The problem is two-fold. First, because the fibres, yarns and fabrics have such low rigidity, it is not possible to put them into a specific position and expect them to stay there. As soon as they are left unsupported, they will collapse under the influence of gravity, even if there are no more forces acting on them, and lose the shape they had before they were released. Second, the basic unit is so small that it is impossible to work with individual components of textiles. It is necessary to operate, literally, on thousands or even millions of fibres at a time. Each of them will behave in a slightly different way from what might be expected when considering the forces acting on it. This creates problems of a special kind.

The solutions that have been adopted over thousands of years of textile production all have in common the fact that operations are carried out on the fibres in large quantities in a manner that attempts to control most of them, while accepting the inevitable need to recognise that some will behave in an undesirable way.

3.3 Principles of textile manufacture

For the reason noted above, the machinery needed to produce textiles cannot be simple. Few portable pieces of textile production equipment exist today, with the exception of hand production equipment such as knitting needles, embroidery frames, looms and drop spinning equipment still used by craft workers or indigenous people. As a direct consequence of this, in the vast majority of cases textile production equipment is massive, complex, expensive and difficult to use effectively in its aim of manipulating millions of tiny particles of flexible units at a speed high enough to satisfy the demand for its products. From the ecological perspective, this has two major consequences. First, textile production uses vast amounts of energy. The high demand and the large size of machinery forces the use of a lot of power in all parts of the world to keep the flow of materials going. Second, because of its complexity, the actual production of the machinery is environmentally very costly. The steel for stable framing, supports, protective covers, shafts, bearings and so on, has to be mined and refined. So too do the various non-ferrous metals used in reducing weight, improving electrical or corrosion resistance properties or providing more durable gears in the equipment. Plastic products used to enhance electrical, thermal or acoustic insulation have to be derived from oil, once it has been extracted from great depths below the surface of the ground or sea, by complex chemical reactions. All of these processes use energy, consume raw materials and produce waste matter as pollution discarded to the air, water or land once the intermediate product of the particular stage has been made.

3.4 Energy

As a result of this high environmental cost (and, even more of a spur, the cost of wasted energy), there have been many attempts to produce energy in less costly ways. The use of coal, oil, gas and electricity has been tried, in turn, over the 200 years or so that have elapsed since the Industrial Revolution first introduced the use of power in textile production.

3.4.1 Coal

Coal, the fuel that drove the Industrial Revolution, is rapidly disappearing from use for electricity generation in the developed nations. It creates too many problems, from those encountered during its extraction to those produced by its combustion. Miners working in risky underground locations are constantly in danger of mine collapse, fire, poisonous gases or lung problems and it is not unusual to read of major disasters in those places where coal faces are still worked. The residual piles of waste make a hideous mess of unsightly scars on the face of the Earth. Burning coal gives rise to smog or other atmospheric pollutants ***(* V-3, A-2, A-3)*** (see Table 1.1 for explanation of codes) and to health problems induced by breathing the toxic by-products resulting from the combustion of impurities in the coal. However, there are still coal-powered energy generation plants in operation in many parts of the world, to the detriment of our environment and the health of people living on the planet.

3.4.2 Oil

The combustion of oil is currently a popular form of energy production. Oil itself is cleaner-burning than coal, but can cause major problems for the environment in its production. The oil wells that proliferate in those parts of the world where 'black gold' is extracted fill the air with fumes ***(* A-2)*** from the burning oil that appears at the top of each well. The scars on the land left after sinking a well are as ugly ***(* V-1)*** as those left by coal mining, and the pipes must often be sunk to a greater depth than these mines in order to reach the oil site. Drilling operations also produce ecological disturbances, from the displacement of wildlife and the arrival of unsightly equipment to the burning of the fuel used to power the rigs. When the oil is moved, too, the spills ***(* W-3)*** that are so common in our modern world can each kill or maim literally thousands of living creatures.

