5
Yarn production

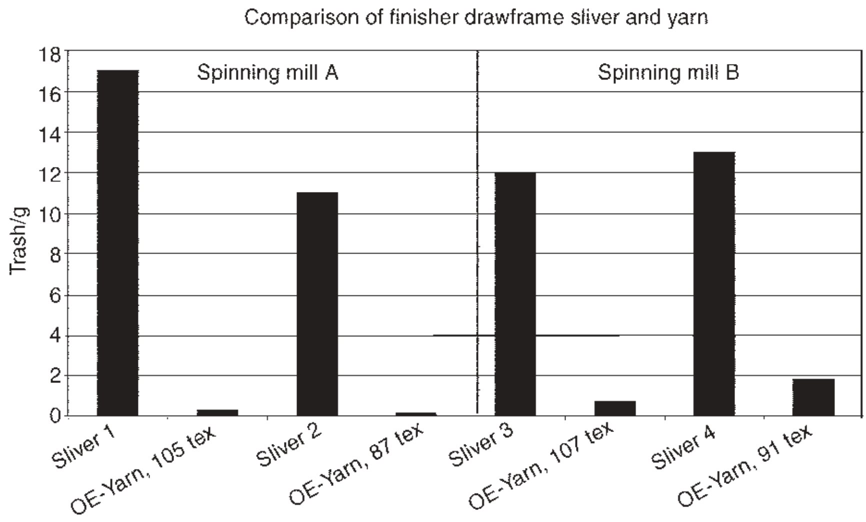
5.1 Starting material state

5.1.1 Vegetable fibres

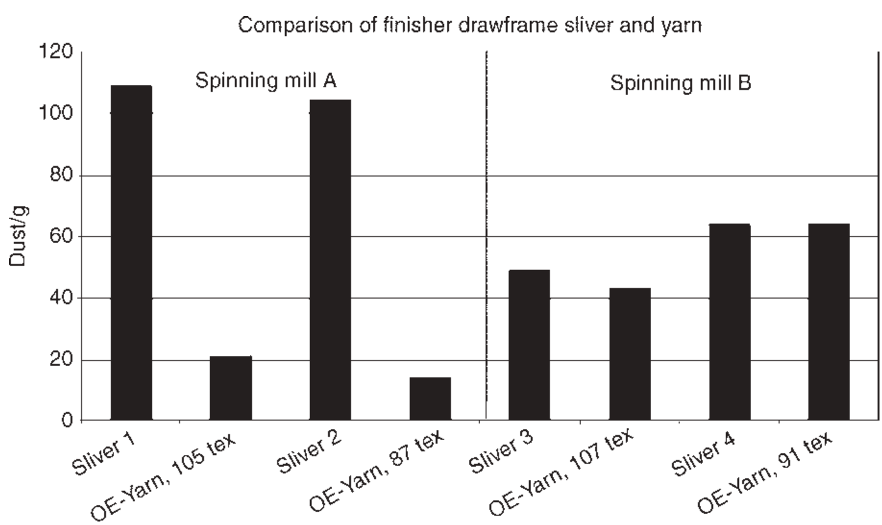
At the end of the fibre production process there are millions of tiny units, ready to be transformed into a yarn or some other type of fibre assembly in the next stage of the textile manufacturing operation. Their actual state depends very much on the type of fibre involved. In the case of vegetable fibres, the product is a dirty, tangled, contaminated mass that may contain a variety of plant or animal by-products. The former will be governed by the efficiency of selecting only fibres, rather than including other traces of the cotton, linen, and so on, plant in harvesting, or the number of local weeds infesting the area that have also been gathered. There may also be animal remains, either from insects that made their homes on the plant, or from larger creatures that were caught up in the harvesting process. Stroiz[1] examines various types of contamination on cotton fibres and associates them with geographic location, pointing out that significant differences can arise for other than obvious reasons. Peters and Söll[2] outline a new scheme for the automatic determination and removal of trash from cotton. Figures 5.1 and 5.2 show how the trash and dust contents are reduced between sliver and yarn by use of the technique.

5.1.2 Wool

When wool is considered, more or less the same animal life residues can be expected, for similar reasons, but the vegetable content will represent the remains of grass, twigs or other plant fragments which the sheep has picked up before the shearing operation. There will also be considerable amounts of grease, since sheep exude a fatty combination of organic compounds in the form of a substance known as wool wax. Ryder[3] examines the properties of this grease in detail, finding that its presence protects the sheep's hair from drying out and reduces damage to it from



5.1 Reduction of trash content from sliver to yarn (source: Zellweger Ustar).



5.2 Reduction of dust content from sliver to yarn (source: Zellweger Ustar).

weathering, sunlight or rain. It also delays the passage of water through the sheep's skin, in either direction, and is instrumental to some extent in killing bacteria. Nevertheless, its presence in wool fibres intended for use in textile articles is undesirable and it must be removed; it is, however, described by Ryder as a valuable commodity in its own right.

5.1.3 Silk

Silk, in keeping with its luxury image, is altogether a different matter. The fibres, lovingly produced by pedigree worms and cossetted by caring hands, are much cleaner in nature. They make their appearance in the form of a skein of fine fibres (although they may previously have been washed or scoured to remove the silk gum).

5.1.4 Synthetic fibres

Synthetic fibres which have never been anywhere near animals or vegetables are scrupulously clean of such contamination right from the start. They may, though, have been subjected to the whims of a careless operator, who has allowed them to overheat, or they may contain residual chemicals from the extrusion stage if they are regenerated, wet-spun or solvent-spun in nature.

5.2 Washing

From the foregoing discussion, it is possible to infer that some elements of cleaning are often needed before fibres can undergo further processing. Washing is the usual way in which this is accomplished, either with water only or, more often, with some form of detergent. Hickman[4] reviews the washing stage in the production of cotton and its blends, including materials in the yarn or fabric state, as well as in the fibre stage. He explores the history of cleaning, with an examination of energy, water, steam and labour requirements, and feels that all of these are reaching their limiting values. For this reason, he predicts that the time is ripe for closed water systems as a likely area for imminent innovation. Ripley and Ripley[5] suggest that lasers can be used for cleaning and to enable the removal of trash to be accompanied by a bleaching operation, thus reducing a step that can be costly both financially and environmentally.

5.3 Scouring

When more severe cleaning is necessary to remove, for example, persistent dirt from cotton, then scouring is adopted. In this process, an additional agent is added to enhance the cleaning operation, sodium hydroxide being the traditional substance used. Lately, the disadvantages of this chemical, both in harming the fibres and in producing environmental contamination ***(* W-3)*** (see Table 1.1 for explanation of codes), have been recognised and other approaches have been tried. The most common of these is the addition to the wash liquor of an enzyme, a natural product that is less harmful to the environment and able to bring about cleansing more effectively as well as more rapidly. Section 1 of the Appendix describes some of the many variations of this treatment currently in use. In the case of wool, an alkali is also commonly added to aid in the removal of the greasy matter (politely referred to as 'suint'), and Section 2 of the Appendix deals with the use of a number of additives used to improve the action of this type of treatment.

Even silk has received some attention in the attempt to improve the environmental load of scouring. Krasowski *et al.*[6] recommend the adoption of ultrasound to degum silk, in conjunction with standard degumming methods such as the techniques using Marseille soap, tartaric acid or papain. They report a significant increase in the mass of impurity material removed, with no obvious harm done to the filaments.

Some vegetable fibres can suffer from the presence of gum that has to be removed. Bhattacharya and Das[7] degum ramie with sodium metasilicate, alone or with other alkalis such as sodium carbonate or trisodium phosphate, instead of using sodium hydroxide. They determine optimum conditions, evaluating the performance of a trial by weight loss, whiteness index and colour strength of the degummed fibres. The new technique is so much better than the older one that bleach may not be needed in many cases, fibres also being much more lustrous and soft. Because the cost is comparable, there is obviously potential for commercial application, as well as for environmental benefits.

