# 7

# Fabric treatment processes

## 7.1 Starting material

Modern standards in textile use seldom, if ever, allow a fabric to be sold to the ultimate consumer exactly as it appears immediately after being manufactured. This greige state, as it is known technically, is unacceptable for various reasons and further treatments are required to bring fabrics to the point where they can be used. In modern mills, the foremost aim is to minimise the financial costs of finishing (and all other operations), so it is common for a plan to be drawn up to control the entire train. Arang and Fernandez[1] describe a computer program aimed at management, with applicability throughout the entire factory and with emphasis on environmental protection. The treatments carried out after manufacture may be broadly classified as either finishing or colouring. It is also not uncommon for a fabric to need washing before attempting any other processing. Washing, either in detergent or merely in water, has already been discussed at the fibre stage, but may be used at various stages in the manufacture and should be considered as having the same potential means of bringing about environmental damage wherever it takes place.

## 7.2 Finishing categories

Once a clean fabric is available, the finishing treatment can begin. The type of finishing selected depends on the fibre content of the fabric and the end use to which it will be put. Finishing is usually divided into two types, mechanical and chemical. These can be distinguished by considering the way in which they are carried out. Usually, it is assumed that a treatment is mechanical if it only involves the use of some kind of mechanical action, but it is often accepted that the use of heat and moisture may also be a part of mechanical finishing. Examples of this category of finishes commonly adopted include calendering, beetling, fulling, decating, brushing, raising, shearing, moiré, shrink-proofing and steaming.

Wool and synthetic-fibre fabrics are often considered to be the ones needing least finishing, because of their ability to be produced with many of the desirable features already incorporated. Wool cloths, though, are frequently given a range of both mechanical and chemical finishes, the mechanical ones of most interest being principally aimed at changing thermal insulation characteristics. Fulling is akin to felting and is achieved by subjecting the cloth to heat, moisture and agitation. Its purpose is to close up the tightness of the weave, so that the fabric retains heat better and is less likely to permit air to pass through and cause wind chill. As in felting, environmental costs result from machinery and energy factors, as well as from the discarded wash liquors ***(* W-3)*** (see Table 1.1 for an explanation of codes).

## 7.3 Mechanical finishing

### 7.3.1 Brushing, raising and shearing

Brushing, raising and shearing are usually considered together; Korner[2] explains the objectives and principles of the processes, together with discussion of the factors influencing them and the requirements for their successful operation. Brushing is, as its name implies, the passage of the fabric over a surface that brushes the fibres to lift them slightly out of the bed of the fabric. In this way, the amount of air enclosed is increased and, because trapped air holds heat well, so is the thermal insulation. Raising takes the process one step further, lifting the fibres still more by brushing them so roughly that the actual weave pattern is obscured. This not only increases insulating capability still further, but can conceal a sleazy cloth to some extent, so an open weave, with its inherently lower strength, can be disguised as a better one. Unfortunately, one side effect of this degree of raising can be an even greater reduction in strength, as the integrity of the fabric cohesion may be disturbed, thus shortening the life expectancy of the fabric. In such cases, there is another kind of environmental cost, that of the premature scrapping of the fabric, to add to the familiar ones of machinery and power consumption. There may also be a cost associated with the breakage of individual fibres, producing a certain amount of waste that cannot be reclaimed for any really valuable or useful practical purpose in view of the extremely short lengths of the fibre segments removed.

After raising, the appearance of the fabric tends to be rather ragged, because of the rough treatment it has received. For this reason, shearing is then carried out. This is a means of cutting off some of the fibres, so that they are all at a uniform height above the fabric surface, by passing the cloth through blades resembling those of a cylinder lawn mower. The side effect, which is a large quantity of waste fibre, is obvious and produces an inevitable environmental cost.

### 7.3.2 Moiré

In moiré finishing, in which a fake watermark is embedded into a synthetic fabric in an attempt to make it look like a silk, heat and pressure operations take place, with one portion of the fabric being forced to run counter to another by passage around suitably arranged cylinders, so that a frictional effect is produced that marks both of the contacting sections of the cloth. Decating, calendering and beetling can also be considered in the same category. Each of these treatments involves the application of pressure, with or without heat and/or moisture, to a fabric. The purpose and the fibre types to which the respective finish is applied are different, but the basic principles (and the ecological effects) are the same in each case. Machinery and energy factors are present once more and, when steam is used, some waste heat is evident when it is allowed to escape onto the cloth.

### 7.3.3 Mechanical shrink-proofing

Shrink-proofing as a mechanical finish uses the overfeed principle, in which damp fabric is pushed onto the pin frame of a tenter (described in Chapter 11, Section 11.3) then subjected to sideways tensile stress while drying occurs. Energy losses are high, as described later, but the resultant fabric tends to be stronger and is less likely to be discarded. The fabric is also unlikely to be thrown away as waste prematurely, as it would be in the absence of shrink-proofing when a garment made from it might no longer fit after washing.

## 7.4 Chemical treatments

### 7.4.1 Chemical shrink-proofing

Chemical treatments associated with shrink-proofing are normally used in modern plants and can be considered as the first example of a chemical finishing process. The mode of operation of such a process is to fill the interstices between the yarns of a fabric with a reagent that blocks the spaces so that the yarns cannot move into a closer juxtaposition. The process adopted may vary, either using impregnation with various resins, or by cross-linking with (for instance) dialdehyde, glyoxal and urea–formaldehyde. In both of these types of treatment, waste effluent of one or more of these chemicals ***(* W-3)*** is inevitable, and its subsequent discarding into the water environment will, just as inevitably, create a pollution problem. Xu *et al.*[3] apply durable press to cotton in a one-step (and hence less polluting) method and compare the outcome to the more usual two-step process. They test results by crease recovery angle and strength measurements, finding that the two-step technique is better for crease recovery, but not as good for strength retention because of the longer curing times needed. These will, naturally, also increase environmental costs, offsetting to some extent the benefits imparted by this modification of the processing train. Optimum conditions for the two-step treatment are quoted as 4.3% citric acid and then 1.7% butane-tetracarboxylic acid. Cheng *et al.*[4] attempt to improve the easy-care finishing of silk by using a multifunctional epoxide that reacts with the tyrosine in the silk to reduce the chemical activity of the fibre. Little or no change in wetting properties is evident, but the rate of hydrolysis in alkaline solution is very much lower after treatment. An anonymous writer[5] reports the production of washable wool by easy-care finishing using oxidative or cross-linking techniques, noting that the process reduces shrinkage from about 30% to about 2%.

### 7.4.2 Water resistance

A similar end result occurs in the various methods used to provide water resistance. The type of reagent involved depends on the degree of resistance needed, whether merely for protection against light showers, or against heavy storms, or to prevent all aqueous liquid entry in, say, a garment for protection against chemical or biological warfare reagents. In addition, there is considerable interest in the development of finishes that are resistant to liquid water, but allow moisture vapour to pass through. This treatment compensates to a considerable extent for the main disadvantage of traditional storm-resistant fabrics, the tendency for the people wearing them to be wetter from their own perspiration than they would be from the actual rain being kept off their bodies.

The types of chemical used (and the resulting effect on the environment) vary, but are typified by insoluble metallic compounds, paraffin or waxes, bituminous materials, linseed or other drying oils and combinations of all these substances. Application in each case is usually achieved by padding, or passage through pressure rollers under or near the surface of the treatment liquid. Again, the inevitable machinery and energy factors must be accepted, but there is also the added problem of disposal of the chemical reagents. Paraffin and similar waxes are relatively harmless and can usually be reused easily, but some metallic compounds, oils and bituminous materials may be highly toxic ***(* W-3)*** and should only be released after considerable dilution. Even then, all of them are harmful in some degree and should be regarded as undesirable. In this context generally, the industry has begun to sound warnings. Lal[6] expresses concern about the effects of pollution on the environment and Soljacic *et al.*[7] propose that a system for eco-acceptable finishing ought to be developed. Gulrajani[8] feels that the Indian chemical finishing system is already environmentally sound, but is antiquated. Mathew[9] suggests that the use of ultrasound in all applicable wet processing steps, such as the preparation of sizes, emulsions, dye dispersions and thickeners for printing, would be beneficial to the planet's well-being because it can reduce the amount of reagent needed. Duschek[10] describes the mode of action of fluorocarbon polymers and the ability, by using a new technique, to apply such a finish in a low-emission manner (about 90% lower) to maintain emissions well below legislative standards and with no thermal after-treatment.