3.4.3 Gas

For reasons of cleanliness and economy, many textile factories have adopted gas as the source of at least a part of their energy. Coal gas, the original fuel in this category, merely transferred the pollution from the point of use to the point of production, since it was manufactured by burning coal. It was also notorious for its toxic ***(* A-2)*** nature. More recently, coal gas has been replaced by natural gas, extracted from the ground along with oil, which is cleaner burning and not toxic. Unfortunately, gas of any kind cannot be carried around easily, so pipe lines or pressurised containers are needed to be able to make use of this fuel. It also has to be refined to some extent to keep it clean and has an odour that can be objectionable to some people. More to the point, even if it is completely pure, it still produces considerable amounts of carbon dioxide when it burns, adding a significant contribution to the global warming problem.

3.4.4 Electricity

All of this brings us to consider the most common source of energy in textile plants, electricity. At first glance, it is the ideal fuel. It is clean, convenient, versatile and has all those other attributes that we seek to make our lives easier. Examine the situation more closely, though, and a different perspective begins to emerge. All those benefits, it is true, are experienced by the user, but the way in which electricity is actually produced is far from ideal. It may be the result of burning coal or oil, with the drawbacks already mentioned. It can also be generated by burning all kinds of waste material, much of which is domestic pollution, with the consequent release into the atmosphere of carbon dioxide ***(* A-1)*** and even more undesirable substances created as by-products of the chemical combustion process ***(* A-2)***. In an attempt to give electricity generation a better image, modern production has relied heavily on hydroelectric generation techniques. These involve allowing a large quantity of water to flow from a higher to a lower level through a pipe in which turbines are caused to rotate by the rushing motion of the water. Apart from the need to produce the equipment, potentially an environmentally costly process in itself, there is often a need to create artificial height differentials so that the water has somewhere to flow from and to. This can mean diverting rivers or streams, building dams, flooding valleys and excavating tracts of land, ecologically expensive ways of providing a flow of water.

3.4.5 Nuclear power

The proliferation of nuclear power plants over many parts of the world is an indication of how much promise this technique was once believed to have as an alternative means of producing energy. The unfortunate truth, of course, is that there are drawbacks to nuclear energy that were either not foreseen or were mistakenly assumed to be trivial.

The first of these to surface was the difficulty in disposing of spent fuel. Nuclear fuel rods contain highly concentrated radioactive elements. Their activity cannot just be turned off once the fuel is spent. At the end of its useful life in terms of an energy source, there is still a dangerously high level of radiation left in the atoms of the radioactive element. This is not enough to make it possible to take advantage by generating electricity, but certainly enough to kill off a few thousand people by radiation sickness if it were to be left lying about ***(* L-2)***.

The solutions adopted to overcome this drawback include reprocessing and storage, but these, especially the latter, remain problematic in view of the costs involved and the risk of leakage over the enormous storage time needed. Even if the material is encased in concrete or stainless steel containers and buried in deep water, cracking or corrosion can occur, so that the nuclear waste ***(* W-3)*** can spill out into the sea. From there, fish and other aquatic life can become contaminated, or air currents, water flow and earth tremors can distribute the harmful material around the surface of the planet. Sadly, the radioactivity is likely to last for a much longer time than the encasing materials, so the results of our careless discarding of radiation are being bequeathed for future generations to inherit.

A second side-effect has been brought to our attention in a dramatic way. Sellafield, Pickering and Chernobyl are names that conjure up images of nuclear power plants that went wrong. The latter, especially, taught us that one careless act at a nuclear plant can bring about a disaster capable of destroying the livelihood, and lives in many cases, of thousands or millions of people. The margin of error between nuclear fuel that reacts fast enough to create energy at a reasonable pace, and that reacting fast enough to blow its container apart, spreading devastation over the face of the earth, is not all that great.

