TECHNICAL BULLETIN

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Foam Applications on Textiles

CONTENTS

INTRODUCTION

"Foam" is defined as a type of colloidal mixture in which a gas is dispersed in a continuous liquid or solid medium. Although foam has been used in textile processing for over a century, foam applications can still be considered a young and experimental technology in comparison with aqueous textile processing.

The motivation for developing foam application technologies has shifted several times in response to changing concerns in the textile industry. Some of the earliest mentions of the use of foam for improving the treatment of textile substrates are found in the series of patents granted to Peter Schmid in the early 1900s. The initial developments in foam application were driven by concern about damaging delicate fibers. A patent granted in 1906 describes a machine that uses pressurized air and heat to create a "soap-lather" for degumming raw silk (Schmid 1906). A related patent granted in 1907 describes "treating the raw silk with the lather only of the said bath in the presence of steam and air, the silk not being submerged in the bath" (Schmid 1907). In 1916, a patent entitled "Foam or Froth Dyeing-Bath for Silk" was granted whereby the "soap-lather" was replaced by a foam made from the silkworm chrysalis (Schmid and Gross 1916).

Foam application technologies continued to develop steadily through the mid twentieth century, when the focus shifted to using foam to apply rubber coatings to textiles. Rubber was applied to textiles for many purposes, including creating waterproof coatings or durable yet flexible belts to be used in machinery. Originally, rubber was applied to both sides of a textile by repeatedly dipping the fabric in a liquid rubber bath and drying the goods until a sufficiently thick coating had built up around the textile substrate. This method required extensive drying time between application of layers. Rubber was also applied to one side of a textile as a paste dissolved in volatile solvents. This method required the use of solvent-recovery systems, and coatings applied in this manner tended to peel away from the textile backing. Foam application was found to be an effective method for applying rubberized coatings to one side of a textile. Applying the rubber as a foam coating allowed manufacturer to create a sufficiently thick layer in one pass, and the porous structure of the foam reduced the drying time (Untiedt 1932).

In the mid 1970s, foam finishing began to generate widespread interest as a replacement for aqueous pad processing; this interest was driven by increased energy costs. However, despite the great advantages of foam processing, many mills found foam application more difficult to control than aqueous pad processing. As concern about energy costs diminished, so did enthusiasm for foam application technologies. Although no revolution in foam finishing of textiles took place, interest in foam application did not disappear, and specialized machinery companies have continued to develop and improve foam application equipment. By the end of 2009, several hundred chemical foam units were in operation worldwide, including at least 90 units in the United States (Farias and Morrison 2010). This bulletin explores the unique properties of foam and the challenges of foam application.

ADVANTAGES OF FOAM

Foam finishing is a versatile application system. Most processes that can be conducted in aqueous padding systems can be performed via foam application, including bleaching, dyeing, and finishing. Pigment dyeing and finishing can be completed in one pass on lightweight fabrics (Gregorian 1987). Foam application can also be used to apply different finishes to the face and back of the fabric in a single pass.

The advantages of a low wet pickup system extend beyond decreased water consumption. An estimated 1,900 BTUs are needed to evaporate a pound of water in a production dryer, where much of the energy is consumed in heating and venting the air (Snyder n.d.). For cotton-rich fabrics, the wet pickup in foam finishing is typically between 15% and 35%, depending on the process, compared with 60% to 100% for a conventional pad application (Gregorian 1987). This reduction in wet pickup greatly reduces drying costs. The low wet pickup also allows the pre-drying step, which minimizes migration, to be eliminated from some application processes. Furthermore, faster drying allows overall production speeds to be increased; in some cases, production speed has more than doubled.

Foam application also potentially results in less chemical waste than with traditional application methods. In an aqueous pad system, the amount of mix in the trough that is discharged into the drain following a run can be fairly large. The small liquor volumes required for foam application result in less waste during a changeover. Some research has indicated that foam application of a wrinkle-resistant finish can result in better performance with less chemistry on weight of the goods (Gregorian 1987). In reactive dyeing of cotton, the dye bath in the chemical pad may contain salt at a concentration of up to 300 g/l; the salt is rinsed from the fabric in later processing steps and discharged in the wastewater (Farias and Morrison 2010). Foam application can allow the chemical pad step to be eliminated, thus reducing the use of salt.

PROPERTIES OF FOAM

The mixture of two phases in foam makes it an inherently delicate and complex substance. The gas portion of the mixture is highly responsive to slight changes in temperature and pressure. The gas bubbles tend to rupture or diffuse into one another soon after being produced, and the liquid barrier between the bubbles drains from the mixture and settles to the bottom of the container. An understanding of the following properties is necessary for the practical application of foam mixtures:

- Density and blow ratio.
- Half-life.
- Bubble size and size distribution.

Density and Blow Ratio

"Foam density" is the weight per volume of foam, typically expressed in units of grams per cubic centimeter. Foams can be generated with densities ranging from 0.005 to 0.3 g/cc, although a range of 0.01 to 0.2 g/cc is more representative of real-world applications

(Ashmus *et al.* 1977). "Blow ratio" is the volume of gas in relation to the volume of liquid present in the foam. If the density of the liquid from which the foam is generated is assumed to be 1 g/cc, then the foam density and blow ratio are inversely related (Schindler and Hauser 2004):

$$\text{Blow ratio} = 1 \,/\, \text{Foam density}$$

Viscosity increases as blow ratio increases (Namboodri *et al.* 1978). As a general rule, foams with higher viscosities are likely to be more stable (Gregorian 1987); however, it is possible for foams of equal viscosity to have different stabilities.

