AQUEOUS FOAM -
TECHNOLOGY & SYSTEMS DEVELOPMENT

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INTRODUCTION

Foam production systems are similar in that they all include a to-be-foamed liquid phase, an expansion gas, and equipment designed to combine, mix, and discharge the foam product.

Foams produced from these similar systems are not similar. The most obvious difference among compressed gas foams is persistence, or lifetime, generally defined as drain time – the time required for the foam to decompose into the original liquid and gas phases. The chemical composition does affect the drain time.

Foam barriers can affect both heat and mass transfer utilizing only the foam structure – bubbles, which are membranes separating small gas volumes.

Foam can be utilized as a delivery system for additional ingredients, which can produce a post-foamed medium.

Commercially successful foam systems are optimized with respect to each option – liquid composition, expansion gas, persistence, delivery equipment, and final foam performance **[1]**.

COMPONENTS

Liquid Phase

The most important physical characteristic of the liquid phase is surface tension, particularly in aqueous systems, as the surface tension of pure water is 72 dynes/cm, a value too high for foaming to occur. The surface tension needs to be reduced for foaming to occur. In general, a surfactant, added to the water in small amounts, 2000-ppm actives, for instance, will reduce the surface tension below 30 dynes/cm – a more than adequate value. Increasing the temperature can also reduce surface tension of water **[2]**.

Expansion Gas

The most common expansion gas in aqueous foam systems is compressed air, an example of an insoluble expansion gas. Soluble expansion gas systems are also possible, using low molecular weight hydrocarbons, nitric oxide, or carbon dioxide, for instance. The dissolution of these soluble expansion gases can also contribute to the reduction of the surface tension of the liquid system **[3]**.

Foam Generating Equipment

There are only two important components in a compressed gas foam generating system: (1) a device for combining the liquid phase with the non-soluble expansion gas; and, (2) an arrangement allowing for the thorough mixing of the liquid phase and the expansion gas.

The combining device can take many forms, but all of them are some combination of flow control devices accommodating the flow rates and pressures of the two components **[4]**.

Often the thorough mixing procedure is neglected or overlooked in the foam equipment design, probably because the real time for thorough mixing is not recognized, appreciated, or understood – the thorough mixing does not occur instantly, so the combined liquid and expansion gas must not be discharged too soon, or the foam quality will be less than optimum – reduced drain time and/or expansion ratio performance, for instance.

After the liquid phase and the expansion gas are combined, there are basically two procedures to satisfy this mixing time objective: (1) pass the combination through a sufficiently long hose or pipe, suitably sized for the flow rate, allowing the modest turbulence to achieve complete mixing **[5]**; or, (2) pass the mixture through a shorter, larger diameter, packed bed, where the residence time is reduced, but the degree of turbulence is greatly increased **[6]**.

Aqueous foams are metastable systems and begin draining as soon as the formation step has been completed **[1]**. This draining action immediately produces a liquid phase, which is the same composition as the original to-be-foamed liquid. Once complete mixing has been achieved, further mixing will not affect the foam. – positively or negatively.

The balance of the equipment is "support and supply" to the above items – tanks, pumps, compressors, power supply (diesel, gasoline, electric), hoses, fittings, and undercarriage (fixed/mounted, skid, wheels, tracks **[6(a), 7]**).

EXAMPLES OF FOAM SYSTEMS

Carbonated Beverages

The simplest foaming systems are carbonated beverages. The to-be-foamed liquid phase is essentially water and the expansion gas is carbon dioxide dissolved in the liquid under modest pressure. The carbon dioxide contributes to the surface tension reduction **[3]**, thereby allowing foaming to occur. The equipment is "one time use" and disposable, simply a can or bottle capable of holding the expansion gas pressure. On opening the container, the solubility of the expansion gas is reduced and foaming occurs. Variables affecting the result include: (1) amount of dissolved gas; (2) temperature; (3) agitation; and, (4) chemical composition **[3, 8]**.

Marshmallows

Marshmallows are an example of a composition generating a post-foamed reaction. They are prepared from a mixture of gelatin, sugar, and water, which is warmed (reducing the surface tension **[2]**), injected with air for foaming, then cooled. The cooling allows the gelatin to "gel" thereby increasing the viscosity of the material and vastly increasing the drain time. Common experience defines that heating marshmallows allows the gelatin to "un-gel" thereby creating a sticky, somewhat viscous, flowable liquid. Cooling this liquid will not reproduce a marshmallow, but will yield a gelled mass, as the foam has drained, leaving only the liquid as a residue.

