SOLBERG

BULLETIN #1007-1

TECHNICAL BULLETIN

Foam as a Firefighting Agent

Introduction

Firefighting foams are the primary agent for controlling and extinguishing flammable liquid fires — water-soluble flammable chemicals and non-water miscible liquids. Non-water miscible liquids are mainly called hydrocarbons (non-polar liquids), which are lighter than water and therefore float on top of a water base. The water-soluble (polar) flammable liquids are mostly organic solvents such as alcohols, ethers, amines, and ketones.

One should be aware that it is not the liquid itself that burns, but the vapors above the liquid. Flammable liquids are low molecular weight volatile liquids with high rates of evaporation. The fire zone is above the liquid surface, where evaporated gases from the liquid mix with oxygen, causing a chemical reaction or a combustion reaction. A fire is an example of such a chemical reaction where combustible materials react with oxygen under high release of heat (exothermic reaction). Combustion is an oxidation, a chemical chain reaction that requires oxygen (O_2). When foam is applied to a burning surface, several different reactions will occur.

The Extinguishing Process

The following points outline the extinguishing process:

- The foam layer protects the fuel from heat radiation of the flames.
- Drained liquid from the foam cools the surface of the burning fuel and adjacent hot surfaces and thus reduces the evaporation rate of the fuel. The cooling occurs because the liquid in the foam absorbs heat from the flames. Some of this liquid evaporates and the heat of the vaporization absorbed contributes considerably to the cooling.
- The foam layer forms a barrier that prevents mitigation of molecules from the liquid fuel to the gaseous fire zone above. It separates the fuel source and the air above.
- For the film forming foams (AFFF and FFFP), the barrier is a very thin film (about 1 µm, or 0,001 mm) of drained foam solution spreading across the fuel surface due to this solution's exceptionally low surface tension of about 16 mN/m. In comparison, the surface tension of pure water is 72 mN/m.
- For the polymer-containing alcohol resistant fluorochemical based foam types used on flammable polar solvents, the barrier will be a "gel-like" coating of dehydrated polysaccharides. This is a polymer membrane that is extracted from the foam solution when it comes in contact with the polar solvent, which will prevent the foam from being dissolved in the fuel.
- The degradation rate of applied foam slows down in correlation with reduced flame intensity as more of the fuel area is gradually covered with foam.

SOLBERG

Common terms and definitions:

Foam concentrate is a foaming agent to be mixed with water to create a foam solution. Foam concentrate and foam liquid are interchangeable terms.

Foam solution is a certain amount of foam concentrate mixed with water, usually 1%, 3% or 6% by volume. It can be mixed as the foam is applied by means of a proportioning device, or it can be made in advanced to create a pre-mixed solution.

Foam is generated by air entering into the foam solution. This can be accomplished by forcing air into the solution as it passes through a nozzle, or it may be accomplished in other ways. All foams are two-phased mediums showing so-called non-Newtonian flow characteristics.

Foam characteristics describe the generation of foam from its drainage rate and expansion ratio. Foam number is another term for expansion ratio.

Expansion ratio expresses how much a given volume of foam solution is expanded when it is generated into foam by the addition of air. 10 litres of foam formed by 1 litre of foam solution gives a foam with expansion ratio 10:1 (Foam Number 10). (Low expanded foam: foam numbered up to 20, Medium expanded foam: foam number between 20 and 200, High expanded foam: foam number >200)

Spreading/Fluidity of foam is inversely proportional to the friction as it spreads across a liquid surface. This depends on the foam type, the rheology of the foam (rheology is the study of a fluid's flow characteristics), the application rate, the foam stability, and partly on the nature of the underlying fuel.

Foam stability is the stability of finished generated foam and a measure for its persistency. The drainage rate of liquid out of the foam is an expression of the foam's stability.

The Extinguishing Process

The following explanation is a step-by-step general description of Class B firefighting foams' extinguishing process.

1. The initial foam discharge hits the surface of the burning liquid and foam degradation starts immediately. The flames are now at the most intense, the heat flux is at its highest, and the foam degradation is at its maximum. The rate of degradation is not linear, but will vary during the course. (See section B. Foam degradation, page 4.) The fuel, to a certain degree, will also influence the rate at which the foam breaks down.