Even when the fuel cells are controlled properly, there are still undesirable consequences of the process. Electricity generation takes place because the nuclear energy heats water to steam, which is then used to drive turbines. The spent water is hot and has to be discarded somewhere, often into the nearest river or lake water. Although it has cooled down sufficiently to avoid boiling any nearby fish in the water, it is still warm enough to make the area uninhabitable for them ***(* W-1)***. Other species, both fish and plant, can take over and change the balance of nature in the region downstream of the plant discharge site. The consequences for the environment and for the people living in the area are not yet understood, but the changes already occurring as a result of this nuclear warming give us cause to reflect that our energy comes at a tremendous cost to our planet's natural health.

3.4.6 New energy sources

One consequence arising from our realisation of the risks of nuclear mishap is the effort to find new ways to provide energy. Solar, tidal and wind energy have all been proposed as ways in which electrical energy can be produced. The hydrogen cell has been suggested as a means of powering devices in place of intermediate electricity generation. At first sight, again, all these methods of providing supposedly unlimited energy seem impressive. They are natural, reliable (with certain fairly obvious limitations, such as location or time of day) and, more importantly, free. There will almost certainly be unexpected drawbacks, as the lessons of history have shown. Before we find them, however, there are obvious ones that can be predicted even without experiencing them, all resulting from the nature of energy supply.

Energy production is complicated. The natural source has to be collected, harnessed, converted into electricity and distributed to its point of consumption. In all of these steps, equipment is essential. This equipment, like that used to make textiles, is generally large, heavy, complex and made of many different materials, making it environmentally costly to produce. Its manufacture and operation produce pollution, because waste material is generated in the former case and lubricants are needed in the latter, contaminating the air, water or land. It also has a relatively short life, because materials subjected to heat and mechanical action from sun, weathering, water or wind will eventually corrode or suffer fatigue fracture. As a safety precaution if for no other reason, they will have to be replaced by new equipment roughly every 20 to 30 years, thus producing a continual environmental cost that never ends.

More importantly, perhaps, is the mental attitude that will be engendered by the use of these 'revolutionary' energy sources. If energy is cheap (free?) and appears to be clean, then we should be able to use it in unrestricted amounts. We can waste it without any qualms of conscience and need not concern ourselves with the consequences of our actions, because neither the environment nor our pockets are being harmed in the process. It is only when we look at the entire cycle, from starting to make the power generation equipment to the end results of using it, that we can begin to realise how wrong our assumptions might be. The actual energy consumed in making or using a product is a minor fraction of its overall environmental impact, because the extraction of materials to manufacture the equipment designed to make the energy or to use it, and the pollution resulting from such extraction, must also be taken into account. Unlimited energy use means unlimited equipment production and hence unlimited ecological degradation.

So the textile industry, like most others, is unlikely to find any sop to its collective conscience with respect to power consumption in the foreseeable future. Unfortunately, this is not the only way in which the environment suffers for the sake of the industry. Every stage of manufacture, from fibre production or harvesting to shipping, inevitably involves damage (considerable in some cases) to the environment. The following chapters will summarise how this damage arises, looking briefly at its consequences and examining the ways in which it can be alleviated. In addition, the way in which textiles can themselves be harmed by the environment in the process of degradation will be considered.

4
Textile fibre production

4.1 Scope of the industry

When the actual ways in which textile goods are made are put under close scrutiny, plenty of instances of environmental concern can be found. These will be looked at in sequence, following the various stages in turn, from growing or manufacturing the starting materials, the fibres, to the point at which an end product is shipped to the final consumer in readiness for use.

First, though, the potential magnitude of any problem is examined briefly by estimating the size of the industry. An anonymous author[1] records annual world production of textile fibres at about 60 million tonnes, of which over 50% is synthetics. This is in agreement with another writer,[2] who quotes a value for world production of textile fibres of almost 58 million tonnes, with chemical fibres amounting to 31 million tonnes. Any growth likely to take place will probably be in the latter type of textiles; Schenek[3] surveys comprehensively the state of natural fibre production and notes that, although the cotton harvest grew by almost 50% in the last few decades of the 20th century, the production of other natural fibres is likely to remain more or less steady. His estimate of total natural fibre production is in slight disagreement with the figures quoted above, since he records it at only about 26% of world total. Vishwanath[4] presents an outline of the history of silk production, with figures giving details of the share from each country, quoting current production at 81 000 tonnes, worth $6.5 billion, and examining the factors that could determine whether or not production will increase from its present level.

