

REC 139394

WU4/F/2/1

**SAWTRI
SPECIAL PUBLICATION**



**A Review of Low Add-on
and Foam Application Techniques**

by

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**P.O. BOX 1124
PORT ELIZABETH
REPUBLIC OF SOUTH AFRICA**

ISBN 0 7988 2746 7
WOL 62
SAWTRI SPECIAL PUBLICATION
February 1984

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type⁷. After the fabric has been padded through the liquor and prior to being squeezed through the rollers of the padder, the liquor is distributed as follows:

- within the fibres;
- in the capillary regions between the fibres;
- in the spaces between the yarns;
- on the fabric surface.

The operation of squeezing the fabric in the nip of the pad mangle largely removes the surface liquor and to some extent the liquor held in the interstitial spaces between the yarns. The liquor held in the fine capillary regions between the individual fibres, and also that held within the fibres is extremely difficult (if not impossible) to remove by mechanical means, even when very high nip pressures are applied. Cotton fabrics, for example, have a lower limit of wet pick-up of about 40% to 45%, which cannot be reduced further by mechanical extraction devices such as the mangle⁶.

The amount of liquor which can be removed from a fabric by a padder depends on factors such as the nip pressure, rubber hardness and modulus, roller diameter and the speed at which the fabric is passed through the padder, and it is generally accepted that it would not be possible to further reduce the wet pick-up levels attainable with conventional padders^{5,8,9}.

The lowest wet pick-up values attainable by padding are partially related to the water of imbibition values of the different fibres. For example, the water of imbibition of cotton is approximately 30%, while that of most synthetic fibres varies between 3% and 20%. In order to obtain wet pick-up values lower than the water of imbibition values for the various fibres, methods other than padding should be sought⁹⁻¹¹.

Reduction in the wet pick-up requires that another very important factor, namely the distribution of the chemical on the fabric, should be taken into account. Too low a wet pick-up will result in an uneven distribution of chemical on the fabric. Rüttiger¹² showed that there is a certain limit below which the capillaries are not adequately penetrated and the distribution of the chemicals within the fabric will not be uniform. In other words, there is an optimum level of liquor application which is just high enough to ensure adequate distribution of the chemicals within the fabric. This critical add-on value depends on fibre type, fabric construction and can be influenced by fabric pretreatment^{6,13}. For bleached cotton this value varies from 31% to 45%¹³. It is clear, therefore, that it is not only the lowest wet pick-up attainable which is important in any low add-on application technique, but also the degree of penetration or uniformity of distribution of chemicals at this wet pick-up. Whatever the method used for obtaining a low wet pick-up, it is important, therefore, to ensure that the impregnated fabric has a uniform moisture profile across its width, length and thickness in order to obtain a uniform deposition of the finishing chemicals.

3. TECHNIQUES FOR REDUCING WET PICK-UP

In the field of techniques for reducing wet pick-up there have been several approaches to the goal of minimising the amount of water used to convey the required amount of chemicals to a textile substrate. Some of these approaches are based on *expression techniques* where the surplus liquor which has been applied to the fabric is removed by squeezing or other means, and others on *topical techniques* which simply apply a limited amount of liquor to the fabric. In this review the expression and topical techniques will be referred to as *low add-on application techniques*. Recently another technique, namely *foam application* was introduced to the market. It differs in principle from the general low add-on techniques because air is used to dilute the liquor and thus reduce the wet pick-up.

4. LOW ADD-ON APPLICATION TECHNIQUES

4.1 Expression Techniques

In these techniques an excess of liquor is applied to the fabric, and as much as possible is removed subsequently by squeezing between special rollers or fabrics. Alternatively, the liquor is removed by vacuum extraction or forced out by compressed air or steam.

4.1.1 Roberto Fibre-Filled Rollers

An interesting alternative approach to rubber-covered pad rollers is the use of pad rollers made from special porous materials. Such rollers can directly replace rubber-covered rollers, and no major modification of equipment is necessary. Figure 1 shows the operation of the Roberto fibre-filled roller^{5,6,8-11,14,15}.

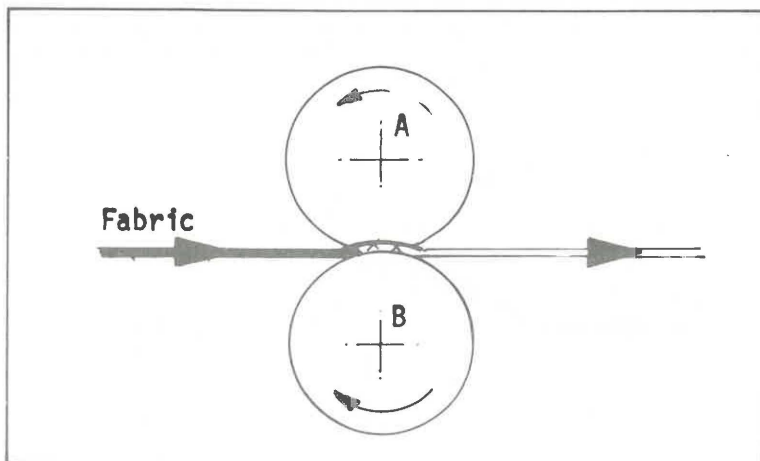


Figure 1: Roberto Fibre-Filled Rollers

The top fibre-filled roller (A) consists of a mass of fibres (each fibre being coated with rubber of microscopic thickness), which tends to absorb the water during the squeezing process. The bottom roller (B), which is normally a steel roller, can also be replaced by a second Roberto fibre-filled roller. The Roberto roller-steel roller combination results in a wet pick-up of just under 50% for cotton fabrics⁹, with corresponding lower levels for synthetics and blends. It has been reported, for example, that with the Roberto roller-steel roller arrangement a wet pick-up of 10% can be obtained on lightweight knitted nylon fabric, but when two Roberto rollers are used, the wet pick-up could be reduced to 5%^{14,15}. As a result of the lower wet pick-up the processing speed could be increased by up to 66%, while an average saving of 20% on power consumption was obtained. Roberto rollers can fit any pad mangle and the conversion can be made easily and at low cost. The rollers are resistant to most chemicals except oxidising agents and strong mineral acids^{14,15}. One disadvantage of this system is the fact that certain polymers tend to clog the pores of the Roberto roller¹⁶. The Prestech rollers¹⁰ operate on the same principle as the Roberto rollers, but to date little information has been available about their commercial use.

4.1.2 The Dehydration System

Apart from squeeze rollers, reduction in the wet pick-up of a fabric can be achieved by various other extraction methods. Although some of these systems have been in use in other industries for many years, it is only recently that such equipment has been considered by the textile industry for reducing the wet pick-up⁵.

Kleinewefers has developed a high capacity dehydration system under the name Hydrofuga^{17,18}, which is illustrated in Figure 2.

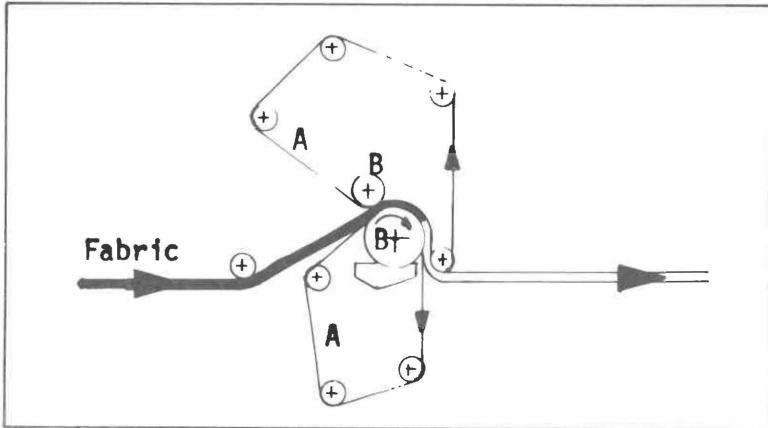


Figure 2: The Hydrofuga System

In the Hydrofuga system two endless non-woven fabrics (A) are passing around two independent roller units and between two rollers (B). The fabric which has been padded is sandwiched under low pressure between the two non-woven fabrics and in the process it transmits moisture to the non-woven fabrics, which in turn are dehydrated mechanically^{17,18}.

It is claimed that this system is suitable for fabrics which can be easily distorted or deformed such as knitted and pile fabrics, due to the low pressure exerted on the fabric. As with all other mechanical expression systems the removal of liquor is less effective on fabrics containing natural fibres. The lowest wet pick-up obtained on a knitted polyester fabric is about 22%, and in the case of a 67%/33% polyester/cotton fabric, the lowest wet pick-up is about 44%¹⁹.

4.1.3 Vacuum Extractors

One of the most common devices for reducing wet pick-up is the vacuum slot extractor. After the finishing liquor has been applied to the fabric, it passes over a vacuum slot where most of the liquor is removed. The extracted liquor is then recirculated and returned to the padder. It is important to note that the fabric must be continuously in contact with the slot for optimum liquor removal and consequently the vacuum slot is mounted in such a position that the fabric passes over it at an angle. Furthermore, the slot can have different types of configurations through which a vacuum can be applied. The most widely used types are the straight slot and a herringbone pattern of single or double rows^{20,21}. Vacuum slots have to be designed for a specific application since factors such as slot width, slot configuration, fabric speed, fabric air permeability, fibre type, and vacuum can have an effect on the removal of water²². The lowest wet pick-up obtained by the vacuum slot extractor for a 100% knitted polyester fabric varied from 10% to 20% and for a 100% cotton fabric the wet pick-up ranged from 40% to 50%¹¹.

A number of systems incorporating the above principle have been introduced to the market in recent years. One such system is the Jawetex vacuum system which incorporates a concave suction bar with offset suction slots to permit the bar to move close against the support roller over which the fabric is passed²³. The lowest wet pick-up values obtained on the Jawetex system are 18% for nylon, 24% for polyester, 64% for cotton and 75% for wool fabrics²³. It has been claimed that the drying capacity can be improved by as much as 60% when the Jawetex system is used²⁴. In the case of the vacuum slot system developed by Textile Vacuum Extractor Co. the lowest wet pick-up values obtained are 10% to 15% for polyester, 35% to 40% for 65%/35% polyester/cotton and 50% to 55% for cotton fabrics. A reduction of 45% in chemical consumption was also reported²⁵.

A vacuum extractor of more recent design is the suction roller extractor shown in Figure 3.

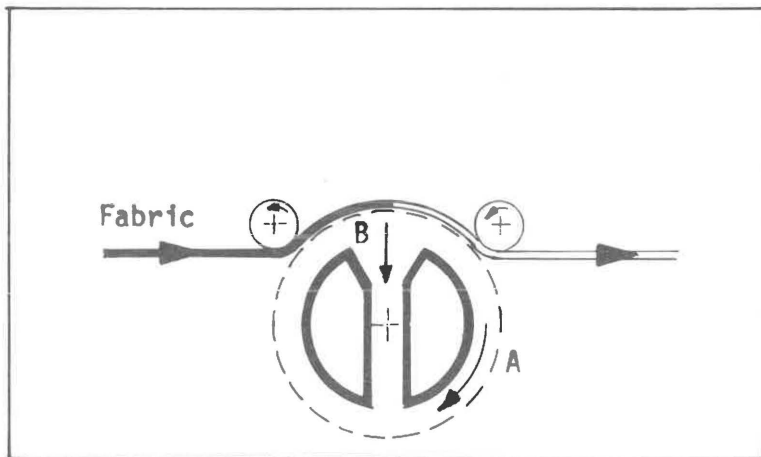


Figure 3: Vacuum Roller Extractor

The vacuum roller extractor operates on the same principle as the vacuum slot extractor except for the fact that the wet fabric is guided over a perforated roller (A) with a vacuum slot (B) inside this roller. The perforated roller rotates with the fabric and consequently the fabric is not pulled or dragged and thus it is not distorted, as can be the case with the normal vacuum slot extractor^{9,11}. Extraction of liquor by the vacuum roller extractor is more efficient than that of the vacuum slot extractor¹¹. The lowest wet pick-up values obtained by the vacuum roller extractor vary from 10% to 20% for knitted polyester fabrics and from 35% to 45% for cotton print fabrics^{8,11}. Maier¹⁰ and Gaston County²⁶ are manufacturers of commercial machines based on the vacuum roller extraction principle.

As far as vacuum extractors in general are concerned, several other companies, such as Albany International, Birch, Tube-Tex, Holland²⁷, Textile Machinery Inc²⁸, Mitter²⁹ and Mohr³⁰ are offering vacuum extractors. Burlington Textiles Machinery Corp. markets a dewatering/vacuum finishing system, developed by Albany Engineered Systems²⁹. Carrington International manufactures the Vac-U-Dry moisture extraction system which operates with a centrifugal fan instead of a vacuum pump²⁷. E-Vac Inc. developed the Vac-U-Pad system, based on the vacuum extraction principle using automatic edge seals²⁹.

A vacuum system which operates on a slightly different principle is the Matex-Vac system developed by Monforts^{17,18,31,32}. This system is shown in Figure 4.

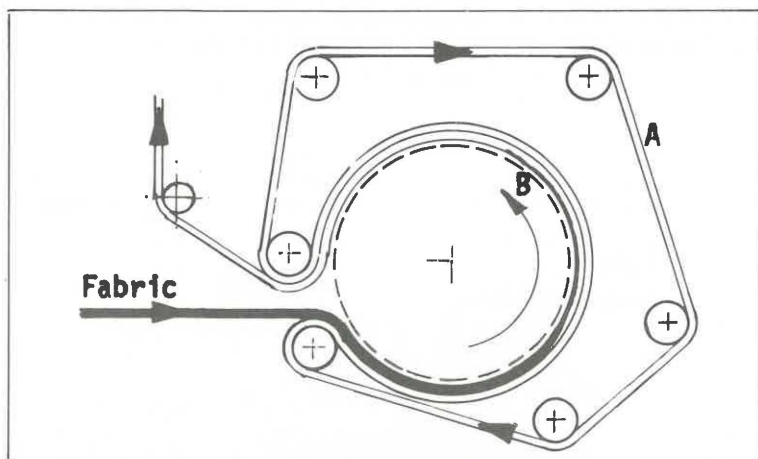


Figure 4: The Monforts Matex-Vac System

The Matex-Vac system consists of a wrapper (A) (non-woven viscose fabric) running around a rotating drum (B). The wet padded fabric is sandwiched between the wrapper and the drum where the liquor is absorbed by the wrapper and subsequently extracted from the wrapper by vacuum^{19,32}. A similar system consisting of an impregnator, suction system and recirculation device in one complete unit, is offered by Mohr³⁰.