How well the rest of the industry follows strictures for ecological responsibility is not too encouraging, as we will shortly see, but all the chemical finishes currently in vogue will be considered here first. In an unusual approach, Barton[11] reports the possibility of 'intelligent fabrics' being developed. These would have fragrances, moisture, antibacterial finishes or thermal modifications incorporated into their structure to provide continuing effects. Until they are commercially realisable beyond the relatively few underwear applications presently available, the industry has to rely on more familiar techniques.

Moisture vapour permeability, in conjunction with liquid water resistance, is currently ardently sought as a kind of 'philosophers' stone' in textile science. The elusive ability to allow complete moisture comfort with the total exclusion of all liquid water and the total capability of perspiration moisture to escape, has not yet been developed. The principle on which a successful technique can be expected to operate is a simple one, the fact that there is a significant difference between the molecular sizes of liquid and vapour aggregates of water. Unfortunately, we do not yet have the ability to control the size of fabric apertures to the necessary degree of accuracy. The methods of approach currently in vogue include hydrophobic finishes, coatings, and laminations of microporous films or membranes. More details of the latter two are provided by Fung.[12]

### 7.4.3 Durability

Hydrophobic finishes tend to suffer from a serious defect, in that the finish slowly disappears during extended use. Thus, a raincoat which gives adequate protection against showers when bought may, after a few laundering or dry cleaning treatments, be less than satisfactory and leave the unfortunate wearer soaked. In terms of environmental damage, the application of the water-resistant finishing agent, usually consisting of a reagent similar to those mentioned above in connection with liquid water resistance, is a problem both at the manufacturing stage, when the surplus chemicals are flushed into the drain ***(* W-3)***, and after use if the garment is thrown away prematurely because it is no longer of any value for its intended purpose. The type of finish will be governed by the degree of water resistance required, but all of those currently in use tend to be slowly lost with time and this approach is not now regarded as having any real future.

Because of this, other solutions have been attempted. One of the earliest of these was the traditional oilskin often used by seamen and cyclists. This consists of a topcoat made from a fabric of cotton which has been saturated with an oil (usually linseed or some related substance) and heated to bake, and hence polymerise, the oil. The actual extraction of the oil, as with all oils, carries the environmental cost mentioned already, and the baking process is likely to produce toxic gaseous by-products ***(* A-2)*** as a result of the high temperatures needed for polymerisation. The garment, too, is usually not completely satisfactory, as anyone who has cycled in one will attest. The inside of the oilskin after pedalling strenuously up a steep hill leaves the cyclist in a sad state of drenched discomfort from perspiration that stays with him, entrapped by the impermeability of the oilskin, for the remainder of the journey.

### 7.4.4 Membranes

The next type of solution to be discussed is the membrane, specifically described in a waterproof and breathable application by Bajaj;[13] the technique is most familiarly typified for the general public by Gore-tex products. In these, a thin membrane of microporous material of polytetrafluoroethylene (PTFE) is sandwiched between two layers of fabric, usually polyester, to reinforce the fragile membrane and prevent it from shredding. The production step involves making PTFE and polyester fabrics, accompanied by all the usual difficulties in polymer manufacture, and in producing an adhesive substance to hold the layers together. The adhesive will impose an environmental cost, as will the subsequent process of applying it by machinery. The approach is not completely satisfactory, as the excellent barrier performance preventing water ingress is not accompanied by a total capability to allow perspiration to escape. In addition, the fabric itself can suffer from delamination, leading to premature rejection. The author has experienced both of these drawbacks, having used such a fabric and redesigned the construction of the sandwich material to minimise the latter problem, in a design for the surgical operating theatre gowns illustrated in Fig. 13.2. As always, prematurely discarding a product is an added load on the ecological equilibrium, so the use of this type of material in water-resistant garments is not to be recommended unreservedly.

### 7.4.5 Coatings

A compromise between the techniques of using a microporous membrane and a finish is the adoption of coatings. In these, a microporous material is applied to the external surface of a fabric (usually polyester again) and is adsorbed directly onto the fibres. This method of production still depends on manufacture of the polymeric materials, but does not involve any separate adhesive, any separate application process or any risk of delamination. It has been shown to be more satisfactory from the ecological perspective. Steps are in progress to bring about further technical improvements to allow it to compete adequately on the basis of performance and financial factors. Kubin[14] traces the development of coating technology and provides detailed information on recipes, process operation and properties imparted for a range of types.

## 7.5 Other finishes

A wide range of other finishes should also be considered. These may be categorised in the areas of treatment designed to modify the nature, appearance or feel of the surface for aesthetic reasons, those designed to lengthen the life of the fabric and those intended to provide enhanced consumer satisfaction. The first type includes softening, stiffening and antistatic finishes, while the second may be exemplified by abrasion resistant or antimicrobial finishes. The third category has become of much greater importance and includes such attributes as a built-in resistance to creasing, flame, oil and stains. It can be deduced that there is likely to be some form of crossover between advantages imparted by the three types.

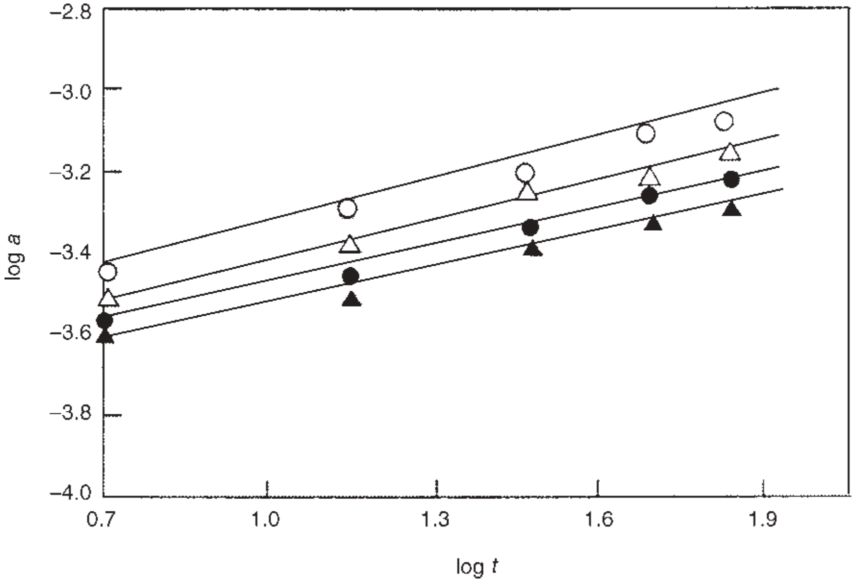
### 7.5.1 Softening and antistatic treatments

Softening and antistatic treatments both use the same type of reagents, such as quaternary ammonium compounds, to achieve their effect. These substances are manufactured in a process that has the customary environmental costs of chemical agent production. Application is seldom, if ever, completely perfect and quantities of the reagents are washed ***(* W-3)*** into the discard stream from the plant, affecting the local water purity. An anonymous author[15] stresses the enormous need for softeners and discusses problems of sewability, yellowing and shearing stability that can arise from softener use.