4.2 Natural fibre production

Having gained some idea of the extent of production figures, the fibre-growing industry will be examined. As examples of typical raw materials, cotton (a plant seed-hair fibre), linen and the similar (bast) fibre jute, silk (an extruded animal fibre) and wool (an animal hair fibre) will be considered. Wool and linen almost certainly predated the other two historically, but history does not have to be followed slavishly, so the vegetable fibres, cotton and linen, will be dealt with first, followed by silk and then wool before looking finally at the artificial (man-made) fibres. Other examples of each type of category exist, but their production techniques resemble those described below for the archetypal ones.

4.2.1 Cotton

Cotton is grown on a bush, 0.6 to 6 metres high, in a field. Good growth of a high quality fibre requires a minimum of about 150 days of sunlight each year and plenty of fresh water. Cotton can therefore only be grown in a relatively narrow belt of the Earth's surface, within about 35 degrees latitude of the equator, and in one or two other areas of the planet where local conditions are atypical for the latitude. The quality varies greatly in different locations, with Sea Island and Egyptian cotton generally considered to be the finest and Pakistani, Russian or Indian inferior.

In order to achieve the optimum quality, efforts are usually made to enhance growth conditions. Fertilisers, insecticides and herbicides are commonly applied during the growing season. A considerable part of an international conference[5] held in 1998 was devoted to this topic. Pertinent subjects discussed include enhancing quality by adjusting growth or soil treatment conditions and control of pests to increase yield. Daniell[6] suggests that genetic engineering provides the best possible way of achieving both of these, since natural breeding has reached its limit because of species incompatibility and the small range of properties that can be incorporated into a plant by natural selection. This view is echoed by Wilson,[7] who reviews current and future biotechnology, suggesting (among less fanciful ideas) the possibility of developing blue cotton plants to avoid the need to dye cotton for jeans. Although this may appear to be a good idea at first sight, it is appropriate to wonder how environmentally costly the process will be, both in the short term, because of the technology needed, and in the long run when different shades of blue are demanded by fickle consumers or when cross-fertilisation by wind distribution has eliminated all bushes bearing natural white cotton fibres. There is also the concern, a notable one at the moment, regarding contamination by genetically modified plants of other plants, not modified by this technology, in the vicinity.

Other contributors at the 1998 Beltwide Conference, such as El-Lissy *et al.*[8] give information about a scheme to eradicate insects, such as boll weevils or budworms, indicating that significant declines took place between 1995 and 1997. However, a conflicting note is sounded by Williams,[9] who estimates that insect losses still represent 9.42% of the crop, the equivalent of 2.5 million bales of cotton and almost $1.5 billion dollars in financial losses. Many papers at the same conference deal with combination of biological and chemical controls to achieve sound management of insect pests, including aphids, leaf whitefly or sweet potato whitefly. Yet other contributors concentrate on soil tillage and methods of actually adding fertilisers to improve yields.

Another important aspect of cotton growth is the need for a plentiful supply of water. Drought conditions can bring about a reduction in the quality of the cotton not only because of the lack of waterborne nutrient flow but also as a consequence of changes in fertiliser effects.[10] For this reason, irrigation water must be pumped to the cultivation site if natural water supplies are insufficient for satisfactory growth. The chemical additives used have adverse effects on the land ***(* L-1, L-2)*** (see Table 1.1 for explanation of codes), as discussed in Chapter 2, and the need to irrigate the plants also brings about problems, though usually not quite such serious ones. First, unless gravitational flow can be harnessed, water must be pumped mechanically to the site, which involves manufacturing and powering machinery for the purpose. This machinery, like all the mechanical aids mentioned already, is itself environmentally costly. Second, the flow of water can exacerbate erosion and chemical leaching problems. Third, unless applications are carefully coordinated, the flow of water can remove some of the chemicals before they have accomplished their purpose, necessitating the application of more of them to control the growth of pests for which they are needed.