The conclusion to be drawn from all this work is clear. This cleaning process is responsible, especially in the case of wool, for a serious assault on the environment. The effluent liquors from the plant have often been allowed, until relatively recently in the West and on a still-continuing basis even now in some parts of the world, to flow into rivers without any effort to treat them. The range of chemicals can be extensive and may include toxic, corrosive or biologically modifying reagents ***(* W-3)***. As can readily be appreciated, the enormous scope of the textile industry, and the need to remove some kind of impurity from virtually every fibre produced, have been of great concern to environmentalists over many decades. Unfortunately, there is little that can be done to avoid the problem, as we will see later, because most efforts to reduce the damage only lead to an alternative category of pollution. The only real solution is to avoid carrying out the washing or scouring in the first place, but this would inevitably lead to a product that would be totally unacceptable to consumers. Thus, even if a textile manufacturer exerts the utmost care, there is little hope of creating an effluent from the cleaning stage that can be discharged into the local water system without treatment. The types of treatment used and the relative effectiveness of each one are discussed in Chapter 9, Section 7.5.

5.4 Bleaching

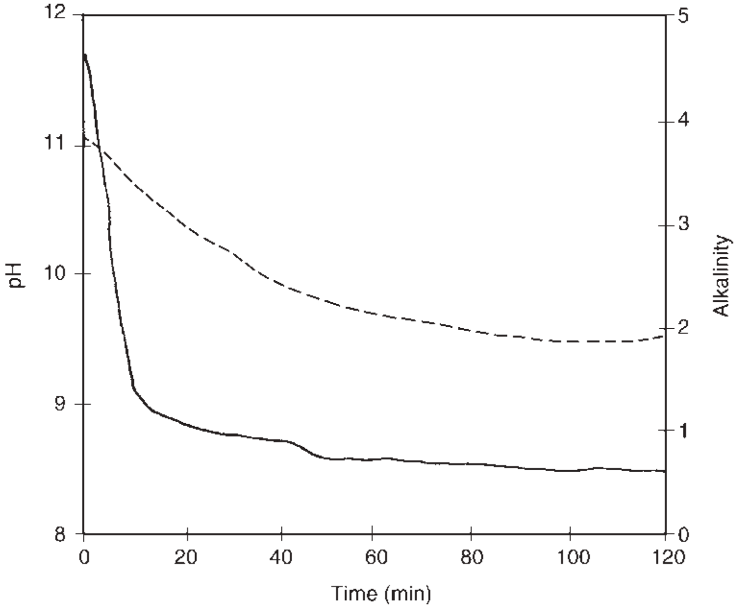
Often, the steps described above are insufficient to bring the fibres to an adequate state of 'cleanness' (defined in this instance as whiteness) for consumer satisfaction. In such cases, yet another process must be added, that of bleaching. This consists of a chemical reaction between a reagent (usually an oxidising or reducing agent) that destroys the molecular bonds responsible for the pigmentation that is the source of the coloured, or off-white, state of the fibres. It can be carried out at various points in the manufacturing process, from fibres to fabrics, but the principles of the reaction are identical no matter what the state of cohesiveness of the fibres. Thus, they will be discussed here, at the earliest point in the production line where bleaching can normally take place.

5.4.1 Chlorine bleaching

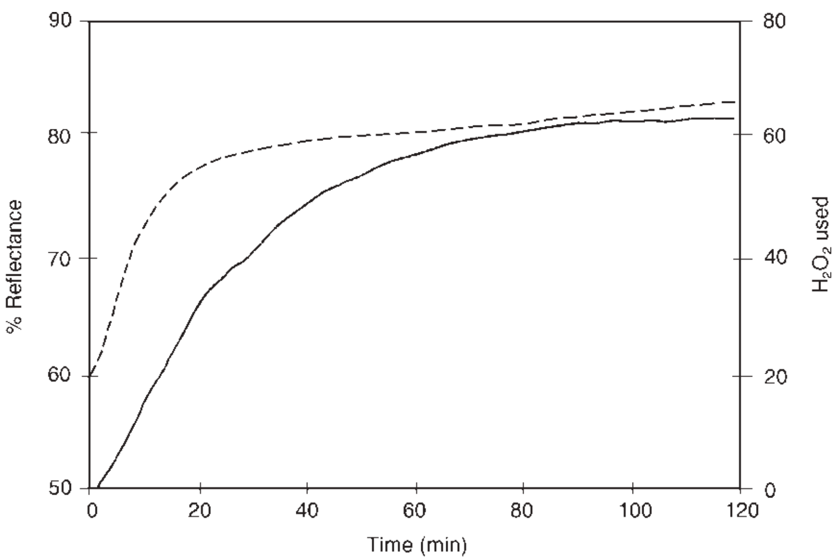
Bleaching can be used for any fibre type, but is not often needed for synthetic ones unless they are blended with natural ones. Traditionally, chlorine has been preferred as a bleaching agent. Huikma[8] describes its use, with an account of the effects on fibre and effluent properties of the various chemicals used. He also considers the possibility of reducing liquor ratio and enhancing safety factors, both important in ecologically driven manufacturing, and provides the diagrams shown in Figs 5.3 and 5.4 to illustrate the changes in pH, alkalinity, peroxide and fibre whiteness during batch bleaching. As can be deduced, there are problems with the use of chlorine. First, it tends to be extremely damaging to protein fibres, so that wool and silk are destroyed if left in contact with the reagent at too high a concentration or for too long a time. Second, of more importance from our viewpoint, chlorine is a major cause of environmental harm. The chlorine itself can be dangerous if ingested, can bring about skin irritation or disease on contact, and, even more critically, can produce very dangerous by-products ***(* W-3)***, such as dieldrins, during oxidation reactions.

5.4.2 Hydrogen peroxide bleaching

Thus, much work has been aimed at finding an alternative means of whitening fibres. The earliest successful substitute was hydrogen peroxide, which, as well as being much milder in its behaviour to proteins, also leaves only water as a residue after reaction is complete. Gürsoy and Hall[9] carry out a series of experiments designed to optimise hydrogen peroxide bleaching, in an effort to overcome its disadvantages of slowness and the catalytic degradation of cellulose in the presence of iron, nickel, copper, cobalt or lead ion impurities. They investigate the effects of a range of chemicals at different concentrations and arrive eventually at an optimum bleach recipe. Moe[10] provides an overview of the mechanics of the bleaching detergents known as peroxyacids that contain hydrogen peroxide and a



5.3 Changes in pH and alkalinity during batch bleaching; -----, pH; ——, alkalinity (source: originally published in *Textile Chemist and Colorist*, Vol. **31**, No 1, January 1999, pp. 17–20; reprinted with permission from AATCC).



5.4 Changes in peroxide concentration and fibre whiteness during batch bleaching; -----, % reflectance; ——, H_2O_2 used (source: *Textile Chemist and Colorist*, Vol. **31**, No 1, January 1999, pp. 17–20; reprinted with permission from AATCC).

bleach activator. These compounds are able to remove stains without affecting dyes (unlike chlorine bleaches) because the dyes inside the fibres are inaccessible to them; they are effective against such difficult stains as grass, wine, tea, grape juice and tomato-based foods, yet are compatible with enzymes or optical brighteners, and possess the useful attribute of being able to bleach dye colours produced on bleeding from one fabric to another.

