzle to straight stream still provides a good reach and good mechanical impact when using wet foam.
- There is also another Safety Aspect for interior attacks: In case of any system failure, a fog-nozzle can be re-adjusted and work with solution only or just plain water.

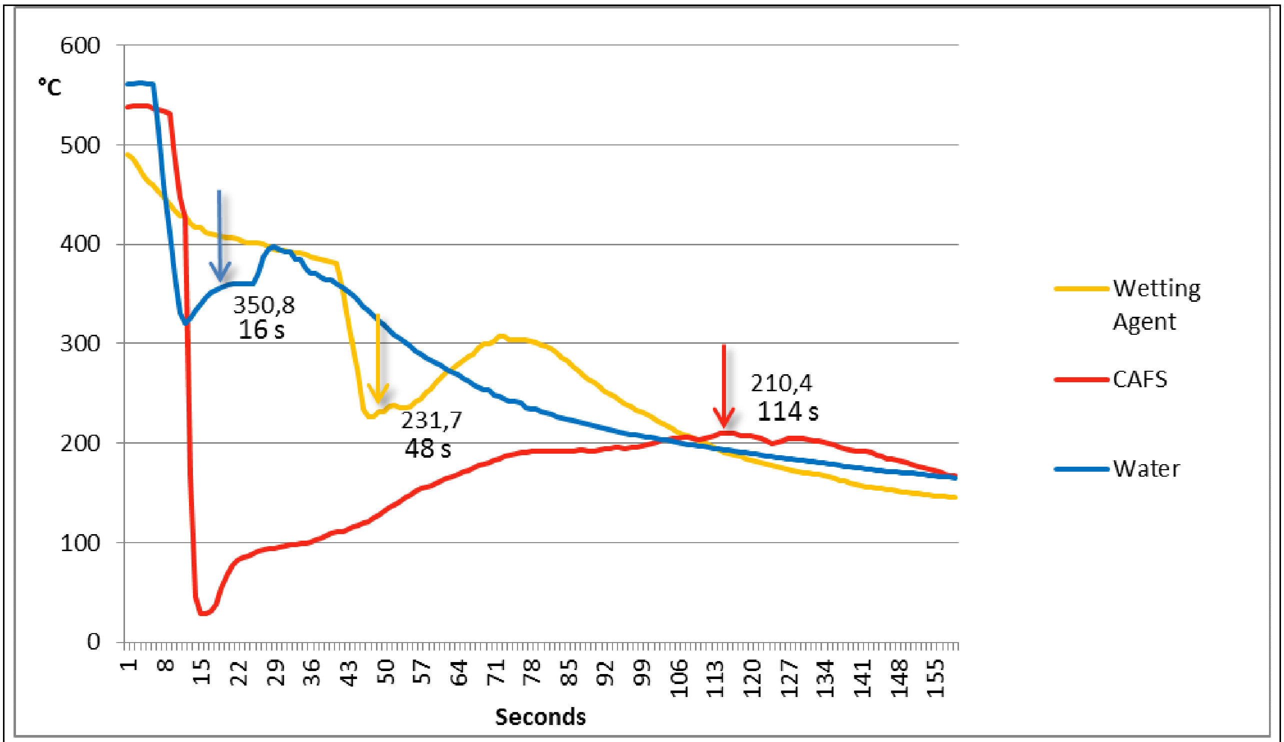
7. Interior Attacks

One constant issue for many municipal fire departments is the fact that staff arriving initially at scene is very limited while a great number of tasks have to be fulfilled without compromising safety. One scenario tested for this publication was an initial exterior attack while the attack-team enters the building and prepares for entry into the rooms actually on fire. Of course the exterior attack needs to stop before the attack team enters from the inside. Communication is critical and must be properly established. Any closed doors to the seat of the fire shall remain close until the exterior attack is stopped and clearance is given for further advance.
The need for an efficient initial attack has become even more significant since building regulations change and outside insulation is being added to new and existing buildings. The insulating material often comprises Styrofoam which is made Fire-Retardant for some time, but burns like any Styrofoam (Hydrocarbons) once this time has elapsed. Rapid fire-spreads with serious threats to the occupants and huge amounts of damage have been witnessed.

The staff initially arriving with the first Municipal Rescue Pumper is barely sufficient to rescue occupants and advance the hose line towards an elevated apartment at the same time. Once the fire spreads to another apartment, the situation may get out of control unless there is timely backup.

One way to improve the situation can be a pre-connected lay flat hose line with appropriate nozzle attached. In lack of other personnel the pump-operator can use this line to suppress the fire while the other firefighters advance into the building and progress to the apartment involved and prepare for entry and final extinguishment. The operator having to fulfill tasks like described is one more reason to require automated, simple and safe pump and CAFS function to the greatest extend.

One goal is to reduce temperatures before entering an area to <200°C which is a known limit for protective-clothing and other equipment. Entering an area at temperatures >200°C implies a much greater risk onto personnel and equipment. At these elevated temperatures stress from heat etc. is significantly higher and causes a much greater risk for injuries. Chances for a successful attack, saving victims and reducing property damage reduce with higher temperatures.



Comparison of the temperature drops from various agents under same conditions. The attack started once flashover was recognized. PPV was established with entering the room. The agents were applied from the outside into the room over the time of approx. 10 seconds for initial suppression.
Final extinguishment was done from the inside by the attack team which entered after clearance from the officer (arrows are showing temperature and time when interior attack was started). Visibility with CAFS was reported better than plain water and no steam stress was reported [17].