Half-life

"Half-life" is the time it takes for one half of a quantity of foam to collapse into the liquid state. The liquor volume that would equal one half the mass of the foam contained in a graduated cylinder is determined from the known densities of the foam and the precursor liquid. Half-life is the time it takes for this calculated volume of liquid to collect in the bottom of the cylinder. The half-life of foam formulations can range from a few seconds to several hours. The desired half-life for most textile processing applications is 5 to 15 minutes. The ideal half-life depends on the specific application.

Bubble Size and Size Distribution

The bubble size and size distribution are influenced by the geometry and rotor velocity of the mixer, as well as the blow ratio, surface properties, and viscosity of the gas–liquid system. Foams with a smaller average bubble size are preferred, as they tend to have higher viscosity, longer half-life, and greater overall stability. A narrow bubble size distribution is favorable, because bubbles of equal size are less likely to destabilize when they interact. Rupturing often occurs when small bubbles with higher pressures come into contact with large, low-pressure bubbles (Kroezen and Wassink 1987). Evenly generated foam with a bubble size of 50 to 100 µm has been demonstrated to have good stability (Namboodri *et al.* 1978).

The most common method for determining bubble size is to coat the underside of a glass microscope slide with foam and photograph the slide as quickly as possible. The slide is placed on raised holders, so that the foam is not compressed before being photographed. The number of bubbles in the photograph is counted, and the average bubble size is calculated by the following equation (Walter *et al.* 1978):

$$\text{Average bubble size} = \frac{2}{\sqrt{\pi}} \left[\frac{(\text{Area})(\text{Liquid density} - \text{Foam density})}{\text{No. of bubbles}} \right]^{1/2}$$

In the equation, "area" refers to the area of the microscope slide seen in the photograph. This method is difficult and underestimates bubble size, because the diameters of the bubbles are larger than they appear when photographed against a flat surface. Figure 1 illustrates this effect. However, more accurate methods for determining bubble size require expensive equipment or are more complicated.

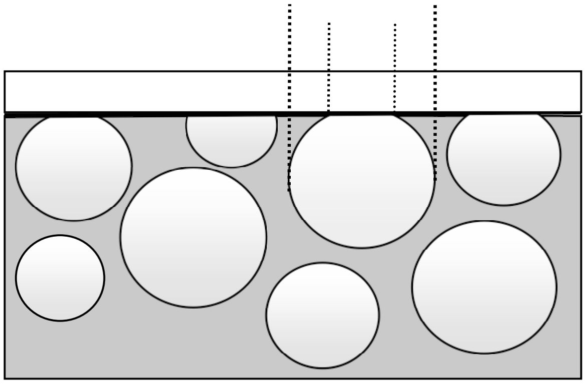


Figure 1. Error introduced in determining the size of a three-dimensional structure against a two-dimensional surface (Kroezen and Wassink 1987).

FOAM FORMULATIONS

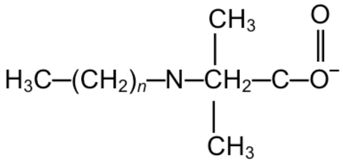
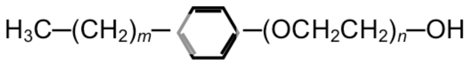
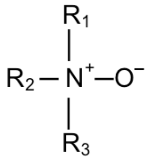
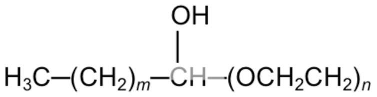
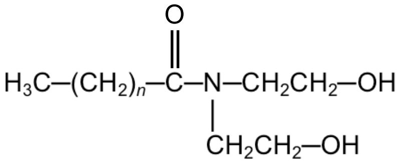
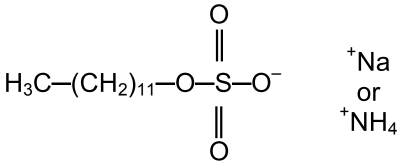
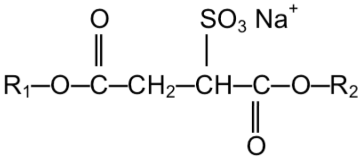
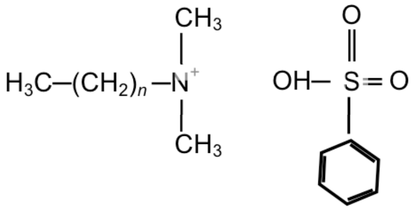
Most processes that can be conducted by aqueous padding can be successfully performed via foam applications. However, foam systems do pose some challenges that are not a concern with aqueous pad systems. Many chemical formulations do not have a natural tendency to foam, so a surfactant often must be added to act as a foaming agent. The foaming agent must be compatible with the ionic nature of the dye system or finish, the required pH range, and the foam stability required for a particular applicator (foam machine or system). Table 1 lists general categories of foaming agents.