5.4.3 Ozone bleaching

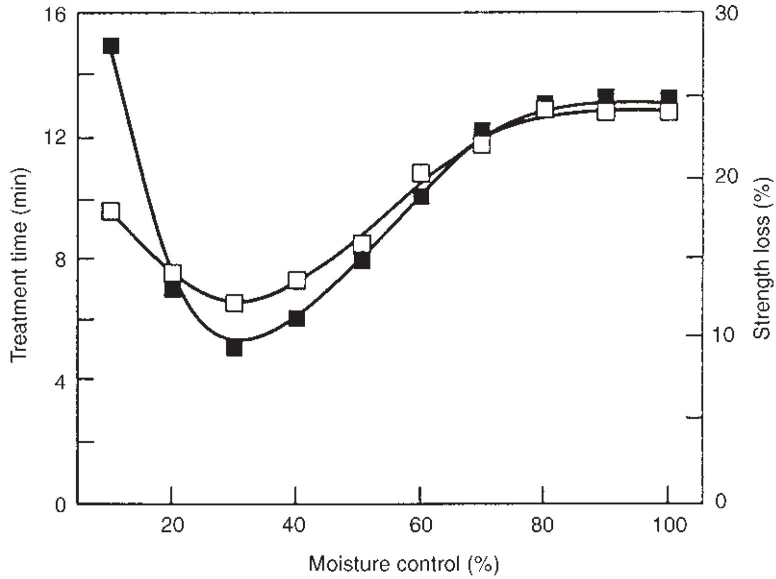
Unfortunately, peroxide is very unstable, so can easily lose its effectiveness as an oxidising agent before the bleaching process is complete. A few ways of attempting to overcome this disadvantage are summarised in Section 3 of the Appendix. Ozone is also suggested as a potentially useful bleaching agent. Prabaharan and Rao[11] stress that, in the ozone bleaching of grey cotton, moisture and pH level are both very important. They find that optimum conditions, with a compromise between best whiteness and minimum damage, are present at a moisture content of 24% and a pH less than 7, and provide details of the design of a suitable chamber. Figure 5.5 illustrates the effects of moisture content on treatment time and strength loss, both exhibiting a minimum value at about 32% moisture content. Figure 5.6 shows the effects of pH on whiteness, indicating that the value is constant at a pH below about 4.5, then diminishes slightly to pH 7 and subsequently falls off fairly rapidly as pH rises.

5.4.4 New approaches

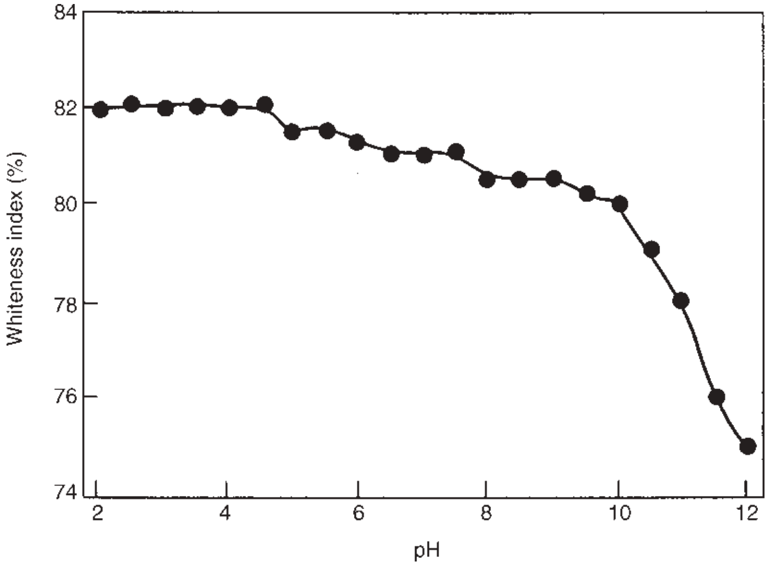
A more recent approach uses an activator, tetra-acetyl ethylene diamine (TAED), commercially sold as Warwick-T, which is recommended by several authors[12–15] because it enables bleaching to take place more effectively under milder conditions. Yet another suggestion[16] is to adopt ultrasound in the oxidative bleaching of wool to break down various bonds, so accelerating the effect of any oxidising agent used and giving increased whiteness in a lower time with no loss of chemical or physical properties. Lorenz *et al.*[17] use the enzyme protease to bleach wool in an environmentally friendly brightening step, but find that the characteristic canary yellow of wool is not removed.

5.5 Carbonising

Yet another type of 'cleaning' (defined as removal of contamination in this case) often used with wool is the process of carbonising. This consists of adding concentrated sulphuric acid to wool, an action which destroys any cellulosic impurities rapidly but is not too drastically harmful to the wool if exposure time is kept short. Developments in the process include the application of a radiofrequency (RF) field to the wool, as described by Baltina *et al.*[18] They claim that with RF



5.5 Effect of moisture content on treatment time and strength loss in ozone bleaching of cotton; □, strength loss; ■, treatment time (source: published in *Color. Technol.* **117** (2001), p. 100. Reprinted with permission from the publisher, the Society of Dyers and Colourists, Bradford, UK).



5.6 Effect of pH on whiteness index in ozone bleaching of cotton (source: published in *Color. Technol.* **117** (2001), p. 101. Reprinted with permission from the publisher, the Society of Dyers and Colourists, Bradford, UK).

irradiation, wool can be carbonised at 100°C, instead of the more usual 120 to 130°C, thus reducing the tendency towards decomposition and yellowing, together with a reduction in energy use, while keeping acid concentration below dangerous (to wool stability) levels. Zanaroli[19] suggests applying perchloroethylene to the wool to convert it into a more hydrophobic material and protect it from acid attack, so that the acid that penetrates and destroys the hydrophilic cellulosic impurities leaves the fibres unscathed. The solvent is recovered and recycled, an essential step for successful adoption of a new process in environmentally sensitive areas, though some solvent escape ***(* A-2)*** must be expected to take place. The same (Carbosol) process is also described elsewhere[20] with the comment that it is not harmful either to the wool or (a claim that perhaps needs to be questioned!) to the environment.

5.6 Drying needs

The fibres need to be dried after cleaning in readiness to be moved to the next stage of production. If the drying equipment is immediately next to the washing or scouring plant, this is simply a matter of a conveyor belt, or its equivalent, to carry them the short distance necessary. This drying step requires large quantities of energy, as mentioned already, and may also produce impurities, such as vaporised solvent ***(* A-2)***, decomposition products ***(* A-3)*** from the leftover reagents present in small quantities, excess waste detergent and its by-products ***(* W-3)***, or other similar substances that are discharged into the air or water. The heat load produced at the outlet from the dryer must also be dissipated, usually by releasing it into the atmosphere inside or outside the plant, with consequent waste of heat energy and contamination of the surrounding area by the above-mentioned impurities.

The same need for movement arises when the dried fibres have to be transferred yet again to another location for further processing. At some point, unless the plant is a mammoth one that carries out all stages in an enormous vertically integrated superfactory, there will be a need to transport fibres over a distance too great for them to be shifted piecemeal. Movement in loose form is difficult if not impossible, since fibres would be scattered widely if an attempt was made to ship them in this fashion. To achieve loss-free transportation of fibres in a suitably constrained manner, a baling process is normally carried out.

5.7 Baling

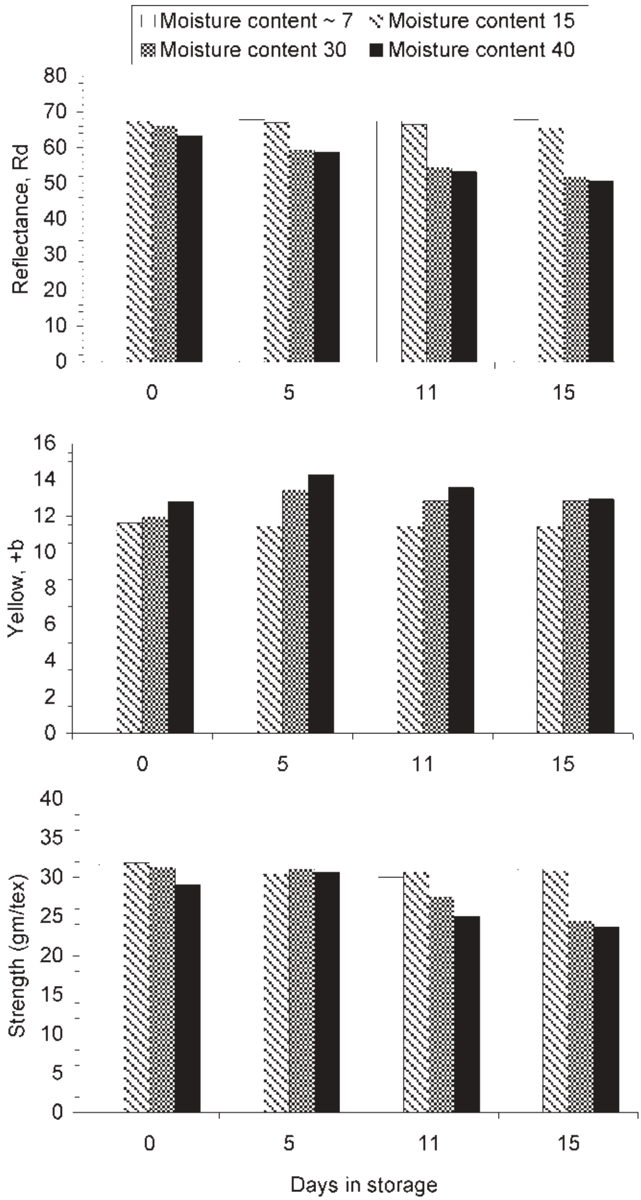
Baling is accomplished by using a large machine to squash down the fibres into a compact package that can easily be transported over long distances. Apart from the usual environmental costs of large machinery, there is little in the way of harm done, but this process represents the first significant occasion on which dirt and noise are a product of textile manufacture. As we will see later in this chapter, in parts of the process where they become more of a nuisance, these can be major sources of harm of a type different from any we have met to date, and can cause difficulties of an unusual kind for human beings, as well as for other species. Teutrine[21] claims that there is a distinct tendency to move towards automation in baling, and forecasts a time, in the relatively near future, when the industry will insist on only one standard packing method to ensure that highly automated procedures for the opening of bales can be established.

