Industrial coloration methods

Introduction

Coloration may be carried out at any stage in the manufacture of textile goods, including the spinning stage of synthetic fibres. Significant quantities of filament are coloured by mass pigmentation methods in which heat-stable pigment particles are dispersed in the molten polymer prior to extrusion. This is a particularly suitable method for olefin fibres that are too hydrophobic to be coloured from an aqueous dyebath, but it may also be used for polyester, nylon and viscose fibres. Other colorants are dissolved in the fibre-forming polymer and remain *in situ* after conversion of the polymer to filament.

A further variation used for acrylic fibres is to bring the freshly extruded filament into contact with a solution of basic dye before the filament is allowed to dry out. This process is referred to as *producer dyeing*, and has been used by Courtaulds and Monsanto in the production of acrylic filaments in tow form (untwisted aligned fibres or filaments collected together in the form of a loose strand).

More commonly, however, colour is applied from solution with the substrate in the form of loose fibre, tow, slubbing, sliver, yarn or fabric. Fabric may be dyed in all its forms, such as woven, nonwoven or knitted fabrics, or as hosiery or garments. Large quantities of fabric are also decorated with a pattern by printing (see page 126).

Batchwise dyeing

Machines intended for immersion dyeing are limited in the amount of goods that they can accommodate at any one time, and if the quantity to be dyed exceeds the capacity of the machine, the load has to be split into more manageable batches. Equipment for batchwise dyeing is constructed to ensure that the goods are in constant contact with the dye liquor. The liquor ratio (see page 95) of the various batchwise dyeing machines ranges from 5:1 up to 30:1 or even higher,

Contents

Home

and the dyebath composition is always formulated with a specific liquor ratio in mind.

It is important that a thorough movement of dye liquor through the goods continues throughout the dyeing process, particularly with highly substantive dyes. If the liquor circulation is inadequate and the rate of dyeing becomes reduced, the final dye distribution will be uneven. The situation is similar to the flow of water in a river. In the middle of the river the water flow is fast and turbulent, whilst nearer the banks it is usually gentler and smoother. When flood conditions arrive, however, the rapid flow and turbulence then extend from one bank to the other.

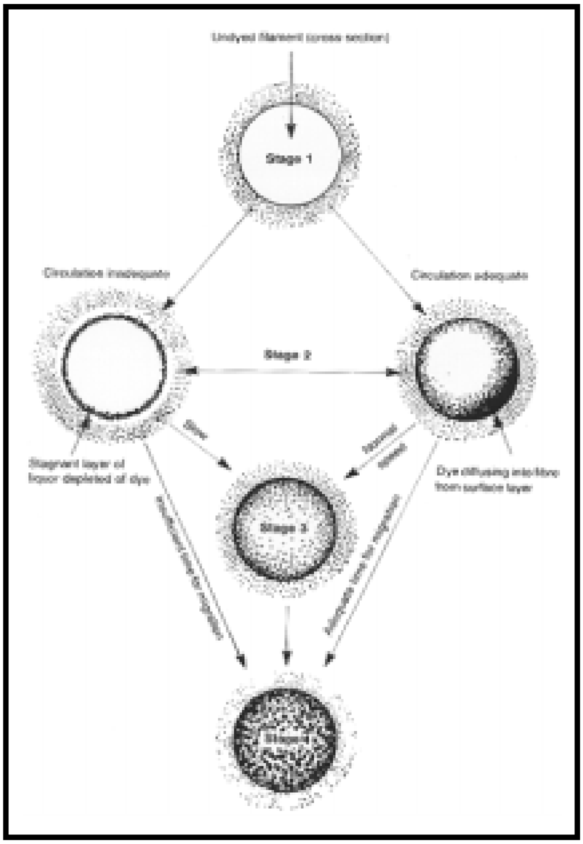

Figure 6.1 *The influence of rate of flow of dyeing liquor during the dyeing process:*
Stage 1 – dyeing begins
Stage 2 – initial dye adsorption at the fibre surface
Stage 3 – diffusion of dye into the fibre (the rate of diffusion depends on the concentration at the surface)
Stage 4 – the ideal end-point of completely uniform dye distribution

When there is insufficient force the liquid at the surface of the fibres is slowed down by viscous drag. This creates a *hydrodynamic boundary layer*, which rapidly becomes depleted in dye. Since no further dye can then reach the fibre surface except by diffusion from the main bulk of the liquid across this boundary layer (Figure 6.1), dye is not replenished at the surface quickly enough and the rate of dyeing is considerably reduced. The problem is eliminated by increasing the rate of flow to a point where it is sufficiently strong to overcome the effect of the hydrodynamic boundary layer.

There are two ways in which the flow of dye liquor relative to the goods is maintained: in some machines liquid is forced through and around the goods, while in others the goods are moved through a stationary liquor. In either case dyeing is allowed to continue until an equilibrium distribution of dye between fibre and dyebath is reached. Any aftertreatments required to fix the dye are then carried out in the same equipment before the washing-off process.

Contents

Home

Dyeing loose fibre

The dyeing of staple fibre (*loose stock* or *raw stock*) or continuous tow is referred to as *pack dyeing*. The tow is usually formed into packages convenient for handling and dyed in machines similar to those used for dyeing packages of yarn. The hot liquor is circulated by the use of pumps through the fibrous mass packed into a large annular basket or cage. The cages are too bulky for manual handling and, as with other dyeing machines, some form of mechanical lifting device is mounted nearby for loading and unloading.

Equipment like this is not widely used, however, because the quality of the tow after dyeing is often disappointing. More often fibres are dyed in the form of yarn or fabric, and several different principles are employed for this purpose.

Yarn dyeing

Yarn is dyed either as hanks or, more usually, wound on to compact reels known as *packages*, mounted on hollow spindles. Packages can take a variety of forms, with names such as *cheeses*, *cones*, *cakes* or *muffs*. Muffs are very soft-wound packages prepared by first winding stretch yarns on to a frame, which is then removed to allow the yarn to contract. Up to a tonne of yarn can be dyed at one time in some machines.

Suitable pumps force liquor up the hollow spindles and through the packages. The flow is reversed from time to time. The whole system is contained in a cylindrical vessel with a dome-shaped lid. The vessel can be sealed to allow pressurised dyeings of hydrophobic fibres such as polyester, thus improving penetration and colour yield; temperatures up to 135 °C may be used. The liquor ratio is around 10:1, and an expansion tank at the side of the main vessel accommodates the increasing volume as the temperature rises. It is also a convenient point at which dyebath additives or further dye may be added.

The prime consideration in dye selection for yarn dyeing is always the economical production of a level dyeing with appropriate fastness properties. Free movement of the dye liquor is essential for the production of level dyeings and several factors can impede the flow if they are not taken into account when the package is being wound. In general permeability is low for regenerated cellulosic yarns, higher for staple yarns and packages, and highest for synthetic fibre packages. Provision must also be made for the effects of fibre swelling or yarn shrinkage, as these may cause a change in

Contents

Home

porosity as the dyeing proceeds. Other factors can be controlled more directly. For example, the package will be required to withstand frequent reversals of the forced flow of hot dye liquor without disruption of the orderly arrangement of the wound yarn. The porosity of the package must also remain uniform, because dye liquor will be able to flow more rapidly through less densely packed regions and this may lead to uneven dyeing. Obviously the use of a high tension during winding will produce a denser package. With nontextured yarns permeability increases with increasing tex, but the finer the filaments, the more readily the permeability is reduced due to flattening of the yarn. The same difficulty may occur with low-twist yarns. Packages of textured yarns and yarns with a rounded compact structure imparted by a high degree of twist are more permeable. Care is needed with nontextured fibres since their dimensional instability can also cause problems. Nontextured filament nylon, for example, is usually wound on to collapsible bobbins and relaxation induced by steaming. The increased tensions produced are then released before dyeing by rewinding on to fresh formers.