Once the plant has produced its crop and the seed hairs are open, harvesting must take place. In these days, despite the fact that hand picking can yield a better quality of product, harvesting is almost invariably done by machine, simply because the cost of labour is too high to make the relatively slight improvement in fibre quality worth the extra cost involved. This machinery adds an environmental load to the process. The timing of picking, too, is less easily controlled when mechanical picking takes place. Manual methods can allow selection of just-ripe bolls to be made, but no machine currently in existence has this capability. Another conference, this time in Bremen,[11] included details regarding the means for carrying out standard tests for measuring maturity, along with stickiness, dust or trash levels, fibre length and high volume instrument (HVI) testing. One method suggested[12] for estimating the time at which cotton reaches its optimum maturity uses image analysis of fibre bundle tests.

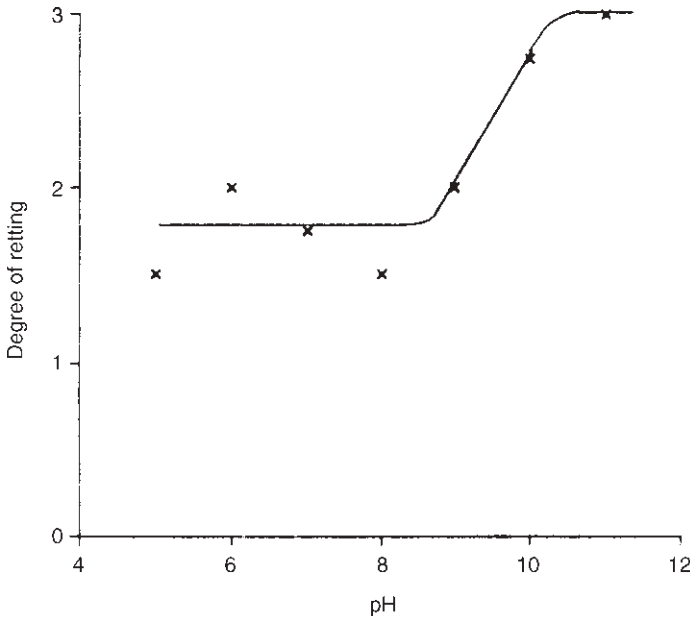
The next stage in cotton fibre production is the ginning operation, frequently taking place in the field in the immediate vicinity of the crop and designed to separate the cotton fibres from the seed fragments. Vizia and Anep[13] claim that ginning is the weak link in cotton processing in India, because it suffers from poor efficiency and problems with cleaning and storage. They outline proposals for improvement in the future. Lugachev,[14] in an effort to improve quality, has devised a new energy-saving technique for doffing fibres in sawtooth ginning by making use of a reflected air flow. Anthony and Byler[15] are more optimistic on behalf of American producers; they suggest that careful control of the ginning process (especially in the matter of moisture uptake and machine type), together with a mechanism that includes computer measurement, improves fibre quality, gives higher yield and produces fewer short fibres and neps. The scheme they recommend is one in which moisture content, colour and foreign matter are measured by standard methods, after which this information is fed forward or back, so that ginning can be increased if necessary or omitted completely if it is not needed, thus providing better separation of seed-coat fragments with minimum fibre damage. These fragments are often regarded as useless but, in a notable example of environmental responsibility, Bader *et al.*[16] use them for cattle feed and as replacement for pine chips in poultry barns.