The CAFS stream applied from a lower elevation outside the building will hit the ceiling of the room, getting reflected towards the walls and other surfaces inside the room. Evaporation occurs and the temperature is being reduced. Steam displaces the oxygen inside the room. Further spread of the fire is stopped.

As an example at 800°C ambient temperature total evaporation from 3 liters of solution creates more than 10 m^3 of steam which displace oxygen and slows down combustion [7]. There is the question, why firefighters have never reported discomfort, threats or injuries from the steam produced. The final answer is still down to further research. From observations during tests, training and real-world incidents it may be assumed that the energy added from compressed air helps to transport the agent trough the flame zone, towards the seat of the fire, which also could explain the rapid knock-down. This may produce the steam in a location further away from the firefighter. It may also be assumed that less superheated steam is produced when using CAFS. Superheated steam is the type causing the most issues for firefighters.

The "displacement" effect from steam may not be seen if the room is well ventilated for example by large openings in the ceiling. However the cooling of the surfaces from contact with the agent does still work very efficiently.

	
Test with no fire, to see application and distribution of the stream being applied from below.	*Reflection and distribution of the agent within the room. With fire the foam blanket evaporates and can only be seen for some seconds.*

There will be situations when the initial external attack is not possible.

If the fire, especially its seat, is visible, the direct attack shall be preferred. Fight the fire from a safe point, e.g. from the doorway. Start with a solid stream. Note: Regarding compressed air foam-efficiency in general, there is no difference between solid stream and a stream from a suitable fog nozzle. Steam from the applied solution will cool down the room and displace the oxygen. Surfaces cooled down to <100°C can be easily recognized as white, as the applied foam no longer evaporates.

PPV may be used immediately to support once there are sufficient outlet vents. The Thermal Image Camera, operated by the second firefighter in the attack team, is the ideal tool to guide the actual nozzle operator. The temperature readings do provide helpful information about the success of the attack and if and where more agent has to be applied.

Another form of the compressed air foam application into the burning room is a circular movement of the stream for about 10 seconds, followed by closing the door again. The time until the door is opened again may vary due to the actual situation (maximum 30 seconds). The door has to be opened for final extinguishment. The described method has to be chosen, if the fire is not visible or cannot be reached with the CAF-stream and sufficient ventilation is lacking. The described method shall only be used if ventilation is an issue.

8. CAFS implementation into tactical concepts

In Germany it is common practice to send two pumpers and one aerial out after a reported building fire, especially if occupants may be still be present. Other countries may have different concepts, however the principle as described can be adopted.
Example: First pumper arriving prepares for interior attack, hose lines are getting prepared for interior and exterior attack. The aerial is set up to allow rescue of any occupants if required and / or to support the attack from outside. The second pumper arriving prepares for PPV, ensures water-supply as necessary and provides the SCBA back-up team. Compressed air foam is used as the standard-agent. The implementation of CAFS into any operation- and training-concepts is critical to success!

9. Environmental Balance

Well trained staff [7], using CAFS correctly will be able to fight a fire as safe and efficient [18,19] as ever possible while minimizing the impact on the environment.

Facts for the incident commander to consider are:

- Every second the fire is not allowed to burn, reduces the amount of resources destroyed and the amount of toxic combustion products being released. Every liter of water conserved during fighting operations, does not get contaminated with toxic combustion-products.
- Compared to the gains, the impact of an environmentally friendly Class A Foam agent, injected at very low rates (0.3 – 0.5%) may become the "lesser evil". Typically Class A Foam Agents do not contain any Fluorine, PTFE or PFOS [27].
- Information about any potential impact on the environment and the bio-degradability of a specific foam-agent can be found in the MSDS.
- Contaminated water getting into open water sources is a threat to marine-life in general (even without foam) and must be avoided in the first place. Conserving water and reducing run-off with the help of CAFS could actually help to conserve marine-life.

All in all the balance for the environment from the use of CAFS shall be a positive one.

IV. Training

CAFS is not completely different from any other firefighting, even if there are specific considerations. Well trained Fire-Service Personnel shall be able to familiarize themselves with these considerations quickly and easily and there is absolutely no need to “re-invent the wheel”.
Training as such shall not become more complicated and difficult because of CAFS. However CAFS cannot compensate for any general training gaps, but training gaps in general could avoid exploring all the CAFS benefits potentially available.
Familiarization with the system, it´s capabilities, properties and behavior is critical to success with CAFS, like it is with any system used by the Fire Service.
Establishing Standard Operation Procedures (SOP), implementing CAFS, for all staff on a vehicle and for typical fireground scenarios may help during training and the actual incidents.

1. Pump Operator training

The pump operator must know all functions and controls of the CAFS, to ensure proper system operation:

a) Engaging System

b) Adjustments to start and maintain operation as requested

- Throttle (pressure)
- Foam Injection Rate
- Wet-Dry adjustments
- Trouble shooting if required

c) End of Operation

- Flush procedures (if required)
- Preparation for the next incident

From an operational view the well trained CAFS pump-operator shall be able to:

- Carry out all system adjustments (pressure, injection rate, foam consistency etc.) as required for the specific incident and per request from the incident commander.
- Read and understand the performance diagram per EN 16327 for the system actually used, determine the system-capabilities compared the specific fireground needs and notify the incident commander accordingly.
- Monitor foam-supply and inform the incident commander timely in case additional supplies are required.
- Re-fill foam tanks as necessary.
- Select the correct foam tank for the incident (if applicable) and adjust the injection-rate accordingly.
- Identify upcoming system issues and take appropriate countermeasures.