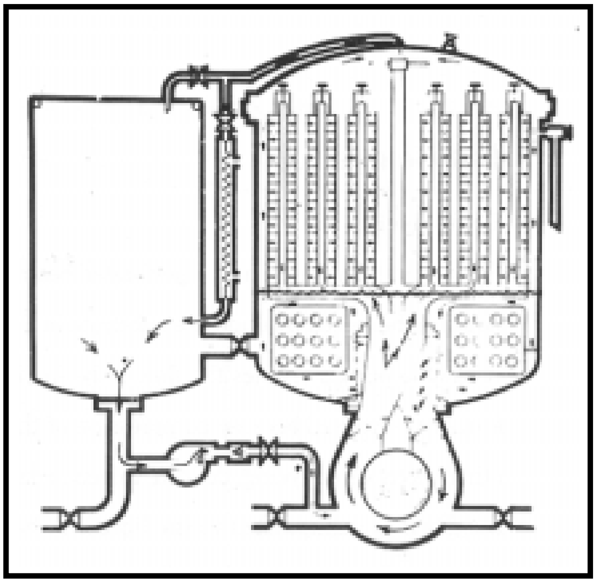

Figure 6.2 Vertical-spindle package-dyeing machine

Nowadays most yarns are dyed in the form of packages mounted on a series of hollow, perforated, vertical spindles situated around the circular vessel containing the dyebath (Figure 6.2). When the dyeing is completed, the yarn is wound back on to bobbins ready for conversion into fabric by knitting or weaving. The packages are initially prepared in ways that help to overcome the difficulties sometimes experienced at this stage. For example, staple fibre yarns tend to cling on unwinding. Spun viscose yarns tend to swell considerably during dyeing. This poses problems that can be eased by forming the yarn packages into the shape of a cone. Cones are unsuitable for taking up vertical compressions, however. Furthermore, flow of liquor through a cone is less uniform than through a cheese.

In some instances the central former of the cheese is removed completely to allow the wound yarn to reach a more relaxed state during dyeing. This is accompanied by an enhancement in the

Contents

Home

stretch properties of the yarn, and the associated improvement in permeability leads to more rapid dyeing. Such yarn packages are used as an alternative to the hank dyeing of high-bulk acrylic yarns and some wool carpet yarns. This procedure allows cost savings in processing because it requires only half the volume of water used in hank dyeing and there is a corresponding reduction in the consumption of energy to heat up the dyebath.

Hank dyeing

Nowadays dyeing of yarn in the form of hanks or skeins is mainly used for lofty yarns such as wool and high-bulk acrylic yarns for knitting and carpet manufacture. The hanks are usually mounted on horizontal bars and suspended in the dye liquor. Traditional machines have a rectangular bath in which dye liquor is gently circulated around the yarns using a suitably placed pump and overflow arrangement. Uniform dyeing is ensured by reversing the direction of flow from time to time.

Fabric dyeing

Beam dyeing

Fabric can be wound on to a perforated beam and dyed in an enclosed vessel. This enables the dye liquor to be forced through the substrate in a manner analogous to yarn package dyeing. The use of reversible pumps enables the flow to be in either the in-to-out or the out-to-in direction, but the former is favoured because compression of the fabric reduces the porosity of the goods. With some other methods of dyeing, delicate woven or knitted fabrics may suffer from creasing due to the way the fabric is manipulated in the liquor. In beam dyeing, however, the fabric remains in an open-width configuration (page 109) and is supported throughout the dyeing operation. Provided the porosity of the fabric mass remains satisfactory, good-quality dyeings are generally obtained. Any dimensional instability of the fabrics will lead to unlevel dyeing, however, because stretching allows localised increases in the porosity within the roll wherein liquor may flow more rapidly. If shrinkage occurs, then the increase in the internal mechanical pressure in the roll brings about flattening of the fibres. With thermoplastic fibres this results in deterioration of the appearance of the fabric surface. Synthetic fibres, particularly nylon, are given either a heat-setting treatment or a scouring treatment before dyeing to minimise such difficulties.

Contents

Home

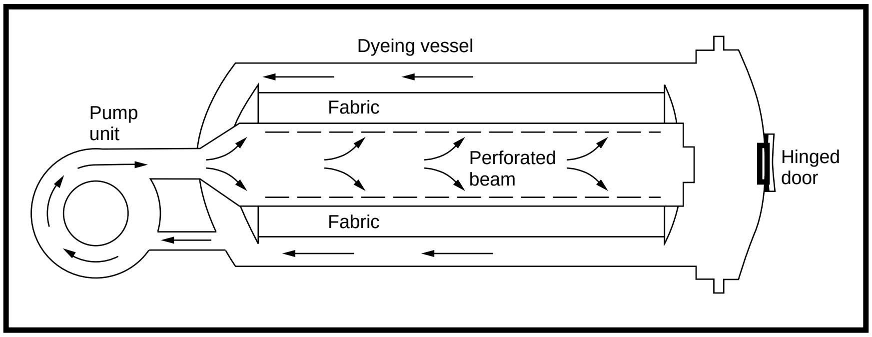

Figure 6.3 *Sectional diagram of a high-temperature beam dyeing machine*

A pressure beam dyeing machine is shown in Figure 6.3. A small expansion tank (not shown in Figure 6.3) is also fitted to enable additives to be introduced at the requisite point of the dyeing process.

Jig dyeing

The jig machine (Figure 6.4) is one of the oldest ways of dyeing fabric in open width. In this machine a batch of fabric is rolled backwards and forwards from one roller to another through the dye liquor. The direction of movement is automatically reversed as the machine reaches the end of the fabric roll. The duration of the dyeing process is monitored by the number of passages or 'ends' through the liquor. Machines open to the atmosphere can accommodate a roll of 500 to 1000 metres in length, but more modern enclosed machines can operate with a roll of 5000 metres. An enclosing lid helps to reduce heat losses and consequent temperature differences between the edge and the centre of the roll. Such differences lead to 'listing', a reduction in the dye uptake at the edges of the fabric. Pressurised jigs are available for the more difficult hydrophobic fibres. These operate at temperatures of up to 130 °C, but beam dyeing is usually preferred for high-temperature dyeing. A liquor ratio of around 5:1 is the lowest used in conventional jig machines. The method is well suited to the dyeing of fabrics that are readily creased, such as taffetas, poplins, suitings and satins, but less well for knitted goods because they distort so easily.

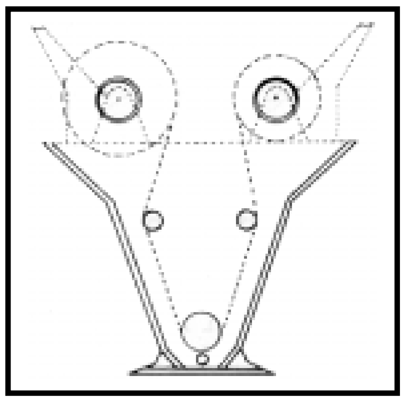

Figure 6.4 *Cross-section of a simple dye jig, showing the method of threading*

Contents

Home

The mechanical action on the fabric is obviously limited in jig dyeing. Consequently the exchange of liquor inside the interstices of the fabric as it passes through the dyebath is less efficient than with machines in which liquor is circulated more forcibly through the goods. The jig is relatively inexpensive to install and convenient to use; moreover, since it operates at a low liquor ratio, it is economical on both water and energy consumption.

Winch dyeing

In winch dyeing machines, the oldest kind of equipment used for dyeing fabric, the fabric is dyed in rope form, gathered together across its width. The method is used widely for fabrics such as woollens, loosely woven cottons, synthetic fibre fabrics and most knitted fabrics. All these can withstand creasing during the dyeing process. The winch machine operates at longer liquor ratios than those employed in the jig, liquor ratios from 15:1 to 40:1 being commonly used, depending on the type of the fabric and the particular model of machine. The warp threads of the fabric remain under tension throughout dyeing, and as a result of this and of the mechanical action used to propel the fabric through the dye liquor the yarns in woven fabric often develop a crimp. With knitted goods there is an increase in loop length. Both effects lead to a fuller thicker fabric with a more resilient handle and improved crease recovery.

The principles of the operation of winches (also called becks, winces or vessels) are illustrated in Figure 6.5. The rope of fabric is looped over the winch reel, which lifts the fabric and allows it to drop into the dye liquor. The free-running jockey acts as a support for the fabric as it is pulled forward. As the fabric drops into the dye liquor it becomes folded over concertina-fashion ('plaited'), as shown. The folding and opening action, which persists for as long as the winch reel is turning, keeps the dye liquor in motion.

Variations in the design details of machinery have been introduced to suit the characteristics of different fabrics. Wool and heavy types are best suited to the deep-draught winch, where fabric piles up on the sloping back and pushes forward the fabric in front. For filament viscose, acetate or any fabrics which crease whilst wet, the shallow-draught winch is preferred because the lack of depth and flat base reduce the compressive pressure of the falling fabric. The design of the winch reel governs the movement of the fabric, which when wet grips the reel because of the gravitational pull and the friction between the wheel and the wet fabric. The reels are usually made of stainless steel.