Generally, vacuum extractors are most effective with non-absorbent synthetic fibres, and least effective with hydrophilic natural fibres. Furthermore, it is very difficult to vacuum extract fabrics with a very low air permeability^{8,9,11,16,31}. Similarly, fabrics with an open construction will not generate or support a high vacuum²². The uniformity of the treatment and the actual wet pick-up are not critical at the application point due to the fact that the subsequent vacuum extraction step will correct any unlevelness²⁰. A further advantage of vacuum extraction systems is the fact that some of the expensive chemicals can be recovered. Although the liquor is recirculated and returned to the padder, certain finishing chemicals can cause problems due to polymerisation in the system. Furthermore, the system is not generally suitable for wet-on-wet applications²².

4.1.4 Air Jet Ejectors

As an alternative to a vacuum, for extracting the excess liquor from a fabric, compressed air can be used to remove or eject the surplus liquor. In principle

such a system will be effective over a broad range of fabric properties and it is applicable even in the case of fabrics with a very low air permeability, because of the higher pressure differential which can be maintained^{5,6,9-11,31}. Pneumatic ejectors are manufactured by Pletec, Brugman and Hikosaka.

A pneumatic ejector for the removal of surplus finishing liquor, based on the Pletec "float on air" principle, is illustrated in Figure 5.

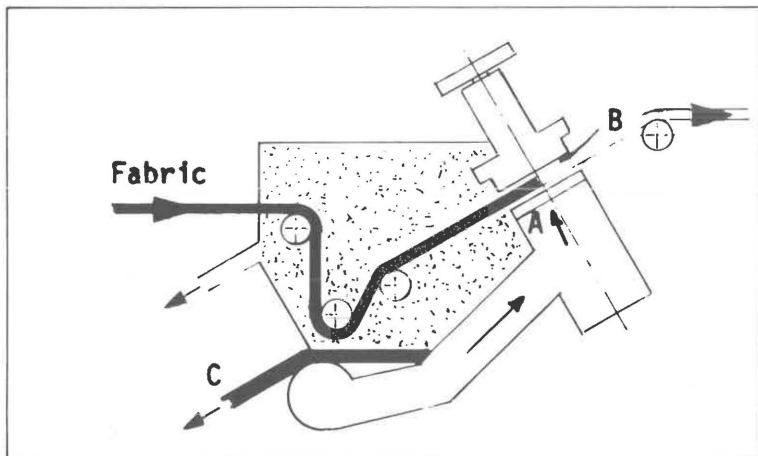


Figure 5: Pletec Ejector

During operation, compressed air (under a very high pressure) is forced through a slit (A) into the fabric moving between two plates, thus removing the excess liquor from the fabric. The gap (B) between the two plates can be adjusted according to fabric thickness. Furthermore, the finishing liquor (C) can be recirculated⁹. As with vacuum extractors, all such ejector devices are more effective in removing liquor from hydrophobic synthetic fabrics than from natural fabrics. It has been claimed that on certain selected fabrics, wet pick-ups as low as 10% to 15% are possible⁸, while on cotton and cotton blend fabrics wet pick-ups as low as 40% to 50% can be obtained⁹.

The Machnozzle of Brugman (Figure 6) operates on a similar principle, using steam (high pressure) instead of air to remove the excess liquor from the fabric^{8,11,33,34}.

The fabric which has been padded with finishing liquor is passed over guide rollers while mechanically driven tension rollers (A) maintain the fabric under tension against the nozzle (B) to prevent it from being blown away. Steam is passed at high speed through a narrow channel to the nozzle which is in contact with the fabric. At this point the steam is forced through the fabric, removing the excess liquor. It is claimed that, due to the small nozzle opening,

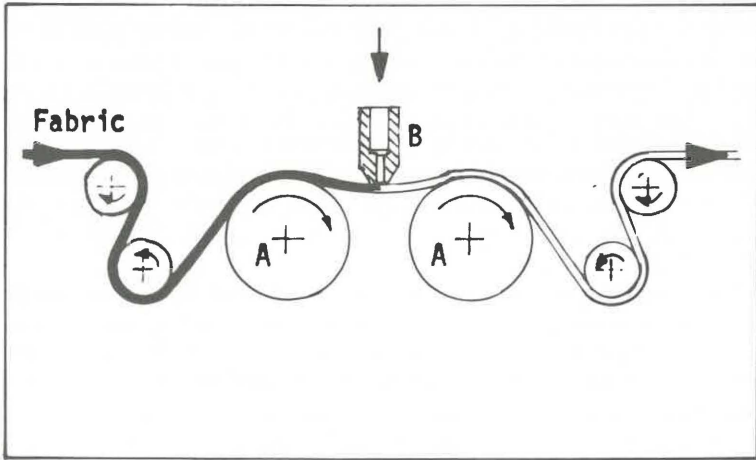


Figure 6: The Machnozzle

the fabric is not damaged³³. Goldstein⁸ reported that this type of ejector is more useful on relatively dense woven fabrics and less useful on knitted or dimensionally unstable woven fabrics. Juby⁹ and Goldstein¹¹ reported that it might be preferable to use compressed air instead of steam, since steam might dilute the finishing liquor. Theusink³³ claimed that the Machnozzle can lower the wet pick-up of cotton fabrics to between 25% and 60%, that of wool fabrics to 30% to 50% and that of nylon fabrics to 5% to 20%.

Another air jet extractor is the Roller-Jet-Squeezer developed by Hikosaka^{35,36}. This system is shown in Figure 7.

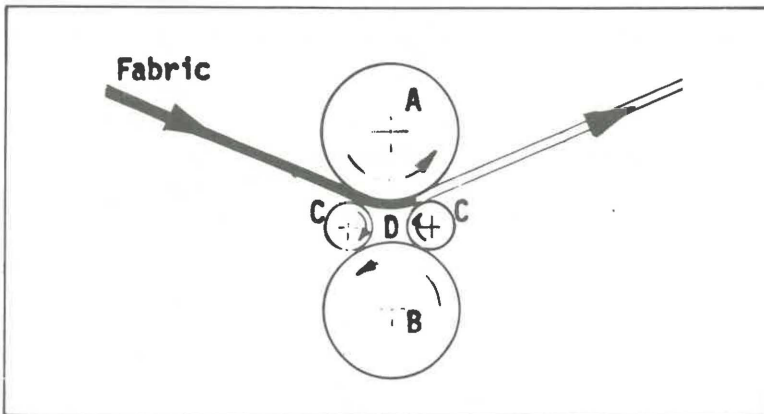


Figure 7: Roller-Jet-Squeezer

The Hikosaka Roller-Jet-Squeezer system consists of an upper rubber-covered roller (A) reclining in the direction of the fabric movement and a bottom rubber-covered roller (B) rotating in a direction opposite to that of the upper roller. There are two smaller stainless steel feed rollers (C) creating a nip with the upper rubber roller through which the fabric initially passes. These stainless steel rollers are driven by the two rubber rollers and, therefore, have the same surfaces speed as the rubber rollers. The section (D) between the four rollers is pressurised by compressed air. After the fabric has been padded it moves through the upper two nips where air is forced through the fabric to remove the liquor³⁵.

It has been claimed that wet pick-up levels can be reduced to 20% for woven polyester fabrics, to 40% for knitted wool fabrics, and to about 40% for polyester/cotton fabrics by the Hikosaka system. A further advantage of this system is the fact that two different fabrics in rope form can be processed simultaneously^{35,36}.

4.2 Topical Techniques

The topical techniques differ from the expression techniques in that a low amount of liquor is applied to the fabric. The liquor can be transferred directly to the fabric, or by means of indirect transfer systems.

4.2.1 Engraved Roller

In the engraved roller application system, shown in Figure 8, the liquor is applied to the fabric by engraved rollers.

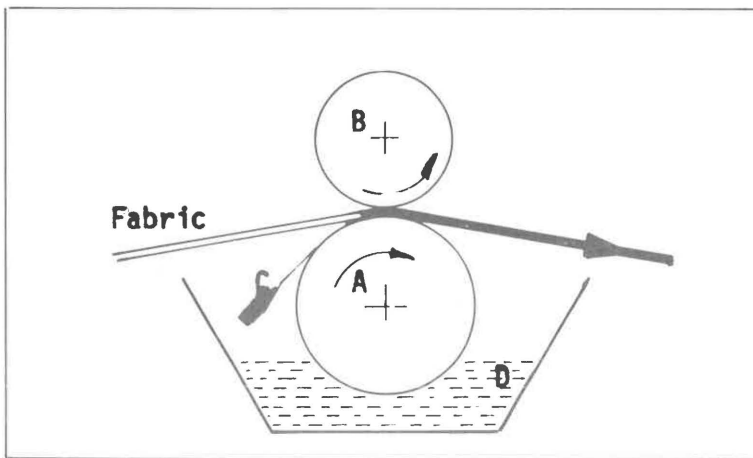


Figure 8: Engraved Rollers

This application system consists of four major components: the engraved roller (A), a rubber roller (B), a doctor blade (C), and the liquor bath³⁷⁻³⁹. The engraved roller rotates in the liquor bath (D) where its cavities are filled with liquor. The excess liquor is removed from the cavities by an oscillating doctor blade. The remaining liquor is then transferred from the engraved roller and forced into the fabric at the nip by the pressure of the top roller³⁹. The construction and design of the engraved roller are critical and the volume of liquor delivered per unit area by the engraved roller depends on the surface of the engraved roller, and the number of cavities^{37,38}. This in fact can be a disadvantage of the system, since the same volume of liquor will always be delivered per unit area by a specific roller. The wet pick-up, therefore, will vary with fabric mass and in order to achieve the same wet pick-up on different fabrics, different engraved rollers with different cavity structures have to be used^{22,40}.

Clogging of the cavities on the engraved roller can be a problem⁴¹. Furthermore, in the case of high viscosity liquors some of the cavities may not be completely emptied (i.e. not all the liquor may be transferred to the fabric)³⁸.

Goldstein¹⁰ and Goldstein and Smith⁵ reported that finishing chemicals could be applied to cotton fabrics at a wet pick-up as low as 10% by engraved rollers, but it was found that below a wet pick-up of 20% to 25%, however, some physical properties, such as the crease recovery angle deteriorates significantly.

A similar system, known as the YS-Mangle, has been developed in Japan by Sando Iron Works^{42,43}. In this system a rubber doctoring roller is used to control the amount of liquor, and not an oscillating doctor blade as in the case of the engraved roller. Furthermore, the engraved roller is replaced by a roller having an uneven surface or a roller which has closely spaced small holes all over its surface⁴². Despite the fact that the finishing liquor is applied to only one side of the fabric it has been claimed that it produces the same properties as the conventional padding process⁴³.

In the Zimmer system a different technique is applied to regulate the amount of liquor applied to the fabric. Spirally-wound metering rollers instead of engraved rollers are used to regulate the thickness of the liquor film on the application roller. This film is subsequently transferred to the fabric. A number of magnetic rollers assist in the transfer of the liquor to the fabric and its distribution on the fabric⁴⁴.

4.2.2 Nip Padding with Doctoring Device

Another development in the field of low add-on techniques is the nip padding system which operates like a normal padder but which utilises a doc-

toring device to control the wet pick-up⁴⁵⁻⁴⁷. This is illustrated in Figure 9.

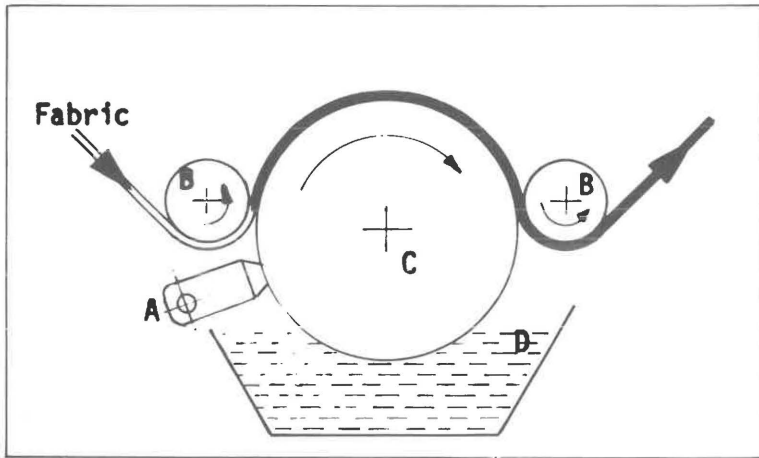


Figure 9: Nip Padding with Doctoring Device

In the nip padding system the wet pick-up can be reduced by adjusting the doctoring device (A) and the pressure and position of the nip rollers (B). The lick roller (C) rotates in a liquor (D) in the direction of the fabric movement. Advantages of this system are claimed to be a saving in chemicals (the trough contains only 15l of liquor), wet-on-wet applications are possible and that no major capital investment is required (this system can be used with existing processing equipment)⁴⁵. It has been claimed that a wet pick-up of 30% to 40% can be obtained on a fabric of 140g/m² using the Mini-Fluid nip padding unit⁴⁷.

4.2.3 Lick Rollers

Lick or kiss rollers have been used in textile finishing for many years, usually for the application of chemicals to the one side of a fabric. Lick rollers are normally used for a specific purpose⁴⁸, for example, for the treatment of corduroy fabrics, where it may be necessary to apply a stiffening agent to the back of the fabric while still retaining a soft pile⁶. Apart from special one-sided applications, lick rollers have been used for the application of durable-press resins to fabrics at low wet pick-up values^{6,13,49}. The different kiss roller systems are shown in Figure 10.

In the kiss or lick roller system (Figure 10(a)), a pad roller (A) is partly immersed in the liquor bath (D) and the liquor is carried upward by adhesion to the roller surface onto the fabric that is being treated. In the single roller

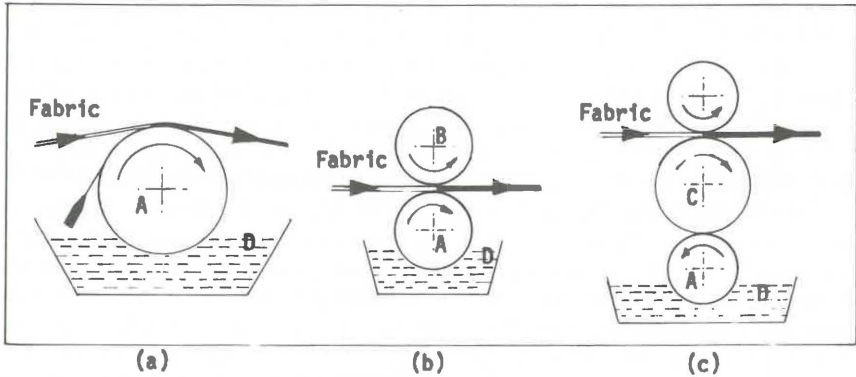


Figure 10: Kiss Roller Systems

system (Figure 10(a)), the fabric is not nipped, whereas in the 2-roller system (Figure 10(b)) a top roller (B) nips the fabric onto the kiss roller⁴⁹⁻⁵². Alternatively, the kiss roller system could have a 3-roller arrangement (Figure 10(c)) where liquor is transferred from the kiss roller (A) by the intermediate roller (C) to the fabric which is nipped by the top roller (B)^{53,54}. The lowest wet pick-up obtainable on cotton sheeting fabric by the single kiss roller system is about 25%. It has been claimed that the kiss roller system produces fabrics with slightly higher wash and wear ratings than those obtained by a conventional padder. The kiss roller is used for coating fabrics and can also be used for dyeing one side of a fabric⁴⁸.