2. Nozzle Operator training

The training for the Nozzle Operators shall consist of the following steps where the emphasis should be on the hands-on:

- CAFS theory and principles.
- Hands-on (cold), hose and nozzle handling under any potentially upcoming situations as part of the familiarization. This shall comprise typical nozzle and hose reactions and all the normally used equipment in conjunction with CAFS on the fireground.
- Hands-on (hot), live fire training, exploring the extinguishing capabilities and properties, subsequently to the cold familiarization.

Suggested Training Schedule (theory):

- How CAFS works on the fire
- General considerations while using CAFS
- CAFS components and system function
- Nozzles and nozzle operation
- Streams, reach and capabilities
- Hoses and related equipment
- Wet and dry foam usage
- Specific considerations while using CAFS for interior attacks
- Implementation of supportive equipment like: Smoke Curtains, Infrared Cameras, PPV[1]
- CAFS and fixed firefighting systems (Sprinkler, Dry-risers etc.)
- Local regulations and /or the SOP´s of the individual department must be implemented as required

Suggested Training Schedule (hands-on cold):

- Nozzle selection and operation in general
- How to adjust a flow from a nozzle
- How to adjust a spray-pattern from a nozzle
- How to apply dry foam as a protective cover
- Use of any special applicators
- Use of ground and vehicle (aerial) mounted monitors
- Use of hand operated nozzles from an aerial device

[1] These are not related directly to CAFS but may still be part of the overall training schedule

- How to establish the safest and most efficient attack, reducing damage with applying as little risk on ourselves and others as possible.
- How to do a combined attack, initial suppression from outside, final extinguishment from in-side, how to implement aerial devices, how to secure proper communication.
- How to reduce room temperature before making an entry.
- How to use the reach of the stream in order to reduce the impact of heat radiation on the at-tack team.
- Most efficient nozzle handling, selecting best flow and spray pattern, application at the target, how to reach the target the best.
- When to stop application
- How to determine cold (<100°C) surfaces
- When to use dry foam
- Special considerations for Class B and Class D Fires

Suggested Training Schedule (hands-on hot):

- How to select the best and safest position
- Placing a smoke curtain
- Door opening procedures
- Initial suppression, direct and indirect attack, fire visible, fire not visible
- The effect of steam within enclosed compartments
- Final extinguishment, how to locate and eliminate the seat of the fire
- Implementation of PPV
- How to use special applicators for deep-seated fires
- How to do a combined attack, initial suppression from outside, final extinguishment from in-side, how to implement aerial devices, how to secure proper communication.
- How to establish the safest and most efficient attack, reducing damage with applying as little risk on ourselves and others as ever possible.
- How to reduce room temperature before making entry
- How to use the reach of the stream in order to reduce the impact of heat radiation on the at-tack team.
- Most efficient nozzle handling, selecting best flow and spray pattern, application at the target, how to reach the target the best.

Considerations for Training on Class A Fires

- Wet foam must be used during the complete fire attack.
- CAFS can be used for direct and indirect attack. Indirect application will stop or prevent flashover if the seat of the fire cannot be reached. Direct application to the fire will stop the release of combustible gasses immediately with application.
- Application shall cover as much surface as possible, move the stream across the ceiling or the combustible material completely.
- Stop application once the surface is covered and / or no more fire is visible.
- Thermal Image Cameras may be used to determine the seat of the fire, even if smoke and stream will hinder visibility.
- Common door opening procedures can be used with CAFS.
- Steam from the application will suppress the fire within enclosed compartments.
- PPV will support the fire attack with CAFS as it will with any other liquid agent.
- The seat of the fire must be reached, removing debris with appropriate tools may help. Deep seated fires may be reached with special applicators without having to turn everything upside down. Dry foam may be used during that operation.
- The lighter hose does help moving around, the best position for the most efficient application can be reached.
- White surfaces indicate temperatures <100°C, no further application required.
- The reach of the stream shall be used, a room may be cooled down towards 200°C by initial application from outside.
- Combined exterior and interior attacks are possible. The interior attack must only start once the exterior one is stopped. Proper communication to be established.
- Dry foam can be used to provide a preventive cover against radiated heat. Use 25 mm straight bore nozzle for application. Re-apply only as necessary.

Considerations for Training on Class B Fires

- Use the commonly known methods like: Rain-Down, Bank-Down or Roll-On. Make sure all team members do understand these methods and are able to carry them out.
- The rule about never ever spraying directly into the flammable liquid and disturbing it becomes even more important to observe with CAFS as the stream contains more energy.
- Use wet foam for maximum cooling until the flames are extinguished
- When using fog-nozzles, widen up stream to approx. 20°
- Take advantage of the wider reach of the CAFS stream, distance is safety
- Application shall be done smoothly, avoid sudden moves with the stream
- Use at least two nozzles to “surround” the fire

- Have an observer (officer) direct the nozzle teams as many times visibility is limited to them and they struggle to direct the stream where it belongs.
- Non AFFF Foam Agents definitely need the foam blanket to do the cover.
- AFFF will cause the film on top of the flammable liquid, allow the film to flow and separate the combustible liquid from oxygen. Try not to disturb the film once closed.
- Streams wider than 20° may be used for cooling and protection once the flames are extinguished.
- Dry foam may be used for protection against re-ignition, apply to surfaces until they remain white (<100°C) then stop application on that particular area and apply to other, potentially still hot, areas. Re-apply foam blanket as required.
- If pressurized fires must be extinguished (for example leaking aircraft fuel) start from the top and work your way down. Use two nozzles to cool down from the sides. Use a dry chemical nozzle or extinguisher to "shoot" out the flames in the center. Keep applying foam for cooling as necessary. If ever possible approach with wind direction.