Contents

Home

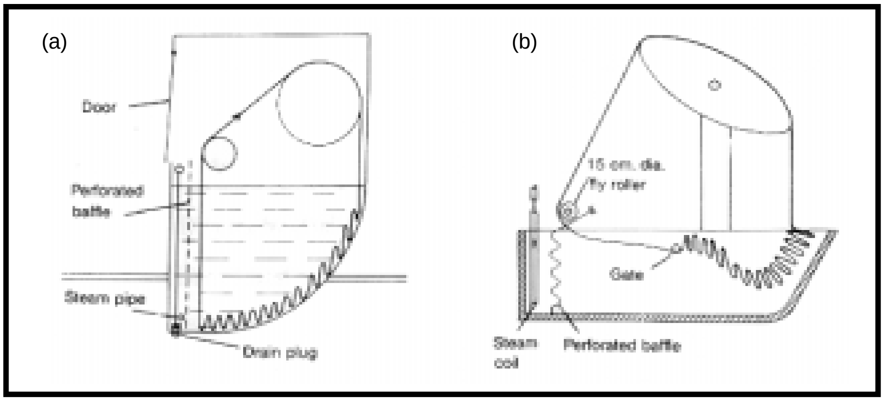

Figure 6.5 *Winch dyeing machines: (a) deep-draught, (b) shallow-draught*

With the deep-draught machine a circular or slightly elliptical reel is used to lift the fabric over the jockey roller, so that it falls straight into the dyebath from the reel with only a little plaiting action. Elliptical winch reels are better for other fabrics and provide greater plaiting. Mechanical action on more delicate fabrics is reduced by the use of a larger elliptical wheel. The presence of an adjustable horizontal bar (the 'gate') in the middle of the bath restrains the fabric at the back of the machine until it is pulled past by the revolving winch reel. This action minimises creasing by straightening the warp direction folds.

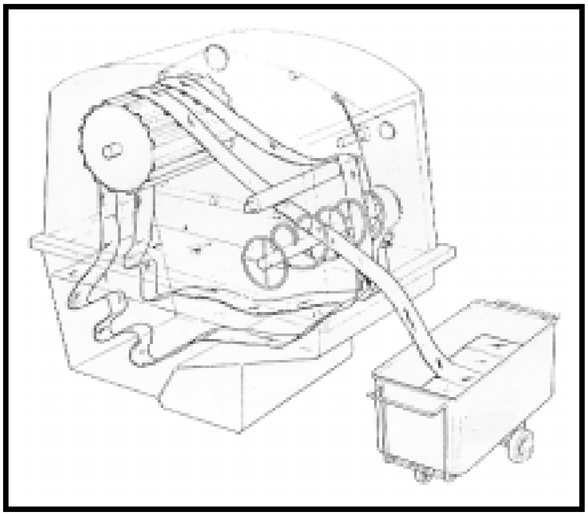

Figure 6.6 *Winch dyeing machine with Autoloda*

Figure 6.5 shows only one rope of fabric, but in most machines many such ropes are arranged side by side, in parallel. In others, a long continuous rope is used in a spiral configuration, and is presented to the machine with the aid of a helical Autoloda spanning the entry to the machine (Figure 6.6). This mechanism saves time in loading and allows a larger batch of fabric to be dyed, thus lowering the liquor ratio.

Contents

Jet dyeing

Recently designed machines have adapted the force from a strong jet of dye liquor to transport the

Home

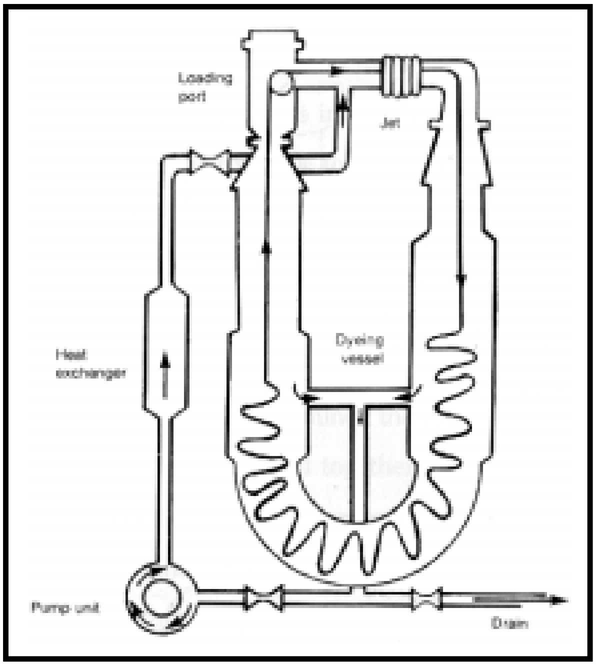

Figure 6.7 Thies Jet Stream fully flooded dyeing machine

fabric from the front to the back of the dyeing machine. Low liquor ratios can be used and the machines are designed to operate above atmospheric pressure with polyester fabrics, particularly when in the form of knitted goods.

The latest machines of this type keep the fabric fully immersed throughout the dyeing operation, eliminating the creasing and foaming that presented problems with the early models. Because the fabrics are constantly immersed and the machine fully flooded, delicate fabrics are supported throughout. The size of the jet may also be regulated to match the best requirements for a particular fabric.

An example of such a machine is shown in Figure 6.7. The goods in rope form are moved along by the force of the jet of liquid into the vertical chamber below, and the liquor is recirculated through the heat exchanger back into the jet. The rope moves slowly whilst in the main chamber, but very rapidly through the tube into which the jet is directed.

Soft-flow machines

A much gentler action is provided by so-called soft-flow machines, in which the force of the flow of dye liquor moving the fabric is reduced by circulating it into the main chamber from an overflow system (Figure 6.8). Soft-flow machines are notable for minimising the creasing of delicate fabrics and the lower overall strain imposed on the goods during dyeing. There are several versions of both jet dyeing and soft-flow machines, and further details may be found elsewhere [1].

Contents

Garment dyeing

Women's hosiery and socks are typical examples of textile goods that can be dyed in garment form, and the dyeing of knitted wool garments is equally long established. Nowadays it is common to dye

Home

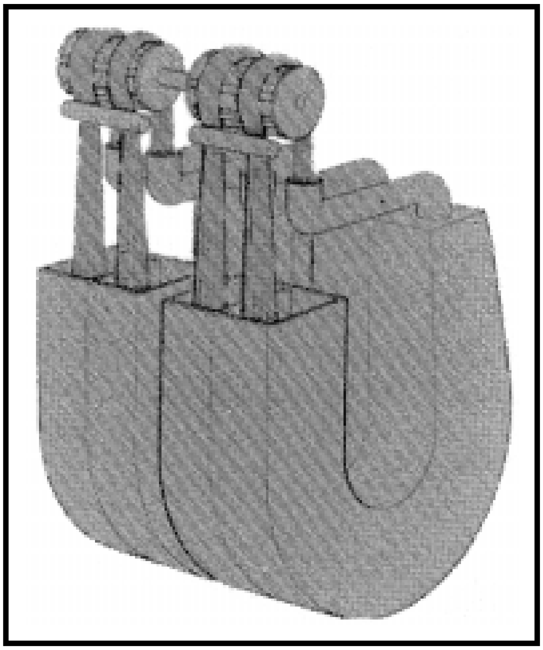

Figure 6.8 *Longclose soft-flow jet dyeing machine*

more elaborate garments too, offering the retailer scope for a quick response to changes in current fashion and a reduction in the level of stock holding. The conventional approach of dyeing the fabric followed by making up is associated with a delay of at least two to three weeks between the preparation of fabric for coloration and its appearance as an artefact in the shop. The time between request and delivery may be reduced to four or five days, however, by holding a stock of undyed garments. Even after making allowance for the manufacture of the fabric and the making-up time, the garment dyeing approach is much faster. A full review of garment dyeing will be found elsewhere [2].

The current interest in garment dyeing has been encouraged by the growth in demand for casualwear and leisurewear. Although garments made from most fibre types can be dyed with commercial success, the main growth in this market has been with cotton goods.

The drawback of garment dyeing is its greater expense. Consequently success is dependent on reduction of the overall cost through retailing methods and attention to design features that are compatible with this method of production.