4.2.2 Leaf and stem fibres

Perfectly satisfactory textile fibres can also be obtained from other parts of plants than the seed hairs, notably the stem and the leaf. Stem, or bast, fibres tend to be less ecologically harmful than seed-hair ones. Linen, a typical example, can grow with virtually no attention or fertilisers, as long as water is available. Tarres[17] discusses the cultivation of flax in the past and predicts how it might change in the future, also describing pretreatments and textile uses. Mackie[18] carries out a similar task with regard to hemp, another stem fibre. For best quality fibres from both sources, a relatively small amount of care needs to be taken. The climate must be very moist but mild. The selection of optimum quality fibres has traditionally been done by hand in many countries. This makes the process more costly financially, but is environmentally beneficial. In recent times, though, mechanical methods of harvesting have been introduced, with adverse effects on the environment and a reduction in the quality of the fibre produced.

Once harvested, the flax must be treated to release the usable fibres from the surrounding woody stalk and interior pith. The most important part of this process is the retting, or soaking, that allows slow decomposition of the woody parts to take place. Schulze[19] notes the impact of flax fibre properties on spinnability. He investigates the performance of flax blended in turn with cotton, viscose, polyester and aramid components, finding that the importance of retting is paramount for successful yarn production. Traditionally, retting was done in pools or ditches, which tend to give a better quality of product, because the advantageous moist conditions are preserved longer in their shelter. If the flax plant is cut by hand and left to ret in the ditch, then the environmental load on the planet is minimal. Jute has similar advantages; Chattopadhyay[20] outlines the retting process and describes the physical characteristics of the fibre, mentioning its chemical composition, sensitivity to alkalis and the need to take precautions to avoid yellowing if bleaching is attempted.

Sadly, modern technology cannot accept such a beneficial solution. Dew retting or tank retting is more frequently used today, using mechanical devices to turn the stalks, maintain high temperatures and remove seeds. Lennox-Kerr[21] reports the development of a new mechanical treatment process for flax to produce linen fibres that resemble cotton in their properties and structure and can be processed on equipment designed for cotton.