Some formulations may require the addition of a stabilizing agent. Stabilizing agents often are used in open foam application systems but are not usually required in closed foam systems (the systems are described in the next section). Effective foam stabilizers include hydroxyethyl cellulose, methyl cellulose, and polysaccharide gums. Hydroxyethyl cellulose has been shown to have good compatibility with a variety of finishing components (Turner 1980). Stabilizers have been shown to hinder penetration of chemistry into the fabric. This could be an advantage if one-sided application of a finish is desired. However, the tendency to hinder penetration can result in face-to-back color differences when dyestuffs are applied (Palmetto Section 1979).

Crosslinking agents such as dimethyloldihydroxyethyleneurea (DMDHEU), triazones, melamines, and carbamates typically are compatible with foaming systems. Most catalysts do not destabilize foam, with the exception of sulfate anions. Softeners and handbuilders such as polyethylene acrylic latexes aid in foam formation, whereas softeners based on fatty acids tend to destabilize foam (Turner 1980).

Foam liquors typically contain 5% to 25% solids. The compatibility of components in the bath becomes critical as the benefits of dilution are lost (DeLoach 1980). Before being attempted in production, all formulas should be tested for foam-forming ability, using a stand mixer with a wire whisk.

Table 1. Foaming agents (Ashmus *et al.* 1977)

Alkyl betaines	 $H_3C-(CH_2)_n-N-\overset{CH_3}{\underset{CH_3}{CH_2}}-\overset{O}{\overset{\Vert}{C}}-O^-$
Alkyl phenols with 8 to 12 carbons in the alcohol group and 12 to 20 ethyleneoxy units	
Amine oxides (amphoteric)	 $R_2-\overset{R_1}{\underset{R_3}{N^+}}-O^-$
C_{11} to C_{15} linear secondary alcohols with 12 to 20 ethyleneoxy units	 $H_3C-(CH_2)_m-\overset{OH}{CH}-(OCH_2CH_2)_n$
Ethylene oxide adducts of linear primary alcohols with 10 to 16 carbons in the alcohol moiety	$H_3C-(CH_2)_m-O(CH_2\ CH_2O)_nH$
Fatty acid alkanolamides	 $H_3C-(CH_2)_n-\overset{O}{\overset{\Vert}{C}}-\underset{CH_2CH_2-OH}{N}-CH_2CH_2-OH$
Lauryl sulfate salts	 $H_3C-(CH_2)_{11}-O-\overset{O}{\overset{\Vert}{\underset{\underset{O}{\Vert}}{S}}}-O^-$ ${}^+Na$ or ${}^+NH_4$
Sulfosuccinate ester salts	 $R_1-O-\overset{O}{\overset{\Vert}{C}}-CH_2-\overset{SO_3\ Na^+}{CH}-\underset{\underset{O}{\Vert}}{C}-O-R_2$
Tertiary alkylamines quarternized with benzene sulfonic acid	

FOAM APPLICATION METHODS

Open Foam Method

In open foam application, the fabric makes contact with a foam bank, and the foam is then collapsed into the fabric. The foam bank is applied by horizontal pad, knife-over-roll, or floating knife. The foam is collapsed into the fabric by squeeze rolls, vacuum, or heat. United Merchants and Manufacturers began developing and promoting various open foam application methods in the mid 1970s. Initially, the horizontal pad method was favored, because it allowed existing equipment to be modified to apply foam at little added expense. Threading the fabric vertically allowed the foam to be applied to both sides of the fabric in a single pass (Figure 2).

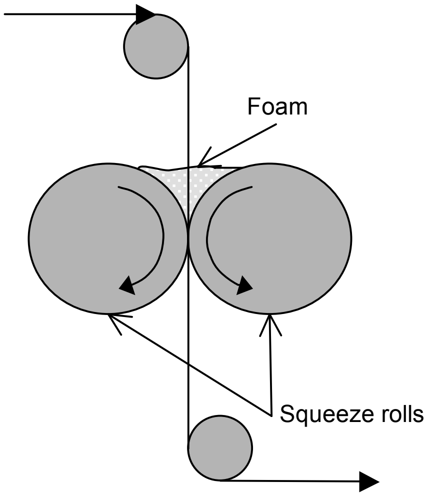


Figure 2. Horizontal pad foam application, United Merchants and Manufacturers.

In the knife-over-roll and floating-knife methods, the add-on is controlled by the height of the blade and the blow ratio of the foam (Figure 3). In an open foam process, the fabric must be kept moving at a constant rate for even application; if the fabric slows or stops, an excessive amount of liquor will be applied at the point where the fabric is in contact with the foam bank.

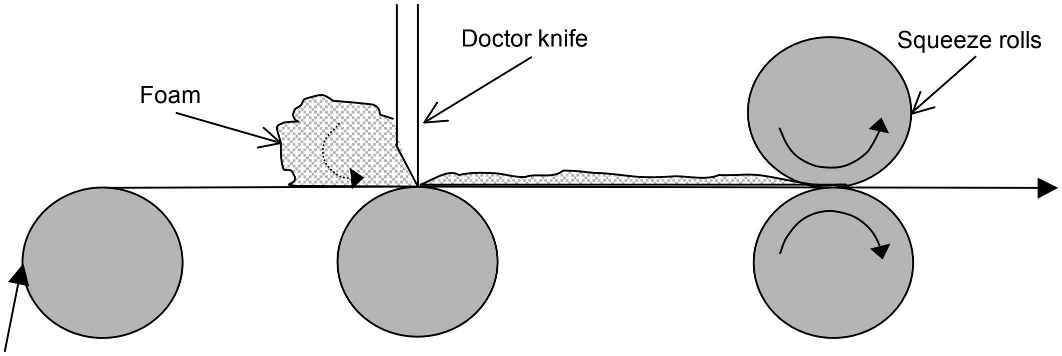


Figure 3. Knife-over-roll foam application, United Merchants and Manufacturers.