There are many variations of the kiss roller system, but probably the most sophisticated and widely accepted is the Triatex MA (Minimum Application) system⁵⁵⁻⁵⁷. Figure 11 shows the basic elements of the Triatex MA system.

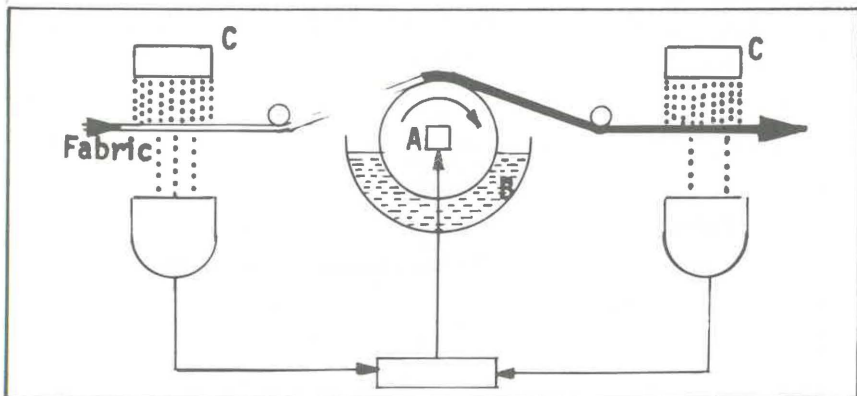


Figure 11: Triatex MA System

In this system a kiss roller (A) is employed to transfer liquor from the liquor bath (B) to the fabric which passes over the roller. The kiss roller rotates in the same direction as the fabric. The moisture content of the fabric is monitored by beta-gauges (C) at each end of the applicator. The difference between the readings of the beta-gauges gives a measure of the wet pick-up and is used to control the rate of rotation of the roller relative to the speed of the fabric and hence the amount of finishing liquor applied to the fabric⁵⁵⁻⁵⁸.

Application levels for cotton vary from as low as 10% to as high as 55%¹³, with 35% reported to be the optimum wet pick-up for uniform application⁵⁹⁻⁶¹. For satisfactory results the fabric must be highly absorbent and thus it must be properly scoured. In addition, only selected chemicals, dispersions and emulsions which will ensure the formation of a uniform film of low viscosity on the roller, can be used^{6,20,55,58,59,62}. It has been claimed that bone dry fabrics cannot be treated on the Triatex system and some conditioning of the fabric is necessary to improve absorbency^{20,59,60}. Some physical properties, such as crease recovery angle, wash and wear rating, tensile strength, and abrasion resistance of cotton fabrics treated with resin on the Triatex MA system are claimed to be better than those of the fabrics treated with the same amount of resin by the conventional padding process^{56,57}. Although the kiss roller system is basically a one-sided application, it has been claimed that the distribution of the finishing chemical is essentially the same on both sides of the fabric⁶³. If the liquor has to be applied to both sides of the fabric, however, a double kiss roller concept can be used⁶⁴.

4.2.4 Wicking System

Another technique for the application of chemicals to fabrics at low wet pick-up levels is the wicking system based upon the rotary-screen printing technique^{6,29,40}. The wicking system is shown in Figure 12.

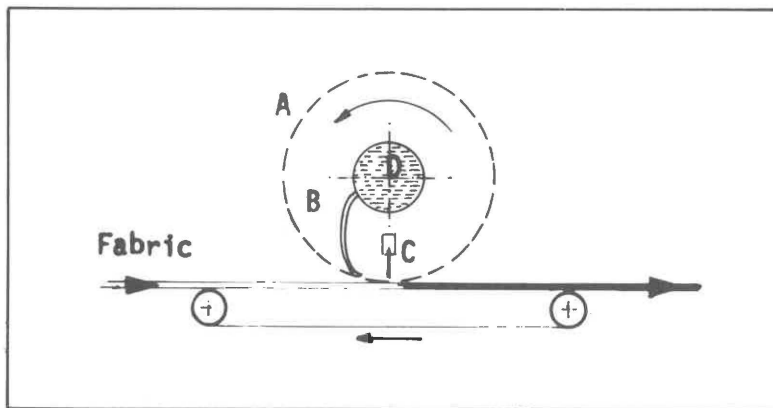


Figure 12: Wicking System

5 Loop Transfer System

Another well known indirect padding technique is the loop transfer system^{40,51}. There are two basic loop transfer systems using a loop fabric and either two or three rollers, as illustrated in Figure 14, can be used.

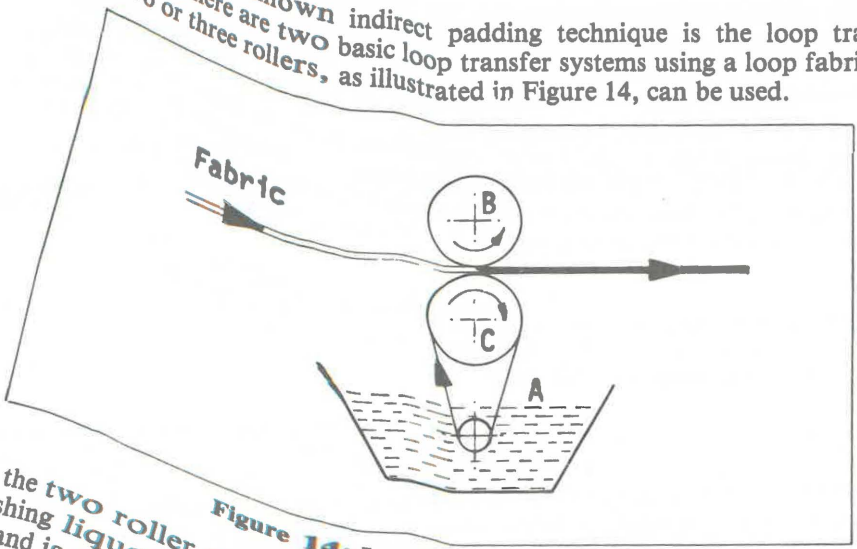


Figure 14: Loop Transfer System (two rollers)

In the two roller system, the fabric loop (A) passes continuously through the liquor bath, and is then squeezed onto the fabric to be treated between the pair of rollers. The wet pick-up obtained with this system varies from 15% to 40%⁵⁰, and this could be further reduced by the use of a roller bar running against the liquor bath to remove excess liquor from the loop^{51,52,66}.

The three-roller pad system, which is shown in Figure 15, is a more sophisticated loop transfer approach.

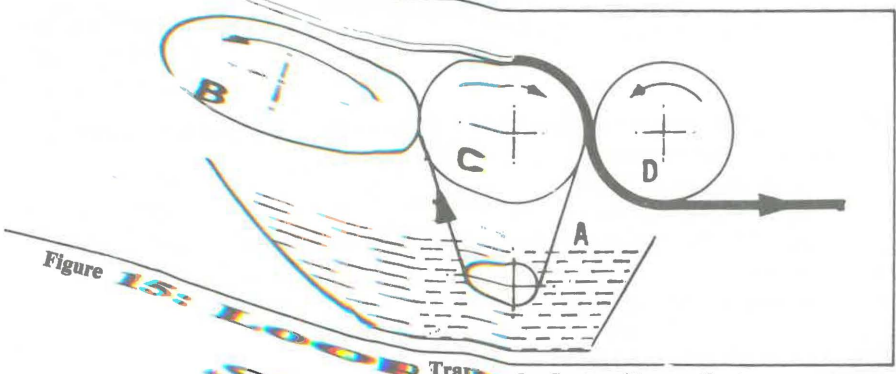


Figure 15: Loop Transfer System (three rollers)

The wicking system operates on the principle of creating a film of finishing liquor on the inside surface of the screen (A) by means of a wick device (B). This film of liquor is then forced through the mesh of the screen onto the fabric by means of a squeegee (C) under a relatively high pressure. The wick is fed with liquor from the pressurised reservoir (D). Little information is available about this method of application. It is claimed, however, that the relatively high squeegee pressure could result in excessive noise levels. Furthermore, it has been reported that low viscosity liquors cause lubrication problems and there is some evidence that it is difficult to control the addition level⁴⁹.

The actual wicking mechanism which is used to apply the film of liquor to the inside of the screen, can also be incorporated into another system, utilizing a 2-roller padding mangle (Figure 13).

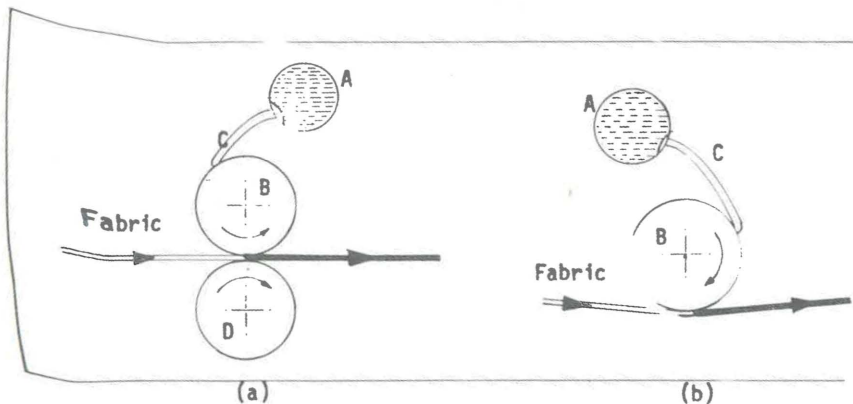


Figure 13: Liquor Transfer by Wicking Systems

The fabric can either be passed into the nip formed by the rollers (Figure 13 (a)), or it can be treated according to the kiss roller principle (Figure 13 (b)). In the former case the finishing liquor is applied from a reservoir (A) as a continuous film to the top roller (B) through a wick device (C). The liquor is then transferred from the top roller to the fabric in the nip formed with the bottom roller (D). In the kiss roller principle (Figure 13 (b)) the roller (B), rotating in the opposite direction to the fabric, applies the liquor to the fabric. The liquor is supplied to the wick (C) from the pressurised reservoir (A). The wet pick-up is controlled by the liquor level in the reservoir^{6,40,49,65}.

The loop (A), placed over the centre roller and under a submerged bar in the finishing liquor, passes through the liquor, travels up to the nip formed between the first (B) and second (C) rollers, and is squeezed to remove excess liquor, thus controlling the wet pick-up of the loop. The loop then passes between the nip formed between the second (C) and third (D) rollers along with the fabric to be treated, so that a limited amount of liquor is transferred from the loop to the fabric. Increasing the nip pressure between the second (C) and third (D) rollers increases transfer of liquor from the loop to the fabric. Proper adjustment of the roller pressures, along with proper choice of loop material, or by the use of wiper or roller bars, can result in wet pick-up values of 10% to 50% for cotton and cotton/polyester fabrics^{6,7,40,50,52,66-68}. Harper⁶⁹ reported that the loop transfer process produced higher crease recovery angles, durable-press ratings and better resistance to abrasion than conventional padding.

Although this technique is simple, there are some problems associated with it. The loop must be seamless and dimensionally stable, build-up of chemicals in the nip must be prevented and uniform absorbency of the loop must be maintained while running^{8,11}.

4.2.6 Pad Transfer System

In the pad transfer system, as developed by Rössler and Pusch^{70,71}, the fabric which is treated can be used as its own transferring loop. The pad transfer system is shown in Figure 16.

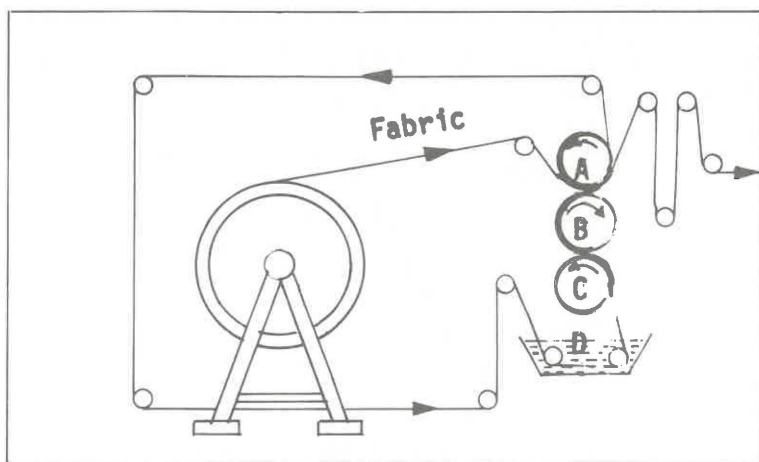


Figure 16: Pad Transfer System

On a conventional padder with three rollers the incoming dry fabric is partially prewetted during the final squeezing between rollers (A) and (B) of the already impregnated fabric. The partially wetted fabric then moves over some guide rollers and is completely impregnated in a liquor bath whereafter it is squeezed at the nip of the top two rollers (A and B) of the padder together with the incoming dry fabric. This process is also known as the Q and S (squeeze/suction) technique^{6,31,67,72-75}.

It has been claimed that the pad transfer system gives more uniform treatment than other transfer systems⁶⁶. Furthermore, it has been reported that the pad transfer system produces higher crease recovery angles, tear and bursting strength and durable-press ratings than the conventional padding process^{51,65}. Some contradictory statements have been made about the wet pick-up values obtained. For example, in Europe, where this system is well established, wet pick-up levels are reported to vary from 15% to 40%^{31,71,75,76}, while in the USA, where it is not so popular, wet pick-up levels on cotton fabrics are claimed to be somewhat higher, namely 60% to 75%^{5,9,66,77}.

There are various other pad transfer systems available which differ slightly as far as the roller arrangement and the way the fabric passes through the system are concerned^{78,79}.

4.2.7 *Spraying system*

Another system for the application of finishing liquors in controlled quantities at low levels to a fabric is that of spraying^{5,6,8-10,16}. In this system the liquor containing the chemicals or finishing agents is sprayed on the fabric through a manifold with spray nozzles (A) as illustrated in Figure 17.