Class D Fires (Light Alloy Fires)

- CAFS does not allow direct extinguishment as any other agent, based on water.
- CAFS does allow to protect the surroundings and extinguish any secondary fires, further spread can be avoided in the first instance.
- Dry foam can be pushed towards the seat of the fire, cooling down the surroundings and slowing down the process.

3. Leadership training

Like the pump- and nozzle-operators need to be well trained in order to receive the full benefits, incident commanders and officers need to understand the following:

- Components and function of the CAFS
- Reach of the streams
- Hoses and related equipment
- Wet and Dry CAFS
- CAFS application exterior and interior
- Class A, B and D-fires

All leaders, through all ranks, up to the Fire Chief level need to understand the following:

- There are no reasons not to use CAFS. Some fires may look small and may be extinguished with water as well, however if CAFS is SOP, troops do get used to it and are familiar with all procedures once a larger fire occurs.
- Avoid the application of CAFS and plain water at the same time onto the same section of the scene. Use the capacity of the available CAFS first, before applying water as well. Establish sections on the scene so the foam does not get washed away with plain water.

- On large fires, use full system capacity through monitors for initial knockdown, prepare hand lines to take over once initial knockdown is achieved and high flows are no longer required.
- The stream needs to reach the seat of the fire for best efficiency, close the nozzle, re-position and fight again to place the agent where it belongs. The lighter hose will help during that procedure.
- Dry foam can only be applied from straight bore nozzles.
- If fires are inside a confined space, not to be approached safely, consider alternative access-routes, like drilling a hole and use a probe for initial suppression until save access becomes possible.

Training shall consider realistic conditions whenever possible.

V. Frequently asked Questions (FAQ’s)

The following FAQs do not origin from the authors, but have been collected from training scenarios, meetings with firefighters and such. As many questions have been raised over again, they have been addressed with appropriate answers. The list of FAQ´s is not final, the authors will accept additional questions and try to find answers. VFDB field research programs are, at least to a major part, driven by the questions raised by firefighters.

1) On which fires will CAFS work the best?

CAFS works on any kind of Class A fires, the higher the amount of hydrocarbons within the combustible material (from plastics, tires etc.) the better. CAFS also works well on Class B fires.

2) Do we need to flush hose lines until foam leaves the nozzle?

Enabling the system and engaging all necessary functions must be done before opening any foam discharge valve! Otherwise the hose lines will be filled with water first which need to be discharged before the foam. This can take significant time, more than the situation may allow. The “power-up” time may vary between system manufacturers. It is still good practice to quickly check the discharged foam before entering a building.

3) Does pump-inlet pressure effect CAFS operation?

Most CAFS manufacturers request “Tank Operation” as the best way to operate CAFS. This has been proven best practice in >20 years and also avoids backflush of foam agent into the water-mains as legally requested in many regions. Common fill-systems and hydrants will keep up with the amount of water required for CAFS operation and the tank is always a safe buffer, if supply may be interrupted. Technically this strong suggestion results from the fact that there is a relationship between pump- and compressor-speed. As an example the engine will run at idle if the desired working-pressure is 7 bar (100 psi) and the pump-inlet pressure is already 7 bar. At idle the compressor will not provide it´s nominal output and a desired foam expansion rate may not be achieved. This will be the potentially negative influence on fireground operation. Hydrostatic compressor drives will not fully compensate this issue as at least “Hi-Idle” is required to make the hydrostatic drive work. Hydrostatic drive components will add cost and weight to the truck and require additional space and service.
CAFS can be used while drafting water from an open source as long as the system does not contain any parts which can be easily clogged by common particles in such water-sources and passing through the pump inlet-strainer.
During “Relay Operation” the CAFS truck needs to be the one close to the fire. The finished foam cannot be pumped through another pump without destroying a certain portion of the bubble structure.

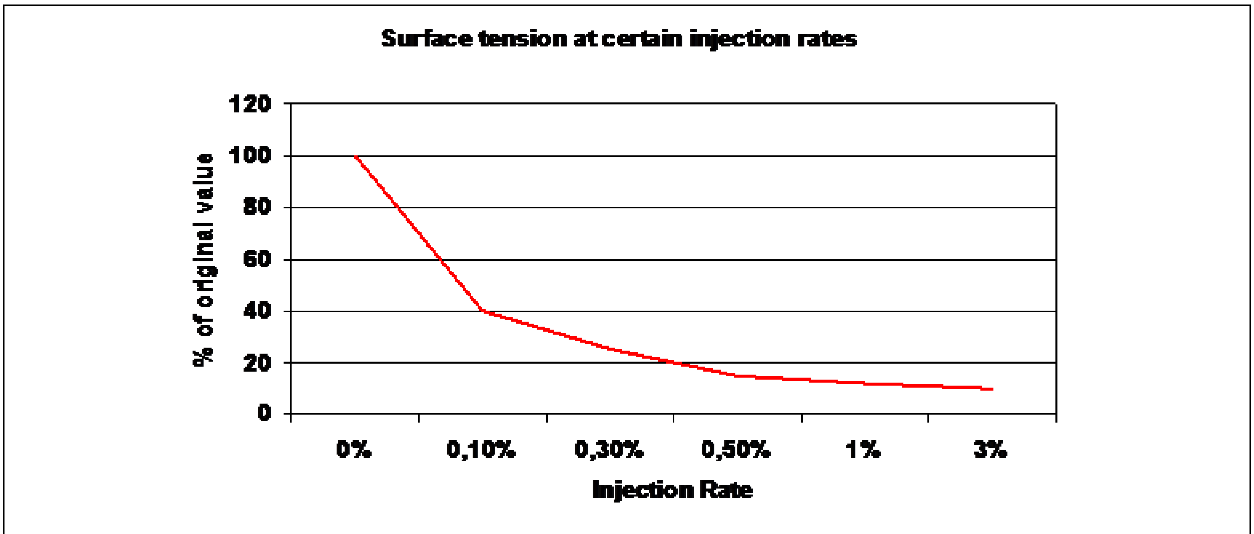
4) How can we check the flow measurement for accuracy?