In readiness for baling, or indeed for any other stage in the manufacturing process, there is often a need to store the fibres or other textile goods. Because of their chemical nature, storage may occasionally create problems, either of disintegration from mould or other hazards (that will be discussed in Chapter 12) if there is too much moisture, or of cracking if the fibres are too dry. For instance, Brashears *et al.*[22] note that various results produced at the harvesting step can change during subsequent storage in a way that can affect fibre properties and list the needs for successful use of storage conditions. Chun and Brushwood[23] point out that storage in moist conditions can reduce stickiness in cotton, but that there is a limiting moisture content of up to about 15% that must not be exceeded if fibre properties (especially strength and reflectance) are to be maintained. Figures 5.7 to 5.9 show changes in strength and colour, sugar content or stickiness taking place as storage time is increased; clearly, it is the effect of moisture content, rather than the storage period, which has greatest influence on these properties.

5.8 Transportation

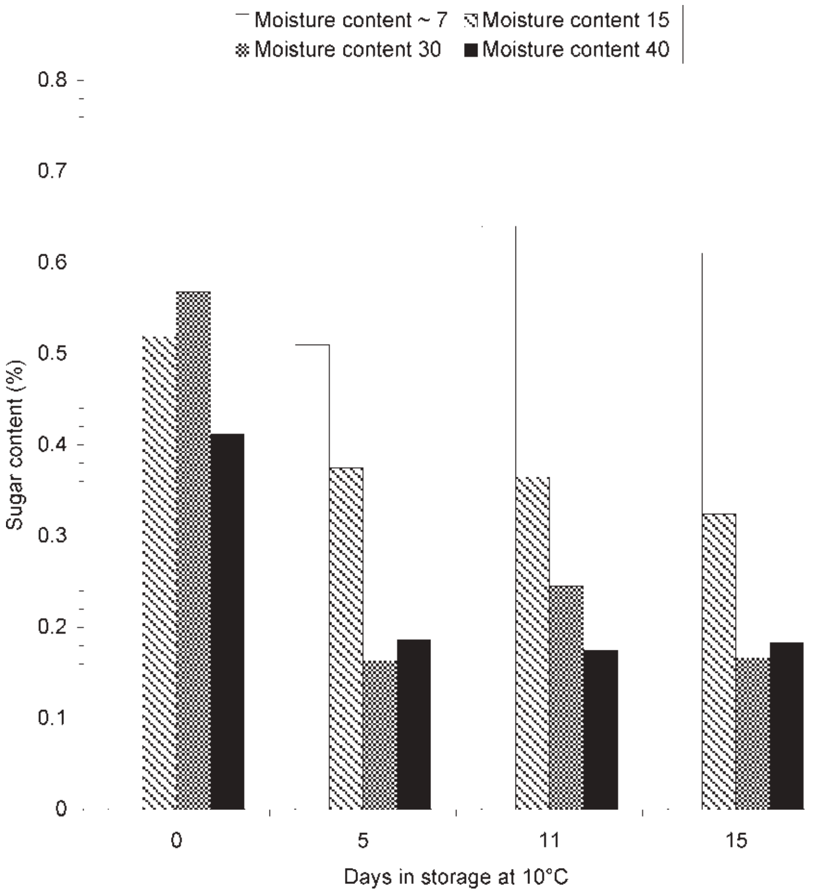
Textile materials have to be transported by vehicles during and after production. Vehicles are environmentally costly, but they also have a more sinister part to play in the planet's degradation. Like textile machinery, they are large and complex, with the customary resultant costs, but there is also the matter of fuel combustion to take into account. Exhaust gases, whether from diesel or petrol engines, contain a multitude of harmful emissions ***(* A-1, A-2, A-3)***. Many of these are toxic or carcinogenic and compulsory legislation has been introduced in many parts of the world to ban some components (notably lead) by modifying fuel chemistry. Approximately half of all the air pollution today is caused directly by vehicle emissions[24] and, although the textile industry is admittedly not responsible for all of these, it must bear a fair share.

The exhaust gases that remain after removing (if this is possible) all toxic and carcinogenic products cannot yet be eliminated, and attempts are still being made to reduce their harmful presence by developing improved fuel economy of engines. This improvement, however, is being rendered ineffective as a result of tremendous increases in the number of vehicles being produced annually. The most critical emission gases, in terms of immediate damage, may include compounds of sulphur, heavy metals and organic by-products of combustion, all environmentally undesirable ***(* A-2)***. Even if these could all be removed by some miracle of science, the unavoidable production of carbon dioxide, a greenhouse



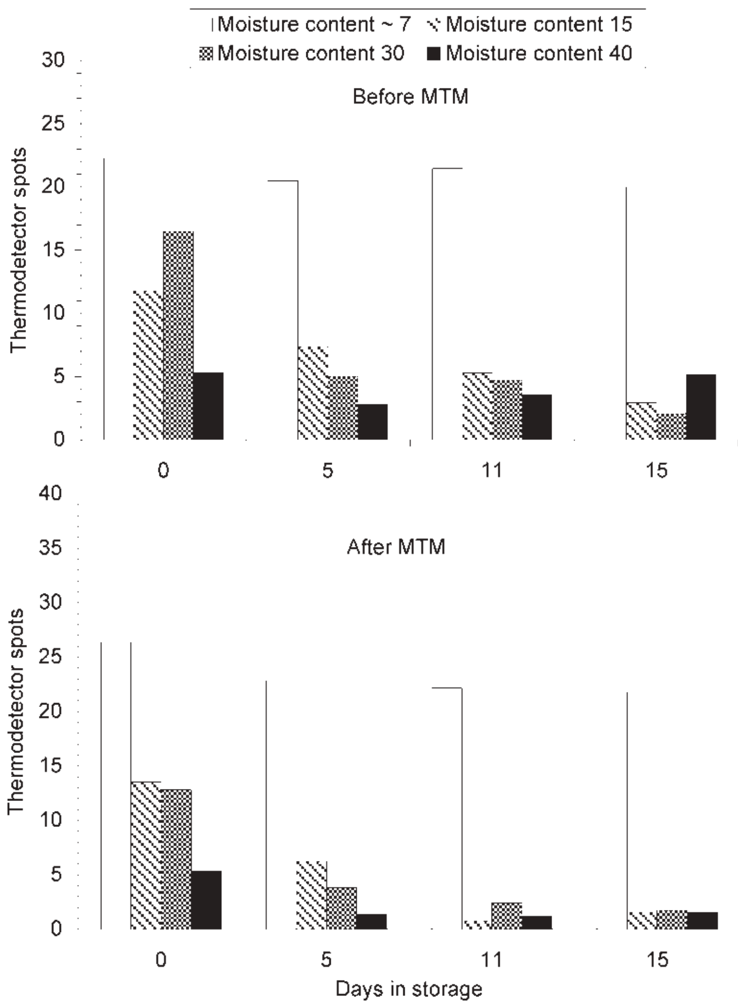
5.7 Effect of storage time on strength and colour of cotton (source: ref. 23).

gas, would still make the exhaust by-products a source of harm in the long term. Transportation also uses oil extensively, as a lubricant as well as a source of fuel. How harmful this substance can be has already been noted.