### 7.5.2 Stiffeners

Stiffeners, such as starch or vinyl compounds, need to be produced, either by extraction from cellulosic plant sources or by a chemical reaction and again are to some degree discarded in the waste stream ***(* W-3)***. A related type of finish is that of mercerisation, the process by which cotton is made more lustrous and stronger by short-term immersion in concentrated sodium hydroxide. The alkali is potentially an environmentally harmful agent if discarded into water or onto land ***(* W-3, L-2)***, so alternatives would be useful. Min and Huang[16] provide details of a one-step process that includes desizing, scouring and bleaching as well as mercerising, but find that poorer dyeing results are produced by its application. Figure 7.1 shows the graph they derive for their cotton fabrics relating dye concentration ($a$) to dyeing time ($t$) on logarithmic axes. The colour level after a given time, but not the slope of the curve, is influenced by temperature, as may be seen in the diagram. Rathi,[17] using enzymes, and Ramaswamy *et al.*,[18] with simultaneous bleaching, also provide suggestions for mercerising, but imply no loss of properties as a consequence of the action. Figure 7.2 shows bar charts derived by the latter authors indicating the effects of bleaching and mercerising on dye uptake.

Abrasion resistance is imparted by the application of some form of lubricating agent to the surface of the fabric. The substance chosen may be an oil, wax or a thermoplastic resin, with results and side effects comparable to those mentioned above in connection with these types of finishing agent. In extending fabric life by enhanced biological resistance, some consideration must be given to the hazards likely to be encountered by the fabric in use. There may, for instance, be a risk of insect damage, especially if wool fibres are present. If the fabric is likely to come into contact with the ground, or is to be used in a damp place, then the chances of rotting may be of concern. If it is to suffer long periods of exposure to the elements,

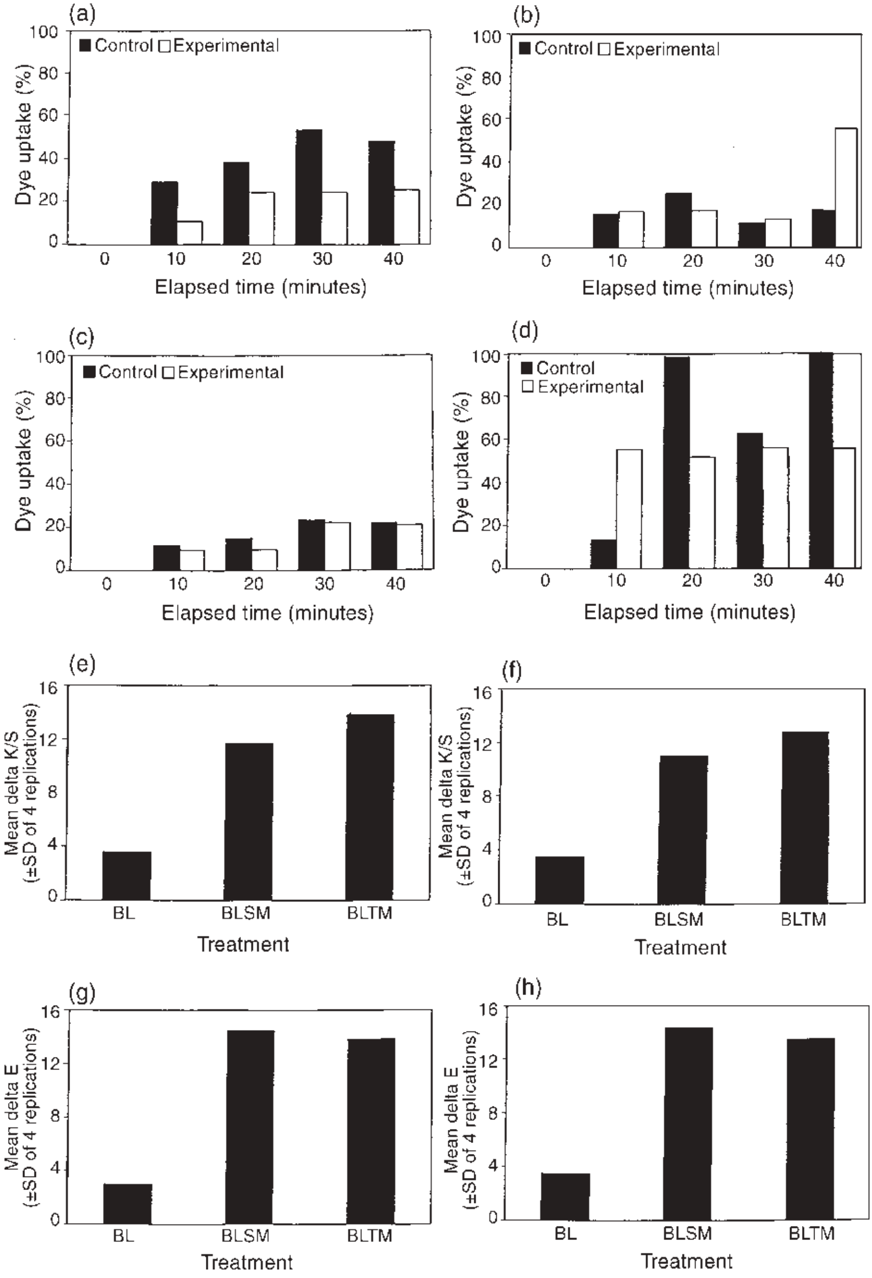


*7.1* Relationship between dye concentrations (*a*) and dyeing time (*t*) for cotton fabrics; dip temperatures: ○, 20°C; △, 40°C; ●, 80°C; ▲, 100°C (source: *JSDC* **115** (1999), p. 70. Reprinted with permission from the publisher, the Society of Dyers and Colourists, Bradford, UK).

especially where bright sunlight is present, then degradation by ultraviolet radiation is a possibility. Finishes have been designed for all of these and are frequently applied in the modern textile industry.

### 7.5.3 Microbiological-resistant treatments

Resistance to biological agents, ranging in size from insects down to the smallest bacteria, can be introduced into textiles in the finishing process. Insect resistance is incorporated into a fabric by germicides (such as metallic salts), resins or organic mercury compounds, with the optimum substance toxic to the specific insect or mildew, and so on, being chosen to minimise damage in comparison with that suffered by an unprotected fabric. The most usual example of a harmful insect is the wool moth, which can degrade large quantities of fabrics by making holes in them. The moth operates by feeding on the disulphide links in the protein of the wool and has traditionally been combated by the use of dieldrin. This substance has been designated as harmful to humans because of its toxic and carcinogenic nature and is now banned in many countries. More recent techniques rely on less effective (in the opinion of many experts) substances, such as fluorides, compounds of antimony or chromium, dyestuffs (mitins or eulans) or formaldehyde to protect the wool ***(* W-3)***.



*7.2* Effect of bleaching and mercerising under various conditions on dye uptake of cotton fabrics (source: *Textile Chemist and Colorist*, Vol. **31**, No 3, March 1999, pp. 27–31; reprinted with permission from AATCC).

All of these compounds, from dieldrin to its modern substitutes, constitute a load on the ability of the planet to renew itself in a healthy manner. The chemical agents (especially the more modern ones, which must be used in far higher concentrations than dieldrin) can produce adverse effects in many species and are toxic to humans. Other insects, such as carpet beetles, are dealt with in a similar manner, with comparable results. The protection of textiles against insect damage is not without effect on the world around us, and the extended life of garments made from susceptible fibres (allowing them to be kept for longer periods instead of being thrown away as a load on the environment) should be weighed against the risks of danger or harm to the various affected species of the planet.