2. After sufficient cooling, a foam blanket starts to form. The area of the blanket will gradually increase because the application rate, $\mathbf{V}_{application}$, must be greater than the breakdown rate, $\mathbf{V}_{degradation}$, which is an absolute condition for the fire to be extinguished. The foam has gained a "foothold" and begins gradually to spread.

3. Foam coverage increases and evaporated combustible material decreases in the fire zone concurrently with a reduction of heat flux from the flames. The inequality $\mathbf{V}_{application} > \mathbf{V}_{degradation}$ (see page 4) is greater now than at the beginning. Remember, $\mathbf{V}_{application}$ is more or less constant while $\mathbf{V}_{degradation}$ is a variable parameter.

4. Some of the heat is absorbed by the fuel, adjacent surfaces, and by the liquid from the foam as it evaporated from the heat. In physical terminology, this means that the enthalpy change ΔH, is negative and the fire's thermodynamic potential decreases.

5. The flames, and therefore the heat flux, decreases. The foam absorbs the heat, the temperature in the fire zone drops, and the foam barrier that prevents combustible gases from reaching the fire zone is getting bigger and stronger. Eventually the concentration of the combustible gases in the fire zone falls below the lower flammable limit for that fuel, and the fire goes out.

The complete extinguishment process is physicochemically complex and is affected by many variable factors. Although the inequality $\mathbf{V}_{application} > \mathbf{V}_{degradation}$ mentioned above is essential and must apply anyway, the following will have an influence on how easy, difficult or at all possible it is to put out a liquid fire:

- The quality of the foam
- Type of fire / scenario
- Type of flammable liquid – flash point, polarity, vapor pressure, boiling point
- Foam application rate
- Application method/equipment and technique
- Quality and type of foam concentrate the foam is made of
- Weather conditions – wind and temperature
- Logistics / competence – well trained firefighters
- Thermal updraft – chimney effect
- Adequate supply of fire water and foam agent
- Sufficient water pressure

A. Foam Application

The foam agent — or the foam concentrate — is proportioned into the water flow at a given percentage, usually as 1%, 3% or 6%, depending on the type of concentrate used. The resulting mixture is referred to as a *foam solution,* and it is generated to finished foam by mixing with air to produce an expanded foam structure through the use of an air-aspirated foam nozzle.

Generated foam has *foam characteristics* of a specific drainage rate and foam expansion ratio. These characteristics are primarily determined by the type of nozzle/monitor, concentrate, water pressure, water quality and temperature. Note that the terms *foam quality* and *foam characteristics* are interchangeable.

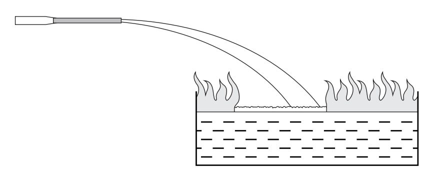
This foam quality concept is presented in many publications that discuss foam rheology. Accordingly, the same foam concentrate can provide foam with quite different “foam qualities” depending on what equipment one chooses to use. This may sound somewhat strange, as one might associate “foam quality” with good extinguishing performance, which is not necessarily the case. The foam quality measurement defines what volume of foam you get from a given volume of foam solution (expansion ratio) together with how stable this foam is (drainage rate). Therefore, it is important to distinguish between the terms *foam* and *foam concentrate.*

The foam may contain varying amounts of liquid, depending on how much the solution has been expanded. By using non-air aspirating equipment, such as conventional water nozzles or open sprinkler heads, almost no foam forms at all. This is at the lower end of the expansion range, with expansion ratios below 2 or 3:1. The foam is created when the air mixes with the solution on its way through the nozzle.

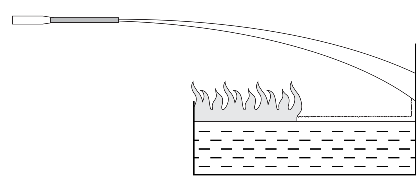
However, many types of foam agents require the use of air-aspirating equipment to provide foam with a higher expansion ratio in order to effectively extinguish a fire. Monitors and other nozzles may be constructed with an air inlet to induce additional foam generation.