Most CAFS use a flow-meter upstream of the Fire-Pump to measure and display the amount of water flowing to the foam-discharges and to control foam injection. This section of the system can be checked for calibration without air-injection by using appropriate flow-meters or test-nozzles, if so directed by the manufacturer. Once air is injected and the finished foam is created these test methods will no longer be applicable. During CAFS operation, the flow-measurement can be checked as follows:

- Connect all required hoses and the required discharge nozzles
- Connect the truck to a hydrant to re-fill the water-tank, use a water-meter within that line
- Adjust the desired conditions and discharge foam, allow approx. 60 seconds to stabilize
- Close the nozzle and leave the system running as adjusted
- Re-fill the water-tank until it overflows
- Read the water-meter
- Discharge foam for a measured amount of time (for example 1 or 2 minutes)
- Close the nozzle
- Re-fill the water-tank again until overflow begins
- Read the water-meter again
- Divide the water-consumption by time which will provide the true solution flow during the adjusted CAFS operation
- The flow-measurement may be re-calibrated if necessary

5) What happens if we increase the injection-rate?

Foam Agent should be injected at the rate given by the foam-agent manufacturer and departments SOP. Raising the injection-rate across the value given by the foam-agent manufacturer may not improve the produced foam, but cause a larger environmental impact then necessary. One primary reason for Class A Foam application is the reduction of the water surface-tension. As shown on the graph overdosing of Class A foam agent will not provide a further significant reduction of the surface tension.



6) What is wrong if the hose line shows erratic pulsing and pressure surges?

Air and water alone will never mix, Foam Agent must be injected in sufficient amounts to create a homogenous bubble structure. Otherwise the hose line will be filled with pockets of water and air, causing severe and uncontrolled nozzle-reaction. Standards like EN 16327 require that air injection is only allowed with foam injection. If a system shows such reaction (slug-flow) the following shall be checked:

- Is the injection rate adjusted to the injection-rate per foam-agent manufacturer´s instructions? This must be checked against the data for the foam-agent actually used

7) Which is the required CAFS operation pressure?

Systems may be designed for fixed or variable working-pressure. Per Standards like EN 16327 max. CAFS operation pressure must not exceed 10 bar (150 psi). By experience a working pressure of approx. 7 bar (100 psi) has proved to be sufficient for most incidents. Common friction- and elevation losses are compensated, flow-rate and stream from a nozzle will provide the most efficient firefighting capabilities. Higher pressures, up to 10 bar, may help to overcome extreme losses while pumping compressed air foam over long distances or onto high elevations.

8) Does a CAFS stream reach further than a water-stream?

As a rough, general rule the reach of a CAFS stream is about 25% further than a water-stream at the same pressure from the same nozzle. This mainly results from the fact that the compressed air is adding energy to the stream, increasing it´s velocity. Unlike with NAFS operation, a CAFS shall not comprise any components creating major friction-losses, like venturi-devices.

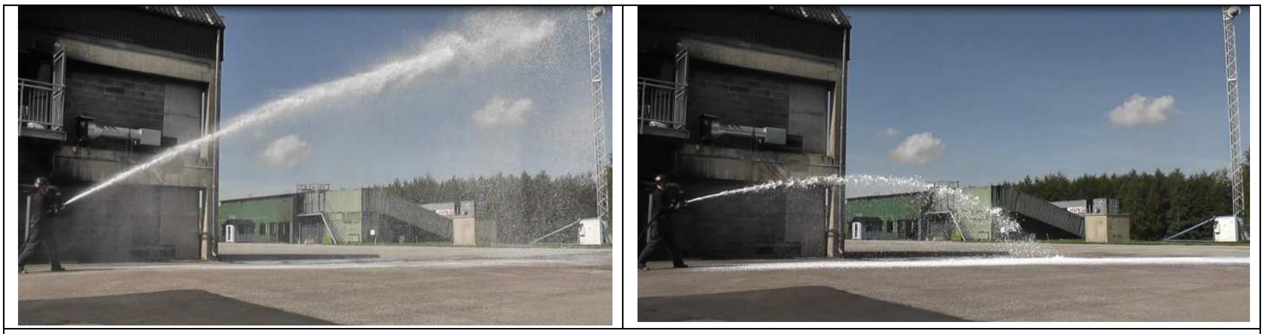
The photo shows both pumps operated at 5 bars, supplying a 38 mm nozzle on the monitor. The water stream catches up to about 70% of the CAFS stream is pressure is raised to 10 bar.