Basic open foam equipment is most suitable for the application of shrinkage-control finishes, softeners, and other forgiving processes in which variation can be tolerated. Sensors and controls have been developed to allow more precise applications by open foam systems. For example, AutoFoam Systems Ltd. uses a laser to detect the height of the foam bank behind the doctor blade; the height of the foam is communicated to the foam generator, where the foam feed rate can be adjusted to ensure even application of liquor to the fabric. A grooved profile bar is used in place of a simple doctor blade, to reduce "dead foam zones" (pockets of dehydrated foam) and encourage even application. Narrow grooves are used for thin or smooth fabric, and wider grooves for carpet or other textured or thick substrates.

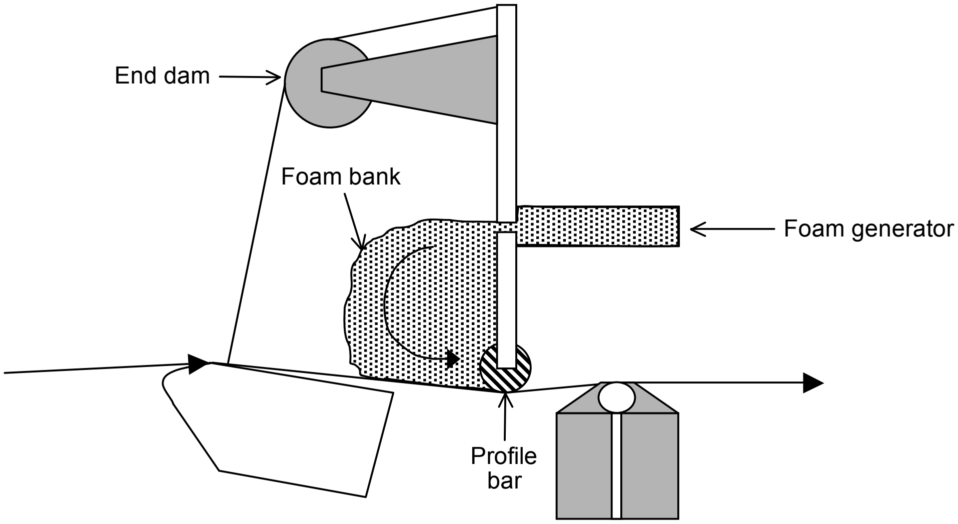


Figure 4. AutoFoam Systems open foam application.

Offset Open Foam Method

In the offset open foam method, a foam bank is spread evenly onto a nonabsorbent transfer agent and then pressed against the fabric. This method reduces problems with uneven application of foam during fabric slowdown or stoppage. The Janus system, by Küsters, uses a nonabsorbent roll as the transfer agent. The contact rollers are configured to allow single- or double-sided application (Figure 5). The even application provided by the transfer rolls allows carpet to be dyed with minimal disturbance of the pile.

The Monforts Vacu-Foam system uses a nonabsorbent belt as the transfer agent. The horizontal orientation of the belt at the point of contact reduces problems with dripping or settling of the foam. The vacuum drum collapses the foam and aids even penetration of the chemistry into the fabric while avoiding problems associated with seams and other surface irregularities (Figure 6).

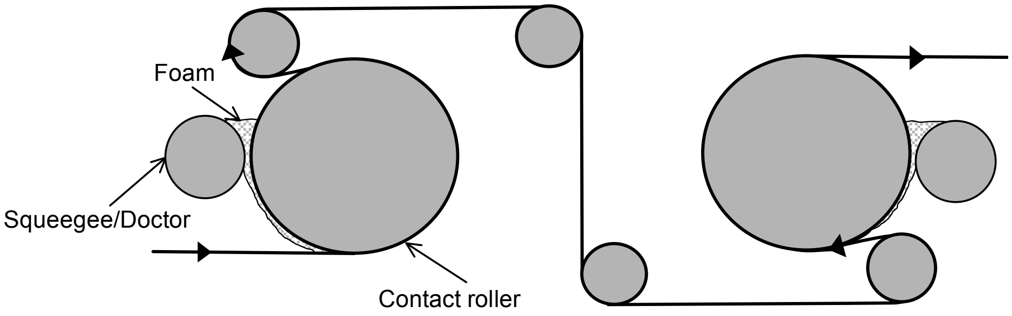


Figure 5. Janus contact roller system, Küsters.