Adequate attention to fabric preparation is essential for satisfactory dyeing, and the fabric must be thoroughly scoured to remove contaminants such as spinning oils. With wool garments some form of shrink-resist treatment is usually applied before dyeing, and with all knitted goods pre-relaxation treatments are equally important for a good-quality end product. Careful selection of stitch type, stitch density, thread tension and thread type helps to reduce problems such as the development of seam pucker due to differential relaxation of the fabric and sewing thread during dyeing.

Other problems are entirely the responsibility of the dyer. For example, fabrics of different construction in the same garment must appear to be of the same intensity of colour, and the compacted fabric enclosed by the seam must be as well penetrated and dyed to the same depth as the rest of the garment. This calls for dyes with good migration properties and a dyeing method that will give good penetration of dye liquor. For this reason hot-dyeing reactive dyes are often used with cotton garments in preference to cold-dyeing types, since the higher dyeing temperature makes for more efficient penetration. For goods that will be subjected to hand washing, however, dyes will probably be selected using the Society of Dyers and Colourists' A and B classification of direct dyes in the dye selection process.

The sewing thread is also of concern. Usually it must remain inconspicuous, and this entails the use of dyes with a similar substantivity on both the sewing thread and the fabric. Occasionally, however, stitching is deliberately used to produce decorative effects, in which case differential dyeing of the thread and the fabric may become a desirable feature.

Knitted wool garments present similar problems of penetration, and in addition care is needed to avoid fibre damage, particularly when long dyeing times or low pH values are used. Again, dyes are chosen to match the requirements of the attached aftercare label. Thus levelling acid dyes are used for garments that will be hand-washed, whereas metal-complex and milling acid dyes provide better fastness and deeper shades for more robust articles. On the other hand, reactive dyes are generally the choice for wool fabrics finished to machine-wash standards (page 86).

Articles such as buttons or zip fasteners may present additional hazards to the dyer. The presence of metal ions in the dyebath from buttons or zips can influence the shade of the dye; conversely, dyebath ingredients such as acid, alkali or reducing agent (for vat dyes) may do irreversible damage to the appearance of such trimmings.

Machinery for garment dyeing

Garments are usually dyed in a simple system in which the dye liquor in a suitable vessel is agitated gently by means of a paddle arrangement. There are several types of machine, differing in the positioning of the paddles, but in all of them the action is gentle. The garments, being loose in the bulk of the liquid, move around freely with the flow induced by the paddle. Thus the liquid is not forced through the structure of the fabric in any way and there are predictable penetration problems with thick seams and with garments made from heavy fabrics. In the special machines designed for dyeing hosiery, the goods are placed in perforated drums with compartments. Some of the front-loading machines are useful for dyeing small garments. None, however, is ideal for present-day needs.

Contents

Home

The Pegg Toroid machine has proved useful for dyeing fully fashioned Tricel and polyester knitted garments (Figure 6.9). Its gentle action is provided by pumping the dye liquor up the centre of the machine so that it is deflected at the top to cascade down the side of the dyeing vessel, giving a whirlpool-like movement of the liquor. A pressurised version allows dyeing temperatures of 130 °C to be attained but the actual relative rate of flow of liquor over and through the garments is still limited, since the goods are free to be carried along in the current of dye liquor.

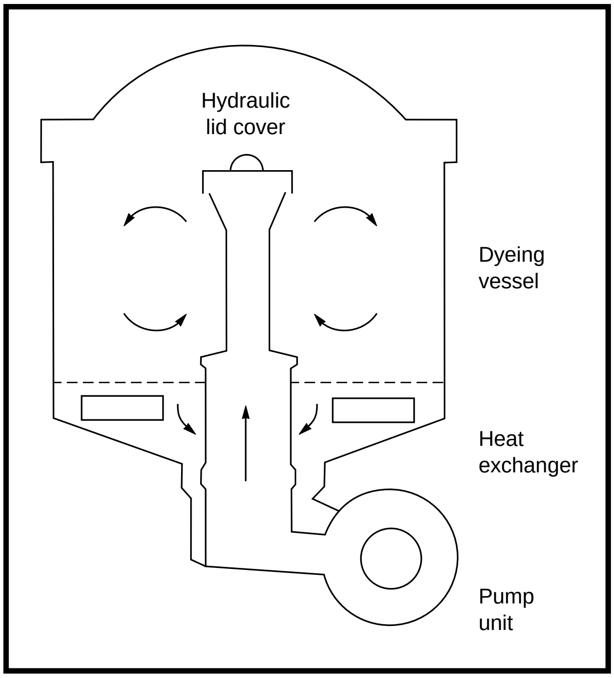

Figure 6.9 *Pegg Toroid machine for garment dyeing*

Modern machines are more sophisticated and operate through electronic control systems; an example is shown in Figure 6.10. They have a rotary action during dyeing and a centrifugal action for eliminating dye liquor or water at the appropriate stages. This feature reduces the energy requirements for drying and the amount of rinsing required, thereby dramatically reducing the processing time. Various degrees and types of mechanical action are employed to suit the finishing operation required. Improvements in circulation have been effected through the introduction of pumps that force the dye liquor through external heat

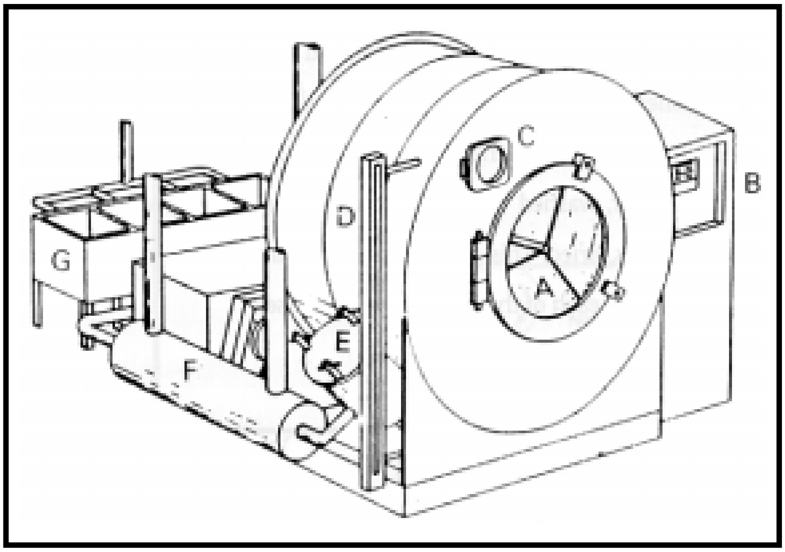

Figure 6.10 *Typical rotary drum garment dyeing machine*
A Perforated drum (with Y-pocket); B Machine controller; C Sampling port; D Liquor level indicator; E In-line lint filter; F Heat exchanger; G Addition tanks

Contents

Home

exchangers. This reduces the mechanical action required, which is good for garments made from thermoplastic fibres (such as acrylics) that react adversely to the extension and compression experienced under the hot, wet conditions of dyeing. Moreover, better seam penetration is obtained with these machines. They are also equipped with an external filter to remove lint fibres which would otherwise adhere to and disfigure the garments.

Continuous dyeing

When there is a large volume of goods, it is usually better to process them continuously without the inconvenience of separating the job into batches and repeating the process several times. In this situation processing is arranged as a continuous uninterrupted sequence of events from start to finish. The goods move at a constant rate throughout, and on completion of the dyeing they are taken up mechanically at the far end of the equipment. The process is run until the whole length of textile has passed through.

Although most continuous coloration is carried out on fabric, equipment is also available for dyeing fibre in the form of loose stock, tops and tow, all of which have been reviewed [1,3]. At the start of each process fibre is sprayed with dye, fed on to an endless rubber belt and carried to the rollers of a padding mangle, where uniform impregnation is obtained as the surplus liquid is squeezed out. In the example shown in Figure 6.11 the loose fibre is carried through a tubular steamer, washed to remove surplus dyebath ingredients and, after the application of any special finishes, dried. This general scheme of impregnation followed by fixation, washing and drying is the same for each of the continuous processes.