5.8 Effect of storage time on sugar content of cotton (source: ref. 23).

Not only the shipping of goods, but also the transportation of people to and from work, has a contributory effect. Vehicles cannot travel without roads, whose establishment is a major cause of environmental difficulties, from the extraction of the raw materials to the mechanical devices used to lay them down. Their presence also eliminates land on which plants for food (or textile production) can be grown, or on which animals could graze, thus introducing a different category of environmental factor. The topic could merit a separate chapter (or even a whole book), but the fact that it is not exclusively related to the subject of textiles prevents more than a brief commentary at this point. However, its contributory addition to the net ecological cost of textile production cannot be ignored and should be borne in mind.



5.9 Effect of storage time on stickiness of cotton (source: ref. 23).

5.9 Opening

Once the bale reaches its destination, either in another part of the plant or after a longer journey, it has to be opened. The opening process consists of cutting or breaking the baling material, of metal or string, then beating the compacted fibres until they burst apart, sometimes in a near-exploding mass. Nakamura *et al.*[25] define the purpose of an opener in terms of producing fine, uniform tufts and investigate the mechanism at this point in the opening sequence. They find that good tuft formation can have advantageous effects on processability and can improve yarn quality greatly. There is often a partial cleaning action accompanying this stage, as impurities are threshed out of the bales so as to be eliminated before the rest of the textile processing occurs. Large quantities of dust are likely to be produced in both of these activities and the surrounding air, in the worst situation, may be filled with a haze that obscures ***(* A-3)*** the light.

5.10 Carding

The next step in the sequence, carding, really starts to cause serious dust and noise problems. The potential for pollution can be envisaged from the report of a range of work in progress[26] on non-wovens, concerned with carding, air-laying and hydroentanglement, in which a large quantity of fabrics intended for medical textiles, geotextiles, filtration and fluid transmission is concerned.

An anonymous author[27] provides a chart of cards currently available, with comparisons made of their performance, efficiency and quality of output product, while Merg *et al.*[28] review previous investigations of fibre movement in the carding process. Carding machinery (usually referred to as carding engines) consists of large, complex equipment, with the usual ecological load, but the complexity this time also has the added drawback of making an enormous din and throwing off plenty of dust. The dust may be particles of fibre or may be the trash (waste substances left in contact with the fibres) left over after the partial cleaning of the previous stage. In addition, lubricating oils are often used to reduce this dust production, but these can then bring about their own problems. At some subsequent point, they have to be removed, since they would be undesirable in a finished product and carding oils are yet another undesirable load ***(* A-2, W-3)*** on the environment.

5.11 Blending

Blending, the mixing of different fibre types, may take place as an independent step or may be a part of the carding operation. It is carried out either by throwing the different fibre types up in a closed container until they are thoroughly mixed, or by passing them repeatedly through machinery that mixes them intimately by separating individual fibres and replacing them in a different position relative to each other. The net effect in both cases may include some dust production and some waste fibres that are thrown out from the fibre assembly, creating disposal or breathing problems ***(* A-2)***.

5.12 Combing and gilling

After carding and blending, fibres may be combed (usually for fine cottons) or gilled (for high quality worsted goods). These processes are essentially similar in nature, in that they both operate by the passage of a number of tines through the fibre assembly to straighten it and to remove short fibres or impurities. Lubricating oils are used in many cases to prevent fibre breakage as well as to reduce dust. In the same way as those in carding, these oils are removed, becoming an ecological burden ***(* L-2, W-3)***. Considerable amounts of waste fibres may also be produced, though they are often recycled to make poorer quality goods. The now-familiar problems associated with large, complex machinery are again evident.

5.13 Drawing

The next step in the yarn production train is the drawing process. In this, thick fibre assemblies are pulled out to make finer ones, known either as tops, slivers or rovings, depending on their final size and (to some extent) the personal preferences of the observer. Essentially, individual fibres or groups of fibres are made to slide past other fibres so as to extend and thin down the rope-like structure in which they are situated. Drawing (or drafting, as it is often known) is usually achieved either by rollers that accelerate each part of the fibre assembly in sequence to bring about the sliding, or by some kind of tine insertion, similar to that used in combing or gilling, for the same purpose. In both types of drawing, energy is used, dust ***(* L-2)*** and waste fibres may be created, and noise levels ***(* N-2)*** can be high, so that the step is the cause of environmental damage of various kinds.

5.14 Spinning

After drawing for one or more stages, the fibre assembly is ready for the last step in yarn production, spinning. This consists of three distinct operations, further drawing to thin the yarn out to the final desired size, twisting of the fibres together to give the assembly stability and winding up to keep the finished product tidily organised. One factor that should always be considered in regard to environmental aspects is that of moisture, because the availability of atmospheric water is crucial for successful spinning, producing better quality yarns that are not likely to be rejected. Price[29] investigates the effects of relative humidity on the properties of cotton rotor-spun yarns and his work illustrates the importance of this matter.

Several methods of machine spinning have been developed in modern times, the most common ones being the mule (now virtually extinct), ring, cap, flyer and open-end techniques. In all of these, energy is used, waste fibres or dust ***(* A-3)*** are produced, lubricating oils ***(* W-3, L-2)*** are used to reduce fibre losses, and considerable noise ***(* N-2)*** is generated, so involving once more the combination of financial costs with the environmental ones that are the subject of this book. In addition to the simple spinning of a yarn, twisting two singles yarns together to form a plied one is a common operation. The process of twisting uses machines with similar characteristics, as far as environmental costs are concerned, to those used in the initial spinning. So also does the texturing operation, in which yarns are given unusual characteristics that add interest by such steps as false twisting, crimping or the knit-deknit process. Each of these adds the extra environmental loading of another machine to the yarn production. Artune and Weinsdorfer,[30] in producing a textured polyester yarn, additionally make use of a high-temperature heater to increase the speed of the operation by 20 to 30%. One noteworthy feature of twisting and texturing machinery is the extremely high speed of operation, which can cause very high noise levels ***(* N-2)*** and increased dust production ***(* A-3)*** compared with those of the spinning operation.

5.15 Noise and dust

Noise and dust are common problems. Both of them will appear again frequently, later in the book, but will be examined closely here. They both cause difficulties for human beings, as well as for the environment, but are distinctly different in nature from any factors so far considered, and as such should be given special recognition.

5.15.1 Noise

Of the two, noise is the more difficult to classify with any quantitative accuracy. Noise can be defined as any sound which, because of particular characteristics (such as volume, frequency, speed or harmonic content), produces a sensation of discomfort or pain in the listener. The vagueness of this definition provides plenty of scope for ambiguity, especially in some of the more common sounds heard every day. For instance, the faint buzz of a mosquito in a bedroom, with its potential threat of blood loss, is a guarantee of a night's insomnia, but for an entomologist, the sound of a mosquito humming to give away its presence may be like music to the soul. Music, too, comes into this category in its own right. The deafening rock music so beloved by some students is an anathema to many other members of society, who prefer to retain their hearing into old age. Similarly, the classical music enjoyed by the author may well be regarded as a special kind of torment by those same students.

There are, however, some sounds that are undeniably and universally classed as noise. An explosion, a pneumatic drill, an aircraft taking off, or heavy traffic surrounding a car driving along a high-speed road with open windows, will always be so regarded, no matter what the acoustic tastes of the listener. There are two criteria that should be used in deciding where the sound fits into the desirable/undesirable continuum used to establish a definition of noise: that of intensity (or volume) and that of ability to please. The two (as for students at a rock concert) may occasionally be in conflict, so that a sound which should be classed as noise because it is painfully loud may be acceptable because it stirs some deep inner emotional chord.