Foam application can be direct or indirect. With direct application, the foam jet hits the burning surface and is the harshest method with respect to fuel pick-up into the foam. However, in many situations this is the only method available to firefighters. An example is a large storage tank fire where big monitors directly shoot low expanded foam long distances to reach the top of a burning tank.

Indirect application is when the foam first hits a wall or something else solid so that it is “slowed up” and therefore flows more gently across the surface. This gives less fuel uptake in the foam and is often preferred in a fire situation, especially with water miscible fuels such as ethanol and other alcohols.



Direct



Indirect

The application method and technique is determined by the choice of equipment and type of fire to be extinguished. All units making up the total extinguishing system must be designed and suited to adapt any potential scenario.

SOLBERG

The application rate is calculated in gallons (liters) of *foam solution* applied per minute per square foot (meter) of the burning surface gpm/ftÿ (l/min·mÿ). The gallons (liters) of generated *foam* per minute per ftÿ (mÿ) are influenced by the equipment used. A foam expansion ratio of 10 would result in 10 times the volume of the foam solution, or 5 times for an expansion ratio of 5. (The exception is generator-produced high expansion foam without any throwing length at all, where the application rate is found by measuring the foam volume. Here we discuss the use of low expansion and medium expansion foams, which is relevant in this context).

Once freshly generated foam hits the burning surface and gets a "foothold", it begins to spread. At the same time, foam breakdown starts immediately (foam degradation is described in section B below). There are two "forces" that oppose each other: foam build-up and spreading, and foam breakdown. If these two "forces" are in equilibrium, a successful extinguishment is absolutely impossible. Again it should be emphasized that the criterion $V_{application} > V_{degradation}$ must be in force. The foam must be able to cool, resist heat, and flow outwards, forming a sealing barrier.

The *spreading property* will vary from foam to foam. It will obviously expand with increasing application rates, type of concentrate, and type of fuel burning, as well as with the foam's density and viscosity, but not with the degradation rate of the applied foam. Viscosity is the internal friction between the bubbles as well as friction between the foam and fuel surface — in other words, how "sticky" the foam is. Foam density is determined by its expansion ratio.

B. Foam Degradation

Firefighting foam with a film forming foam is a two-phase system consisting of air bubbles dispersed in a continuous water phase. It is unstable and eventually collapses, regardless of whether the foam is applied to a burning liquid surface or just on the ground. Applied on a burning liquid surface, the breakdown rate will naturally be much faster than on a non-burning surface due to heat radiation, and it will be greatest in the beginning when the radiation is strongest.

If we let V stand for rate, the following inequality must — as mention before — always apply if a fire should be extinguished with foam:

(1) $$V_{application} > V_{degradation}$$

Foam breakdown is caused by three factors: a) evaporation of the liquid in the foam, b) drainage of fluid out of the foam due to thermal radiation from the flames, and c) so-called conventional drainage. The latter is non-thermal related drainage, or drainage that would occur even without flames present or sometimes called "drainage by gravity", which is drainage that takes place anyway and that is energetically conditioned.

The rate of foam breakdown equals drainage rate plus evaporation rate:

(2)
$$V_{foam\ degradation} = [V_{evaporation} + V_{drainage\text{-}thermal} + V_{drainage\text{-}conv.}]$$

(1) then becomes:
$$V_{foam\ degradation} > [V_{evaporation} + V_{drainage\text{-}thermal} + V_{drainage\text{-}conv.}]$$

(In some cases these rates should be equal, $V_{application} = V_{foam\ degradation,}$ when talking about *critical application rate*. Then we will not be able to put out any fire, no matter how long we keep on applying foam).

The $V_{drainage\text{-}thermal}$ value would be large in the beginning because of the heat radiation, as would the value for $V_{evaporation}$. Therefore, given a constant application rate, the inequality above will increase as a function of time. Remember that foam breakdown is a mass transfer, where the liquid in the foam disappears due to evaporation and drainage, accounting for all of the mass change.