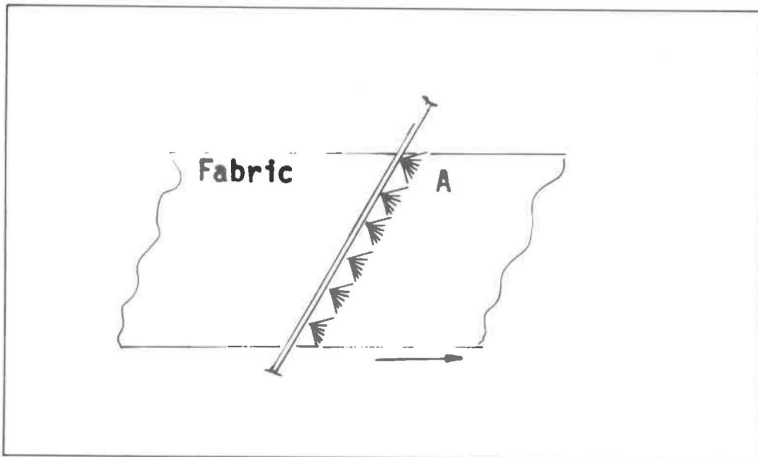


Figure 17: Spraying System

The amount of chemical to be deposited is controlled by the concentration of the liquor, the diameter of the nozzles and the pressure inside the manifold¹⁶. It has been claimed that this system requires a great deal of control⁹, and that the overlapping sprays from adjacent nozzles can result in an uneven distribution of the chemicals^{6,40}. Coban *et al*⁸⁰ claimed that the application of crease resist finishes and flame retardants to cotton fabrics at a wet pick-up of about 35% by a spraying system produced better results than a conventional padding process. Furthermore, Rath *et al*⁸¹ claimed that fabrics treated by the spraying system had higher crease recovery angles and resistance to abrasion than those treated conventionally. On the other hand, Coban *et al* reported that conventional padding produced better water repellency results than spraying. It is interesting to note that the spraying system is apparently not only used for finishing, but also for the continuous fixation of prints and pad dyeings on polyester and cotton fabrics⁸².

Some of the more innovative spray systems marketed by Brückner, Weko, Farmer Norton and Burlington Textile Machinery Corp., will now be discussed briefly.

Brückner has developed two different spraying systems. In the one system the liquor containing the chemicals is first sprayed by nozzles on an inclined distribution plate which vibrates and transfers the liquor to the fabric⁸³. In this system there is no overlapping sprays from adjacent nozzles^{6,40}. In the Brückner Rotta-Jet spraying system the fabric (wet or dry) passes into an enclosed plastic unit where it is charged by the action of a high electrostatic field (a 150 kilovolt at 1 mA potential difference). High energy spray nozzles are employed to spray the finishing liquor, which is rapidly taken up by the charged fabric, either on one side or both sides of the fabric^{19,22,84,85}.

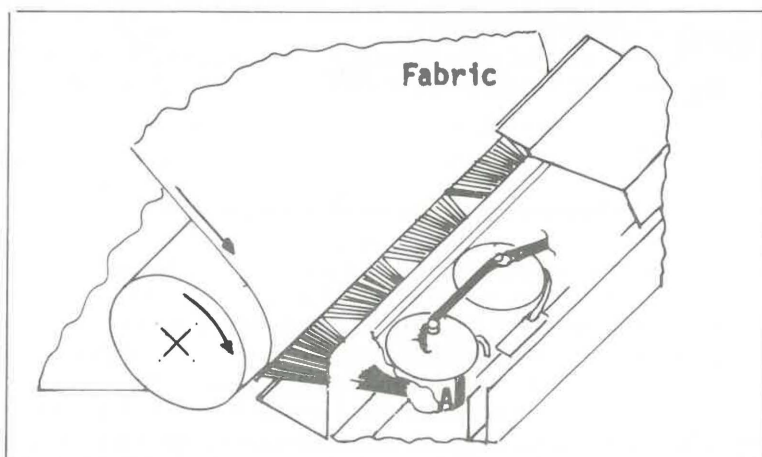


Figure 18: Weko Spray System

4.4 Some Limitations of Low Add-on Application Techniques

It has been reported that fabrics should be well prepared and uniformly absorbent for treatment at low wet pick-ups^{13,98,101}. If the wet pick-up is too low, the penetration of chemicals will be incomplete resulting in an uneven distribution of chemicals¹⁰. Very low wet pick-up levels can also create problems in width stretching during drying⁹⁷. It has also been reported that the treatment of tubular knitted fabrics by the low add-on application techniques was not successful²⁰. It is known that the *topical* low add-on application techniques cannot be used on all the fibre types and fabric constructions. Furthermore, certain finishing chemicals cannot be applied in this manner⁹. The *expression* low add-on application techniques, on the other hand, are not suitable for wet-on-wet applications²².

5. FOAM APPLICATION TECHNIQUES

5.1 Historical Development of Foam Processes

Despite the fact that many people are under the impression that the wet processing of textiles with foam is an entirely new development, this is not the case. In fact, as long ago as in 1907 a patent was granted for an improved process for degumming silk using soap lather¹⁰². Later (in 1930) a method was described for simultaneous scouring and dyeing of fabrics with foam¹⁰³. More recently (in 1961), a process for engraved roller printing with foamed printing pastes was disclosed¹⁰⁴. Foams have also been used for some time in the Sancowad dyeing process¹⁰⁵.

In foam applications a large percentage of the water (about 50% to 95%) which is normally used to apply the chemicals to the substrate is replaced by air, offering the advantage that significantly less water has to be evaporated during the subsequent drying operation. Furthermore, it is frequently possible to use existing equipment such as the conventional padder for foam application techniques. A number of mills have, in fact, developed their own relatively simple foam applicators for a wide variety of uses¹⁰⁶.

Several manufacturers of textile machines, however, have patented new developments, such as Union Carbide and Gaston County¹⁰⁷⁻¹¹⁰, United Merchants and Manufacturers¹¹¹⁻¹¹⁴, Monforts¹¹⁵⁻¹¹⁶, Mitter¹¹⁷⁻¹¹⁹, Dinting¹²⁰ and Küsters¹²¹⁻¹²³. It is clear that there is a rapid growth in the field of foam application and machine manufacturers offering foam equipment and foam finishing machines increased from 2 at ITMA 1979 to about 10 at ATME 1980^{124,125} where foam finishing equipment was one of the biggest attractions^{126,127} and 28 towards January, 1982¹²⁸. At ITMA 1983 the total number of foam equipment exhibited was more than 30¹²⁹.

Practically all the chemicals which are used for the conventional treatment of textiles can be applied to textiles in a foam medium provided that a suitable foam can be produced. A survey of the literature showed that pro-

ducts such as dyes, durable-press resins, softening agents, soil-release products, water- and oil-repellent finishes, stiffening agents, flame retardants, optical brightening agents, bonding agents, non-slip finishes and anti-electrostatic finishes can be applied by foam^{113,130,131}. Furthermore, chemicals used for sizing¹³²⁻¹³⁷, bleaching¹³⁸, mercerisation¹³⁹, wool carbonising¹⁴⁰⁻¹⁴² and the shrinkresist treatment of wool¹⁴³⁻¹⁴⁴ can also be foamed. Foams can be applied to a wide variety of fabrics (from lightweight to heavyweight woven and knitted fabrics), non-wovens, fusible interlinings, industrial fabrics, carpets^{113,119,145,146}, and they can also be applied to yarns^{147,148}.

5.2 Different Systems for the Application of Foam

There are several basic mechanisms for the application of foam to textiles. The foam can be applied either to one side or both sides of the fabric. In the former case a doctor blade or knife, or a doctor roller, or pressure or suction can be used, and for two-sided applications a horizontal padder or a pair of transfer or kiss rollers can be used. Figure 20 shows the basic approaches employed for the application of foam.

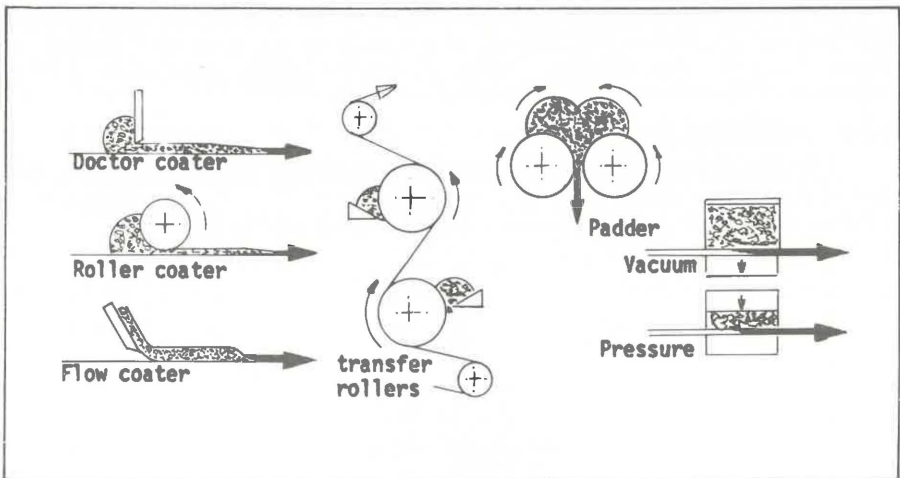


Figure 20: Methods of Foam Application

After application, the foam has to be broken down or collapsed before the liquor can diffuse into the fabric. Several methods are available for the collapse of the foam on the fabric. The simplest method, however, is to allow the foam to collapse by capillary action which withdraws the liquid from the

foam into the fabric. The foam can also be collapsed by squeeze rollers, or the application of pressure or vacuum^{130,149} as illustrated in Figure 21.

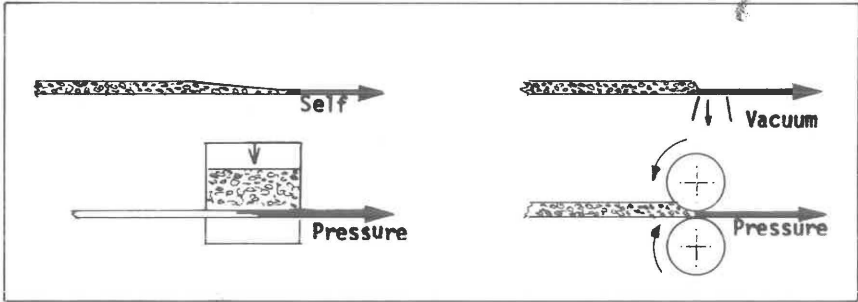


Figure 21: Methods to Collapse Foam

It is also possible to collapse the foam through methods utilising temperature, the presence of destabilisers, and shear forces¹³⁰.

Upon the collapse of the foam the liquor should completely and uniformly penetrate the fabric. The add-on or wet pick-up depends on a number of factors such as foam density, volume of foam applied, mass of the fabric, thickness of foam layer and the production speed^{44,150-152}.

5.2.1 Horizontal Padder

The pad mangle, which is in operation in almost every textile mill, was one of the first machines used for foam application^{73,76,153-158}. The treatment of a fabric with foam on a horizontal padder is illustrated in Figure 22.

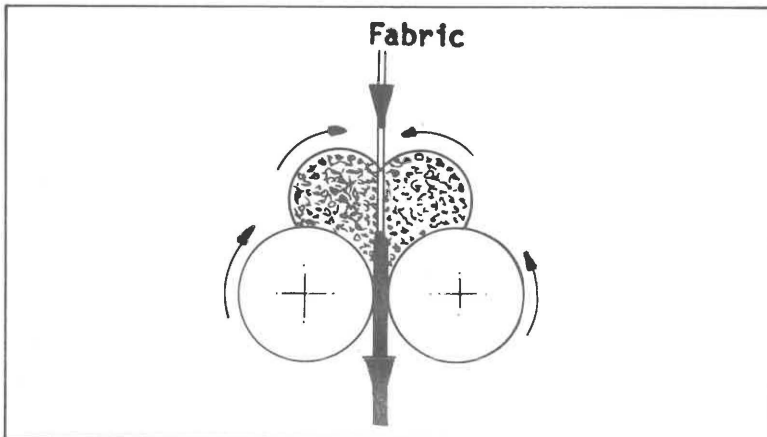


Figure 22: Horizontal Padder

In the horizontal padder the foam is applied to both sides of the fabric which runs vertically through the foam contained in the nip of the padder. The foam collapses at the nip of the padder, ensuring a uniform application of liquor^{106,130,153,155-161}. In this particular technique foam stability is an important parameter. An unstable foam will form an excessive amount of liquor in the nip, resulting in an uneven application, whereas a more stable foam will tend not to collapse in the nip by the action of the pad rollers^{106,153,160}. The wet pick-up of the fabric is controlled by the foam density and the nip pressure¹³⁰. Generally, the horizontal padder is used to apply foam to woven fabrics¹⁵⁹. The main advantage of the horizontal pad system is that a conventional padder can be easily converted into a foam padder with very little capital investment^{130,159}.

United Merchants and Manufacturers^{158,162} were one of the first companies to patent and commercialised the padder for foam application.

It has been claimed that finishing liquors can be applied to cotton and cotton/polyester fabrics by the horizontal padder at a wet pick-up of about 30%^{145,155,156,159,162}. United Merchants and Manufacturers^{125,127,128,163,164} also developed a pad foaming system for circular knitted outerwear fabric and licensed Tube-Tex to market the system. The finishing liquors can be applied to 50%/50% cotton/polyester tubular knitted fabrics at a wet pick-up of 20% to 30%¹⁴⁶. Mohr^{150,165,166} built a machine operating on this principle for the foam treatment of non-wovens. Bruchner and Hall and Boyden are manufacturing similar foam application systems¹²⁸.

Fleissner developed a special foam application system for the production of non-woven interlinings. This system is closely related to the pad system¹⁶⁷⁻¹⁷⁸ and is shown in Figure 23.

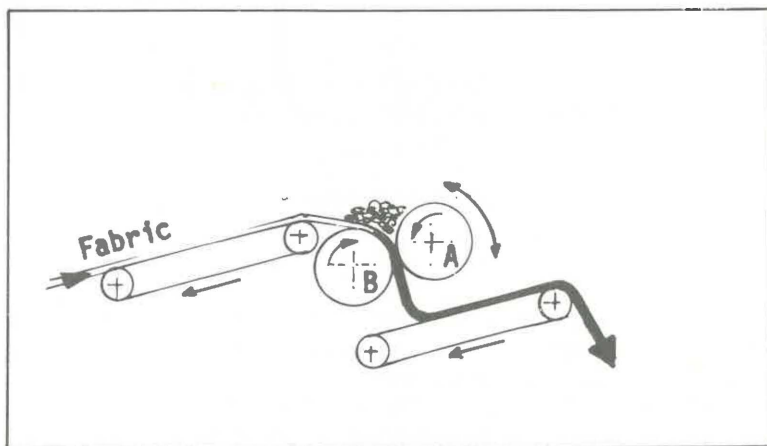


Figure 23: Fleissner Foam Applicator

The coating roller (A) rotates in the opposite direction as the movement of the fabric and transfers the foam to the fabric in the nip of rollers A and C. The metering roller (B) controls the amount of foam which is applied to the fabric by the coating roller^{5,8,10}.