Water could be considered a special case of this example. If the surface tension of water is reduced via the addition of a surfactant, for instance, and foaming follows, the foam produced will start draining immediately, and completely drain within about 30 minutes. However, if the foam is frozen, drainage will essentially stop until the temperature has been increased above the freezing point.

Baked Goods

Baked goods - bread, cakes, etc. - are similar to marshmallows, except that the foaming is thermally induced, during cooking. The expansion gas source is included in the pre-cooked formulation and the heat causes the carbon dioxide source to decompose, producing gas and generating foam. The heating process "cross links" the foamed product, increasing the viscosity, increasing the drain time, and thereby producing foam, which is essentially permanent. These bakery products cannot be reversed, as they have undergone a chemical reaction, as compared to marshmallows and ice/water, which have only changed physically.

These concepts are the basis for most (non-aqueous) foamed materials produced from polymers, including polystyrene, polyethylene, urethanes, foamed concrete, and gypsum board.

Fire Fighting Foam

Fire fighting foam is a particularly interesting material as it exhibits an array of foam attributes **[9]**. The objective of fire fighting foam is to separate the fuel source from the oxygen source, thereby interrupting the combustion process and extinguishing the fire. Minimizing the heat transfer from the fire zone to the fuel zone is also important. For all practical purposes any nonflammable foam composition could be used for fire extinguishing, but the differences between the "good ones" and the "others" is efficiency – the best fire fighting foams extinguish faster and with less material.

All of these fire-fighting foams utilize reduced surface tension water as the liquid phase and air as the expansion gas, regardless of whether the foam is compressed air foam or air aspirated foam. The better fire fighting foams have the liquid phase modified to improve efficiency – better heat resistance, for instance, among other features.

Even though the fire fighting foam is produced with air, as opposed to nitrogen, the extinguishing procedure works well, contrary to intuition. The foam barrier completely stops migration of the fuel to the air source as long as the barrier is continuous.

This mass transport characteristic, exhibited by all foam systems, has been exploited in the environmental field. A foam barrier (blanket) can be placed on a substrate – solid or liquid – thereby stopping the mass transport of material on either side of the barrier to the opposite side. Proper modification of the foam composition allows this technology to be widely applied in many varied applications – landfill daily cover, volatile organic compound (VOC) emissions, industrial site remediations, and other hazardous waste applications **[10]**.

USEFUL FOAM PROPERTIES

Volume

A cubic foot of water, 62.5 pounds, will provide a cubic foot of "result" volume, but as foam the "result" volume may be 10 to 50 cubic feet, depending on the expansion ratio of the foaming system.

Flow Properties

All foams are thixotropic - the viscosity is shear dependent – therefore, without a shear force being applied, foam will not flow. This characteristic allows foam to be stacked or piled, and flowing will only occur as the shear force increases with foam depth. Altering the physical properties of the foam, mainly viscosity, can allow foam to be piled in thick sections – more than several feet, if desired.

Controlled Release Medium

Since the drain time of foam can be "designed" and the foam can be accumulated in stacks, piles, walls, or barriers, components in the liquid phase can be deposited in a fixed location for a time period dependent upon the drain time property of the foam.

In a similar manner, the expansion gas used to prepare the foam is "stored" in the foam structure. The release rate is equivalent to the drain time of the foam composition.

POTENTIAL FOAM APPLICATIONS

Barriers

Simple foam barriers, by themselves, will not likely offer any advantages, as machines and people can simply pass through once the barrier is recognized and understood. However, foams containing suitable additives can offer possible benefits **[11]**. For instance, the foam medium can include a variety of dye ingredients, which can be transferred by contact and utilized for identification via post-contact evaluation.

The expansion gas, or the liquid phase, can contain (store) obnoxious materials, like RCAs, which can be transferred by contact (skin irritants, for instance), or released as the foam barrier is disturbed by the passage of individuals or machines.

Foam systems could contain friction reducing agents, like polyethylene oxide, which could render roadway slopes impassable – inclined ramps to highways, for instance.

Equipment

In general, there are two types of foams – compressed gas foams and air aspirated foams.