Textile equipment can also be included in such a list. If the machine is running smoothly, with a quiet and steady, gentle hum, its sound might be regarded as pleasant by the engineer responsible for its maintenance. If its volume is extremely high, to the point where it is painful to the hearing, or if it is emitting a shrill, high-pitched note, then pleasure disappears and excessive noise is eventually, if reluctantly, associated with its operation, even by the most dedicated engineer. The test of volume and frequency can thus be applied to any textile machine to determine its position on the noise spectrum. A measure of sound intensity, expressed in decibels, is used to quantify this property. The basis of the measure is an arbitrary allocation of 0 dB(A) as the intensity which is just barely perceptible to the healthy hearing of a young person, where the (A) suffix refers to a system of filters used in electronically weighting the measuring instrument to make its sensitivity comparable to that of the average human ear. As sound intensity rises, the measure increases and, again arbitrarily, the scale is defined in such a way that an increase of 3 dB(A) represents a doubling of volume. The net result of this allocation is that a sound intensity of about 30 dB(A) represents a comfortable conversational tone and one of about 140 dB(A) is loud enough to cause physical damage instantaneously to the ears of somebody exposed to it.

In most industrial countries, the danger of subjecting people to high intensity sound has been recognised and legislation exists to limit the exposure time of workers. A typical example uses a derating scale, illustrated in Table 5.1, to define the time a worker may spend in an environment where high noise levels exist. From this can be derived the information that people are not legally allowed to remain in a noisy area at 90 dB(A) for more than eight hours in the working day, and may not be allowed to enter the area at all if sound intensity is 115 dB(A) or higher, with intermediate times being permitted at levels between these two. The legislation also includes the possibility of permitting exposure at higher levels if approved hearing protection is worn, although there are two problems with this loophole. The first is that brain damage can occur via skull bone transmission of vibration even if the ears are protected, which means that the only suitable protection should include a helmet with acoustic insulation incorporated into its structure. The usual hearing protection, earplugs, is useless in preventing harm, even though it meets the requirements of the law. The second problem is that of the machismo image. Because it is regarded by many textile plant operatives as ‘soft’ to protect their hearing, they simply refuse to wear the appropriate devices unless forced to do so by supervisors.

So why spend such an inordinate amount of time dealing with the topic of noise? And why are we hearing more and more about the subject of noise pollution? Is it that we have begun to care about the quality of life, lowered by the unpleasantness of noise, or have we suddenly become concerned about the welfare of our workers? Have the level and quantity of noise increased drastically as a result of the modern development of larger, faster, or more complex machinery? There is considerable truth in all of these possibilities, but there is also another reason, much closer to the heart of the true textile manufacturer, the fact that noise costs money. The cost may be direct or indirect, but it is considerable and should be recognised as a genuine environmental reason as well as a financial one.

Table 5.1 Permissible noise exposure

Noise level dB(A)	Permitted unprotected human exposure time (hour)
less than 85	No restriction
85–90	8
90–92	6
92–96	4
96–98	3
98–100	2
100–102	1.5
102–105	1.0
105–110	0.5
110–115	0.25
more than 115	No exposure permitted

The direct cost concerns the nature of noise. It arises as a result of a process taking place in a machine. The process may be a small explosion, as in the internal combustion engine, or frictional contact between two surfaces in a gear train or other type of mechanism. Noise is a form of energy and as such must be generated from a power source. The electricity (or other type of fuel) used up in the process cannot then be harnessed to carry out work, so is wasted. Money is paid out to generate electricity, so the money used to pay for this waste is irretrievably lost from any chance of creating profits. As a final point, the generation of electricity is environmentally costly, and again the waste cannot be reversed.

Indirect costs are more subtle. Work carried out in various industrial premises, including textile plants, has brought to light the suspicion that the hearing damage brought about by noise exposure can cause workers to suffer social harm. They may experience increased boredom and loneliness or become withdrawn from social contact as their deafness worsens. In some cases, they may blame the machines that have caused their deafness and deliberately take revenge by harming these perceived sources of a disintegrating lifestyle. Neglect of maintenance, slow correction of operating faults, or even deliberate sabotage, may occur in senseless acts of vengeance. All of these cost the manufacturer money and can exert a cost on the environment in the form of wasted energy or raw materials and excess exhaust gases. The noise that seemed to be of minor importance to our Victorian ancestors has become of crucial significance now that fuel prices have begun to constitute a noticeable proportion of a manufacturer's costs.

5.15.2 Dust

Dust consists of extremely tiny particles of solid materials that are produced when the larger units of these materials break into fragments as a result of mechanical, chemical or biological action. Because of their small size, they are easily blown about by air currents or may float in the air for long periods of time without settling. In textile production, they are of two types, the extraneous matter brought into the factory because of its contact with the original fibre sources (as packaging, for instance), and the fragments of the actual fibres themselves produced by the high forces exerted on them during the various stages of production.

Once dust particles are released into the ambient air, their subsequent behaviour can cause a variety of problems. The most obvious one is the formation of an undesirable film on every surface in the vicinity. This necessitates frequent cleaning to keep the factory (or the house, because dust is also a domestic problem) looking neat and tidy, requiring extra labour. When the particles fall onto the moving parts of machinery, they can interfere with its successful operation, bringing about an increase in the frictional force between components or an increase in the viscosity of lubricants and, eventually, a breakdown if they are not removed by maintenance. If they fall on the product, of course, they can make it appear dirty, so that it has to be washed, or may even be rejected. All this brings about an additional burden on the environment, from the need to use either detergents, fresh lubricants or cleaning materials and from increased energy consumption. Significant increases in the cost of production can also be caused, a matter that may encourage some manufacturers to take the efforts to reduce dust production more seriously.

The second type of problem caused by dust is its health hazard, mainly for human beings but also, to a lesser extent, for other species. Some types of dust are harmful because of their chemical composition, others merely because of their particulate size. Cotton dust, for instance, has long been associated with brown lung ***(* A-2)***, a degenerative disease of the pulmonary system in humans and animals, caused by chemical impurities in the fibres, usually with debilitating or even fatal consequences. Asbestos dust, which has a slightly larger particle size, has been shown to be responsible for lung cancer, purely (as far as is known) from the actual dimensions of the asbestos particles lodging in the lungs ***(* A-2)***, interfering with their function of cleansing the blood and themselves. Other, less harmful difficulties include the fact that wool dust can set up allergenic reactions and other types of dust can cause sneezing attacks, asthma and related diseases. Apart from any purely humanitarian concerns arising from these health problems, the increased absenteeism brought about as a consequence is, once again, of significance to the thinking manufacturer. Finally, dust can also interfere with the health of growing plants by coating their leaf surfaces ***(* L-2)***, so preventing them from absorbing carbon dioxide from the air and releasing oxygen back into it.

For all these reasons, limits of permissible dust production are slowly being established in the industrial world and applied to textile processes. Chellamani and Chattopadhyay[31] stress the need for workers' health, to reduce fly and fluff production, and suggest control measures such as moisture addition, infrared lamps at strategic points, floating condensers, acid treatment of roller cots and use of overhead cleaners. Schmitz *et al.*[32] measure dust levels in the German woollen industry quantitatively, distinguishing between respirable (total airborne) and alveolar (finely divided) dust. They find that the permissible limit of 6 mg/m^3 of total dust is not exceeded in any part of the factory where their testing is performed and that new proposals to limit production to 4 mg/m^3 of total and 1.5 mg/m^3 of alveolar dust are achievable without any major effort. Van Nimmen and van Langenhoven,[33] noting a sharp increase in contamination of fibres by foreign matter, such as plastics or wrongly coloured stray fibres, give an overview of proposed solutions to the problem, with benefits and problems of each one.

Kuratle[34] distinguishes between dust and trash for cotton, including in the latter term seed-coat fragments and all foreign materials not originating in the actual fibres (such as pieces of cloth, plaster or string), then suggests means of recognising them by optical techniques, followed by mechanical removal. Kechagia and Xanthopoulos[35] describe new electronic devices that permit objective evaluation of such quality characteristics as dust or trash content in cotton, noting that their successful detection and removal are crucial in maintaining spinnability, quality, and hence the economic value of the products.

We can see that yarn production can be a source of environmental problems from many angles. Human beings are a species that has consistently and deliberately, and to its own detriment, used oxygen to create carbon dioxide, in contrast to plants, which do exactly the opposite. If common sense is to prevail, we need to minimise dust production, as well as to deal with all the other undesirable ecological effects of yarn production as effectively as we possibly can!