Fire Pump Pressure [bar]	Deck Gun CAFS	Deck Gun Water
5	2.0	0.8
6	2.2	1.0
7	2.8	1.2
8	3.0	1.5
9	3.3	1.8

The table shows the pressures measured during the test as shown in the adjacent photo.

9) Is it possible that the stream breaks down during operation?

For safe fireground operation it is mandatory that the system is capable of delivering a continuous CAFS stream during the entire operation, even if the nozzle is kept open over several minutes. EN 16327 provides a table to allow system selection based on the nominal solution-flow rate, which should be matched to the tasks the system is intended to be used for. A system selected too small for a certain job may still provide an initially strong stream due to the energy stored within the hose line. The stream will become weak, potentially insufficient for firefighting, once the stored energy has been discharged.



The stream on the left is sufficient, as propelled by the energy stored within the hose line. As the system does not re-supply enough solution and air once the nozzle is kept open over a longer time, the stream becomes insufficient. This is not a CAFS issue in general, but caused by incorrect sizing of system and discharge device [5].

10) Is it physically possible to flow wet compressed air foam with a liquid content of 800 l/min (212 gpm) through a 75 mm (3”) hose line?

Indeed, yes which has been proven by tests and measurements:

- A typical CAFS 800 per EN 16327 did show a flow-rate of 1250 l/min through a length of 2 x 20 m of 75 mm hose with the air turned off.
- Once the air is turned on and the system is set to fully wet foam the solution flow-rate drops to 830 l/min.

During the test, the compressed air has replaced 420 l/min of the original flow. At 7 bar operation pressure the 420 l/min will equal 2940 l/min of air at atmosphere pressure [20]. The calculated ratio (solution / air) is approx. 3.5 and almost represents the full wet definition within EN 16327.

11) Are CAFS hoses really lighter?

As part of the volume is filled with compressed air, the hose becomes lighter, easier to be moved around on the fireground, reducing firefighter´s stress. With typical wet foam the weight is reduced by at least 25% with typical dry foam, the reduction is at least 50%.
Note: If larger diameter hoses need re-arrangement on the fireground, it is possible to switch to “Dry”, move the lighter hose and then switch back to “Wet” again.

12) Will CAFS hoses come off their couplings?

As pressures are the same as when working with solution or plain-water, physically there can be no additional stress onto the fixture of the hose on the coupling while working with CAFS. Correct fixing procedures when installing couplings on a hose and appropriate hose-testing are required with CAFS no different from using other agents [21].

13) Will hoses filled with compressed air foam be destroyed by heat sooner as such ones filled with water?

Extensive research about this subject has been carried out by Karlsruhe University in Germany for example. Details of the research results can be found in report #150 on the University´s website.
The report has compared several hose qualities against their temperature resistance over time with water and compressed air foam. In fact CAFS does not imply a higher risk of hose failure from temperature during average fireground operations [22].

As an absolutely strong recommendation only wet foam and an appropriate MAR must be used for internal fire attacks.
Field experience also determines that mechanical failure of fire-hose (cuts from sharp objects as an example) is very much more likely during an incident and appropriate countermeasures must be considered independently from the agent used.
Critical situations for an attack team can only occur if hose failure and the lack of backup as well as a proper escape-route will come together. Same as with any agent, each team entering a building must be backed up appropriately and a potential escape-route must be considered!

14) Do hoses leak with CAFS more than they do with water?
Certainly not, as it is physically impossible. As plain water may only leak as very small drops of very fine spray, difficult to recognize on the fireground, the same leak on a CAFS hose shows as bubbles, easy to spot.

Leak on a CAFS hose, easy to spot.

15) Will CAFS hoses burst more likely than the ones filled with water?
Again this is not physically possible. Age, wear and quality of the hoses will have an influence, not the agent being pumped. As a generally recognized issue the request for lower cost and lighter weight hoses led to an increased number of failures and has been addressed by some relevant Standards committees. Standard committees have taken action and standard requirements were reworked. The numbers of failures seen in the field have reduced in the recent past again, which may indicate that the overall quality of fire hose has been improved.

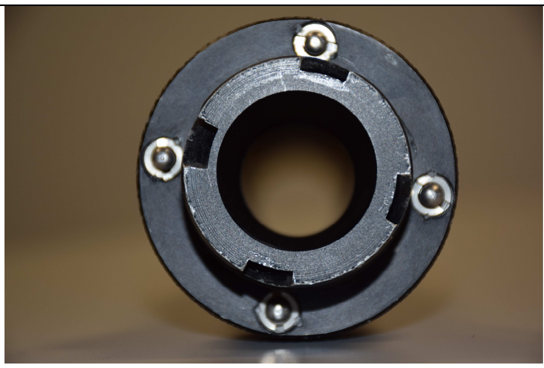
16) Will the burst of a CAFS hose imply any additional risks over a burst of a water hose?
The CAFS hose hold a larger amount of energy, so the noise during a burst may be louder and the time for releasing the stored energy can be longer. Noise measurements were under the critical level of 135 db C, which is the threshold value given by Health & Safety by EC regulations [23].

17) Will compressed air foam freeze within the hose line?
Like with any agent based on water, extremely cold temperatures may require to “crack” a discharge valve a little bit, so the agent keeps flowing and does not freeze. Wet foam will freeze less likely than dry foam.