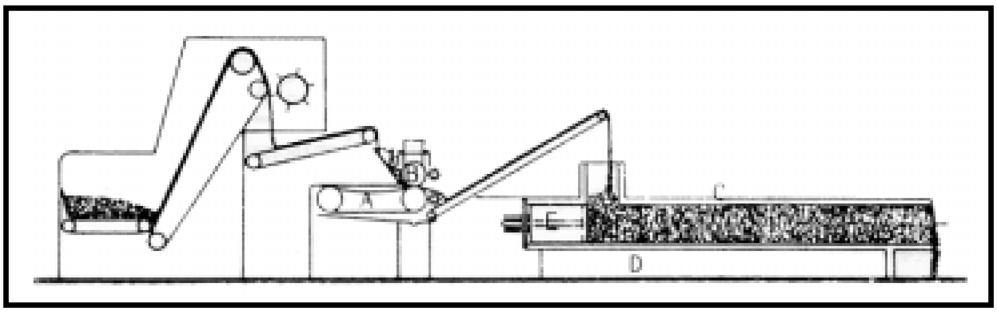

Figure 6.11 *Continuous fibre dyeing*
A Rubber conveyor belt; B Nip rollers; C Tubular steamer; D Front of steamer; E Piston

Contents
Home

Various sequential operations are used for the continuous dyeing of fabric. These have already been outlined in Chapter 5, with reference to dyeing with reactive dyes on cellulose. An initial padding stage is common to all sequences. It involves immersion of the fabric in the dye liquor contained in a trough of minimal volume, which is kept constantly replenished from a stock tank. A liquor ratio as low as 1:1 may be used; in general, low-substantivity dyes are used in continuous dyeing processes (see page 96). Next, the fabric passes in open width through a 'nip'. The nip is the padding mangle, in which heavy rollers (called bowls), pressed closely together along their length, are rotated in opposite directions to carry the fabric through the system at a constant speed, squeezing out the superfluous dye liquor (Figure 6.12 (a)). Heavier fabrics are passed through two consecutive troughs and a second nip, using a three-bowl mangle.

The fabric, now uniformly impregnated with dye and the appropriate dyebath auxiliaries, usually passes directly to a steamer or dry heater for fixation (Figure 6.12 (b)). In some cases, however, where evaporation of the water in the fixation chamber causes unwanted directional migration of dye, the fixation step follows a preliminary drying operation. After fixing, the fabric passes from the fixing chamber to the washing range and is dried either on heated cylinders or by some other means such as radio frequency heating. Finally it is wound on to a beam ready for transportation. The sequence is similar for all processes, but of course the dyes, additives and operating temperatures vary from one situation to another.

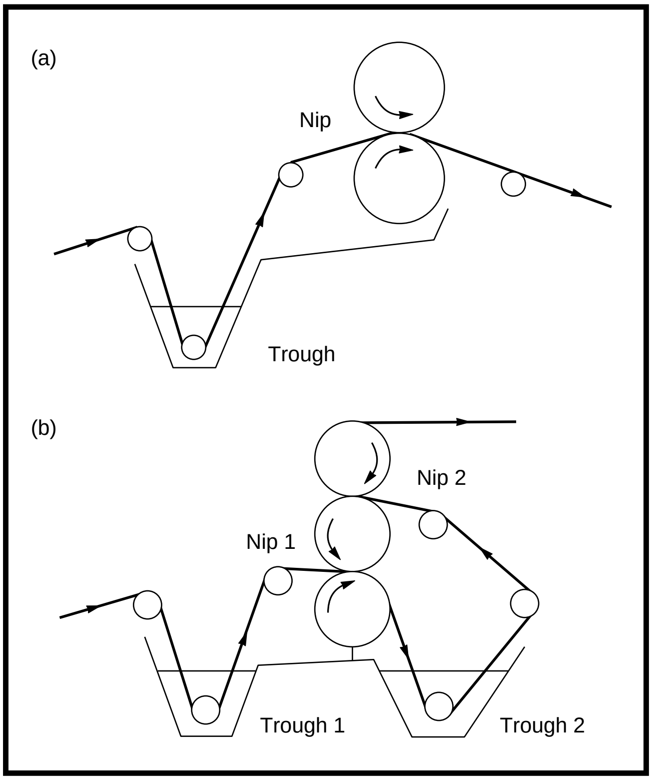

Figure 6.12 *Principle of pad mangle operation: (a) two-bowl mangle, (b) three-bowl mangle*

Carpet dyeing

A serious difficulty in the coloration of carpets by conventional continuous dyeing methods is the very high pick-up of liquor required. This

Contents

Home

may range from 400 to 1000% of the mass of the carpet, and clearly can give rise to a very high consumption of water, processing energy and chemicals. Attempts have been made to alleviate these difficulties by replacing much of the bulk of the liquid with air by using surface-active agents that suspend the dye and chemicals as a stable foam. Various forms of foam applicator have been devised to produce plain-coloured carpets. Unfortunately the foam is required to be highly stable if the colour is to be uniformly distributed, but this very stability hinders the penetration of dye into the carpet pile.

Dispensing the dye liquor through a series of fine sprays is an alternative and more rewarding approach to the problem. Various spray applicator mechanisms have been designed, and these allow operation at much lower add-on values of about 150–250%.

Textile printing

Modern procedures for printing textile goods may be traced back to the block printing of silks in ancient China. In this method a wooden block with a raised pattern on the surface was dipped into the printing colorant and then pressed face down on to the fabric. The desired pattern was obtained by repeating the process using different colours. Printing by brushing colorant through thin metal stencils and the transfer of illustrations to the printed page from engraved rollers in a printing press were also widespread by the fifteenth century.

Block printing remained a practical proposition until the roller printing machine was invented by James Bell in 1783. This enabled six colours to be printed at a rate equivalent to that of 40 hand-block printers. The success of the machine depended on the hard rollers, each of which bore an engraving (i.e. an intaglio engraving, in which the depth of the recess on the roller determines the intensity of the print produced) corresponding to a particular colour component of the design. The machines were capable of continuously printing six different colours in sequence, with the rollers pressed against the fabric.

Traditional screen printing

The use of screens can be traced back to the ancient Japanese, who used fine threads of silk or human hair to 'tie' the freely suspended solid areas of the stencil in place. The threads were too fine to leave a perceptible mark in the final print.

Contents

Home

The modern forms of screen printing began with the introduction of screens of fine woven fabric that allow colorant to be passed through any areas where a solid paper or painted pattern did not block the mesh. The dimensional stability and hydrophobic nature of modern synthetic fibres has made it possible to construct screens that provide a high precision in the placing of differently coloured components of the design. The high tensile strength of the filaments enables them to be stretched over a metal frame and remain taut during repeated use. This is a marked improvement over the older hydrophilic silk screen stretched over a wooden frame, and one that has led to the mechanical simulation of the older craft process. The screen can now be raised mechanically whilst the fabric moves into the next position, and then be replaced in exact register. A fully continuous operation was made possible by the development of electrodeposited screens in the form of hollow seamless cylinders, through which the print paste may be pressed from the centre as the screen rotates and beneath which the fabric is carried on a moving blanket.

Printing paste

In textile printing the printing paste on the fabric may be regarded as a miniature localised dyebath containing the dye and all the additives necessary for the coloration process. Thus print pastes for reactive dyes will contain alkali, those for vat dyes will contain reducing agent, and so on. Dye diffuses into the fibre from the paste, aided either by a rise in temperature and absorption of water within a steamer, or by the fibre becoming a more favourable environment as the paste becomes affected by the heat of a dry fixation process. To a certain extent the nature of the fixation process to be used influences the type of additive mixed with the print paste.

Textile printing pastes are usually water-based, but for paper printing a solvent base may be chosen since for this purpose rapid drying through evaporation is more important than substrate penetration. Compared with a dyeing process on a similar fabric, dyes of lower substantivity and high water solubility are often chosen, so as to ease the final washing-off process.

The viscosity of the print paste needs careful attention to ensure that it flows smoothly from the source of application on to the fabric. Too high a viscosity impedes transfer and penetration, and if the paste does not spread evenly on the fabric the surface appearance will be unsatisfactory. Most thickening agents are polymeric in nature, and the overall chemical composition of the paste must be compatible with the dye fixation mechanism. For example, there is little point in using a polysaccharide thickening agent (such as starch) for reactive dyes, because of its chemical similarity to cellulose: the dye would react with the thickener before it reached the fibre. Similarly thickeners with cationic groups will react with anionic dyes, and vice versa. A variety of thickening agents is available, ranging from polysaccharides (polymers of sugar monomers) such as starches and natural gums like locust bean gum, guar gum or gum arabic, the last-named being obtained from acacia trees, to alginates (from seaweed) and synthetic materials such as poly(vinyl alcohol) and acrylic polymers.