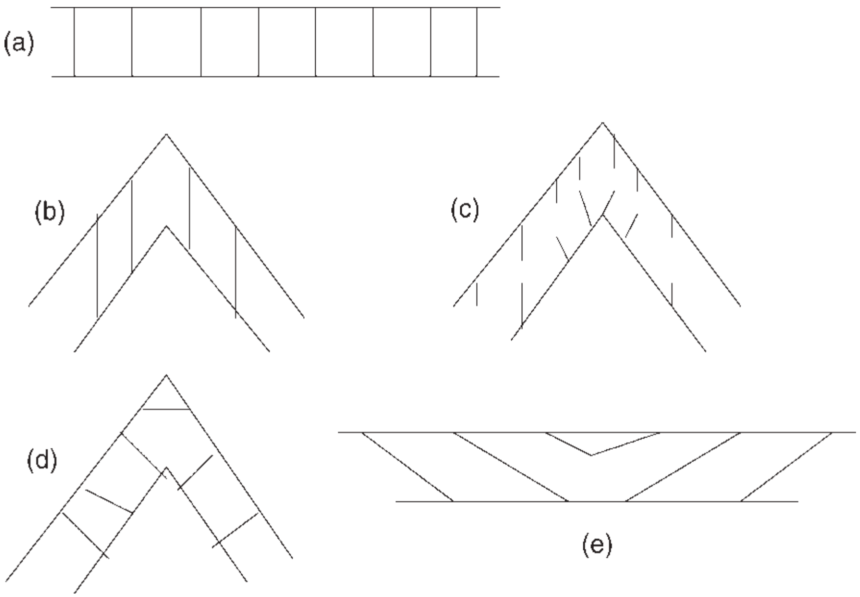
An exactly similar argument also applies to rotproofing agents, such as metallic salts, condensation resins or cellulose acetate, which function in the same way to prevent damage by microbiological agents, such as moulds or mildew that are present in soil or damp locations. These treatment substances, which operate either by preventing contact between cloth and the harmful agent or by inhibiting microbiological growth, also create hazards to planetary species when they are discarded ***(* W-3)***. Efforts are made to minimise the amount of all of these reagents sent to waste, but the best processing conditions, unfortunately, can still bring about appreciable risk of damage from effluent chemicals. These smaller-scale undesirable biological entities have aroused interest because, if they cannot be removed, they can either destroy the fabric or can make it unacceptable, both of which lead to environmental stress as a result of premature discard. In general, the same types of chemical reagent have been used in the past to deal with problems on this scale as have been adopted for controlling larger pests.

### 7.5.4 Ultraviolet resistance

Ultraviolet resistance is imparted to fabrics by protecting them with an agent that absorbs radiation in the relevant portion of the electromagnetic spectrum. Instead of attacking the chemical structure of the fibres, the incident radiation uses its energy to bring about an increase in the vibration of specific bonds in the absorbent molecule, thus allowing the fabric to survive unscathed. Once more, these substances (including amines, sulphonated or benzoyl compounds and other complex organic reagents) are unsafe ***(* W-3)*** if released into the water system and impose difficulties on ecological protection capabilities.

### 7.5.5 Easy-care finishes

The third category of treatment purposes is that of consumer satisfaction (including protection). When it is of importance, easy-care finishes such as crease-resistance, soil or stain resistance or repellency and flame resistance are crucial. Crease-resistance depends on the application of an agent capable of allowing the fabric to retain a preset shape by ‘locking’ the molecules into a



*7.3* Bonding changes during crease-resistant treatment. (a) Original fabric with unstretched bonds, (b) crease in fabric; bonds stretched, (c) bonds broken chemically, (d) bonds reformed chemically in less stressed positions, (e) flattening of crease produces restoring stresses in bonds.

particular conformation, as illustrated in Fig. 7.3. The initial molecular structure is placed into the desired form (a crease, pleat or a flat surface, for instance) and a reagent (or its precursor mixture) selected from urea–formaldehyde, melamine–formaldehyde, epoxy resin or a vinyl compound, is spread onto the cloth. The combination is then heated to bring about the essential reaction, so that either the molecular interstices are filled by the polymerised substance or there are added cross-linkages formed between molecular chains. When a potentially creasing force is applied to the fabric in use, the resulting distortion of the fabric is resisted by the blocking action of the space-filling layer or the stretching of the bonds, and the set shape of the fabric is quickly restored once the distorting force is removed.

Formaldehyde is a familiar carcinogenic agent, so that any residual amounts of this substance that remain uncombined with the urea and are discarded are dangerous on being released ***(* W-3)*** into the environment. In addition, the baking process can bring about the production of gaseous toxic substances ***(* A-2)***, released into the atmosphere as part of the emissions from the treatment process. Saraf and Alat[19] address this particular concern with their paper on new developments in the search for alternatives to formaldehyde as a cross-linking agent in resin-finishing of cotton and of cellulose/polyester blends. They investigate the effectiveness of natrium at various temperatures on crease recovery and yellowing.

Vukusiae *et al.*[20] recommend the use of polycarboxylic acid with a mixed catalyst as an ecologically sound alternative, but find that it is too costly and discuss means of overcoming this defect.

The ability to repel oily stains is provided by the application of compounds such as silicones or organofluorochemicals to the fibres. These materials function by preventing any permanent attachment between the hydrophobic molecules of the oil and the fibre molecules by interposing an oleophilic layer between the two. As usual, the substance is a toxic agent, so its effects are felt if disposal ***(* W-3)*** in waste water is attempted, and its manufacture also involves environmental risks. Scott[21] provides details of a coating treatment that can make fibres resistant to water, oil, grease and solvent staining and which is durable in use. The coating has been applied successfully to cotton, synthetic and glass products, at the fibre, yarn or fabric stage, by gas plasma techniques. An anonymous writer[22] also mentions a water-resistant coating that can be used as an alternative to polyvinyl chloride (PVC), based on a copolymer of polyolefin and ethylene vinyl acetate, that is claimed to be ecofriendly on the basis of using no chlorine or bromine. Vohrer[23] notes that, as a result of societal demands for textiles produced by environmentally sound methods, plasma treatment (the application of an electrical discharge in a gaseous medium) is likely to become more common in the near future.

### 7.5.6 Flame resistance

Flame resistance is a topic that has occupied the attention of textile scientists for several decades. It is an inevitable end result of exposure to an open fire that a material which, like many textiles, contains a large amount of carbon in its molecule, may well burst into flame. If it does, the person wearing the material is likely to suffer burns, while others in the vicinity may be overcome by the fumes emitted or may be trapped in a building because they are unable to see through the smoke evolved. The methods adopted by the industry as far as possible to counteract these risks are, unfortunately, somewhat suspect. The principle involved, as a result of legislation enacted in many countries, is one of preventing ignition or, more often, slowing down the rate of spread of any flame occurring. The first of these approaches, though apparently unimpeachable, is seen to be flawed on practical examination. The finishing agent used, usually a compound of phosphorus, nitrogen and/or a halogen, may (as is normally the case for most finishes of any kind) be removed by extended care procedures, such as washing or dry cleaning. Thus, after a period of use, an article thought to be resistant to ignition can in fact burn and a false sense of security may be engendered in the owner.

Finishes designed to slow down the rate of spread of flame, in the same chemical categories, suffer from the same defect, but are also dangerous from another, more important, perspective. If, say, a cotton fabric ignites, it burns quickly and there is little time for intense heat to be produced in any one location. If it has been treated to slow down the rate of flame spread, the hot flame remains in contact with the fabric for a longer period of time, so heat buildup can occur in a small area. The resultant damage to an arm covered by the cotton will be more severe and can include third degree, rather than superficial, burns that will leave permanent scars at least and may well damage the arm so badly that a skin graft is necessary. If, alternatively, the flame spread rate reduction is achieved by blending with a (less rapidly consumed) synthetic fibre fabric, this fibre can melt and stick to the skin, causing even greater problems.

Both categories of finish are inherently undesirable in the ecological sense. The reagents themselves are harmful when discharged into the waste water stream ***(* W-3)***, and may also cause skin reactions in some people. Disposal of the garments after prolonged use will allow leaching of any residual finish to take place, with further harm resulting once it reaches the underground water table. The end products of the combustion reaction if burning does take place are more dangerous for a treated fabric than for an untreated one, since there is an additional evolution of harmful chemicals such as hydrogen cyanide, halogen compounds or oxides of nitrogen, as well as a higher concentration of carbon monoxide as a result of incomplete combustion induced by the presence of the finish ***(* A-2)***. In addition, smoke density increases significantly in the presence of flame-retardant finishes, a factor that not only increases danger from a fire by preventing people from seeing an escape route ***(* A-3)*** but also adds to the pollution resulting from the combustion.