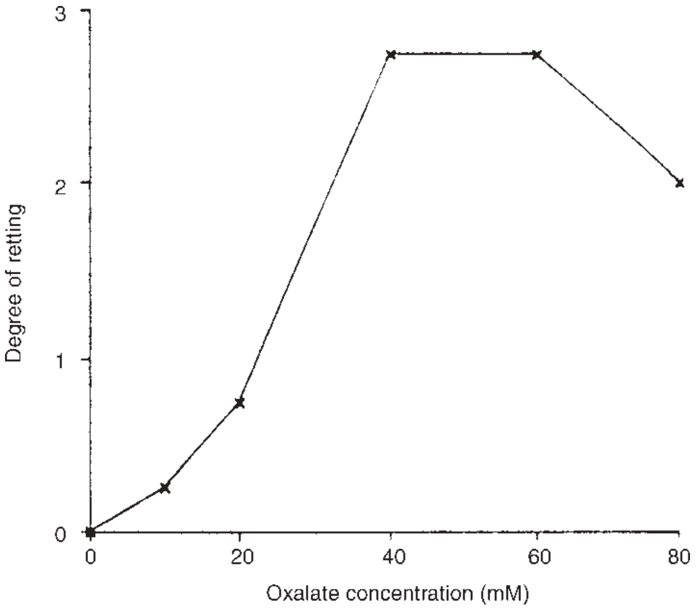


4.1 Effect of pH on flax retting (source: see ref. 22).

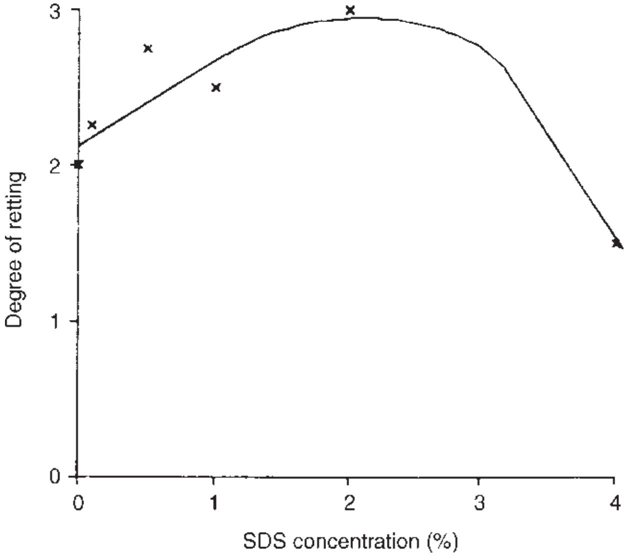
Mechanical harvesting speeds up the cutting process and chemical agents reduce the retting time from two or three weeks to a few days or even less. Henriksson *et al.*,[22] for instance, propose an oxalic acid-based system for chemical retting of flax that compares favourably with the more common enzymatic retting. Figures 4.1 to 4.4 (showing the effects of pH, oxalic acid concentration, sodium dodecyl sulphate concentration, time and temperature on retting) indicate that higher pH conditions bring about better retting, which is highly temperature dependent. The authors find that retting is virtually complete if treatment is continued at 75°C for as short a time period as a mere two hours. The presence of a detergent is needed to obtain satisfactory retting. Tests of tex, tenacity and elongation properties again indicate that the fibre can be processed on cotton production equipment. Although there are continuing arguments about whether the fibre quality is enhanced or reduced by the change from manual to mechanical or chemical processing, it is the economic aspect that really plays the most important part in the debate. The end result is, once again, a damaged planet.

4.2.3 Silk

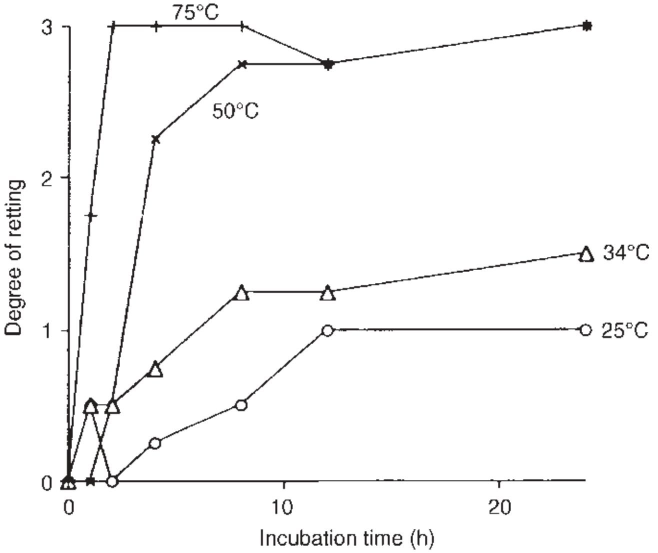
Silk production brings about a different set of considerations. The process involves rearing the silkworm grubs to the chrysalis stage, then unwinding the silk filaments from which the case enclosing this chrysalis is formed. Most commercially