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6
Fabric production

6.1 Traditional fabric production methods

Once the yarn has been produced, there are several ways in which it can be made into a fabric. The traditional ones include weaving, knitting and minor techniques such as crocheting, tatting, lace-making and net-making. In addition, fabrics can be made directly from fibres, without passing through the intermediate stage of yarn production. The oldest such technique is felting, but others have been developed in recent decades. These include non-wovens, fibre-to-fabric and film fibrillation. We have also seen the advent of newer techniques, such as laminating, needle-punching, bonding, tufting, stitch-knitting and braiding. Each of these can be examined in turn to assess any influence it may exert on the Earth's health.

In every case, virtually without exception, there is an involvement of mechanical action, creating the risk of dust production, fibre breakage and hence waste. In some of the techniques, though, particularly those carried out by hand, these drawbacks are minimal, solely because the mechanical action is considerably reduced by the slow nature of the process and the consequent reduction in high-speed contact between fibre assemblies and abrasive surfaces. The price paid for this reduction is, naturally, a much lower output.

6.1.1 Knitting

Knitting machines are a relatively recent invention, dating originally from the 1400s and developed into a mechanical form in 1598, when Rev. William Lee first produced his replacement for the hand knitting that had been used up to that time. Whether it brought about an increase in attendance at his place of worship, because it provided his parishioners with more leisure time to enable them to take Sundays off, is not recorded, but it certainly improved the speed at which knitted goods could be produced. His work was subsequently improved until, by the middle of the 19th century, the circular machine was invented.

In terms of environmental effects, the familiar factors of machine size and complexity, and of energy consumption, still exist. The need for a lubricant ***(* W-3)*** (see Table 1.1 for an explanation of codes) to reduce frictional contact between needle eye and yarn, thus reducing breakage (and hence waste), is also regarded as essential for today's high-speed machines.

6.1.2 Weaving

Weaving, the oldest of the techniques used to make fabrics from yarns, dates from prehistoric times. In those 'good old days' it was, presumably, possible to make goods without doing much harm to the planet, but making the same assumption today would be a sad distortion of the truth. Weaving no longer simply happens by shoving a yarn through two other sets of yarns previously strung on a frame between two trees. Nowadays, the warp has to be produced first, by using a winding operation known as beaming to place the warp yarns in the correct location on a beam in readiness for feeding into the loom. In addition, the weft yarns have to be wound onto a shuttle (or other weft insertion device) so that they can be threaded into the fabric in the correct sequence without tangling the entire system so badly that it cannot function. All of these steps require relatively complex machinery, with the associated environmental costs we have already met, and involve such factors as transportation between them or storage facilities that have to be added. Once these preliminary matters are arranged, the loom proper has to be set up in advance of its operation, with its yarns in the correct sequence for production, a process that can be lengthy and tedious.

Operation in traditional looms is very damaging from the point of view of the planet and its inhabitants. Vast amounts of force are needed to hurl the shuttle repeatedly and reliably through the shed but, at the end of its travel, the device still retains almost all of the energy originally provided for its propulsion. This energy is then absorbed, with an enormous emission of noise, by allowing the shuttle to slam into a housing at the end of the race. As a consequence, the sound pressure level can reach 110 to 125 dB(A), making the weaving shed notoriously dangerous ***(* N-2)*** for the hearing of workers.

Noise pollution, however, is not the only disadvantage to bedevil weaving. In modern looms, higher speeds are sought to enhance production rates, bringing about an increase in frictional contact between heddles and yarns and between adjacent yarns themselves. As the warp yarns are only moved in very small steps of progression through the loom, it is clear that they will suffer many such abrasive contacts before finally reaching the point at which they become embedded in the fell of the fabric. This brings about a great reduction in the fabric manufacture rate as a result of the need to keep stopping the machine to repair broken yarns, also increasing the amount of dust or broken fibres produced. In order to eliminate the rubbing, fibre breakage and dust production as much as possible, sizing is used as a means of lowering the effects of frictional contact.

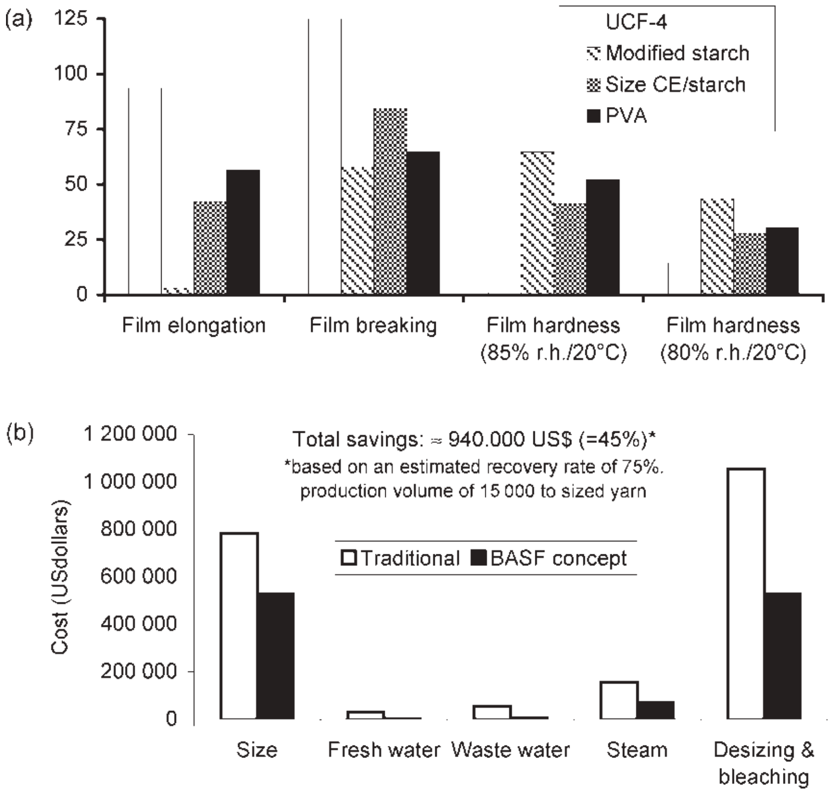
Sizing is the application of a size, or binding agent, onto the warp yarns, usually before they are wound onto the beam. The effect is akin to a glue that holds the fibres in place. The size may be made of natural materials, principally starch, or may be of a synthetic nature, made from polyvinyl or polyacrylic compounds. Sadly for the planet, neither of these two classes of compound can be allowed to remain on the fabric, because they are very stiff and create bulky regions in the yarns. These would not only be unacceptable to the consumer, but would also create difficulties in subsequent processing steps, such as dyeing or finishing. For this reason, they have to be removed in a desizing operation after the fabric is woven. This step is not easy to carry out, as the size is usually bound fairly firmly to the fibres in order to act successfully. Scouring or solvent extraction are used respectively to remove the two kinds of size and the by-products of these operations are an environmental hazard of the same type as those mentioned earlier in discussing scouring and solvent spinning. Water pollution is especially of concern, since the balance of aquatic species can be totally distorted by the presence of these substances ***(* W-3)***. In an effort to reduce pollution, Min and Huang[1] describe a one-step design to desize, scour, bleach and mercerise cotton; they study the dyeing kinetics but find that dye absorption is not as good as with the conventional sequence of processes.

As a result of these concerns, considerable interest has been shown in sizing and desizing operations. Stöhr[2] notes that an ideal size would be one that could be reused repeatedly, indefinitely and without limitation, and deliver optimum sizing results. He feels that such a compound exists, developed in a manner that allows both the size and the water associated with the process to be recycled. The new material, coded as UCF-4, can be removed easily from the fabric with hot water, with no chemicals and reused as long as ultrafiltration is carried out to isolate its synthetic polymer molecules. Figure 6.1 compares the results of using the new size with those from more traditional ones, indicating that it has superior strength and elongation even though it possesses lower hardness. Reports of conference proceedings and of extended research programmes appear in the literature (see Appendix). When the need to remove the size arises, there are suggestions of how best to carry out this step, with enzymatic desizing appearing at first sight to be one of the most promising of these. Some of the relevant papers, both for sizing and desizing, are summarised in Section 4 of the Appendix.