## 7.6 Colouration

One of the most troublesome current areas of concern in the textile industry is the pollution brought about by the colouration processes of dyeing and printing. Although they are not, strictly speaking, finishes in the generally accepted sense of the word, colouring agents are normally dealt with in this category. The main problem with the compounds used for applying colour is the fact that they are almost always, especially with reference to the original synthetic dyestuffs developed in the 19th or 20th centuries, highly toxic ***(* A-2)***, carcinogenic or (for good measure) both. Until fairly recently, they were released freely into the waste waters from the plant and could be seen boldly proclaiming their presence to all and sundry as a brightly coloured, but somewhat nasty, area of water. Of late, however, the industry has been trying valiantly both to reduce the effluent emerging from its dyehouses and to develop less harmful dyes but, although there has been some success in both of these aims, there are still large amounts of dangerous quantities of rejected dyes ***(* W-2, W-3)*** released from the washing treatment used to remove excess colour before continuing the fabric production train. Benisek[24] provides a summary of ecofriendly dyes and packaging materials, while an anonymous author[25] reviews a seminar devoted entirely to environmental issues, with particular reference to natural dyes, thickeners for printing paste and ecofriendly finishing.

### 7.6.1 Dyeing with natural dyes

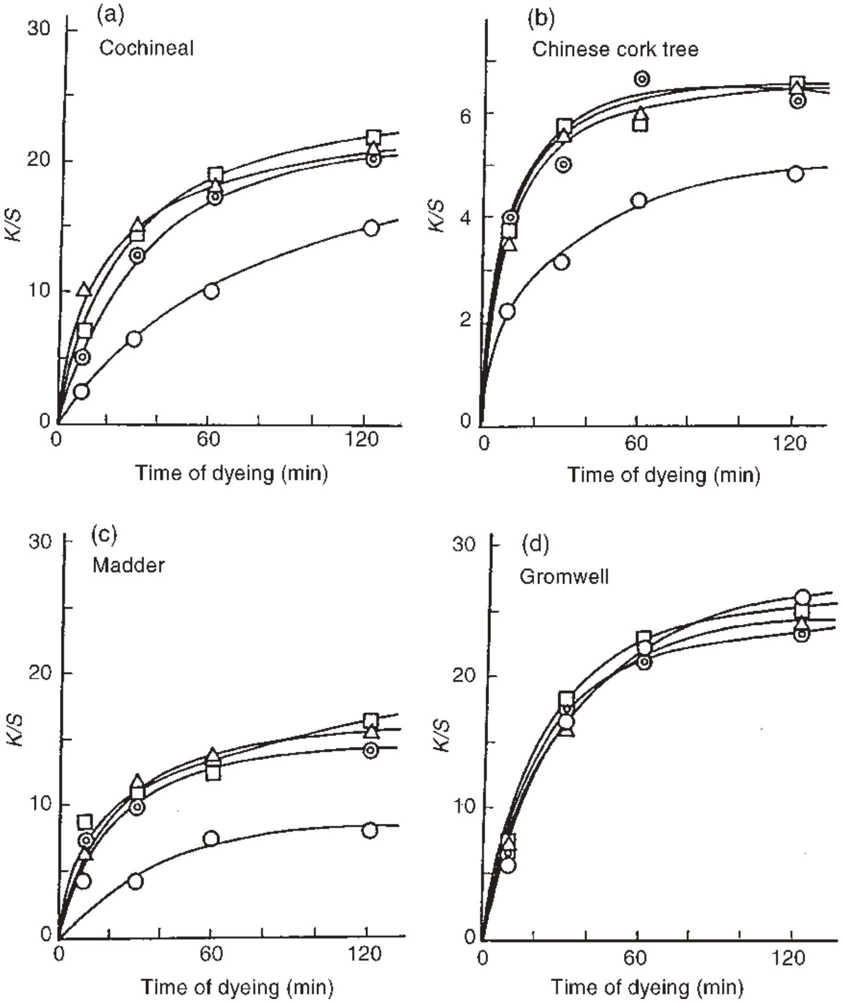
The use of natural dyes, as opposed to synthetic ones, is often touted as a means of reducing environmental damage. Bhattacharyya and Acharekar,[26] for instance, feel that the dyeing of jute with natural dyes to eco-specifications is now commercially feasible. There are, according to one author,[27] benefits in lowered energy use, water consumption and allergenic effects, accompanied by easier biodegradation, though the problems of availability and colourfastness are noted. More serious concerns are voiced by Achwal,[28] who points out that colour variation in natural dyeing can be so great that redyeing is needed, thus increasing the use of energy and water, with a consequent increase in both financial and ecological cost. Other writers[29] add the observation that the necessary amount of dyes required would denude nature to an unacceptable extent, thus offsetting any possible advantages.

### 7.6.2 Synthetic dyes

For all these reasons, recent work has tended to seek new means of adopting synthetic dyeing techniques with lower planetary loading, a matter of increasing importance according to one writer,[30] who notes that the initial cost is high enough to discourage many manufacturers. However, the long-term savings in water, dyestuff, energy and waste treatment costs are appreciable. A crucial change in dye chemistry is being sought by several authors, mainly as a result of the harmful effects of certain dyestuffs, while a second approach suggested[31,32] is the use of plasma treatments (low-temperature electrical gas discharges, such as those that can be achieved with a corona glow) to accelerate dyeing, increase brightness or improve penetration and hence fastness. Figure 7.4, taken from the former paper, shows the effects of plasma treatment on the dyeing rate (for various natural dyes) associated with the use of oxygen, ammonia and carbon tetrafluoride sources. It can be seen that there is virtually no change between treatments as a result. Similar plasma treatments have been used to increase fibre quality in wool combing (with less waste water),[33] or to modify wool surfaces in other applications,[34] and thus are worth examining as a technique for improving dyeing. Detailed information on all of these areas can be found in papers summarised in Section 5 of the Appendix.

## 7.7 Pollution aspects

The discharge of pollution from colouration processes occurs in two critical ways. First, when the dye is applied to the fabric (or to some other fibre assembly if dyeing is carried out at an earlier stage of the production), the colouring agent is not all picked up by the fibres. There are inevitably some residual amounts of dyestuff that cannot be adsorbed and, although efforts are currently made to recycle them (as detailed in Chapter 13 and the Appendix), there are large quantities that cannot



*7.4* Effects of different types of plasma treatment on dyeing time of wool with various natural dyes; ○, untreated; Δ, oxygen plasma; ◎, ammonia plasma; □, carbon tetrafluoride plasma (source: ref. 31).

be reused, either because the particular shade is no longer applicable for the next fabric batch, or because the dilution is too great to make recovery economically viable. It is possible to distinguish to some extent between the different types of dye used, in order to allow some estimate of the relative harmful effects of each one to be made and a comparison of the chemistry of various dye types is of value in this exercise.

### 7.7.1 Acid and cationic dyes

The simplest dye types are probably the acid and cationic (or basic) ones. These are applied directly to the fabric and are obtainable in a wide range of colours. However, they tend to have poor fastness, bringing about premature rejection of the dyed product (and hence early pollution) and many of them are carcinogenic or otherwise toxic ***(* W-3)***. More recently, substantive direct dyeing has been introduced with the aim of increasing fastness and hence reducing waste, a beneficial step from the ecological as well as financial point of view. Azoic dyes generally need low temperatures (for which energy is expended) and use toxic ***(* W-3)*** chemicals for their production. Mordant dyes, which depend on an auxiliary compound to provide fastness to light and washing, suffer from the fact that most mordants are heavy metals (notably chromium) that can bring about serious environmental problems once the excess reagent is discarded. Recognising this drawback, Parton[35] suggests that alternative dye types should be sought and recommends reactive dyes with an increased range of colours without the chromium effluent. These combine chemically with the fibre, tending to be exhausted reasonably effectively. Disperse dyes, used in colouration of synthetic fibres, tend not to be as wasteful as are some other types, because the dye is insoluble in water but soluble in the fibres, so is less of a problem to extract once the process is complete. Sulphur dyes, also insoluble in water, can similarly be removed from waste liquors slightly more easily than most other types. Thus, both of these provide a means of reducing pollution. Vat dyes are applied as a colourless precursor and need the presence of oxygen to develop their colour; they may therefore be more difficult to control (since the precise depth of shade cannot be seen until dyeing is complete), with the resulting possibility of increased chances of rejection of the dyed goods. Finally, solution dyeing, in which the colour is developed by solubility of the dyestuff directly inside a synthetic fibre, is possibly even more easily prevented from polluting the water supply.