Küsters have developed two foam processing systems, the Mini-Foam applicator for wovens, knits and non-wovens and the Maxi-Foam system for carpets and heavy pile fabrics^{29,125,127,163,166,185-191}. The Mini-Foam system is built in three standard models, for one-sided application on the face of the fabric, for one-sided application on the back of the fabrics, and for simultaneous two-sided application. The latter model is known as the Janus Mini-Foam system^{29,163,192} and is shown in Figure 27.

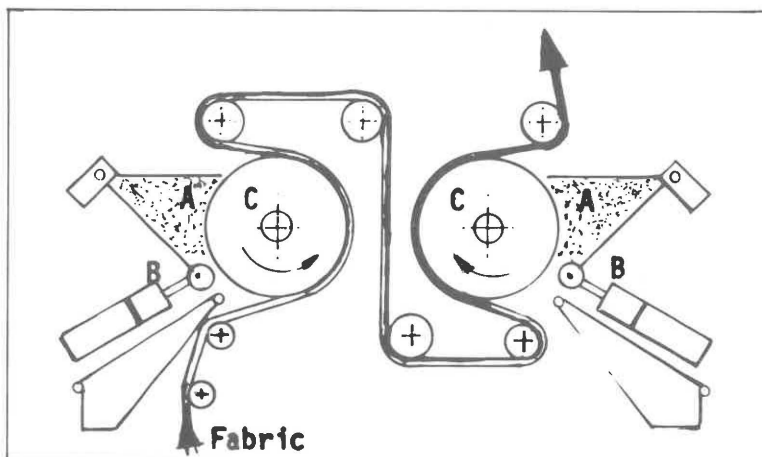


Figure 27: Janus Mini-Foam Applicator

In the Janus Mini-Foam system the foam is fed into the foam trough (A) by an oscillating feed-pipe. The trough has adjustable sides which can be set to the appropriate fabric width. An adjustable doctor roller (B) at the lower end of the trough controls the amount of foam and thickness of the foam layer (0,4mm to 40 mm) on the rotating application roller (C). The foam is then transferred to and pressed into the fabric as it passes 180° around the application roller^{20,186,193-197}. In this system the foam is collapsed by capillary forces and pressure^{186,192}. The two distinct mechanisms involved are the application of foam to the application roller, followed by the transfer of the foam to the fabric²⁹. The twin roller Janus machine comprises two such applicators enabling both face and back of the fabric to be treated. In this instance two different foam liquors can be applied separately but simultaneously to the two

sides of the fabric^{29,125,128}. Parameters which determine the wet pick-up are the speed of the application roller, width of the gap between the doctor roller and the application roller, foam density and the speed of the fabric^{130,186,192}.

It has been claimed that the wet pick-up varies from 15% to 30%. Certain finishing chemicals, however, are applied at a wet pick-up of about 35%^{127,128,163,197,198}. The two-sided application using one or two different foams is normally recommended for woven and knitted fabrics of 150g/m² and more¹⁹¹.

The Maxi-Foam system^{163,186,188,190,192,194,198-200} for applying foam to carpets and pile plush fabrics is illustrated in Figure 28.

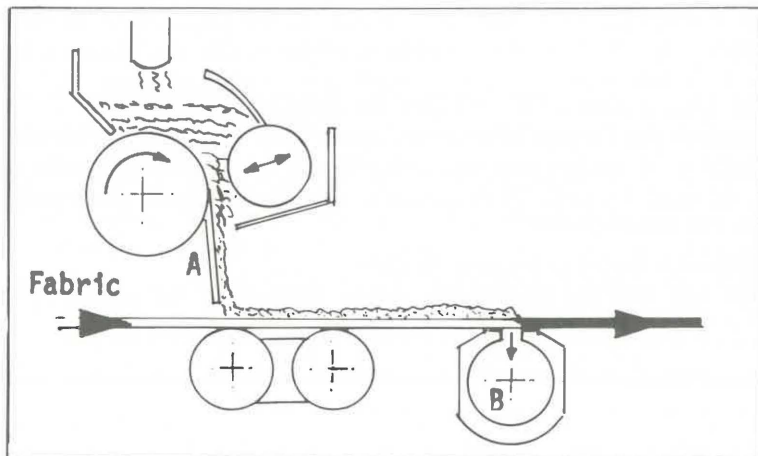


Figure 28: Maxi-Foam System

The Maxi-Foam system operates basically on the same principle as the Mini-Foam system, except for the mechanism of foam transfer to the fabric and the collapse of the foam. In this system a uniform layer of foam flows down an adjustable vertical doctor blade (A) onto the face of the carpet, followed by vacuum extraction (B) to collapse the foam^{152,189,194,199,201}. The speed of the application roller and the opening of the gap between the application roller and the doctor roller determine the amount of foam supplied to the fabric^{186,189}. In a typical dyeing operation, the first step is a padding operation to a residual wet pick-up of 50% to 70%, which supplies a part of the dye necessary for medium and heavy depth shades. This is followed by the application of the foam containing more dye to produce the required shade. The foam is applied at a pick-up of about 80% and the total wet pick-up, therefore, ranges from about 130% to 150%. It has been claimed that this compares favourably with conventional carpet dyeing which requires an initial wetting-

out treatment of 80% plus a further 450% for dyeing^{127,128,186,198,201}. With some qualities of carpet foam dyeing can be carried out without applying vacuum to collapse the foam. It has been reported that variations in carpet permeability could cause streaks, but despite this, better yarn and tuft definition was maintained¹⁹⁸ and dyestuff fixation was higher^{199,201}. There are also other versions of this system which have an adjustable blade acting as a "reversed doctor"²⁰².

Although it was originally suggested that the Küsters dyeing system could be combined with the TAK or Küsters Colour units^{186,201}, it was not possible in practice due to the nature of the foam dyeing process¹⁹⁸. Recently a new multicolour foam dyeing machine, known as Küsters Foamcolour, was developed. In this system as many as four different coloured foams are delivered on a doctor blade and multiple options are available to break up the colour and create designs. Air, mechanical fingers, jets etc. are used for this purpose. For each colour a separate foam generator is required, and careful control of foam properties is necessary for consistent results²⁰³⁻²⁰⁷.

In general the Küsters Maxi-foam application system is not suitable for the application of foamed coatings to textile fabrics. Furthermore, the system has been developed mainly for carpets and it is not possible to treat lightweight fabrics at low wet pick-ups¹⁹¹.

5.2.3 Knife-Over-Roller Coating System

Foam can also be applied to textile fabrics by the knife-over-roller system^{73,106,127,155-157,202}. This system is shown in Figure 29.

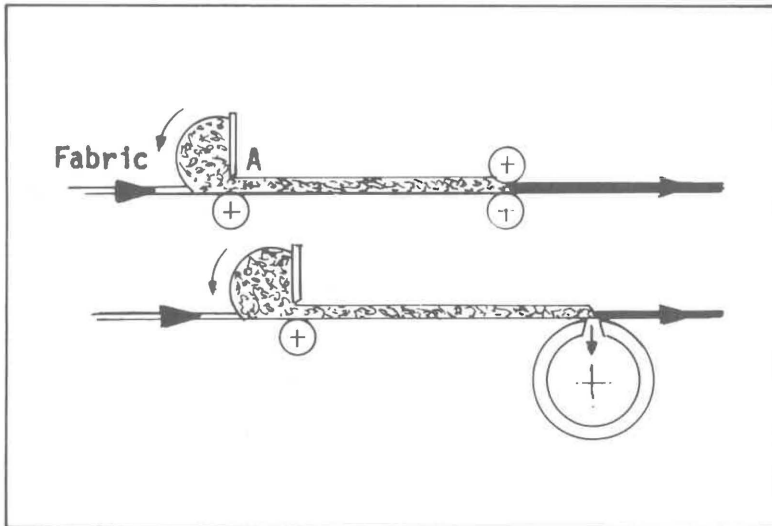


Figure 29: Knife-Over-Roller Coating System

The foam is applied as a uniform layer to the fabric surface by a doctor blade or roller (A). The thickness of the foam layer is controlled by adjusting the height of the doctor blade or roller. Since a relatively stable foam is used, the foam has to be collapsed by a pair of pressure rollers (B) or by means of vacuum (C) as illustrated in Figure 29. The wet pick-up is in the range of 30% to 35%¹⁵⁷ and is controlled by the foam density and the setting of the doctor blade or roller^{76,84,130,151,157}. The knife-over-roller system is suitable for one-sided application or coating finishes, e.g. for upholstery materials or mattress ticking¹³⁰ and for the dyeing and finishing of pile fabrics^{157,163}.

United Merchants and Manufacturers have used the knife-over-roller system followed by the two pressure rollers to collapse foam^{111,112,155,159,208}. They claimed that when a 50%/50% polyester/cotton fabric was treated with a durable-press resin, the wet pick-up could be reduced from 60% to 30%, while the processing speed could be increased from 30 m/min to 38 m/min. Furthermore, the temperature of the curing oven could be reduced from 177°C to 107°C, resulting in a total gas saving of about 74%^{155,159}. Some improvements in durable-press ratings, crease recovery angles and shrinkage during washing were recorded²⁰⁹.

The Monforts machine (Figure 30), also known as Vacu-Foam, uses a knife-over-roller (A) to meter a uniform layer of foam on a rubber blanket (B). Transfer of the foam to the fabric occurs when the blanket makes contact with the fabric. Penetration of the foam into the fabric is assisted by vacuum as the fabric passes round a perforated drum (C)²¹⁰⁻²¹⁵.

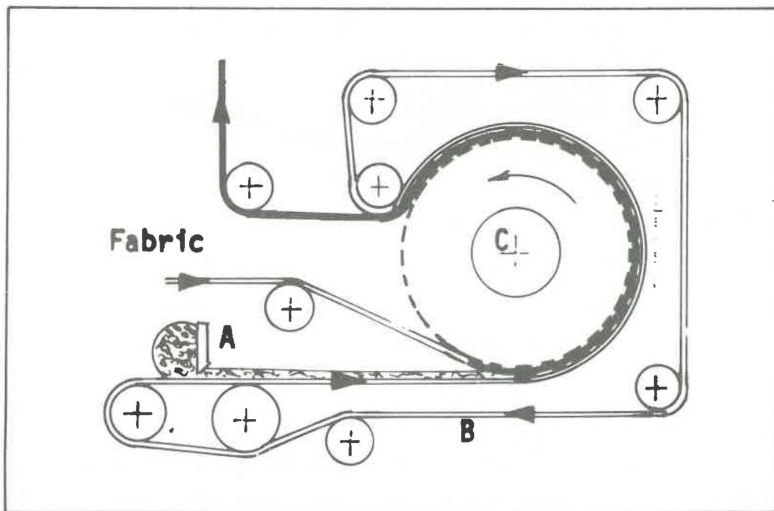


Figure 30: Monforts Vacu-Foam System

The add-on is controlled by the foam density and knife clearance whereas the rate of foam collapse is dependent on factors such as capillary forces, the vacuum inside the perforated drum and the pressure on the fabric^{130,150,211,212}. The wet pick-up obtained by the Monforts system is about 35% to 40% for cotton and about 10% for polyester. Foam can be applied to one side only as well as to both sides of woven and knitted fabrics. Even elastic warp knits and pile fabrics can be treated on this system^{128,151,211,215}. It has been claimed that the crease recovery angle and resistance to abrasion of the cotton fabrics treated with foam compared favourably with those treated by the conventional padding process²¹⁵.

Other manufacturers of knife-over-roller systems are, for example, Mondomix¹⁹⁷ and Greenville Machinery who in collaboration with Galaxy Carpets developed the Vivadye process for carpet dyeing and foam systems^{185,198}. Mathis offers a foam application unit which is based on the combination of a doctor blade, vertical padder and vacuum system²¹⁶, as well as a laboratory foam application unit²¹⁷.

5.2.4 Knife-on-Air System

A modification of the direct application of foam by the knife-over-roller system is the air knife, floating knife or knife-on-air system (Figure 31).

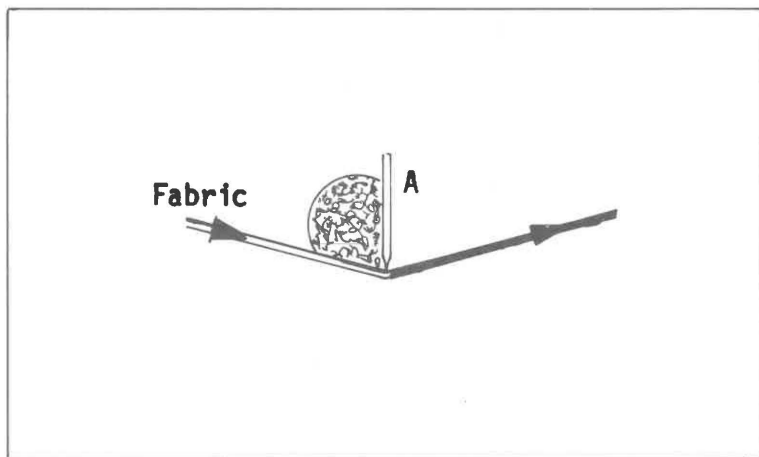


Figure 31: Knife-on-Air System

The foam is applied to a fabric in a uniform layer by a knife or doctor blade (A). In this system the foam is collapsed by the shearing action of the knife. The wet pick-up ranges from 30% to 35% and can be controlled by the foam density and the amount of foam applied to the fabric¹⁵⁶⁻¹⁵⁹.

One of the best known knife-on-air processes is the Valfoam process of United Merchants and Manufacturers^{111-113,156,157,218-220}, which is illustrated in Figure 32.

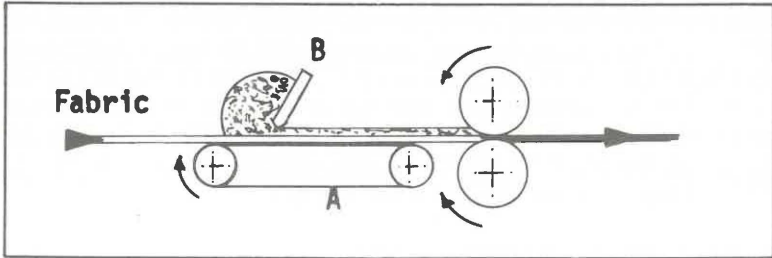


Figure 32: Valfoam Process

The fabric is conveyed on a conveying belt (A) with the doctor knife (B) directly above. Foam is applied to the fabric in front of the doctor knife which spreads it in a uniform layer. Subsequently, the foam is collapsed by pressure rollers¹¹¹⁻¹¹³. This system can apply resins and softeners to different fabrics at a wet pick-up ranging from 10% to 40%. One side or both sides of the fabric can be treated^{209,219,220} and this system has also been successfully used for dyeing carpets²²¹.