6.2 Other methods

6.2.1 Felting

In the methods of producing fabric without passing through a yarn-making stage, felting has to be considered first, not merely because it too predates history, but also because it creates major ecological difficulties in the modern manner of production. Felting occurs because wool fibres, with their sawtooth edge profile, can lock together under conditions of pressure, moisture, heat and agitation, to



6.1 Comparative behaviour of UCF-4 and traditional sizes; (a) size film performance, (b) cost savings (source: ref. 2).

produce a dense, thick mat that provides an efficient thermally – or acoustically – insulating barrier. In modern machines the process is accelerated beyond the early simple one in order to reduce the time of production from days or weeks to a few hours. This is accomplished by the addition of detergents to the fibres and by the use of mechanical agitators plus superheated steam to enhance fibre contact and heating rates. The result is an unpleasantly hot atmosphere for workers in the production area, a waste of heat energy and an effluent that contains harmful substances (particularly detergent and fibrous matter) that have to be released into the water system ***(* W-3)***. As before, the large complex machinery and the high temperatures needed are both expensive environmentally, while the release of the chemicals in the effluent brings about secondary effects in the form of problems for species dwelling in the waterways.

6.2.2 Non-wovens

Non-wovens (often lumped together with fibre-to-fabric) is a term used to describe a number of similar techniques. All of them have in common the fact that they start from a bed of fibres, laid in a parallel, random or crosswise manner and then treated in some way to allow them to be held together in a stable lattice. Techniques for maintaining their integrity include using a glue ***(* W-3)***, using heat to melt some of the polymeric components added for this purpose or merely using high pressure to squeeze them together. Some may also use the felting of wool fibres as a binding device, though there must be at least 50% of the bulk in the form of wool to enable successful adhesion to take place. An anonymous author[3] describes a spunbonding and spunlacing process using a single-step water-jet method, claiming that this represents an ecologically harmless cost-saving technology with minimum energy consumption, water circulation and downtimes, as well as providing good entanglement. Despite this claim, though, the usual hidden environmental costs are inevitably present.

6.2.3 Minor methods

The remaining minor methods of fabric production may be divided into two categories, those in which hand production is carried out and those in which machines are used. Some of the techniques lend themselves to both categories, with a gradually increasing transition to the mechanical methods as old skills are lost by the attrition of the practitioners able to use them. Of the methods quoted, to the best of the author's knowledge, only tatting is still carried out solely by hand, though embroidery (not strictly a fabric production technique) is done by hand in a slightly diffrent manner from machine embroidery. This technique is currently beginning to enjoy a renaissance, as described by Selm *et al.*,[4] because it is ideally suited to production of the complex structures needed for certain medical implants.

Techniques formerly carried out by hand but now converted to machine production, including net-making, braiding, crocheting and lace-making, all need the now familiar complex machinery that pervades the entire industry, with the inherent essential losses to the environment. None of the techniques uses any significant quantity of chemicals in the actual production equipment, though it must not be forgotten that the yarns, which are raw materials of each stage, have already accumulated significant ecological costs before the process begins. In addition, even the techniques carried out by hand need these raw materials and this should be borne in mind when assessing any advantages and drawbacks of a process. The issue of carrying forward a 'debt' is one that is often overlooked in attempting to produce an environmental audit. This is a timely place in which to consider the matter.

6.2.4 Environmental aspects

At any stage in a production train, there are factors that do not strictly belong to the step being considered. All the raw materials, for instance, are assumed to be present, as are the items of equipment needed to carry out the step. Nevertheless, each of these components has an environmental cost associated with it that should be taken into account if a complete evaluation of the step is required. The analytical procedure has been described in detail elsewhere[5] and leads to a complicated process of iterative calculation that can trace the costs back to the initial step of extracting the minerals for the production of metals or polymers used in manufacturing the equipment from the Earth. Additionally, the costs of acquiring and using the sources of energy necessary to operate the machinery at all stages in the overall production train, from fibre and iron ore, to working equipment and yarns, can be derived. The net result is that no process is entirely free of environmental cost. If one is strictly pedantic, even the production of carbon dioxide by the people breathing can be considered an environmental cost, since this gas is an important source of global warming. When the need to provide them with food, housing, transportation, working space and all the other luxuries they use at the expense of the planet are also taken into account, it becomes more and more clear that human beings are a major source of environmental cost whether or not they even operate any textile operating machinery. The crucial point about this method of analysis is that, if the production at any stage is faulty, the cost to the environment does not just include that of wasting the product of the step where it is discarded, but also the entire production train up to that point. The later in the overall process a rejection occurs, the more cost to the environment is involved. Fortunately, this is a parallel cost to the financial one, leading manufacturers to try to avoid such waste by finding an alternative use for substandard materials instead of rejecting the goods totally.

6.2.5 Stitch-knitting

The next production technique, stitch-knitting, is one which is never carried out by hand. There are several versions of the method, including ones with names such as malimo, maliwatt and arachne. In all of these, a layer of fibres is placed on a horizontal carrier plate and is then passed through a piece of equipment that is, essentially, a sewing machine. The machine places stitches into the fibre layer, holding the individual fibres together to form a loose, thermally insulating batt that is soft to the touch. From the environmental perspective at least, needle-punching may be regarded as a modification of this type of manufacture, since it involves the piercing of a fibre layer by barbed needles to bring about entanglement, but this time with no yarns in the needles. In all of these techniques, apart from the cumulative ones incurred and those resulting from the complexity and power consumption of the machinery used, there are normally no added costs to be debited specifically to the method of production.

6.2.6 Coating and laminating

Coating is usually understood to involve the application of a polymeric layer to the surface of a fabric, while laminating consists of the combination of two layers of material, previously produced by another method, by the application of a third layer in the form of a glue or binder. Both techniques are described in comprehensive detail by Fung,[6] with an account of their newer methods of production and their many uses. Again, the machinery in both cases is large and complex, with the accompanying environmental costs. In addition, the bonding agent (normally some kind of polymer) has to be manufactured and heated, while the waste products are more than usually inconvenient as they are a combination of different materials ***(* W-3)*** that cannot easily be recycled. Bonding, in which the same kind of glue is applied to a fibre batt, has similar drawbacks in ecological terms.

6.2.7 Tufting

Tufting, the major method of carpet manufacture nowadays, consists of the insertion of a pile yarn into a premanufactured layer of fabric. The machinery used, as may be expected when a large piece of fabric like a carpet is being produced, is very large in size, requiring high energy consumption and thus placing an environmental load on the planet once more. In addition, chemical compounds ***(* W-3)*** are applied to the system to stabilise the relative juxtaposition between the yarn and the fabric and heating is used to set this bonding agent.

6.2.8 Film fibrillation

The final means of making a fabric, relatively new but increasing in popularity, is film fibrillation, a process described, for instance, by an author from the Kuralay Company.[7] In this process, a polymeric film is produced by extruding the raw material in sheet form onto a flat bed, piercing it with mechanical or ultrasonic energy and simultaneously applying a high tensile force, in order to stretch the film rapidly in the crosswise direction at an unusually large rate of extension. As a consequence of this action and because of the high speed of application of the force, there is no opportunity for the energy applied to be dissipated into the layer and large numbers of local breaks occur. This gives the layer the appearance of a fabric, with many small holes interspersed throughout a continuous solid matrix. Clearly, the environmental costs incurred here, apart from the usual machine operation ones, will be mainly those of making the polymer, as already discussed when the production of polymeric filaments was considered in the Chapter 4.

Thus we now have our textile goods in the form of fabrics, whether made via yarns or by a more direct process. Serra-Verdaguer *et al.*,[8] looking at the whole picture, develop bases for eco production and finishing of textiles made from all natural and chemical fibres, and propose criteria for extending a labelling system, together with a survey of the main ecological aspects of fabric production and processing. The fabric itself is not yet ready for the consumer. A considerable amount of work must be carried out on it to make it acceptable to our modern tastes. The types of costs incurred by these subsequent treatments are the subject of the next chapter.

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