### 7.7.2 Relative hazards

In all cases it must be remembered that the actual chemicals from which the dyes are made may be harmful in varying amounts, so that the escape of a small quantity of an efficiently applied dye type may be more dangerous than the leakage of a larger quantity of one that cannot be controlled as well. The human factor, too, should not be ignored. If the technologist carrying out the dyeing operation makes a miscalculation or fails to follow instructions properly, even the most efficient dyeing process can lead to disastrous production of large quantities of dangerous waste material. Shukla[36] derives a list of the chemicals used in textile auxiliary treatment in 1997, noting that there is a shift towards environmental concerns in the selection of chemical agents used. His list incorporates not only dyeing and printing auxiliaries, but also those used in softening, flame resistance, oil repellency, antifoaming agents and fibre-protective substances of various types. Efforts to reduce the emission of harmful agents are in evidence, as found in material also included in summarised form in Section 5 of the Appendix.

### 7.7.3 Supercritical dyeing

Other approaches are being sought. Lennox-Kerr[37] discusses new developments in dyeing with supercritical fluids, especially in attempts to reduce the current high cost that makes the process not economically viable. The theory behind this approach is that, if a substance that is normally a gas at room temperature is subjected to extremely high pressure, it can be liquefied. In this state, if it happens to be a suitable solvent, it can dissolve the chemical in question (a dyestuff in this case) and, when pressure is released, the liquid will evaporate, leaving the dissolved substance behind in the position to which it has been carried (i.e. the interior of a fibre in this example) while in solution. Lennox-Kerr notes that, in place of the most commonly used supercritical fluid, carbon dioxide, others like alkanes, ammonia, carbon monoxide and nitrous oxide, should be or are being tried and gives a summary of the process. Kawahara *et al.*[38] examine the behaviour of a new type of polyester, made by a high-speed spinning technique, during supercritical dyeing with carbon dioxide. In comparison with conventionally produced fibres, the new polyester (which has comparatively large crystallites and low birefringence) is superior to the conventional one in dye uptake at low temperatures, but not very different at higher ones. The reason deduced for this behaviour is that fibre swelling in the supercritical fluid needs to reach a certain level, after which the dye diffusion is promoted and the larger crystallites mean that the new fibre reaches that level at a lower temperature.

### 7.7.4 Plasma treatments

Özdogan *et al.*[39] use plasma polymerisation to increase the dyeability of cotton in low temperature media. The treatment introduces to the anionic surface a cationic phase, and the resulting enhanced dyeability reduces water consumption, pollution and amount of dye needed. The authors suggest that there may be a benefit from developing modified dyestuffs to take advantage of the new technique when commercial applications are in progress.

## 7.8 Printing

In turning to printing, we should note first that virtually all printing processes use the same reagents as do dyeing treatments. Thus, the identical potential for harm exists in printing and the same relative risks for each type of dye used are also present. There are, though, added problems involved in printing and, in partial compensation, some minor benefits too.

### 7.8.1 Principles

Printing involves the localised application of dyestuffs to selected areas of a fabric. In order to prevent the dyes from straying outside the desired area, some means of lessening the ability to move must be incorporated. The aid used is a printing paste, a thick substance such as starch, gum or resin that increases greatly the viscosity of the colouring agent applied. This thickener is, of its own accord, a pollutant and can cause water pollution ***(* W-3)*** when excess amounts are discarded after the printing process is complete and the equipment is washed in readiness for the next batch, of a different colour. There is an awareness of the problem; Galgali[40] proposes, for example, that ecofriendly pigments (ones causing no evolution of carcinogenic formaldehyde) should be adopted, a step that appears slow to be accepted. Zacharia[41] collects kerosene from printing by using a cool chimney effluent and separates the substance from water in order to lower pollution.

In compensation for the increased pollution risks, though, is the fact that a printing paste can often be more easily collected, with lesser amounts lost, than can a dye liquor. In addition, because the whole purpose of a printing step is to force colours into fibres, there is often less need to wash out the excess colour, so leading to lower quantities of discarded pollutants.

### 7.8.2 Direct methods

As in dyeing, there are several variants of printing methods, including block, roller, screen, resist, discharge, flock and transfer. In the first three of these, classed together as direct methods, the colouring agent is merely applied to the fabric surface and pressure (derived from a wooden block, a metal roller or a rubber squeegee, respectively) is used to force the dye paste into the body of the fabric for absorption by the fibres.

### 7.8.3 Resist printing

In resist printing, a protective coating is first applied to the surface to prevent contact or attachment between the dye and the fabric in that region. The resist paste is applied in exactly the same manner as a printing paste, using chemical agents that block either the physical access of print paste to the fabric or the ability to form a chemical bond between fabric and colouring agent. Substances used (in addition to thickeners, which are needed to restrict movement away from the area that is to be prevented from becoming coloured, in the same way as direct methods) include paraffin and various resins. Each of these, but especially the latter, can be responsible for environmental risks ***(* W-3)*** after the excess is discarded. Once the resist paste is in place, the fabric is piece-dyed. The problems involved in the step exactly match those used in piece-dyeing itself.

### 7.8.4 Discharge printing

In discharge printing, the order of operation is essentially reversed. The fabric is piece-dyed initially, then a discharge agent (one that destroys the colour of the dyestuff) is applied to selected areas to create a pattern of a white zone on a coloured one. The latter two methods are both used as a means of obtaining a richer colour in the dyed areas, since piece-dyeing gives a much greater intensity of shade than does printing. From the environmental perspective, the processes combine the worst aspects of printing and dyeing, because the disadvantages of using paste are supplemented by those of piece-dyeing, and the need to add extra reagents in the form of the resist or discharge agents compounds the problem still further.

### 7.8.5 Flock printing

Flock printing consists of the application of short dyed fibres to the surface of a fabric, either over the entire surface or in specific areas, with permanent attachment to the fabric being achieved by the use of a resin or other type of glue. Again, the ecological aspects of dyeing (of the fibres) have to be considered, in addition to those of the fixing agent when excess amounts are discarded to the environment ***(* W-3)***.

### 7.8.6 Heat-transfer printing

Heat-transfer printing is an attempt to decrease pollution problems. It is most easily applied to polyester fabrics, using a dye-impregnated sheet of paper as an intermediate medium to contain the dye in readiness for application. The paper and fabric are placed in close contact, heat is applied to cause sublimation of the solid dye to a vapour phase, which is transferred across to the fabric as a result of the temperature gradient. The dyes (of acid or cationic class where dyeing of natural fibres is attempted and disperse dyes which are used to best advantage for synthetic fibres) provide a wide range of deep colours (thus preventing to some extent early discard of fabrics that have faded) and are able to attach themselves readily to the fibre molecules, with moderate to good permanence. The effect is to remove completely all need for liquids and printing pastes, omitting the washing, steaming or drying steps in conventional drying, so reducing the ecological harm. However, the need to make special paper and for a separate printing stage when applying dye to it, together with the disposal of the paper ***(* V-2)***, reduce considerably these advantages.