One of the most recent knife-on-air systems is the Autofoam system developed by Dinting Engineering (Tootal Ltd.). This system (Figure 33) can be installed onto an existing horizontal padder^{84,222-227}.

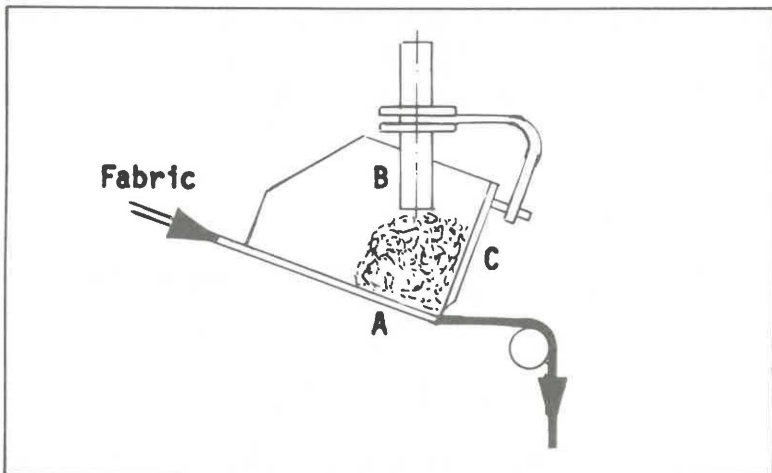


Figure 33: Autofoam System

The Autofoam system has been specially designed so that, once the details for fabric mass and wet pick-up are set, foam delivery to the fabric (A) is controlled automatically by a foam roll size probe (B) positioned in front of the doctor blade (C) to compensate for any variations in the processing speed^{222,225,226}. The wet pick-up obtained on polyester/cotton fabrics is about 15% to 25%^{159,223,224}. This system has been recommended for lightweight pile fabrics, such as corduroys, velvets and velveteens¹⁶³. It is claimed that there is a saving of about 15% in chemical cost and about 50% in energy consumption. Furthermore, the Autofoam system is suitable for a wide variety of fabrics including needle-punched carpets. It is also suitable for wet-on-wet applications²²⁸. A laboratory machine is also available⁸⁹.

5.2.5 Screen Printing System

In this system foam is applied to the textile substrate by means of the screen printing technique. The foam can be applied to a fabric through a flat screen, a flat screen with a doctor roller, or a rotary screen with a squeegee or magnet roller^{185,191,202}. Examples of commercial foam application machines using the screen printing principle are those manufactured by Mitter, Printaire, Zimmer and Stork. The principal operation of some of the more important of these machines will now be discussed.

In the Mitter system (Figure 34) foam is applied to a fabric using a screen and a doctor blade, which is based on the same mechanical principle as that used in the conventional printing system^{117-119,229-234}.

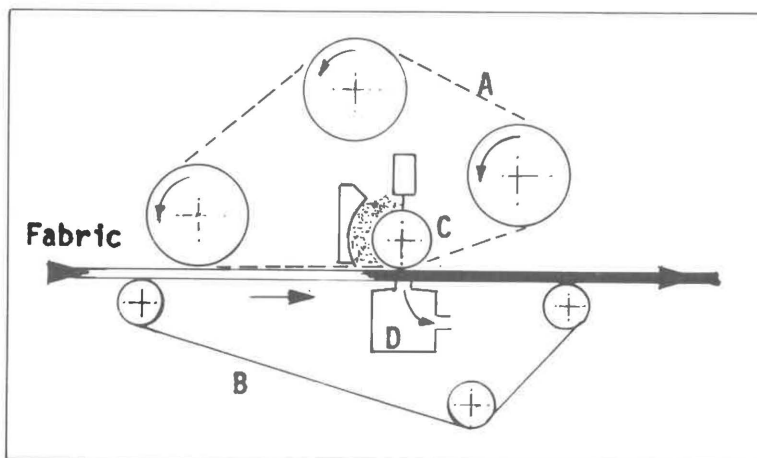


Figure 34: Mitter Foam System

The Mitter foam system, also known as the Triangular Print Head employs a printing head consisting of a triangular screen belt (A) under which the fabric is conveyed on another screen (B), all travelling at the same surface speed. Foam is applied without pressure to the fabric by means of the upper screen and the doctor roller (C). The foam is then collapsed and allowed to penetrate into the fabric by the action of the vacuum slot (D) which is placed below the screen directly under the printing head. The degree of penetration depends on the amount of vacuum applied to the fabric²³⁰⁻²³⁴. The Mitter foam system is mainly used for dyeing and printing of carpets and pile fabrics^{160,163,229,235,236}. The wet pick-up obtained during carpet foam dyeing is claimed to be 40% to 110%, compared with a wet pick-up of 500% to 600% for conventional carpet dyeing^{229,231,234}.

Printaire is also offering foam equipment for dyeing (CFD 11) and printing (OMNI) of carpets^{127,128,198,199,236-238}. The Printaire continuous foam dyeing (CFD 11) system (Figure 35) operates on a principle entirely different from the other foam application techniques.

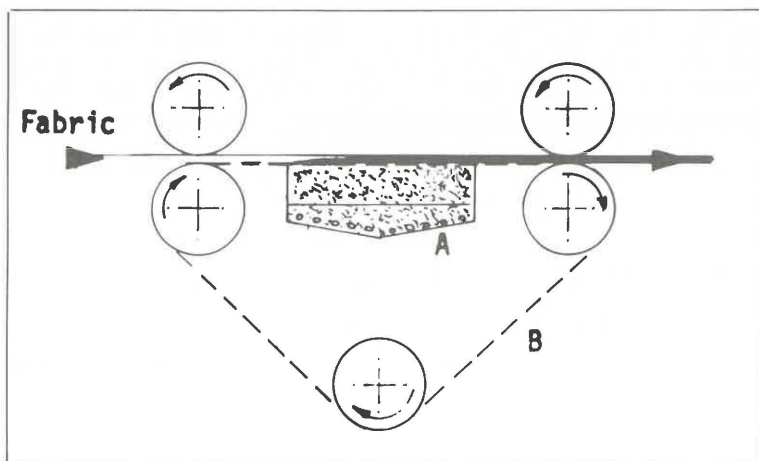


Figure 35: Printaire System

In the Printaire system foam is generated in situ, using a bath (A) with liquor placed directly beneath and in contact with the carpet surface, eliminating the use of a separate external foaming unit. Air jets cover the bottom of the dyebath containing a solution of dye and a foaming agent. The air which passes through the liquor produces coarse foam bubbles. As the carpet passes pile down over a screen cover on the foam bath, the foam passes

through the 16 mesh rotary screen (B) into the carpet^{202,204,236,238}. A special seal arrangement is used to facilitate an increase in the pressure in the liquor bath in order to improve dye penetration. The denser and heavier the pile, the greater the pressure which is applied^{128,163,202}. Screens of different porosities can be used in order to vary the degree of penetration¹⁹⁸. The wet pick-up is controlled by the pressure, the foam density and the air flow rate²³⁶. It has been claimed that the wet pick-up ranges from 40% to 120% depending on the type of carpet^{128,152,198,238}. Some units have both upper and lower screens to sandwich the carpet. The Printaire foam dyeing system (CFD 11) uses a 100% open mesh screen for solid dyeings, whereas the foam printing system (OMNI) has a patterned mesh screen for design printing²³⁶. The foam dyeing system is particularly suitable for dyeing long shaggy pile carpets¹⁸⁵. More recent development of the Printaire system is being carried out by the West Point Foundry and Machine Co.²⁰⁴.

Another modification to the doctor roller for foam application is found in the Zimmer system. Textile processing equipment based on flat and rotary screen printing and coating technology are used for the development of the Magnet-System principle for the application of foam. A number of systems are used for foam application, e.g. the Magnet roller rod, Magnet doctor squeegee, Hydroslot and Variopress²³⁹⁻²⁴⁶. Some of these systems will now be described. The magnet roller rod system in Figure 36 shows the application device which was originally designed for the application of glue, but is now used for applying a layer of foam to the fabric.

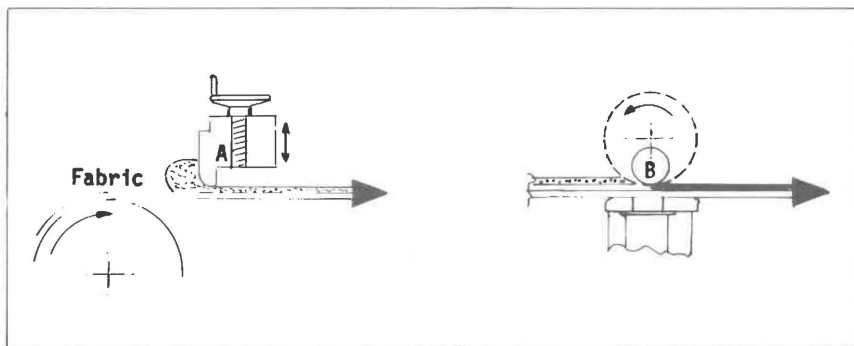


Figure 36: Magnet Roller Rod System

The thickness of the foam layer can be adjusted by lowering or raising the doctor blade (A). The foam is then allowed to collapse either on its own or through the use of magnet roller rod (B). The diameter of the rod and the magnetic pressure can be adjusted independently^{239,241-244}.

A further alternative (shown in Figure 37) is to use a rotary or flat screen printing machine for foam application with the use of a magnet roller rod (A) or a magnet squeegee with an open mesh or an engraved rotary screen (B)^{239,240,245,246}.

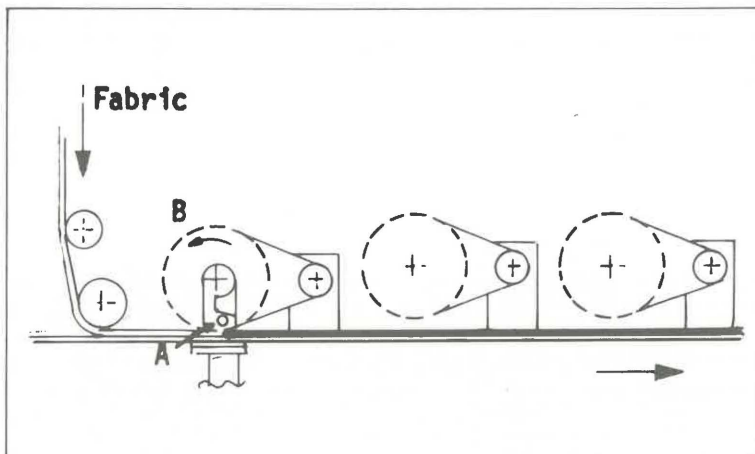


Figure 37: Magnet Squeegee System

It is claimed that all Zimmer flat screen printing machines can be modified into rotary machines operating with the Magnet system. This system is used mainly for printing, coating and finishing of textiles or non-wovens^{242,243}.

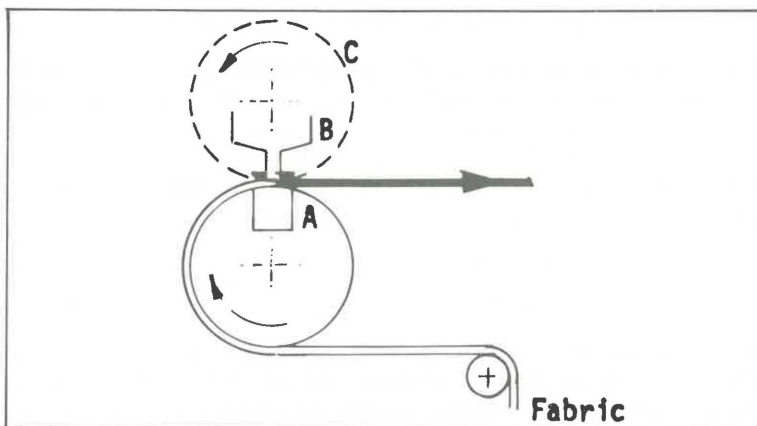


Figure 38: Hydroslot System

The Hydroslot system, (see Figure 38), which is well established in the carpet printing industry, can also be used for foam application²⁴⁰. As the textile fabric passes around a magnet roller (A), foam is applied to its surface by the slot squeegee (B) through a rotary screen (C). Foam can also be applied without a screen. The add-on level is determined mainly by factors such as the screen characteristics, the squeegee slot width and the processing speed^{239,242,244}

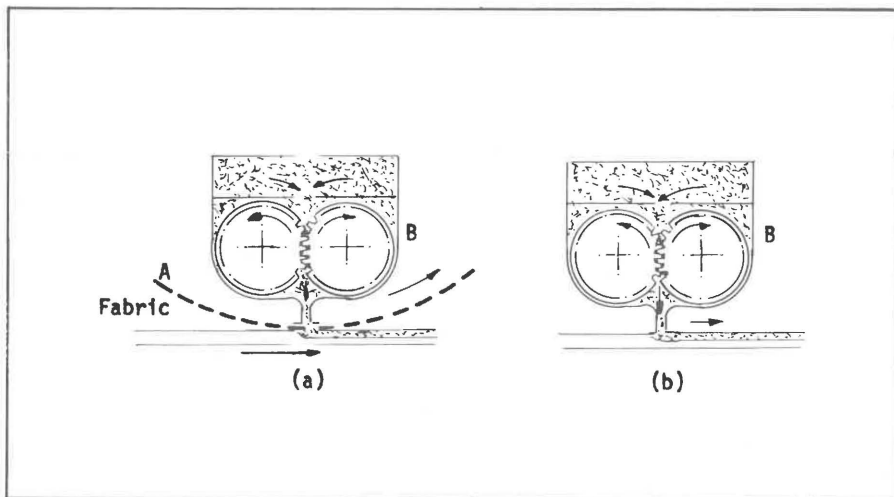


Figure 39: Variopress System

Figure 39 shows the recently developed Variopress system, which can be used for direct applications, such as foam dyeing, or in combination with rotary screens for foam printing. The Variopress system can be used with (Figure 39(a)) or without (Figure 39(b)) a rotary screen. Without a rotary screen (A) the Variopress unit (B) can be set at various heights to give controlled surface application or penetration of the foam to a controlled depth^{239,241,243}. It has been claimed that a wet pick-up of 15% to 40% could be obtained in foam finishing and coating of woven and knitted fabrics and non-woven by the Zimmer systems^{185,202,246}.

Stork introduced its first rotary screen printing machine in 1963²⁴⁷, followed by wallpaper and vinyl floorcovering installations and a coating machine at a later stage^{248,249}. This coating machine, with the PD-111-C unit, forms the basis of the RSF (Rotary Screen Foam) system^{249,250}. The RSF 'air

flow' or hydrostatic squeegee is illustrated in Figure 40.