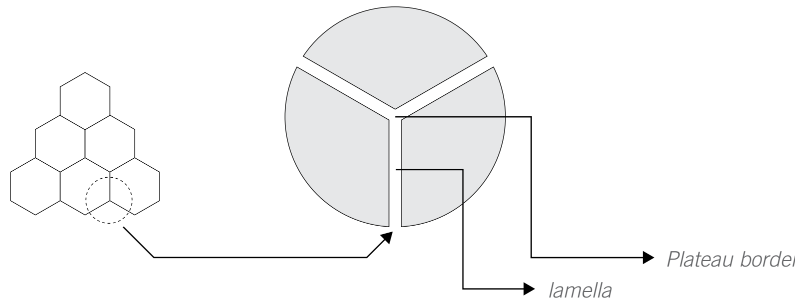
The drainage rate is not a linear function of time. Its initial value is zero, reaching its maximum value after a certain time, and then gradually decreasing. Low expansion foam has a higher drainage rate than higher expanded foams, or a shorter drainage time.

The terms drainage time and drainage rate are different terms. Drainage time is simply a measurement of time, while drainage rate is the rate of mass change over time. In other words, the rate of mass transfer of fluid out of the foam, or mass transfer per unit time.

The density of the foam decreases as it ages because it loses mass, therefore increasing the expansion ratio. The foam expansion can increase by up to several times its original value, which is consistent with data from measured drainage rates on different foams. Expansion ratio, drainage rate and density are key concepts in foam rheology.

The foam consists of bubbles of different sizes. A thin two-sided liquid film of foam solution, called a lamella, separates the bubbles. This film is very thin, and as the liquid phase is drained out, it stretches. At a certain critical thickness of around 50-100 Ångstrom, Å (one Å = 10^{-7} mm) it collapses and bubbles merge. Since the pressure is greatest in the small bubbles, these diffuse into the larger ones. Foam bubbles have a more or less stable polyhedric structure where three or more bubbles meet in what is called the Plateau border (see figure). The liquid pressure is lower here than elsewhere in the lamella, and this is where the drainage will occur.

Although the polyhedric (honeycomb) structure is the most energetically favorable configuration, in reality bubbles vary in both shape and size due to physical-chemical laws and different external influences. And foam is not static, but a highly dynamic medium.



Two-dimensional illustration of a three-dimensional polyhedric structure.

The contribution of the foam agent.

Foam breakdown is influenced by the type of chemical components in the water phase of the lamella. So the composition of the foam concentrate that has been used to make the foam solution generates finished foam.

Different types of foam concentrate provide different foams depending on the chemicals the foam liquid is composed of, even if they are generated with the same equipment and at the same temperature. Foam characteristics, degradation rate (stability), cohesive strength, tolerance to heat radiation, flow properties, etc. will vary. For example, foams that are able to form polymer membranes on polar flammable liquids will generally be more stable and slow draining. This has to do with the fact that they often contain macromolecules of carbohydrates, which interact with other components, surfactants, electrolytes, and additives — contributing to increased viscosity on the lamella liquid. The friction increases, the elasticity of the lamella changes, and the mobility of the liquid is affected. Both mechanical and chemical "forces" are involved.

The composition, types of chemicals selected for the foam concentrate, and proper equipment determines how foam solution can be generated to foam. The same can be said with regard to the permeability of the underlying flammable gases, that is, to what extent they are able to penetrate the foam blanket. Foams that easily pick-up volatile flammable gases; are poor extinguishing foams. The concentrate they are made of contains the incorrect chemicals or component composition. Such fuel pick-up will also play a considerable part in rate of foam breakdown.

AMERICAS
PERIMETER SOLUTIONS, LP
1520 Brookfield Avenue
Green Bay, WI 54313
USA
Tel: +1 920 593 9445

EMEA
PERIMETER SOLUTIONS, LP
Polígono de Baiña, Parcela 23
33682 Mieres (Asturias)
Spain
Tel: +34 985 24 29 45

ASIA PACIFIC
PERIMETER SOLUTIONS, LP
3 Charles Street
St. Marys NSW 2760
Australia
Tel: +61 2 9673 5300