## 7.9 Drying and shipping

One further process needs to be considered, fabric drying. Again, it is not strictly a finishing treatment, but virtually all of the fabrics undergoing a finishing stage need to be dried at least once, and often more times, at some point in manufacture. The process is considered in Chapter 11, but is mentioned here because it is so important in finishing.

The fabric has to be packed for shipment. This step, which is essential for protection from the elements, needs some form of outer coating, such as kraft paper or plastic, that has to be manufactured, with the usual environmental cost. In modern factories, it also involves the use of machinery, incorporating its costs. Finally, the matter of transportation should be considered. As before, this may be necessary during all parts of the production train, but the shipping of finished cloth is probably the largest single use of the operation.

These then, are the harmful effects on the planet associated with the manufacture of textile fabrics. Unfortunately, the problem does not end here. After the finished articles are passed on to the consumer, there are still more costs incurred as a consequence of their use. These will be the subject of the next chapter.

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# 8

# Use of textiles

## 8.1 Primary and secondary production

Once a textile fabric has been manufactured, its potential for causing damage to the environment does not end. A fabric, no matter how high its quality or how well it is finished, coloured and generally enhanced, is of little or no use unless it is made into something. The possible products of this further processing include such widespread objects as clothing, upholstery, drapery, bedding and industrial goods. We normally tend to regard the primary (i.e. fabric production) and secondary (i.e. products made from fabrics) textile industries as separate ones, but the environment makes no such distinction; pollution is pollution no matter what its source may be. One of the major problems facing the entire industry today is a lack of communication between these two different areas, since there is often a misinterpretation of the needs of the secondary sector by members of the first one, as well as a misunderstanding of the capabilities of the primary industry by the secondary one. Nature may benefit substantially by the development of a closer connection between the two, reducing the number of discarded materials that result from these failures to match needs, abilities and production.

## 8.2 Types of use

In view of the nature of this book, a distinction is proposed here between different types of use in a way not normally adopted. Those uses intended to protect the environment in some way will be separated from the others and treated in Chapter 13. This is obviously not a simple matter, because there will be immense grey areas where the two cannot readily be distinguished. A geotextile barrier designed to prevent flooding of houses in an area inundated with water from a burst river bank, for instance, is clearly intended to keep the human inhabitants of the threatened region safe and alive. A geotextile used to contain polluted substances in a landfill site from leaching out into the water table is intended to protect the environment. Yet, the flood barrier also prevents erosion of land by water flow, while the contained pollution is also prevented from poisoning human beings, so that both end results are met in each case. The distinction here (which is totally arbitrary and personal) is to determine what seems to be the more important criterion for use and to allocate the application to the section that makes most sense in that case. In this chapter, the ‘normal’ uses will be dealt with and the ‘environmental protection’ uses will be deferred to Chapter 9.

## 8.3 Normal uses

### 8.3.1 Clothing

The most obvious normal use of textiles is in making clothing, a use that has been around for thousands of years. For the purpose of this chapter, products of the garment sector will include only clothing and accessories. As always, the machines needed to make them are complex, though usually much smaller in scale than those used in textile yarn and fabric manufacture. Cutting, sewing, pressing and other machines all need to be made and operated, at the now-familiar cost to the planet. There are frequently excess pieces of fabric that are cut away in making clothing to be discarded. It is, admittedly, possible to recycle these scraps, as will be discussed in the next chapter, but large, complex machinery is needed to put them back into the production train. Although such scraps may be too small anyway to make recycling worthwhile, one author[1] describes yarns made with fibres recovered from the garment industry, noting that they avoid excess pollution by eliminating the need for fertilisers and dyes. Uses as socks, blankets and upholstery materials are mentioned specifically, a point that gives the key to this over-optimistic attitude. These articles differ from most textile end uses in that colour is not critical, unlike virtually all other applications. In more usual recycled goods, especially as they are almost invariably coloured, some process for removing all the dyestuffs is always needed. This involves chemical reactions in which bleaching agents or dye strippers are used to destroy the dye molecules or change their molecular structure to render them colourless. These substances are waste products that can harm the Earth once discarded into the environment ***(* L-2, W-3)*** (see Table 1.1 for an explanation of codes).

### 8.3.2 The fashion industry

One of the most powerful driving forces influencing the manufacture of clothing is the fashion industry, which has increased considerably in importance in the centuries since the Industrial Revolution. Clothing is one of the easiest ways to display wealth conspicuously, so it is now accepted among people in many parts of the world (and particularly in the developed nations) that new outfits should be purchased at every season of the year. Seasonal variations in climate are an added major incentive for these expenditures and, in practice, the resulting annual production of clothing may be regarded as too great to be justified as environmentally responsible. Few people actually wear more than one outfit at a time, which means that many garments are stored in environmentally destructive plastic bags for a great proportion of their useful life. After the season ends, it is currently fashionable, in a kind of lip service to planetary well-being, to 'recycle' the articles via alternative outlets, such as second-hand clothing stores or factory shops selling designer clothes at reduced prices. Even this gesture is not entirely altruistic in terms of the Earth's welfare; the loss of an article of clothing invariably leaves a gap that must be filled by something new in the wardrobe of the person making this supreme sacrifice. The premises where the unwanted garments are resold also need to be built, heated, lit, staffed and so on.

Unfortunately, the pressures of the fashion industry appear to be increasing rather than declining, as would be preferable for ecological welfare. The problem, as always, lies in commercial interest. Modern people, especially in the developed world, are accustomed to the need to follow a fashion cycle on an annual or even seasonal basis, so that the fashion industry (and those connected with it) has a vested interest in ensuring a regular turnover of garments. It is inevitable that a large reduction in sales would lead to a major loss in employment, because it is not only the textile and clothing manufacturers who would be out of work, but also the designers, alteration staff, marketing specialists, transportation personnel, retailers, magazine editors or artists, and anyone else with an ancillary interest in the fashion world. The cumulative psychological effect on Society of the need of all these people to be kept in employment is difficult to resist, meaning that the relentless drive to be up-to-date will continue for as long as we (or our planetary home) are prepared to tolerate it.

## 8.4 Environmental aspects

### 8.4.1 Laundering

The renewal of the fashion requirement per se does not merely cause environmental problems in the debate regarding recycling versus disposal. As a consequence of our modern lifestyle and technology, dust and dirt are omnipresent, and soiling necessitates emergency procedures in the form of laundering or dry cleaning. Both of these can cause environmental difficulties. Laundering involves exposing the textile article to the combined effects of water, heat, agitation and detergent. Often, an optical bleach or a fabric softener is added to the mix, and machine drying is frequently used. Both of these procedures give a much more luxurious feel than do an untreated wash and outdoor drying on a clothing line. The energy needed to heat the water and operate the machinery, together with the chemicals ***(* W-3)*** discarded into the drain, are a source of harm, as also are the heat needed to operate and the polluted exhaust emitted ***(* A-2)*** from the dryer. The thermal load from both washing and drying can also affect the surrounding air or water ***(* W-1)***, making it unsafe for other species to exist in the neighbourhood of the discard point unless precautions are taken to reduce the rise in temperature occurring on discharge.

### 8.4.2 Dry cleaning

Dry cleaning also has ecological consequences. The machinery needs to be built and operated, while the solvents used for extracting the dirt are often toxic or carcinogenic. Even though strenuous efforts are made to contain them and recycle them for later use, there is still an inevitable loss ***(* A-2)*** because of entrapment in the fibres or escape into the air via the garment transport path. Jipp[2] describes non-toxic stain removal using solvents without chlorocarbons, so that the chemicals can be regarded as being kind to both fibre and environment. Nevertheless, all of the reagents used in maintenance, even these more harmless ones, have to be manufactured, with expensive loading on the environment.