18) Will CAFS hoses kink more likely than the ones filled with water?
Hoses filled with wet foam at an operation pressure of 7 bar will not kink any different from a water-hose. Any hose incorrectly laid out inside a staircase for example will kink with either water or compressed air foam.
The following advice can be given:

- Like when using plain water, lay out hoses in such a way that they cannot kink, stop or reduce the flow
- Make sure wet foam is being used for firefighting
- Ensure sufficient operation pressure like 7 bar is maintained
- Like with plain water, allow any trapped air to blow off from a hose line, before entering a building.

19) Can we use a straight bore nozzle with wet CAFS?
Absolutely yes.



Example of a pistol-grip shut off with a straight bore nozzle attached. Note that there are no obstructions to the flow or breaking down the bubbles.

20) When shall we use a straight bore nozzle?
This is the considered "Classic" CAFS nozzle by many users and may be used for:

- Whenever good reach of a stream and high mechanical impact is required. This may be the case while fighting fires from outside buildings or inside larger scale buildings like warehouses, factories etc.
- When dry foam shall be applied for preventive action. Note that "shaving cream" foam can only be produced from a nozzle with no obstructions, like shown above.

Note that a 25 mm (1") straight bore nozzle will flow approx. 900 l/min (238 gpm) at 5 bar (73 psi) nozzle-pressure. With wet compressed air foam this nozzle may still flow up to 400 l/min solution depending on system adjustment.

21) Can we produce dry foam from fog-nozzles?
Definitely not, due to the fact, that internal obstructions inside such nozzles break down too much of the bubble structure.

22) What are dry foam applications?
As explained never for firefighting, but protective cover which will last a long time and use very little water. Such cover can indicate surface temperatures <100°C once the foam stays on and does not evaporate. Re-application can be done as required. A typical flow-rate can be as low as 50 l/min, not sufficient MAR for safe firefighting.

Another application can be overhaul, where pipe (diameter >19 mm) is used as a probe to get the foam into the center of any hot debris piled up. Once the probe is inside, the valve shall be opened until the foam flows out from the center of the pile. The valve shall be closed and the next spot for application shall be searched.

Dry foam may also help during Class D fires, once the surrounding secondary fires are extinguished. Dry foam may then be rolled on towards the remaining light-alloy fire, cooling the surroundings and slowing down the process by reducing temperature. The foam must never be sprayed directly onto the light-alloy on fire.

23) Can we pulse with CAFS?
An often raised question and therefore field-tested with some long-term experienced training officers. CAFS can be used with pulsing with no negative effects on the nozzle-operator and the system. If pulsing is the best practice for fighting a specific fire in general, may be discussed independently from the fact that it is technically absolutely achievable.

24) Can we provide a self-protection stream with CAFS?
Yes, as long as a fog-nozzle is used, the spray pattern may be adjusted to “self-protection” to reduce radiated heat for example.

25) How many nozzles can we advance from our CAFS?
This is a function to be calculated from the rated solution flow of the system and the actual discharge of solution through the nozzles used.
A typical CAFS 800 per EN 16327 may supply up to three typical hand operated nozzles with wet compressed air foam. If a monitor uses the complete solution flow of a CAFS 800 (800 l/min or 212 gpm) then this will be the only nozzle which can be advanced. For these reasons it is important that the operators know the nominal output of the systems they have in use.

26) What about nozzle reaction forces?
These can be calculated from the operation-pressure, the flow-rate and the density of the medium. By calculation at a solution flow of 200 l/min from a CAFS stream the reaction force will raise only by 0,4%. There may be an initially harder “push” when opening a CAFS Nozzle which can be compensated by familiarization and training.

27) Can we feed compressed air foam into wet or dry risers?
By experience dry risers had been used with CAFS without any problems. The friction and elevation losses will be less than known from plain water. Once the incident is finished, the system will be drained like with any other agent and shall be allowed to dry out completely. That process may take more time vs plain water as the bubble structure must break-down. The drain valves may be kept open over some days.
If feeding into wet risers and Sprinkler systems can be successfully done will depend on the actual system installed. If and how such systems can be used with CAFS must be evaluated on a case by case study as part of the incident pre-planning procedures for that particular object.

CAFS operation has been tested in conjunction with leading Sprinkler System manufacturers and did not show any issues. In these cases the Fire Service connection of the system had been used to "feed" the system with compressed air foam instead with plain water.

28) Which elevations can be reached while using CAFS?
Experience and Fire Science have determined that a solution flow from approx. 200 l/min upwards shall be considered as MAR when fighting fires inside buildings. Field tests proved that wet foam can be pumped to 120 m above street-level through existing dry risers, still providing a sufficient and permanent stream for firefighting [24]. There had been "Record Announcements" about even higher elevations which have been achieved, but they must be taken with caution as they were all achieved with dry foam which must not be considered for firefighting. Some results were achieved with pressures >10 bar, which is a contradiction to EN 16327 and NFPA 1901.
For judgment, pressure, elevation and permanent flow-rate within the MAR must be considered.

29) Can we use compressed air foam while electrical equipment is still live?
The German VDE 0132 regulation may be used as a common guideline about this subject, as it has been recently updated with evaluations about CAFS.
The min. distances from electrical equipment charged up to 1000 Volts, while the solution flow-rate is 235 l/min shall be:

- 5 m with straight-stream
- 1 m with fog-stream (nozzle adjustment approx. 20°)

The measured current during the relevant tests was below the "recognition-threshold" determined by VDE 0132 [25].

30) Is gas-cooling possible with CAFS?
An adjustable fog-nozzle with a minimum nominal flow-rating of 300 l/min shall be used. The steam created from this action may reduce temperature and dilute the oxygen-content within the compartment towards a level when combustion becomes impossible. It is important to consider the same solution flow-rate (MAR) as used without CAFS.
Alternatively, if the fire and it´s seat can be reached, direct attack with a straight stream shall be considered. The production of combustible gasses and their ignition is actually stopped at it´s origin.