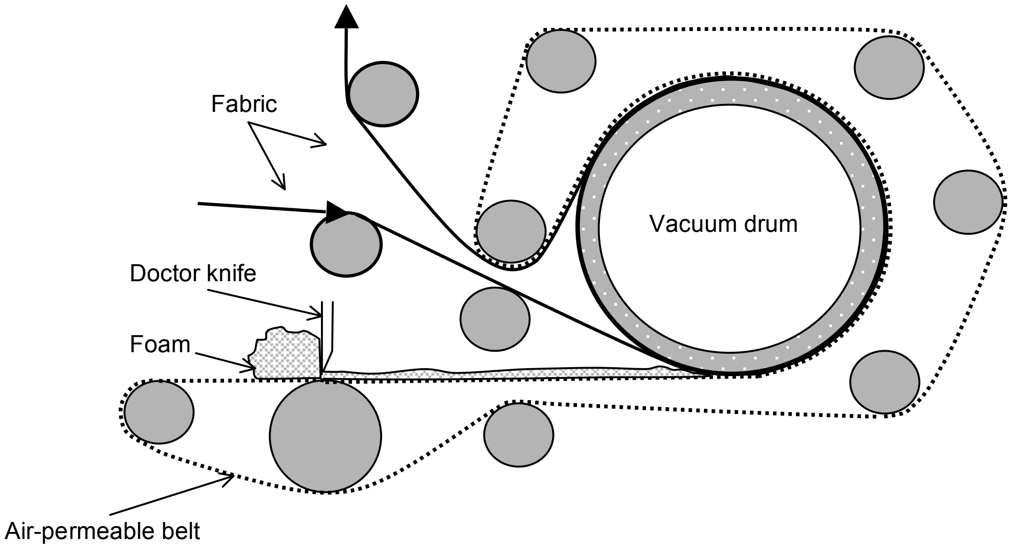


Figure 6. Belt and vacuum drum system, Monforts (Wersch and Pabst, 1982).

Closed Foam Method

In the closed foam method, the foam is applied directly to the fabric from a closed distribution chamber, rather than being spread onto the fabric from an open foam bank. The closed distribution system allows control of wet pickup by linking liquor flow rate to range speed. This method of controlling the application eliminates the influence of foam density and fabric absorbency on wet pickup. Closed systems typically use semi-stable foam made from a low-viscosity precursor liquid that is intended to break on contact with the fabric.

The first closed foam system to be used in the textile industry was the Foam Finishing Technology (FFT) unit, introduced by Gaston County Dyeing Machine Company in 1978. Foam was generated at the tapered end of a fantail distribution chamber and spread onto the fabric through a narrow slot at the broad end of the chamber (Figure 7). The unit was equipped with automatic guides to prevent foam seepage around the edges of the fabric, provided that the fabric was not too much narrower than the applicator. The fantail design required a large amount of space. It also created dead foam zones, because foam traveled farther between generation and application at the edges of the fabric than in the center, resulting in side-center-side variation in foam application.

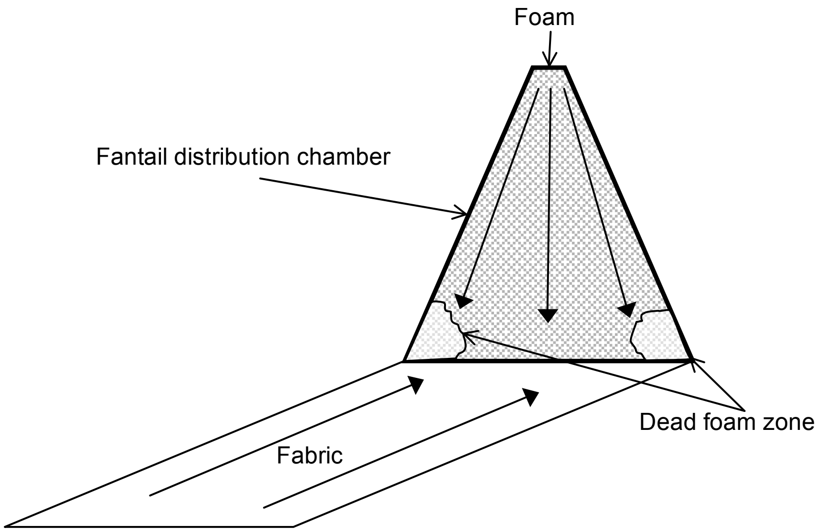


Figure 7. Fantail closed foam applicator, Gaston County Dyeing Machine Co.

Gaston County made several improvements to address issues with the original FFT unit design. The first improvement was to wrap the fantail chamber around a barrel, which conserved space and allowed multiple heads to be used to apply foam to both sides of the fabric (Figure 8). The second major development was the invention of a parabolic applicator for the Chemical Foam System (CFS), to replace the fantail design (Figure 9). In the parabolic chamber, all foam travels an equal distance from the foam inlet at the parabolic head to the fabric, thus eliminating the dead foam zones.

The engineering team responsible for the development of the CFS unit has continued its work under the name Gaston Systems. The development of a multiple-foam-head unit has led to an improvement in reactive dyeing with foam. Very low wet pickup is added at each of six foam heads (three on the top and three on the bottom). For even dyeing, 5% wet pickup may be added at each application point in a six-slot unit, rather than introduction of 30% through a single foam applicator or 15% at both points on a dual-sided applicator. When multiple foam heads are used, fabric tension is critical, because excessive tension can result in shaded light and dark areas, or “chatter” (Farias and Morrison 2010).