Roller printing

The principle of roller printing is illustrated in Figure 6.13. The fabric travels round a large cylinder (A) referred to as the pressure bowl. This is covered with a thick layer of textile material, the lapping, around the circumference of which the fabric to be printed is carried on an endless blanket, usually of polyester/cotton material. Thus a resilient backing is provided for the material during the impression stage. Any excess colour is absorbed by a layer of unbleached cotton (the 'back grey') placed between the printing blanket and the printed fabric. As the bowl revolves it carries the fabric forward from a roll situated behind the machine for as long as the engraved printing rollers are under mechanical pressure rolling over the surface of the fabric. In this way the resilience of the backing forces the fabric into the engraving from which the print paste is removed. Colorant is transferred from the trough containing the printing paste (the colour box) to the engraved roller through the intervention of a furnishing roller dipping into the printing paste.

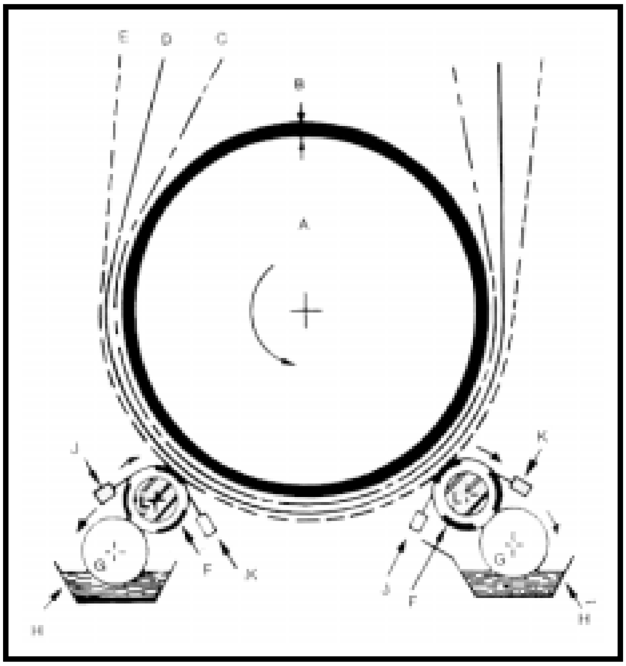

Figure 6.13 *Diagram of a two-colour machine*
A Pressure bowl (impression cylinder), B Lapping,
C Endless printing blanket, D Back grey, E Fabric to be printed,
F Engraved printing cylinder, G Furnishing rollers, H Colour box,
J Colour doctor, K Lint doctor, L Mandrel

Surplus print paste is removed from the printing roller by a sharp stainless steel 'doctor blade' before the roller makes contact with the fabric. Any loose threads or hairs that adhere to the

Contents
Home

roller after transfer of the print pastes are removed by a second doctor blade, the lint doctor, before the engravings are refurnished with print paste. Only two printing rollers are shown in Figure 6.13, but several rollers may be positioned around the bowl, each contributing its own coloured motif in the exact register required for the printed pattern.

From the bowl the fabric passes to a dryer, a steamer or any other treatment appropriate for fixation, from where the fabric travels to a washing range in which spent print paste, surplus chemicals and dye are removed.

In one machine the fabric passes over two bowls, so arranged that the inside of the fabric being printed on the first bowl becomes the outside when it reaches the second bowl. In this way the fabric may be printed on both sides to give a duplex printed fabric.

As we have seen, the composition and consistency of the printing paste are critical factors in the attainment of high-quality prints. In particular, a low viscosity can lead to frictional damage to both the doctor blade and the engraved roller. Any resulting imperfections in these metal components as a result are likely to lead to the unwanted appearance of fine lines of colour on the print. The absence of small particulate foreign matter in the paste and scrupulous cleanliness of the rollers are further requirements for perfecting the products.

Engraved roller printing is notable for high resolution and excellent reproduction of intricate patterns. Unfortunately the high cost of engraving the rollers and the need to adapt to shorter runs has gradually eroded the old supremacy of roller printing, to the advantage of rotary-screen printing.

Rotary-screen printing

The value of continuous rotary-screen printing first became apparent in the 1960s. The hollow screens, each applying the appropriate motif, are arranged sequentially as in roller printing, but they are aligned over a moving horizontal blanket that carries the fabric between the two. As the fabric moves forward the screens rotate and apply the colour.

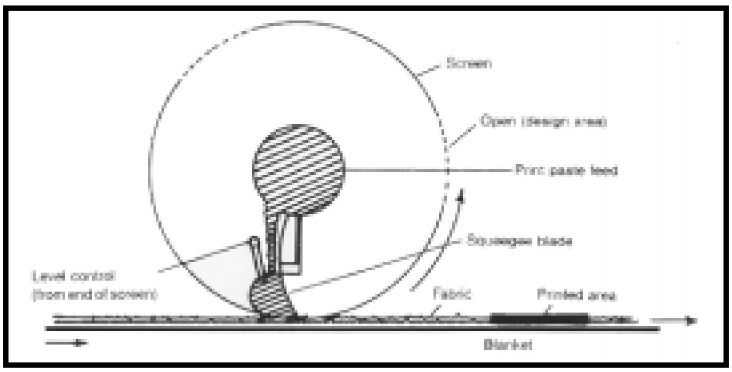

Figure 6.14 *Rotary screen printing section*

One arrangement for the delivery of print paste is shown in cross-section in Figure 6.14. The

Contents

Home

squeegee blade is flexible to accommodate any variations in pressure required to force the paste evenly through the mesh of the screen across the width of the fabric. In some models the squeegee is replaced by a metal rod held in position by a magnetic field. This is more suited to heavier fabrics, since the mechanism imposes a higher limit on the minimum amount of paste that can be delivered. In general the rotary-screen printing machine requires a lower pressure between roller and fabric than is used with engraved rollers.

As with all screen printing, some control of delivery can be obtained through variation in the mesh size, a larger mesh being appropriate for fabrics made from coarser fibres or areas of solid colour, whilst a finer mesh is better for producing fine detail or for fabrics made from fine fibres.

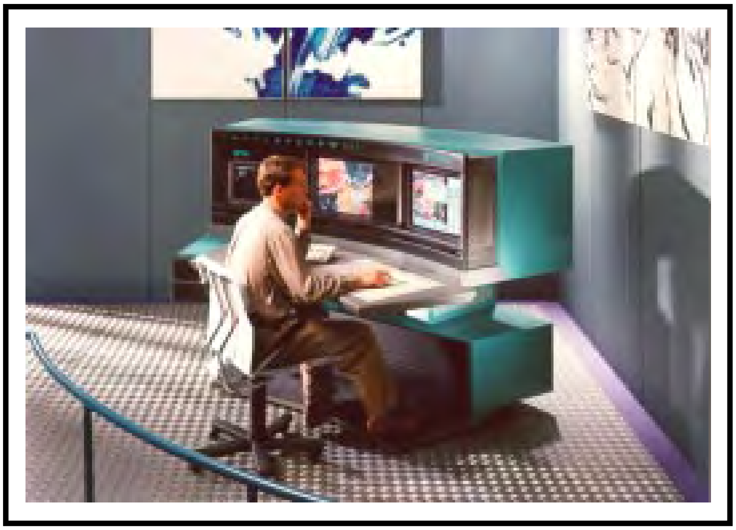

Figure 6.15 *A modern CAD system for digital processing of textile designs*

The advantages of rotary-screen printing machines over engraved-roller machines include faster production rates, greater ease of setting up and a lower dependence on experience for successful operation. Computer-aided design techniques for printing screens are now increasingly widely used (Figure 6.15).

Transfer printing

The ability of disperse dyes to sublime on heating (page 18) has led to a very different approach to textile printing. In this the design is first printed on paper using disperse dyes. The paper can then be inspected for faults; if any exist, that area of paper can be discarded to avoid wastage of fabric. The fabric is placed face down on the printed surface of the transfer paper, and the two are squeezed together in a heated press at a temperature high enough to vaporise the dye, which transfers in the vapour phase to the fabric. Transfer printing has the advantage that no printing paste is applied to the fabric and so no washing-off is necessary.