31) Can we use CAFS if there are potentially still missing persons inside the same room or apartment?

Absolutely yes, the immediate knock-down, the faster temperature-reduction and the improved visibility in conjunction with reduced or eliminated chances for re-ignition, will actually increase the chances for survival of any trapped victims significantly. Even if the compartment actually on fire may no longer allow any survival in itself, the spread into the next compartment can be avoided and any victims who may have been seeking shelter will have a better chance for survival. Contamination of any body parts with foam does not apply any additional risk to victims vs firefighting with water.

32) Is it possible that compressed air foam is shifting gas-layers inside a compartment?

That is not a result of CAFS, but from insufficient agent application at one single spot inside the room, not maintaining MAR. Independently from the agent being used the issue must be avoided by maintaining MAR and trying to cover as much area as ever possible when applying the stream.
Correct CAFS stream handling, trying to hit the seat of the fire, while maintaining MAR cools down under ignition-temperature, prevents the further release of combustible gasses and dilutes the oxygen at the same time.

Extensive research has been conducted if a fire will spread once a MAR maintained CAFS stream is applied though a window from the outside. No Flashover could be provoked. In fact regular developing Flashovers were knocked down within seconds [26].

33) Does compressed air foam move the smoke layers inside a compartment in such a way that there can be zero visibility?

No, the exact opposite has been explored in comparison to plain-water.

34) Does the compressed air foam add oxygen to the combustion process?

The amount of air within compressed air foam is contained within the bubble structure in the first place and not relevant to the ventilation process of any fire by number. The normal ventilation process of a fire drags in multiple times the amount of air than contained within the foam bubbles.

35) How do we clear our facemasks from foam during an incident?

Not different from working with NAFS. Foam may fall down from the ceiling or reflect off from obstacles and end up on the face shield. Wipe off with a glove, preferred a dry one.

36) Will compressed air foam cover any cracks, gaps or holes on a fire-scene, imposing an additional risk?

This is indeed a potential risk with any foam firefighting, not related to CAFS and to be considered in general. Advantage of the wet CAFS foam-layer is, that is only approx. 5 – 10 mm high, unlikely to “hide” dangerous spots on a fireground. The risk is higher with Medium- or High-Expansion Foam.

37) If we have a larger incident, can we use CAFS and NAFS together?
Yes, with the following recommendations:

- Use the capacity (nominal flow-rate) of the available CAFS Trucks before advancing additional NAFS lines, if possible close down NAFS lines first.
- Establish sections on the fire-scene to define where CAFS and NAFS shall be used.

38) What are we supposed to do with the foam left on a scene?
Correctly applied to a typical house-fire, the CAFS foam will have evaporated or soaked into the debris with very little foam left to be considered before leaving the scene. The foam actually may help to prevent re-kindle and will break up over time.
If the foam does not cause any hazards or major disturbance, simply allow to break up and dry out.
On a street, for example after a car fire, a broom may be used to move the foam away with the debris which has to be cleared off anyhow.
Run-off into the sewers is not an issue as long as the sewer is not going into an open water-source but connected to a sewage treatment plant. The amounts of detergent used with the Class A Foam by the Fire Service are normally only a fraction of the amount used by the population. There may be situations when the sewage plant will require notification.
Proper procedures shall be established as part of incident pre-planning in conjunction with the sewage plant and / or other authorities involved. The MSDS (Material Safety Data Sheet) for the foam agent does provide the required information for determinations. Local authorities may have published corresponding instructions, like DWA –M 718 in Germany, about how to deal with run off from fire sites [27].

39) What are environmental considerations?
The more efficient fire-suppression and the lower total water-consumption clearly speaks for CAFS application as the “environmentally friendly” fire suppression.
Class A Foam Agents to not contain substances like PFOS or Fluorine. The MSDS explains their biodegradability.
Contaminated run-off from fires (with or without foam) into open water-sources are critical to marine-life and have to be avoided in the first place, independently from the agent used. It is quite likely that run-off can be reduced, if not avoided, when CAFS is used. Note that the run-off from fires could contain substances quite more harmful to the environment than the ingredients of a Class A Foam Agent.
Class A Foam application has no influence on the debris which has to be taken care off. Class B Foam application very likely happens in an industrial environment where the correct handling of any run-off is part of the incident pre-planning procedures. As CAFS could reduce total water-consumption, there is less risk to exceed the storage capacity for run-off. Training foam may replace Class B Foam agents during training where possible.

40) Will there be separation of air and solution within pipes and hoses?
Hoses and pipes are filled with the bubble-structure under pressure. The solution is held inside the bubbles. The homogenous bubble-structure is transported inside hoses and pipes during a dynamic situation (nozzle open).
In a static situation (nozzle closed), because of gravity, the solution will slowly start accumulating in lower sections while the upper sections are still filled with a bubble structure. This process will start

several minutes after there has been no agent flowing. Immediately after flow recommences (nozzle opened), the accumulations are mixed back into the bubble-structure. The process may take 1 – 2 seconds depending on the amount of hoses and pipes involved.

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Cover picture: Fire in a pup, Seydelstraße/Neue Grünstraße, Stefan Rasch; roof on fire, Dolziger Straße, press office Berlin Fire Service, other pictures: Ingolstadt Fire Service

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