In general, there are two types of equipment – man portable and machine portable, including fixed mounted units.

Obviously, man portable equipment cannot cope with compressors, pumps, and other somewhat complex, large, and heavy equipment that may be suitable for a vehicle-mounted system. This leads to the conclusion that man portable units should emphasize air aspirated foam systems with the liquid being "pumped" by a displacement gas.

This could be achieved by placing the liquid phase in a low-pressure container with discharge controlled with high-pressure nitrogen, for instance, from an attached gas cylinder. When the system has been emptied, it could be refilled at atmospheric pressure and a new gas cylinder installed, or the discharge unit could be discarded.

By contrast, machine mounted foam systems can incorporate far more complex equipment, including compressors, dilution systems, and additive systems. In machine mounted foam systems, particularly those with high volume foam output, available power is an important design parameter, as the most efficient approach often involves a central power unit for driving the wheels or tracks, plus pumps, compressors, and auxiliaries.

Human Interaction

There are several interactive issues here:

(1) Professionals (terrorist) or amateurs (protestors);
(2) Groups or individuals;
(3) Threat level – primary military, difficult prisoner, or unruly civilians;
(4) General "chemical/human" interaction.

For the sake of this discussion, terrorist activities and major military threats will not be considered, emphasizing instead the civilian related issues.

Many reports concerning sticky foam suggest use of the material for "civil unrest" is unjustified, too complex, or too risky, specifically with respect to chemical interaction issues. On the contrary, for terrorist activities and military applications, it may be perfect. However, there are safer foam approaches, which may be able to circumvent some of the sticky foam negative features.

Foam systems can be formulated with an array of RCAs, but even this approach may too severe compared to water cannons. Simple foam systems for individual or group control can be formulated without RCAs but still provide serious negative emotional interactions with an ordinary civilian. Small amounts of carbon black can make foam black **[12]** instead of white and that alone imparts significant negative reaction from a target. Additionally, extremely low levels of odorants can be added and these can very much increase the negative response from a target.

If adhesive properties, like sticky foam, are desired, various levels of materials can be added, including sugar **[13]** or molasses, as well as commonly available polymers. When sticky, black, odorous foam is discharged onto a target, the response should be compliance and/or quick exit.

Even though the public may use similar ingredients in everyday life experiences – foods, cosmetics, household products, etc. – when the police or military use the same materials they become chemical agents and the uproar begins.

There are procedures for counteracting this chemical phobia. Most of the properties needed to achieve these results can be obtained using chemical components with good, safe human interaction. It is beyond the scope of this document to list all the choices, but consider a few as examples:

(1) Foaming surfactant – consider using sodium lauryl sulfate, the surfactant in toothpaste.
(2) Something sticky – styrene-butadiene polymer **[12]** is approved for use in chewing gum.

(3) Thickener, viscosity modifier – instead of using an industrial chemical, like a paint thickener, use gelatin, which is GRAS (generally regarded as safe) or one of many modified starches **[14]** (GRAS), specifically those used as fat substitutes in baked goods. Both are edible!

(4) Post-foam clean up – formulate with (warm) water-soluble materials, which can be directly discharged to the drain.

(5) Odorants – choose from those that are edible – propyl mercaptan from onions, garlic disulfides, mold odorants from cheese, as examples.

CONCLUSIONS

- Foam systems are generally defined by their drain time, which can be controlled by the chemical composition.
- Foam systems can produce barriers.
- Foam systems can deliver ingredients for post-foaming reactions.
- The two phases of a foam composition can perform as a controlled release medium.
- Selecting the formulation ingredients carefully can minimize human interaction problems.
- The conventional physical and chemical rules governing condensed phase materials also apply to foam systems, thereby allowing logical development.

REFERENCES

This paper has been posted on the Internet as part of the Aquafoam, Inc. web page, "The Foam Book", http://www.aquafoam.com, and is located at the following address: http://www.aquafoam.com/NDIA2000.html. The Internet version is directly linked to many of the references cited.

(1) General references to foam technology are presented on the Internet at http://www.aquafoam.com/fb11.html. The most complete and general references are: (a) Bikerman, J.J., "Foams: Theory and Industrial Applications," Reinhold Publishing, NY, NY, 1953. Library of Congress # 53-8705; and, (2) Bikerman, J.J., "Foams," Springer-Verlag, New York, 1973. ISBN 0387061088.

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