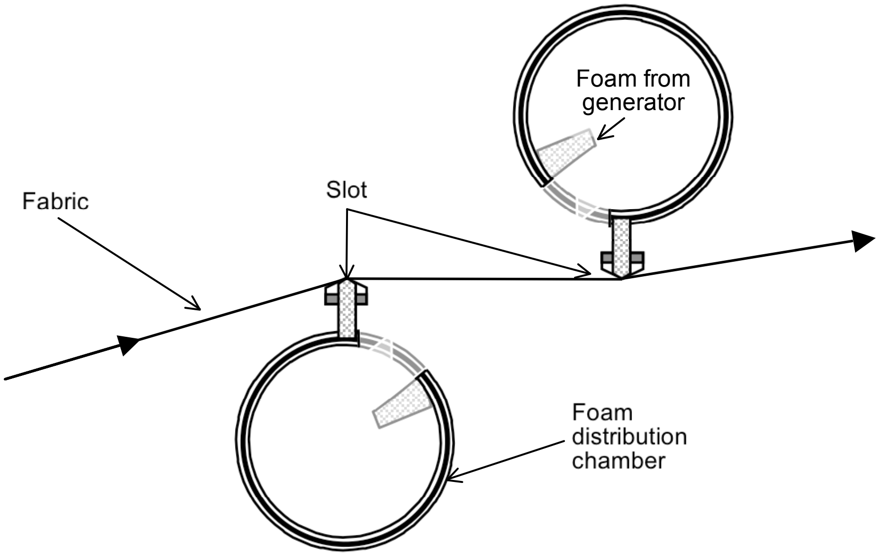


Figure 8. Multiple heads with barrel-shaped distribution chambers, Gaston County Dyeing Machine Co.

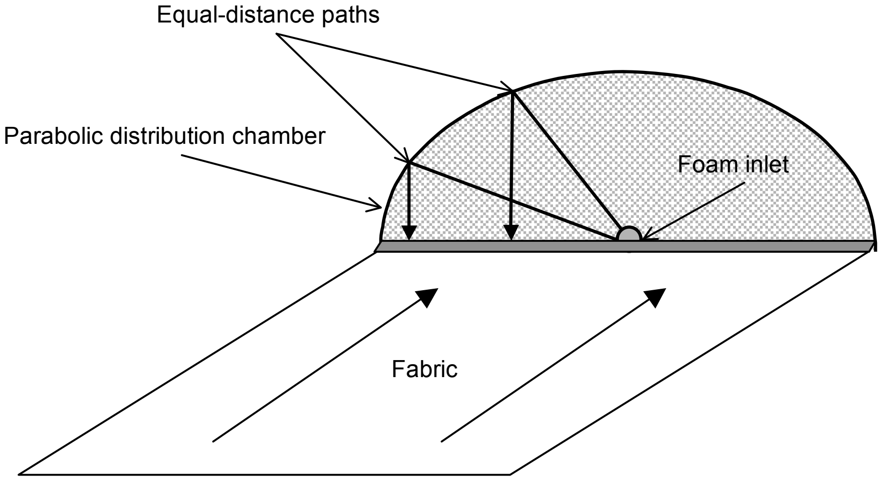


Figure 9. Parabolic closed foam applicator, Gaston Systems.

In 1980, Stork Brabant introduced a system for applying foam through a rotary screen. The Rotary Screen Foam (RSF) equipment consists of a foam distribution chamber with two squeegee blades housed inside the rotary screen. Foam enters the distribution chamber from both ends, to reduce variation. An air bladder is used to regulate the gap width, to prevent damage to the screen (Figure 10). Stork has continued to manufacture foam finishing equipment; the Coating and Finishing Technology (CFT) system is designed with interchangeable or adjustable components that allow it to be used to apply foams with a variety of stabilities and end uses. Figure 11 illustrates a configuration suitable for applying unstable or semi-stable foam for dyeing or finishing, and Figure 12 illustrates a configuration for applying stable foam coatings where the thickness of the coating is controlled by the angle of the knife. Stork and Gaston County Dyeing Machine Co. currently offer closed foam ranges equipped with an advanced control system that responds to the range speed. The controls allow the operator to enter the desired wet pickup and blow ratio along with the fabric width and weight and a correction factor. The control system automatically adjusts the liquor and air flow rates to match the range speed.

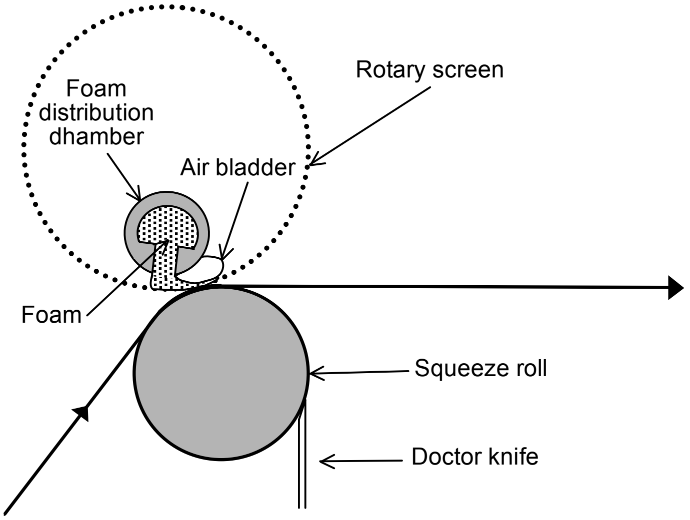


Figure 10. Rotary Screen Foam applicator, Stork.