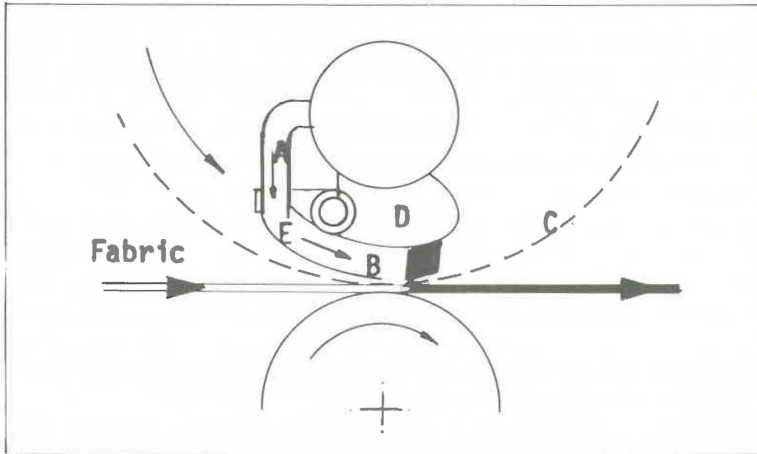


Figure 40: RSF Squeegee/Screen System

In the Stork rotary screen foam system the foam is delivered by the foam generator to a chamber (A) formed by two stainless steel blades. The upper blade (B) has a tip of synthetic material and is pressed against the screen (C) by air bellows (D). The lower blade (E) is pressed against the screen by combined mechanical and hydrostatic foam pressure. The system has a foam exhaust unit which removes excess foam from the screen and the counter-pressure roller and carries it back to the liquid reservoir. Furthermore, there is a counter-pressure roller cleaning system^{247,249-253}. The amount of foam squeezed through the screen depends on the squeegee setting. If, for example, the upper blade of the squeegee is set to a light pressure, the amount of foam fed to the nip is small¹²⁵.

During operation, the foam passes continuously through the screen in the appropriate amount to the passing fabric. A special 40-mesh Penta-screen was developed, which has a wall thickness of about 250 μm and an open area of 35%. The screen has a 91,4 cm circumference, which provides sufficient contact with the fabric^{29,226,248,254}. Furthermore, due to the closed system both unstable and stable foams can be used in the RSF system to give wet pick-ups from 15% to 40%^{205,254-259}. To achieve optimum penetration of the chemicals into the fabric an unstable foam is used^{248,249,254}. Since foam is applied to only one side of the fabric, the degree of penetration depends largely on the mass and construction of the fabric²⁰⁵. A control system ensures a constant foam supply, which means that the amount of foam supplied will increase or

decrease automatically and proportionally with an increase or decrease in production speed^{247,249}. Furthermore, the amount of air fed to the generator and therefore, foam density, is controlled electronically and this means that precise control of the foam characteristics is possible^{127,226,247}. The liquor add-on level is controlled by the foam density, squeegee pressure and screen mesh number^{130,150}. The surface speed of the screen is equal to that of the fabric. This, together with the very low mechanical pressure of the squeegee inside the screen, give frictionless delivery and consequently even highly sensitive (e.g. plush) and unstable (e.g. knitted) substrates can be processed^{29,125,247-249,254,255}. The system can be used for coating and to apply one-colour printing^{29,197,247,260}. Furthermore, the system can be used for spot printing, coating with mechanical stable foam and single-colour pattern printing²⁶¹. Both sides of the fabric can be processed in one continuous passage by combining two such units similar to an arrangement used for double-face printing operations¹⁹¹. With the RSF system wet-on-wet application can also be carried out thus eliminating intermediate drying operations^{255,256,259,260,262-264}.

During the treatment of a typical 100% viscose curtaining fabric (400 g/m²), it was found that the wet pick-up could be reduced from 80% to 20% using the Stork RSF system. Furthermore, the drying temperature could be reduced from 180°C to 120°C and the speed increased from 20 m/min to 60 m/min^{247,250,251,253,259}.

Other manufacturers of rotary screen printing machines for foam application are Zappa and the Rotamec unit of Buser¹²⁸.

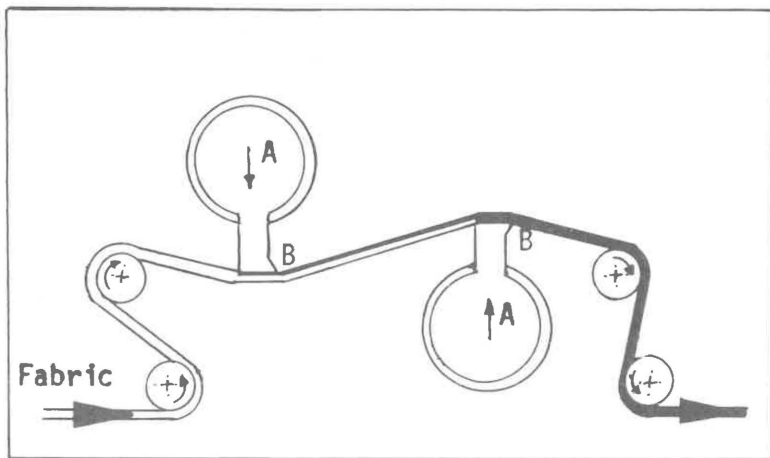


Figure 41: FFT Application System

5.2.6 Slot Applicator System

Another application of the direct pressurised foam application technique is the Foam Finishing Technology (FFT) system utilising a slot applicator unit. Originally the process was invented by Union Carbide in the early 1970's and Gaston County developed the commercial equipment in 1977^{107-110,265-272}. Furthermore, the FFT system was one of the first foam technology machines on exhibition at ITMA in 1979. Since then 70 commercial FFT foam application systems have been sold worldwide. The FFT foam application system is illustrated in Figure 41.

Foam is supplied continuously in a specific quantity by the foam generator to the distribution chamber (A) and eventually to the slot (B) of the application unit. The applicator is constructed of stainless steel with a flexiglass inspection panel immediately under the application section. The slot width can be adjusted between 0,3 mm and 25 mm and the angle of contact that the fabric makes with the inward taper of the slot is between 5° and 15° (C). It is at this point where shearing forces are responsible for the final collapse of the foam. The foam, while held under pressure in the distribution chamber and slot, is then applied directly to the fabric, which passes over the slot at an angle of between 15° and 25°. The degree of penetration of the foam into the fabric is determined by the pressure in the slot. The slot applicator is of a special design and, together with photo-electric sensors which control pneumatic edge seals, ensure that foam is uniformly distributed across the width of the fabric, and that this is maintained along the length of the fabric as it continuously passes through the machine. The meta-stable foam collapses immediately upon contact with the fabric²⁶⁷⁻²⁶⁹. The wet pick-up of the fabric is controlled by the liquor flow rate, the fabric speed and the fabric mass and it is thus independent of foam density²⁷³⁻²⁷⁶. Any variation in the speed of the fabric will electronically control the rate at which the foam is applied to the fabric.

The FFT system was initially designed with a single slot applicator for one-sided applications. Recently an application system with a dual application unit has been developed, however, for applying foam to both sides of the fabric using the same finishing liquor²⁷⁷⁻²⁷⁹. Alternatively, two different finishing liquors can be applied to the two sides of the fabric from two different foam generators²⁷⁷. Furthermore, a new slot applicator was designed recently for the treatment of open-weave fabrics with foam²⁸⁰. It has been claimed that lightweight fabrics (to 140 g/m²) can be processed with the single slot applicator system. This system can also be used for processing heavier fabrics if only one-sided effects are required, such as anchoring the pile threads to the ground upholstery fabric, or special surface finishing operations^{128,281}. The dual slot applicator can be used, for example, to apply a softener to the face of a corduroy fabric and a binder to the back of the fabric²⁸². It has been reported that a wet pick-up of 10% to 25% can be obtained on

cotton/polyester and cotton fabrics^{20,274,283,284}. Wool fabrics can be treated with foam at a wet pick-up of 15% to 30%^{143,144}. The system can also be used for backcoating^{192,285} and wet-on-wet applications are also possible¹⁴⁴. Apart from the application of durable-press resins²⁸⁶, experiments have been reported in which the application of foamed size formulations are discussed²⁸⁷. Shrinkresist treatments²⁸⁸ and the application of dyes²⁸⁶ by foam have also been studied using the FFT system.

It has been claimed that the FFT system offers several advantages over conventional padding when cotton fabrics are treated with a DMDHEU resin. For example, it was found that the crease recovery angle of the fabrics treated on the FFT system at a wet pick-up of 25% was the same as those fabric treated conventionally at a wet pick-up of 65%. The flex abrasion resistance, on the other hand, of the fabric treated on the FFT system at a wet pick-up of 25% were higher than that of the fabrics treated by conventional padding^{5,10}. In general, it has been claimed that the more efficient use of chemicals can save between 10% and 25% in chemical costs and that the energy savings vary from 50% to 75%²⁸⁹.

Gaston County also manufactures a 50 cm wide FFT laboratory unit with a slot applicator^{290,291}.

5.3 Other Systems of Foam Application

Apart from the suppliers of foam processing equipment already mentioned, a great number of other manufacturers of finishing equipment are currently investigating various aspects of foam application. Most of these foam application systems do, however, more or less follow the same broad principles outlined previously. Those manufacturers of foam application systems active in this field will only be briefly referred to. Otting developed the Jet-Foam dyeing machine^{198,204,292,293}, Sando Iron Works manufactures a U-shaped foam tube²⁹⁴, Smith Textile Machinery developed a foam application unit¹²⁸ and Hirano offers the A.D.C.S. foam applicator⁴³.

Special narrow width laboratory scale foam application equipment are built by machine manufacturers such as Benz²⁹⁵⁻²⁹⁷.

5.4 Foam Generators

The foam generator forms the heart of all foam application machines. It is important, therefore, that brief reference be made to the various foam generators which are available, and to the principles on which they operate.

Foam is generated by dispersing air in a liquid, such as a finishing liquor containing the finishing chemicals together with the foaming agents. Foam can be produced under static conditions, e.g. by injecting air under pressure into the liquor, or dynamically by mechanical agitation^{149,205}.

In the *static foam generator* system, a stream of air under pressure is introduced into the liquor to produce irregular shaped foam bubbles. Foam

can also be generated by feeding a liquor together with air through a chamber containing a number of closely packed glass balls, stainless steel shavings, plastic chips or with an internal series of baffles. Both air and liquid (Figure 42) are metered into the head where they are mixed to produce the foam. The liquid and air pressure propel the foam to the point of application²⁰⁵.

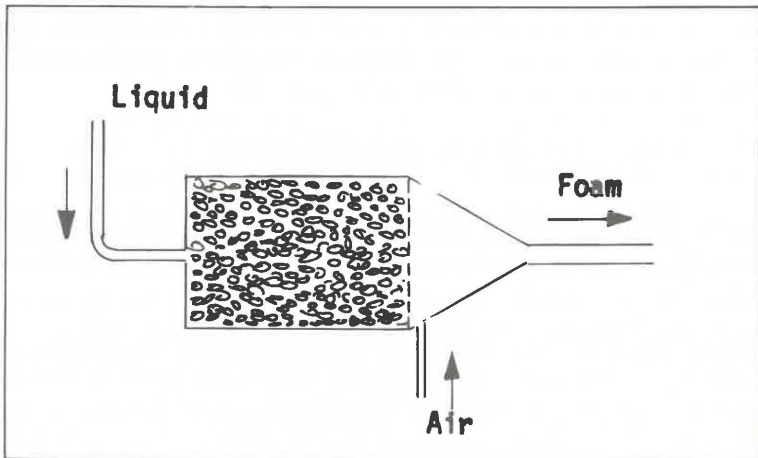


Figure 42: Static Foam Generator

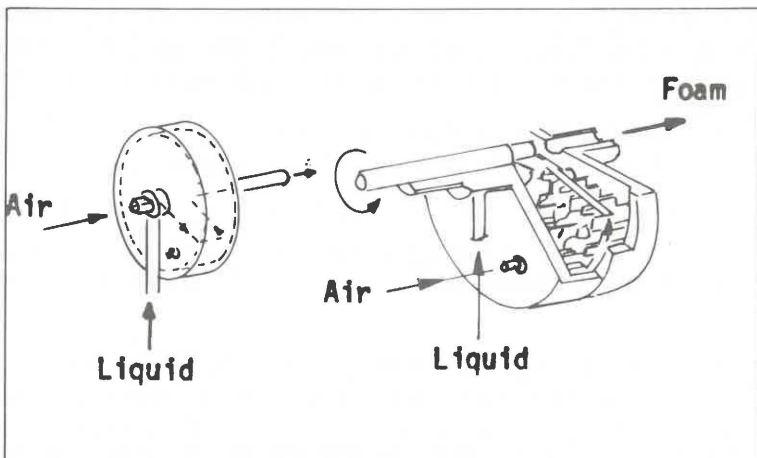


Figure 43: Dynamic Foam Generator

Static foam generators are manufactured by various companies, e.g. Zima Corp. United Merchants and Manufacturers use static generators of their own design on their equipment²⁰⁵. The Otting Machine Co. produces a unit which forms a fine foam in the form of a spray by mixing air and a liquor at a spray nozzle²⁹⁸. The static foam generation method is used in the Hoechst Bubble Process for the production of irregular colour effects which resemble a printed pattern^{299,300}, while the Printaire foam dyeing system is used for carpets^{236,238}.

The principle of *dynamic foam generation* involves the introduction of air under pressure into a liquor and subjecting the system to high shear forces. The dynamic foam generator is shown in Figure 43.

The dynamic foam generator consists of a chamber or mixing head, a liquor flow pump, an air metering unit, and a method for delivery of the foam to the point of application^{130,244}. The mixing head consists of a chamber capable of being pressurised and containing a rotor with a series of pins or teeth, normally square-edged, mounted either radially or axially on its surface and rotating between similar teeth on the surface of the stator^{160,301,302}. The liquor and air are metered into the chamber and are forced between the stationary and moving teeth where it is subjected to the shear forces and turbulences generated. The magnitude of the forces and turbulence generated in the mixing head is controlled by factors such as the speed of the rotor, the number and shape of the teeth, and the clearance between the stationary and moving teeth^{190,191}. Foams produced by the dynamic foam generator have only uniform characteristic for a set of fixed parameters^{130,202}. Foams produced by the static foam generator, on the other hand, are always the same regardless of the amount of air used. Foam properties can only be changed if for example, the packing in the chamber is changed. The static foam generator, however, produces a more uniform foam with better consistency than those of the dynamic foam generator. Furthermore, the static foam generator is less expensive and requires less maintenance than the dynamic foam generator²⁰⁵.