The production of transfer printing paper for textile purposes began to grow rapidly in the early 1970s but so far its use is restricted to the application of disperse dyes, and hence to the printing of synthetic fibres. The paper can be prepared by gravure printing, in a manner similar to the engraved roller printing of textiles (Figure 6.16). An alternative is flexographic printing, in which the image is formed in relief on a composite rubber moulding (Figure 6.17) using sophisticated methods for cutting the pattern; this method has the advantage that wide paper may be printed satisfactorily. Another method is lithographic printing, which involves the preparation of a discontinuous design on a plate by photographic techniques.

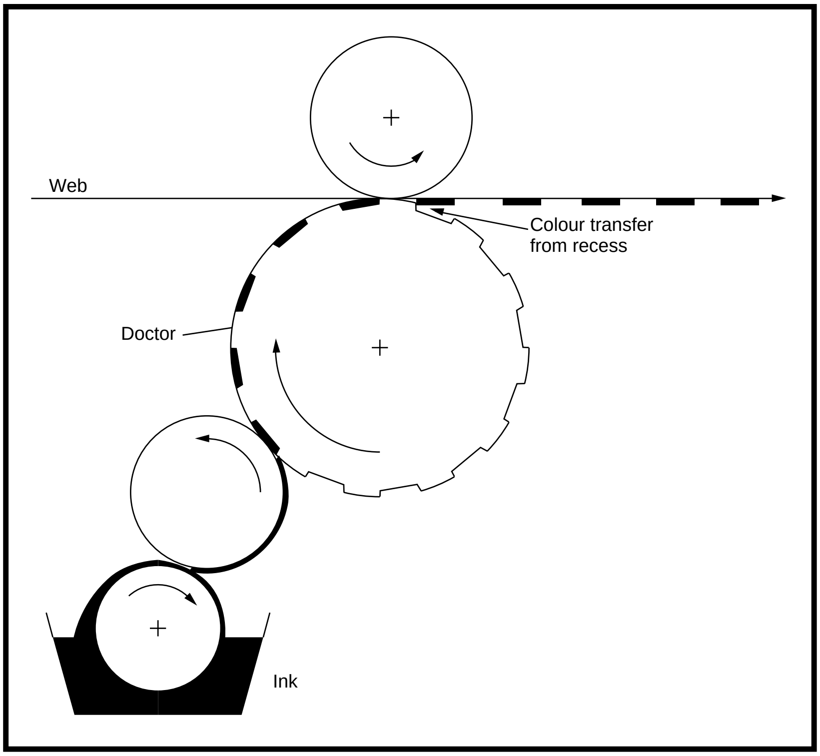

Figure 6.16 *Gravure printing: single colour*

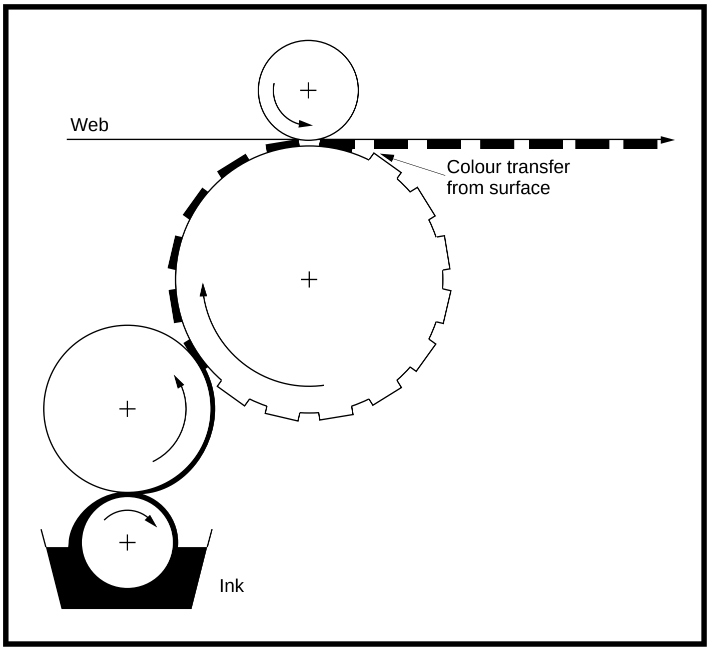

Figure 6.17 *Flexographic printing*

The fabric and paper are brought into close contact using a continuous calender type of processor (Figure 6.18). The fabric and paper are placed face to face and held close to a heated cylinder under

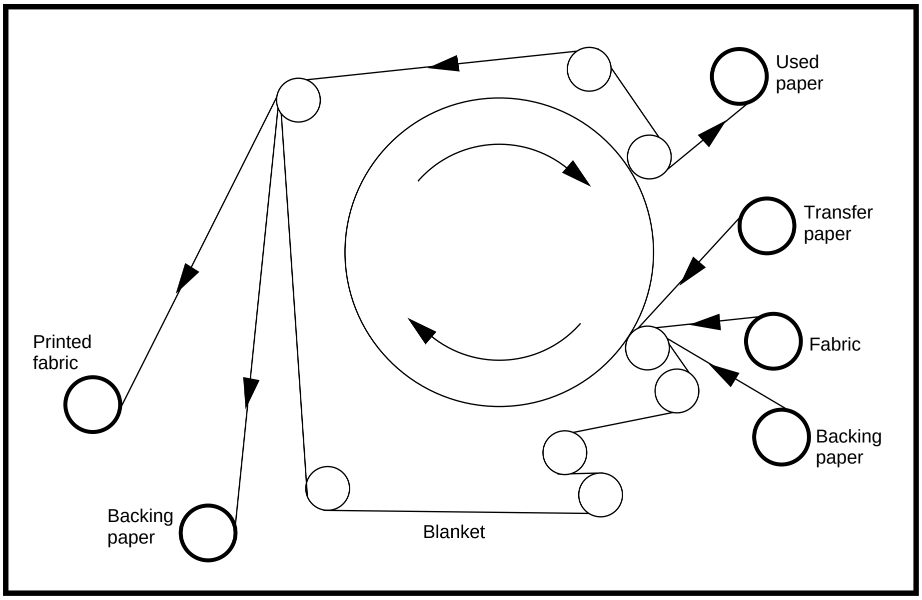

Figure 6.18 *Continuous transfer printing*

light pressure from an endless blanket, often made of the heat-resistant material Nomex (see page 60). Fast rates of production are possible with this system.

Discharge printing

In addition to the straightforward application of dye, textile printing offers the designer certain styles that can be used to obtain specific aesthetic effects. Discharge printing, for example, can provide intricate printed patterns on a coloured background (the ground colour). The new pattern may be white, or it may be a different colour from the original fabric, in which case it is referred to as an 'illuminated' style. Effective discharge methods have been developed for both natural and synthetic fibres.

Discharge printing is carried out where small areas of pattern are required on a large area of ground colour, too large to be produced efficiently by printing methods. It enables finely detailed patterns of good definition to be introduced on to the fabric, which adds significant value to the end product. The technique depends on the fact that some dyes may be chemically removed from the dyed fabric using a *discharge agent*, to leave a corresponding white area. The necessary discharge agent is mixed with a colour-free printing paste and the pattern printed on to the previously dyed fabric as usual. Drying or steaming and then washing follow. For illuminated styles a discharge-resistant dye is incorporated into the paste so that discharge and coloration with the illuminating colour occur simultaneously.

The efficiency of the discharge reactions is critically dependent upon the selection of suitable dyes. Easily discharged dyes are required for the ground shade, while discharge-resistant dyes are needed for the *illuminating discharge*. The method can be used on fabric dyed with indigo vat dye either by destroying the colour with an oxidising agent, or more commonly by converting it to a leuco compound using a reducing agent, which then combines with the leuco compound and prevents its reoxidation.

Selection of the thickening agent for the print paste is also more critical than for direct printing because it must remain chemically resistant to the reducing action and retain its viscosity throughout. If the latter proves unsatisfactory, migration of the print paste beyond the required area carries the reducing agent with it, blurring the definition and fine detail of the pattern. This effect is called 'flushing'. In illuminated discharges it appears as a white surround to the printed pattern, in which case it is referred to as 'haloing'. It can be controlled, however, with proper attention to preparation of the print paste.

Resist printing

Resist printing offers a way of producing an effect similar to that of discharge printing. It also uses dyes that can withstand the discharge process, so that high fastness standards are possible.

The principle of resist printing depends on preventing dye from reaching, or becoming fixed on, defined areas of fabric. Both mechanical and chemical techniques are adopted to provide the resist. Inert compounds such as waxes, resins, fats, china clay, zinc and titanium oxides, and salts of lead and barium all act as mechanical resists for the dye.