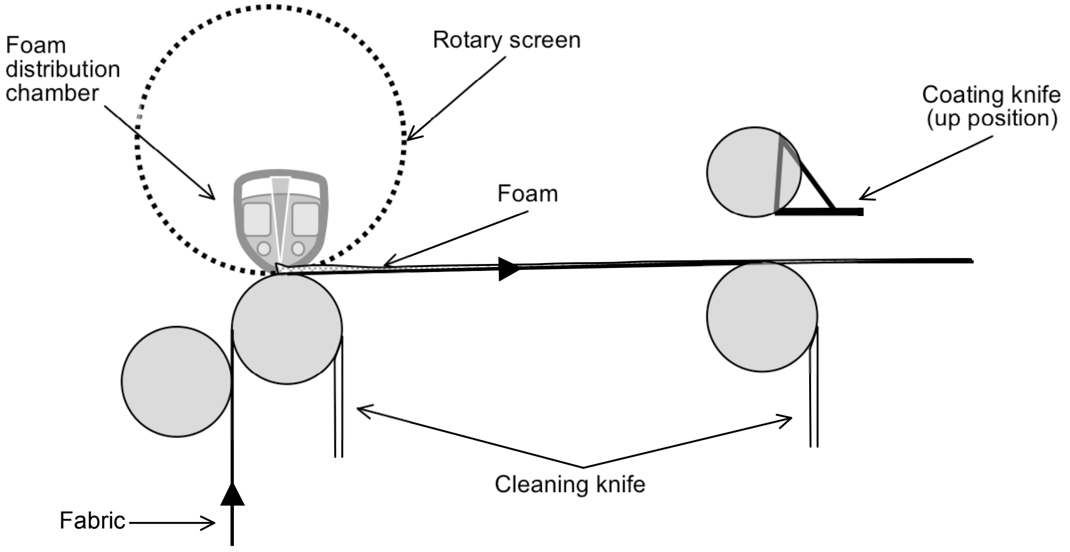


Figure 11. Coating and Finishing Technology for applying unstable or semi-stable foam, Stork.

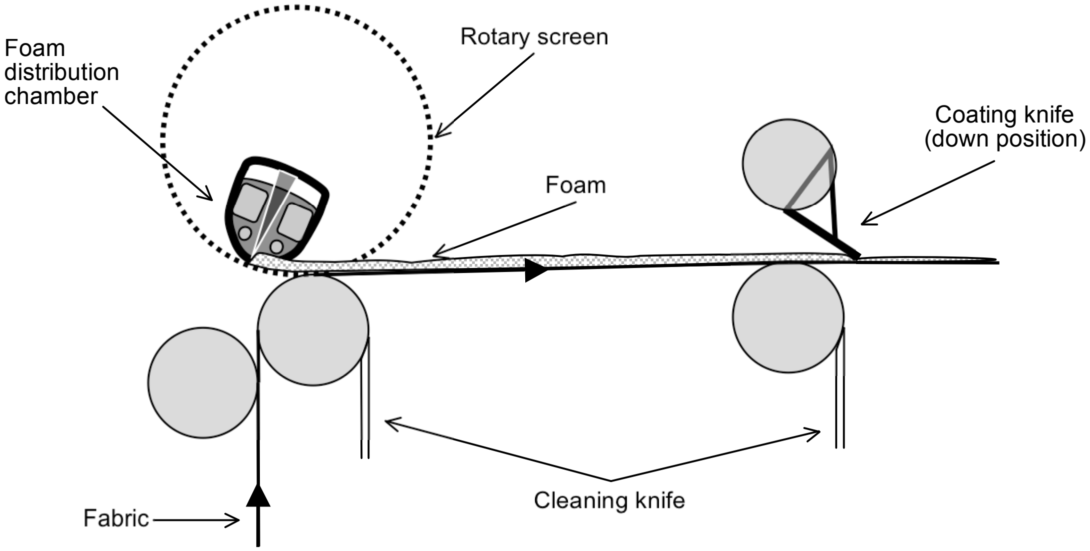


Figure 12. Coating and Finishing Technology for applying stable foam coatings, Stork.

Continuous foam processing is potentially faster than aqueous systems, because drying time is reduced. The rate at which uniform foam can be generated by the equipment limits the maximum range speed; foam application will be uneven if foam is generated more slowly than it is absorbed (Ashmus *et al.* 1977). The operating potential of the foam mixer also must be considered; if the equipment is pushed beyond its intended operating range, it can overheat, and the excess heat can destabilize the foam bath.

MOISTURE CONSIDERATIONS

For the practical application of foam, wet pickup must be carefully considered, along with the foam properties discussed above. For most foam applications, the wet pickup limits range from 10% to 35%. Foam applied at extremely low wet pickups tends to yield uneven coverage. Lower wet pickups have been used to achieve randomized discontinuous coating for moisture-management functions (Greeson n.d.). Higher wet pickups tend to give more uniform coverage of the fabric and provide more dilution, to alleviate issues of compatibility among bath components. With wet pickups greater than 30%, migration may occur during drying (Farias and Morrison 2010).