Several dynamic foam generators are available at present, for example, Campen³⁰³, Mondo-Mix^{43,197}, Hansa^{131,304}, Latex Equipment^{43,305}, BIP¹³¹, Cowie and Riding¹⁸⁵, Ease^{128,205}, Hall and Boyden¹²⁸, Mohr¹²⁸, Oakes^{131,301}, Pendhill⁹⁵, Textile Rubber³⁰⁶, Air-O-Matic³⁰⁷, Weserland¹³⁰, Mascoe³⁰⁶, Dinting¹³⁰ and SKG²⁰⁵. Laboratory foam generators are available from manufacturers such as Werner Mathis³⁰⁸, Oakes³⁰⁹, Benz³¹⁰ and Cowie and Riding³¹¹.

5.5 Some Characteristics of the Foams used on Different Systems

The conditions under which foam is generated and delivered to the point of application must be closely controlled for uniform application not only across the fabric width, but also continuously during production runs³¹¹. Furthermore, the foam must have certain specific characteristics depending on

the application system and the substrate to be treated. The most important characteristics of a foam are stability, density (blow ratio), viscosity and bubble diameter^{149,311}. It must be emphasized that different foam application systems utilise foams of different characteristics.

Depending on the particular system and the specific substrate, a foam can be either unstable or metastable^{153,281,312}. If the foam is too unstable, there may be premature collapse. On the other hand, if the foam is too stable, there may be difficulties in collapsing the foam uniformly through the fabric. Foams which are used for the treatment of textiles are of the metastable type²⁸¹. The Gaston County (FFT) system uses metastable foams having a stability (half-life) of between 1 min. and 60 mins^{109,275}. The Küsters system uses foams with a half-life of 5 mins to 15 mins for dyeing, whereas the foams used for printing require a higher degree of stability, namely 1 to 2 hrs, but it can be as high as 5 hrs¹⁸⁵. The Printaire system for foam dyeing uses a foam which has a half-life of between 0,5 mins and 1,5 mins²⁰². In the Mitter foam printing system, a foam with a half-life of between 45 mins and 100 mins is normally used³¹³. In general, the half-lives for foam dyeing was reported to range from 30 mins to 180 mins, while that of foam printing varied between 8 hrs and 10 hrs¹⁵⁵, and that for foam finishing varied from 30 mins to 45 mins⁹⁵.

Various application systems employ foams with different densities. The FFT system uses a foam with a density ranging between 0,30 g/cm³ and 0,005 g/cm³^{109,275}. The foam density of the United Merchants and Manufacturers knife-on-air system varies between 0,50 g/cm³ and 0,05 g/cm³^{112,113}, that of the Printaire system 0,05 g/cm³ to 0,01 g/cm³^{185,311}, whereas the foam density of the foam used in the Küsters system varies between 0,13 g/cm³ and 0,08 g/cm³¹⁵². The foam density of the Otting foam dyeing system is 0,025 g/cm³²⁹⁸, of the Mathis system 0,33 g/cm³ to 0,03 g/cm³³⁰⁸, and for the Stork system a foam density of 0,33 g/cm³ to 0,08 g/cm³ is used^{249,254,261}. The Mitter system uses a foam density of 0,13 g/cm³ to 0,08 g/cm³ for printing³¹³, but a foam density of 0,20 g/cm³ to 0,07 g/cm³ for continuous dyeing²³⁴. In general, foam densities of between 0,13 g/cm³ and 0,08 g/cm³ have been recommended for various types of application²⁰⁵, while a foam density of 0,14 g/cm³ to 0,07 g/cm³ has been proposed for foam finishing⁹⁵, and a foam density of 0,33 g/cm³ to 0,20 g/cm³ has been suggested for foam printing¹²⁷. In the case of foam application systems where the foam density is used to control the wet pick-up, a decrease in foam density will result in a decrease in the wet pick-up^{152,210}. In certain foam application systems the selection of the density of the foam depends on the fabric mass, and the foam density has to be increased when the mass of the substrate increases¹⁵⁵. It has been suggested that for open weave fabrics a low foam density and for tightly woven heavyweight fabrics a high foam density should be used²⁰⁸. In certain other foam application systems, however, such as the FFT system, the foam density should be decreased for heavyweight fabrics in order to increase penetration¹⁰⁹.

Foam viscosity depends on the foam density as well as the viscosity of the unfoamed liquor¹⁵⁹. Generally, an increase in foam viscosity increases foam stability. The foams used in the Mitter foam system for printing are generally stable and show the highest viscosity, ranging from 2000 mPa.s to 2250 mPa.s. On the other hand, the viscosity of the foam used in the Küsters foam dyeing system varies between 400 mPa.s and 600 mPa.s³¹³, while the viscosity of the foams used in the Hoechst dyeing system varies from 10 mPa.s to 50 mPa.s^{299,300}.

As far as the diameter of the foam bubble (generally referred to as average bubble size) is concerned, foams with a smaller average bubble size tend to be more stable than foams having a greater average bubble size^{106,130,149}. The average bubble size of a foam depends on the particular foam application system and it varies in diameter from 0,001 to 0,1 mm for the Monforts system¹¹⁵ to between 10 mm and 50 mm for the Hoechst dyeing process^{299,300}. The average bubble size of foams used in other foam application systems vary from 0,05 mm to 0,5 mm for the FFT system^{109,110}, from 0,05 mm to 0,10 mm for the United Merchants and Manufacturers knife-over-roller and pad systems¹⁵⁹, from 1,0 mm to 2,0 mm for the Printaire system^{185,311} and from 0,4 mm to 4,0 mm for the Küsters foam application system²⁹.

5.6 Advantages of Foam Application Techniques

Reference has already been made to certain specific advantages of the different foam application techniques discussed so far. Apart from the claims which refer to certain specific foam techniques or machines, there is a substantial amount of information available about the advantages of foam treatments in general. It is not possible within the context of this review to discuss all the claims and findings reported by the various research workers and manufacturers of foam application machines and only the more important information in this field is mentioned. Furthermore, it is not possible to compare all the results directly because of the diversified nature of the machines which were used, and the textile substrates which were treated.

The escalation in drying energy cost was one of the main reasons for the development of low add-on techniques such as foam application. It is clear from the literature that foam treatments offered substantial saving in drying energy costs^{314,315}. The actual savings differ considerably and vary from as low as 15%³¹⁶, to values as high as 80% in other cases³¹⁷. In general it seems that drying energy costs can be reduced by about 50%.

Apart from the actual savings in the drying energy cost foam techniques offer several other related advantages. For example, the drying temperature can be reduced considerably³¹⁸. Certain workers claimed that the drying temperature could be reduced by 38°C¹⁵⁴, while others reported a reduction of 65°C²¹⁸. It is of course also possible to maintain a relatively high drying temperature but to increase the processing speed¹⁴⁹. Certain workers have

reported, for example, that the processing speed of the fabric could be increased by 40%⁹⁵, while others claimed that it could be increased by 100%^{125,167,192}.

One of the main advantages of foam treatments is the fact that the water consumption could be reduced^{314,315}. The reported reduction in water consumption varies from 30%¹⁷² to 90%^{172,180,201,218}. Furthermore, foam treatment can also lead to a reduction in the volume of effluent water^{156,298,314}, and it has been reported that the effluent treatment costs could be reduced by 50% to 60%^{160,163}. It is interesting to note that certain authors claimed that air pollution could also be reduced^{22,146}.

Another advantage of foam application treatments is the fact that chemicals are utilised more efficiently¹⁵⁶. Chemical consumption and costs can therefore be reduced^{22,76,237,249}. It is frequently possible to reduce the concentration of certain auxiliaries, such as printing thickeners, and in some cases they can be eliminated entirely from the formulation^{160,182,185,298,319}. A number of workers have reported that less dyestuff can be used, compared with the conventional padding process^{160,198,230,233}. It is interesting to note that certain workers claimed chemical savings of less than 10%^{134,273}, whereas others reported savings as high as 50%^{172,180,251}.

The migration of durable-press resins during drying is one of the most serious problems encountered in the conventional finishing of cotton fabrics. The migration effect is generally reduced when the wet pick-up is reduced³²⁰. Thus, by using a foam to apply chemicals, migration can be reduced or eliminated to produce a uniform distribution of the chemical on the fabric^{95,130,150,153,161}. This can improve the quality of the product considerably. For example, the crease recovery angle^{2,95}, resistance to abrasion^{2,5,95,321}, tensile strength^{145,209}, bursting strength^{22,146} and resistance to flex abrasion^{5,10} can be improved. Furthermore, it has been claimed that the width shrinkage during washing^{192,209,269,272,315,318} can be reduced, while the handle^{130,146,152,155,160,314} and wash and wear properties¹⁶¹ of the fabric are improved.

Some other advantages of foam application techniques are claimed to be a reduction in dusting liberation^{145,209} and the elimination of predrying^{10,192,226,275,315} which makes it possible to do wet-on-wet applications^{144,315,317,318,322}. It is also possible to process delicate fabrics under low tension by foam application techniques^{192,257,261,265,317}. It has been claimed that the quality of cut pile carpets, upholstery fabrics and furs, is improved due to a lower degree of pile deformation during application^{149,152}. Furthermore, different finishes can be applied to the face and back of a fabric^{22,125,274,279,318}. Alternatively, one-sided applications are possible^{149,253,322}.

As far as foam dyeing is concerned, it has been reported that dye yield can be improved^{152,172,198}, while several workers reported that fixation values^{194,233,234} and the rate of fixation^{199,202,208,311,323} of dyes were higher. In some cases dyeings were carried out successfully in the absence of the usual auxiliaries³²⁴. Furthermore, steaming times could be reduced²⁰¹. It has been claimed that the

washing-off process can be shortened³¹⁴ or even eliminated in the case of light shades^{155,185,202,219,221}. Certain workers reported that rubbing fastness could be improved^{118,149,234}, while the occurrence of streaky dyeing of carpets could be reduced^{189,201,234,314}. It is possible to dye the two sides of a fabric independently in one process, for example, by applying a basic dye to an acrylic pile face and a direct dye to a cotton back¹⁸⁶. Alternatively, only the one side of a fabric can be dyed^{272,277}. It has been reported that the volume of dye liquor can be reduced by 25% to 35%²⁹⁸ and as a result of the construction of the foam application system no contamination of liquor can take place at the point of application^{116,210,234}.

Various workers have reported that printing with foam offers several advantages, e.g. the prints are of a better quality^{229,230} having good definition^{145,229} with less strike through and softer handle¹⁵⁵ than conventional prints. In general, the penetration of the print can be controlled^{253,261} and it is possible to overprint a dark colour with light colours³²⁵. In some cases washing-off of the printed fabrics can be reduced or even eliminated^{150,319,326}. Wet-on-wet applications are possible and foam printed fabrics, for example, can be foam finished without an intermediate drying¹⁵⁵.

5.7 Some limitations of Foam Application Techniques

It has been reported that it is essential to have a well prepared fabric for foam processing^{131,315,318}. It is known that variations in fabric absorbancy will result in variations in the wet pick-up^{265,268,327}, and thus in the application of chemicals¹⁶¹. Special attention should be paid, therefore, to the preparation of the fabric to ensure adequate and uniform absorbency.

At very low wet pick-up values, the uniformity of application is critical^{10,149} and penetration of the chemical into the fabric can be inadequate¹⁴⁹. In practice there is often the temptation to reduce the moisture level to such an extent that the fabric is not sufficiently wet and it cannot be stretched to the required width in the stenter^{20,224}. Furthermore, in cases where the production speed could be increased due to the lower wet pick-up, it was found that certain drying units are not designed for such high speeds²⁶⁵.

Another very important consideration is the fact that the liquor preparation in any low add-on application system is more critical than in conventional application systems^{130,161}. To maintain the same solids add-on level the concentrations of chemical in these liquors are normally considerably higher than those in conventional liquors^{130,153} and consequently the chemicals have to be screened for high solubility and compatibility with the foaming agents²⁰. Furthermore, some of the commercial products contain antifoaming agents²⁶⁵, which may inhibit foam formation. Solvents and mineral oils which are used for certain processes will also inhibit foam formation³²². It has been reported that certain optical brightening agents and softeners as well as the presence of sulphate ions often reduce foam stability³²⁸.

It has been stated that foams should generally be applied to both sides of a fabric³²⁹, especially with high density woven fabrics where one-sided applications could result in a difference between the two sides of the fabric^{208,328}.

It has been pointed out that foam dyeing could result in unlevelness¹⁶ and that shades are difficult to match at low add-on levels³¹¹. Furthermore, it is difficult to produce deep shades at low wet pick-up levels because of the limitations of dyestuff solubility^{16,283}. One case was recorded¹⁶ where the prints produced by foam application systems were duller than those produced conventionally. It has been claimed that any contamination of the liquor or of the fabric will have an adverse effect on the uniformity of the application²⁰.

6. SUMMARY

Some of the systems of low add-on application techniques which have been discussed use existing well established commercial equipment. Others, however, are only at the development stage and it is not yet certain whether they will find commercial acceptance. It is clear that the various low add-on application techniques which are available today differ considerably in their degree of sophistication and in price. Furthermore, certain systems are very versatile and can be used on a wide variety of fabrics, whereas certain others are very limited in their application. It is also clear that the actual wet pick-up obtained on the different systems varies considerably.

Both the topical and expression low add-on application techniques appear to offer several advantages over conventional pad application systems. The topical application techniques offer one main advantage over the expression techniques, namely that they are suitable for wet-on-wet applications.

From the literature survey it appears that there is substantial interest in and a progressive growth of foam application techniques, so much so that this topic appears to be firmly established in modern textbooks on wet processing of textiles³³⁰. Most of the emphasis has been on the application of durable-press resins, softeners, and other finishing agents to woven and knitted fabrics, as well as non-wovens. The foam dyeing of carpets is well documented in the literature, but the foam dyeing of fabrics has not been explored to the same extent.

Comparing foam application techniques with other low add-on application techniques, it is evident that despite the fact that the other low add-on application techniques (expression and topical) have been available for quite a number of years, foam application appears to be more popular with a higher growth rate. Furthermore, the foam application techniques generally appear to be more versatile, and they appear to offer several advantages over the traditional low add-on application techniques. It is likely, therefore, that the foam application techniques will take up an increasing share of the market and it is possible that they may even extend further into other fields of application.

Finally it must be pointed out that, despite all the advantages offered by the low add-on and foam application techniques, the conventional padder is still being used very widely today. There are various reasons for this but the most important ones probably are its versatility, reliability (little or no maintenance required), simplicity of operation and low cost, compared with most other systems. It is highly unlikely, therefore, that the traditional padder will ever disappear completely from the dyehouse.

USE OF PROPRIETARY NAMES

The names of proprietary products where they appear in this publication are mentioned for information only. This does not imply that SAWTRI recommends them to the exclusion of other similar products.

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**Published by
The South African Wool and Textile Research Institute,
P.O. Box 1124, Port Elizabeth, South Africa,
and printed in the Republic of South Africa
by Nasionale Koerante Beperk, P.O. Box 525, Port Elizabeth.**

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ISBN 0 7988 2746 7