Chemical resists, on the other hand, act to prevent the fixation mechanism from operating. Consequently their use requires an awareness of the chemical reactions involved in dyeing the ground shade. A nonvolatile acid, for example, will prevent the alkaline fixation of reactive dyes on cellulosic fibres, an oxidising agent will prevent the reduction of vat dyes, and so on. A more detailed review of discharge and resist printing has been provided elsewhere [6].

'Burnt-out' printing techniques have also been developed in which part of the fibres themselves is chemically removed to produce a clear-cut, shaped space in the fabric. Effective results are obtained in this way with polyester/cotton blends, with areas in which the cotton fibres have

Contents

Home

been 'burned away' leaving the coloured polyester threads behind. The effects produced depend on the original colours of the two types of fibre and they are achieved without undue loss of fabric strength.

There are many other possible printing styles available, notably those producing African prints, some of which have evolved from tie dyeing or the mechanical wax-resist 'batik' style. A full discussion of these and other styles is given elsewhere [4].

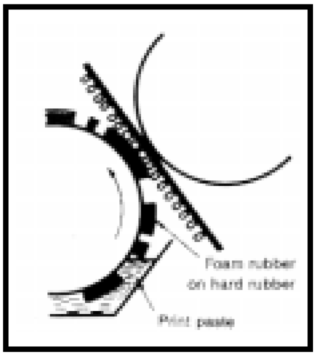

Figure 6.19 *Carpet printing: one type of roller action*

Carpet printing

The introduction of carpet printing was stimulated by the desire to expand the possibilities for producing patterned tufted carpets. Various machines have been designed, similar in principle to those used for printing fabric. Figure 6.19 shows one type of roller, in which a sponge rubber or nylon flock fibre design caps the cut-out pattern in the rubber surface of the roller. The face of the carpet is pressed successively on to the upper surface of each of four rollers arranged one above the other in a line at 45° to the horizontal. The principle has proved popular but its application is restricted by the relatively poor resolution of detail that it can achieve.

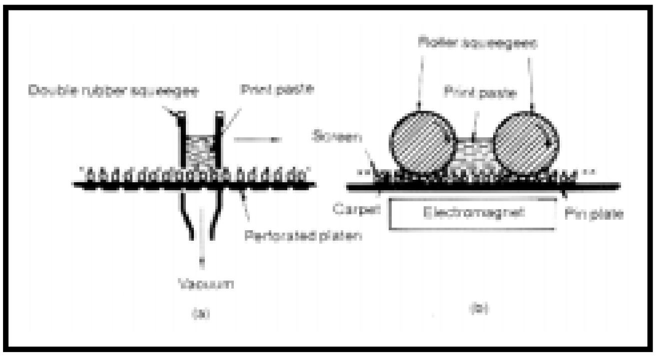

Figure 6.20 *Principles of the (a) BDA and (b) Zimmer machines*

Flat-screen printing

Penetration of the pile is important in carpet printing and there are two principles upon which flat-bed machines have been constructed. The BDA machine, which is no longer widely used, employed an ingenious arrangement in which the reservoir of dye was trapped between the blades of a double squeegee passing over the screen, penetration of the pile being assisted by the application of a vacuum from beneath (Figure 6.20 (a)). In the Zimmer machine the print paste is trapped between the electromagnetic rollers that form the double roller squeegee (Figure 6.20 (b)). Penetration in this case is encouraged by the pressure created by the second roller running over the wedge of paste, which it traps as it

Contents
Home

moves forward over the screen. Shorter pile lengths are preferred for this machine. There are also other versions of the rotary-screen printing machines with heavier gauge screens and rollers.

A more novel method for applying colour to carpet substrates is through the use of a bank of miniature jets of dye. This principle was first used in the Millitron machine of Milliken & Co., although other similar machines are now available. The jets are controlled by computer-operated electromagnetic valves, and the mechanism has eliminated the need for screens. Since there is no distortion of the pile, optimum surface appearance is maintained and the pattern can be changed simply by the use of different computer software.

A more detailed discussion of the printing of carpets has been published [4].

Coloration of fibre blends

The properties of synthetic fibres have been exploited in many different ways since their first appearance. They have given a much greater degree of freedom to the designer faced with the task of matching the properties of textile goods with the requirements of a particular end use. Very often this involves blending mixtures of natural and synthetic fibres in the same yarn, or including natural and synthetic yarns together in a fabric. A variety of benefits may be gained from blending fibres of different chemical origin, including economy – blending natural with cheaper synthetic fibres enables a yarn to be produced at a lower cost. Very often, however, the main attraction is the combination of the unique advantageous properties that each fibre has to offer.

Blends of polyester and cellulosic fibres are particularly popular. Polyester confers good tensile strength, abrasion resistance, dimensional stability and easy-care properties to the goods. Cotton is responsible for good moisture absorption properties (and hence comfort in wear), antistatic properties and a reduced propensity to pilling. Combinations of acrylic fibres with wool are noted for their good dimensional stability, wear resistance and pleat retention. Nylon fibres are often included in carpet yarns alongside wool to give improved durability and elastic recovery whilst retaining the warmth and bulk usually associated with pure wool.

These and many other widely used fibre blends add complexity to the dyer's task. Often the requirement is to colour hydrophobic and hydrophilic fibres in the same fabric – yet, of course, they need completely different approaches. Sometimes this may require a separate dyeing operation for each fibre component, but through ingenuity on the part of both dyer and dye manufacturer some

Contents

Home

single-bath operations have been developed. For example, it is possible to find conditions under which a combination of disperse dyes and vat dyes, or of disperse dyes and reactive dyes, may be applied together from the same bath. Dispersol T dyes (ICI), for instance, were designed to dye the polyester portion of cotton/polyester blends but to become soluble in the hot alkaline conditions required for applying a reactive dye to the cotton component after the dyeing of the polyester was complete: thus on washing the residual disperse dye could be removed from the cotton component. Subsequently ICI developed the Procion T dyes, which react with cellulose under acidic conditions. Thus the Dispersol T and Procion T dyes could be applied in one bath and fixed simultaneously.

Other combinations of fibres may require the use of anionic dyes for one component and cationic dyes for another, which without proper control could lead to chemical interaction between the different dye classes or dyebath auxiliaries, thus preventing or at least hindering the attainment of the desired effect.

The most frequent requirement is for a solid shade, where each fibre component is of exactly the same colour. But this does not preclude requests for reserve effects (in which one component remains undyed), contrast effects (where each component is dyed a different colour) or shadow effects (with each component dyed the same colour but to different depths). The situation may be compounded further by the use of three different fibres in one blend.

A systematic approach to the formulation of dyeing methods is therefore adopted through a classification of fibres into groups according to their dyeing properties. Thus the 'disperse dyeable' group includes the cellulose acetates and polyesters, the 'anionic dyeable' group contains wool, nylon and cellulosic fibres, whilst the 'basic dyeable' group contains acrylic fibres and some modifications of nylon and polyester. Reference to these groupings may then be made to indicate whether the components of a blend require dyes from the same or different dye classes. The dyeing of ternary blends may be formulated on similar principles.

The dyeing of fibre blends is a vast and complex subject, and those with a special interest in this area are directed to more advanced texts [5].

Contents

Control of coloration processes

In the finishing of textiles, as elsewhere in industry, moves towards greater efficiency have led to the automation of many aspects of production. Over recent years the various mechanical devices used to

Home

ease the physical work required have increasingly incorporated equipment that aids or even replaces human mental effort. Fully computer-controlled systems are well established in many large chemical plants, oil refineries, steel works and paper mills, so it is not surprising that microprocessor technology is also growing in textile processing organisations.

Computer control involves monitoring processes and initiating corrective action towards specified targets in an attempt to 'get things right the first time round'. This can lead to reduced costs in plant and raw materials, increased safety, improved working conditions, savings in manpower and improved plant management and supervision. Computer monitoring of temperature, flow, pressure, pH and concentration of dyebath chemicals is becoming commonplace.

One of the most dramatic transformations witnessed by dyers over recent decades is the replacement of lengthy preliminary laboratory dyeing trials, formerly routinely required to match a customer's shade, by instrumental measurements of the coloured pattern. These are coupled with information concerning the adsorption properties of the available dyes on the given substrate to provide a recipe for precise matching of the shade, together with information concerning fastness properties and cost, within only a little time. The basis of this aspect of quality control in textile coloration is the subject of Chapter 7.

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