For most applications, the foam is applied to a dry substrate, and the fabric is dried at a low temperature and then baked or cured at a higher temperature. For some applications, the initial drying step can be eliminated, for additional energy savings. This process replaces the aqueous pad, dry, chemical pad, and then steam process. Wet-on-wet processes have been attempted, with limited success. Foam applied to wet substrates is prone to migration, resulting in irregular coverage. The migration issue reintroduces the need for pre-drying, diminishing the energy savings of foam application. Wet-on-wet foam processing is sometimes necessary to alleviate bath compatibility issues. The tendency for foam to migrate in wet-on-wet processes can be an advantage for some specialty applications. For example, tie-dyeing effects can be achieved by selectively wetting areas of the fabric; the foam migrates towards the edges of the wetted areas, while non-wetted areas are treated evenly (Walter *et al.* 1978).

FINISHING

Table 2 outlines basic foam formulations that have been used successfully by Cotton Incorporated for two-sided application of a combined wrinkle-resistant and dual-action (repel/release) finish. The formulas in Table 2 were applied to the face and back sides of 7.5 oz/yd^2 cotton twill fabric with a Gaston CFS foam applicator (Greeson *et al.* 2006). The concentrations of chemicals used depend on the wet pickup and blow ratio; the concentrations are higher with lower wet pickups and lower with higher wet pickups.

Table 2. Formulas for two-sided application of a wrinkle-resistant finish with dual-action repel/release

	Concentration (g/l)	
Component	**Face (fluorocarbon)**	**Back (DP resin)**
Water	685	739
Fluorocarbon for oil/water repellency	90	–
Fluorocarbon for soil release	120	60
DMDHEU crosslinker (glycolated)	–	160
$MgCl_2$ catalyst	–	60
Polyethylene softener (medium density)	45	10
Silicone softener (fluorocarbon compatible)	45	10
Non-rewetting surfactant (amine oxide)	15	15
Wet pickup	20	30
Blow ratio	20:1	20:1

COLORATION

Applying color by foam processing requires much more control than applying finishes, because slight nonuniformity is easily detected and unacceptable. At Cotton Incorporated, pigments have been found to be well suited for foam application. Pigments have been successfully mixed with resin and softener finish formulations and applied to 100% cotton shirting fabric with a single slot foam head (Farias and Turner 1998). The formula used is shown in Table 3. Foam application of pigments has also been used to tint the surface of nonwoven fabrics.

Direct dyestuffs have been used for tinting denim fabrics. To dye denim with indigo, nitrogen gas has been used to generate foam from a mixture in the leuco state. A few dozen units are being used commercially for the application of indigo to denim fabric or yarns.

Table 3. Formula for combined application of pigment coloration, durable press, and softener

Component	Concentration (g/l)
Aqua ammonia, 26° Bé	2.5
Acrylic copolymer binder	120.0
Polyoxyethylene decyl ether foaming aid	20.0
Antimigrant	5.0
Pigment	30.0
Buffered DMDHEU crosslinker	108.0
$MgCl_2$ catalyst	27.0
Polyethylene softener	30.0

Foam application of reactive dye with a single-slot unit was attempted, with poor results. In a follow-up study, results were improved by pretreating the fabrics with low levels of surfactants and re-wetting agents, then drying them before applying the foam dye formula, but the results were not satisfactory for commercial production. Recent investigations into using multi-slot foam applicators have been more successful. Table 4 shows an example of a reactive dye formulation successfully applied at Cotton Incorporated. The wet pickups required for even reactive dye application with this type of equipment are higher than those needed for other foam finishing processes. When higher wet pickups are used, careful drying is required to prevent migration. Nonetheless, wet pickups of 25% to 35% are still an improvement over the 60% to 100% wet pickup needed for conventional aqueous processing.

Table 4. Formula for reactive dyeing, medium shade, 27% wet pickup (6.75% x 4 slots)

Component	Concentration, g/l
Reactive dyestuffs	9.0
Foaming aid	30.0
Wetting agent	3.0
Antimigrant	10.0
Sodium carbonate	10.0
Urea	50.0
Reserve salt flake	0.25

The need for alkali in reactive dyeing introduces additional challenges for foam application. If the dye is in contact with the alkali for an extended period, it is likely to hydrolyze. Vinyl sulfone reactive dyes may be less stable under these conditions than combined anchor reactive dyes. Ideally, the alkali and dyestuffs should be introduced into the foam mixer from separate holding tanks with as little delay as possible before application to the fabric.

SUMMARY

Foam finishing is a versatile system with great potential to decrease production costs and increase efficiency. Advantages of foam finishing include reduced wet pickup, reduced energy for drying, increased production speed, and reduced chemical waste. However, foam application can be more difficult to control than aqueous pad application. The following factors must be considered in order to gain the maximum benefits from foam:

- Foam properties such as density, blow ratio, half-life, bubble size, and bubble size distribution.
- Chemical formulation issues, such as compatibility of bath components and the need for surfactants or stabilizers.
- Which application method is most suitable (open foam, offset open foam, or closed foam).

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