### 8.4.3 Maintenance chemicals

The actual chemical substances used in maintenance can be examined in more detail to ascertain their potential for harm. As a consequence of our current fascination for cleanliness, garments are washed or cleaned far more often than is necessary for the sake of health or even hygiene. For this reason, the quantities of detergent, softeners, bleaching agents, dry cleaning solvents or other chemicals expelled are enormous. Detergents contain alkalis and organic chemicals that act as pollutants ***(* W-3)***. They also often contain phosphates, used as ‘builders’ to enhance the effectiveness of the washing action, which are known to encourage the growth of algae in large bodies of water. These can take over the oxygen available in the water, preventing other species (both animal and vegetable) from having access to it, As a result, fish can die and the balance of the local aquatic plants can be disturbed seriously, bringing about major changes in the locality and eventually resulting in a dead body of water where fish no longer exist and weeds choke the entire surface. Fabric softeners, usually quaternary ammonium compounds, are becoming more and more popular. These bring about water pollution ***(* W-3)***. They are produced by relatively complex chemical reactions, with the usual environmental concerns and their disposal brings about harmful changes in the local water supply.

## 8.5 Household textiles

In the home, textiles find widespread use, from household furnishings such as carpets, cushions and table linens, to towels, bath mats or dish cloths. David Rigby Associates[3] give an overview of the various types of textile applications in home furnishing products, suggesting that the largest growth in the foreseeable future will occur in non-wovens or fibrefill categories, rather than in the more traditional woven or knitted fabrics. Two unusual applications in the household category have been reported in the literature; one author[4] writes of the usefulness of wool tightly woven and attached to gypsum board (in the form of decorative panels) as a means of combating the relatively new hazard of sick building syndrome by absorbing the formaldehyde reputedly responsible for this problem. The second application[5] consists of a system used to wrap houses during construction to maintain acceptable working comfort, for craftsmen operating on the outside walls of the house in adverse weather conditions, with enough moisture vapour permeability to ensure that breathing comfort can be retained.

## 8.6 Industrial and medical uses

### 8.6.1 Technical textiles

Bhonde[6] gives an overview of textiles used in applications beyond those of clothing or household purposes, while Legler[7] examines technical textiles from the perspective of recent advances. Both authors more or less agree on the list of end uses, including geotextiles, agrotextiles, industrial products (including composite reinforcement), automotive, space, protective and medical ones. Not mentioned specifically in this list is the use of textiles in building, which may be extended to the subject of architectural fabrics. Their adoption, according to Hill,[8] reduces building time significantly and saves natural resources (a valuable advantage from our point of view!), while providing long life and cost-effective, aesthetically pleasing appearance. Swedberg[9] describes applications of tent structures using PTFE-coated fibreglass with steel tubing and cables and, in a later paper,[10] the use of air-inflated beams for supporting massive structures in high wind or loading conditions with potential applications in aerospace or nautical projects. Other interesting applications are the use of a composite of high-tensile glass with epoxy resin to make a reinforcement beam as protection against earthquake collapse[11] and wrapping corroded bridge columns with carbon fibre[12] to prevent further damage.

### 8.6.2 House construction

House construction can also be aided indirectly by fibres, when used as reinforcement for concrete or in other aspects of building. In such applications, the environment is preserved by preventing premature failure of the material, allowing it to last longer. Peter[13] recommends Kevlar for concrete reinforcement, because it imparts low density, non-catastrophic failure (and resistance to repeated impacts) to the concrete. In addition, because the fibres are electrically insulating, Kevlar permits building to take place more safely near high-voltage power lines. Komatsu *et al.*[14] assess the durability of geotextiles in reinforcing asphalt concrete, noting that this process increases viscosity of the material and reduces the stress concentration of wheel loading. Locatelli[15] reports the production of a stretchable roofing felt that can be installed and maintained without shrinkage when used in a layered system. A French company[16] is marketing a woven structure that can be laid across soft, sandy or swampy ground, allowing vehicles to pass safely. In temporary houses, such as tents, fabrics are invariably used for their combination of light weight, easy folding ability, weather (especially wind) resistance and versatility.

### 8.6.3 Motor vehicles

Fung[17] provides a detailed description of the many applications of textiles, in the form of coated or laminated fabrics, in vehicles. He includes in his listing seat materials, headliner structures, other interior coverings, air bag components, convertible coverings, liners for bonnets or wheel arches, carpeting, noise control items and drive belts. In view of current traffic hazard concerns involving motor vehicles, the air bags used to enhance safety in crashes have received particular attention. One writer[18] recommends the use of nylon 4.6 in making them, because of its better thermal stability. Barnes and Rawson,[19] after devising a new test to assess the efficiency of coated fabrics for this end-use, find that nylon 6.6 is better than either nylon 6 or polyester in this regard. They also report that a silicone-based coating should be applied to the fabric to increase thermal resistance still further. Gutlein *et al.*[20] recommend a polyurethane bladder in a textile net for making side-impact bags, while yet another author[21] would like to see needle-punched construction methods used to increase permeability in a controlled manner and describes conditions for achieving optimum gas transfer characteristics.

### 8.6.4 Medical textiles

Medical uses of textiles should also not be ignored, as they constitute a major area of advance for the industry. They are summarised in Section 6 of the Appendix, where more information regarding applications (such as in surgical uses of clothing and inserts into the body, or general medical clothing and health care) can be found.

### 8.6.5 Industrial applications

The widespread use of textiles in industrial applications, however, is not generally discussed in any detail. Various authors[17, 22] write articles dealing with the many valuable attributes of technical fabrics, including those intended for space activity, automotive filtration, airbags, composites, marine uses, laminating, seismic protection and resistance to harmful agents. Applications range widely in type and some consideration of representatives of all the varieties of application should be included. They may be divided into those used directly by industry, those used in leisure or sport activities and those in which heavy duty use is needed in everyday life. Textiles used directly in industry include such diverse items as tarpaulins, filters, acoustic or thermal insulation and protective garments for workers.

### 8.6.6 Other uses

Three specific types of more interesting use can be identified. First, transport via heavy lorries is rendered less perilous (and has a lower risk of polluting the road or causing accidents by losing part of the material being shipped) by the use of a new kind of tarpaulin,[23] knitted from stretchable textured polyester, that conforms to the shape of a load, reducing flapping as the vehicle moves. Second, filters appear to be popular subjects for research, an occurrence caused at least in part by the need for a cleaner environment. Third, leisure or sport applications are rapidly increasing and include items such as tentage, sleeping bags, boat sails, mooring ropes or other marine cordage, aircraft skins, parachute fabrics, climbing ropes, bungee cords, balloon fabrics or guy ropes. Little attention appears to have been paid to most of these applications, although there are some papers worth mentioning in the literature. The work taking place in each of these areas is summarised in Sections 7 and 8 of the Appendix.

Finally, one or two less obvious uses may be mentioned. Newberry[24] reviews new developments in the use of composites in corrosion-resistant applications such as piping, lamp poles, and tanks to contain hot brine or for use in deionised brine service. Risks of harm from mobile phones, reportedly causing brain damage from electromagnetic radiation, are supposedly counteracted[25] by the use of a flexible metal-coated fibre, preferably an acrylic one coated with copper or nickel. Plates used to press boards of plywood, or those for printed circuits, lined with textile cushions designed for high-temperature use, are reported,[26] while Marsh[27] discusses the use of fibre-reinforced plastics for improving under-sea oil extraction; the smooth surface, chemically inert nature and low weight mean that lower losses from corrosion and oil escape will occur, so providing an ecological benefit. Kotliar[28] uses textile and carpet waste to produce a low-cost, wood-like material by incorporating them in a high-modulus phenol/formaldehyde matrix.

Other heavy-duty uses in everyday life include tyre cords, seat belt webbing, vehicle upholstery, carpeting, wall hangings, conveyor belts, drive belts, tow ropes, isolation suits, protective clothing, space suits, architectural fabrics and geotextiles. In addition, cleaning cloths, surgical clothing or drapes, bandages or other dressings should also be added to the list. Many of these will be dealt with later in the book but, as a final general comment here, we should note that all of them, in common with all the cases mentioned above, have a production process that tends to be an expensive one from the environmental perspective and, in many cases, create difficulties in disposal.

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