4.2 Effect of oxalate concentration on flax retting (source: see ref. 22).



4.3 Effect of sodium dodecylsulphate concentration on flax retting (source: see ref. 22).



4.4 Effect of temperature and incubation time on flax retting (source: see ref. 22).

produced silk is of the cultivated variety, depending on feeding the worms a carefully controlled diet of mulberry leaves grown under special conditions. This need gives rise to the environmental costs of establishing controlled atmospheres and employing rigid growth conditions. Wild ('tussah') silk production, conversely, involves minimal interference with nature, so there is a great deal of interest in developing the fibre commercially. Akai[23] surveys the available techniques, focusing on the main points of manufacture and on predicting the importance of commercial manufacture of wild silk in the 21st century. Jahagirdar[24] feels that marketing is the main constraint, in view of the lower quality (compared with cultivated silk), but stresses that the fibre can provide a major source of income for millions of tribal people in India. Krishna Rao *et al.*[25] agree, noting that the income is year round rather than seasonal, and point out that the forest cover is an easy source of food and plants, so constituting a base for commercial development. Ghosh[26] describes improved techniques for enhanced quality and productivity and mentions the slow transition to better working conditions and higher incomes for workers, describing advances in powered machinery for reeling and spinning. In the context of this book, an important point is made by Nadigar,[27] who notes that wild silk is exceptionally ecofriendly, since it uses no hazardous chemicals and encourages the socially beneficial activity of preserving the forests. He sounds a note of caution in that the dyeing and printing chemicals currently used are toxic substances ***(* W-3)***, but maintains that ecofriendly dyestuffs can readily be substituted for them. Shetty and Samson[28] describe the production of silk without the need for traditional mulberry leaves, an obscure craft of tribal and hill peoples up to the time of writing, but suggest it as a potentially important commercial crop.

Problems shared by all types of silk are brought to light in the literature. The first of these is the need to control reeling in automatic processing, a need that Hu and Suzhou[29] discuss in some detail. Second is the importance of understanding the effects of cocoon shape or quality on filament uniformity, a topic reviewed by Singh *et al.*[30] Maribashetty and two colleagues[31] analyse why silkworms fail to produce satisfactory cocoons, dividing them into pathological, physiological, environmental and genetic reasons. They discuss abnormal development in the silk gland, spinneret and nerve malfunctions, and hormonal or disease causes, noting that control of both temperature and relative humidity is critical during the larval period.

Cultivated silk, in addition, needs other special conditions. Selected mulberry trees are grown to act as homes for the silkworms and their leaves are hand picked daily. The trees, like cotton plants, require fertiliser and pesticide applications, though they tend to have lesser demands than cotton plants. They also have to be selected carefully, as the silk quality is highly dependent on the diet fed to the worms. One major problem that has emerged is the need to protect them from poisoning; Patil[32] outlines the sources of contamination of mulberry leaves, describing the symptoms of poisoning ***(* A-2, L-2)*** by agricultural fertilisers, tobacco, factory exhaust gases and biopesticides, with a list of precautions to be taken in order to minimise the effects of these modern toxins. Thus, the carefully controlled conditions needed for silkworms to work their ‘miracles’ are environmentally expensive to maintain. Establishing the perfect atmosphere for the grubs needs a supply of clean air, apparatus to heat or cool to the correct conditions and power to operate the entire system. Extraction of the fibres by steaming to kill the silk chrysalis requires steam. The unwinding step depends on sensitive machines that are designed not to break the fragile threads. The cleaning process, necessary to prevent the newly wound threads from sticking to each other, uses hot water (often with detergents) to remove the silk from the gum, and the waste liquor is usually discarded to the ground water, acting as a pollutant ***(* W-3)*** once more. All of these components of the production process are environmentally costly.

Silk, however, is not the only animal fibre grown directly or indirectly from insects; spiders can also produce a similar filament, though their ability has not yet been adopted with any commercial success because of the difficulty of unwinding the thread without breakage. However, there is one piece of work in this general area that deserves to be mentioned as it may represent the type of future development that can be expected in the industry. Smith[33] notes that genetic engineering has enabled a Canadian company to insert a gene from a spider into the DNA of a goat so that the goat’s milk contains a spider silk protein that can be extracted and made into a filament with extremely high strength. Projected uses include medical sutures, vascular grafts, military and law enforcement protective clothing, structural engineering and packaging.

4.2.4 Wool

Wool is a natural animal fibre of a different kind, made from the inner fine hair of the sheep or goat. Again it is responsible for a new set of constraints. It is often advertised as the ‘perfect’ fibre, as a result of its desirable properties and is indeed at first glance worthy of that compliment. As we shall see later, though, its perfection is considerably reduced when its overall ecological impact is taken into account. Its production nowadays is complicated by a multitude of chemical treatments that add considerably to the environmental cost of achieving a fibre that is satisfactory to fussy modern consumers.

The sheep is, admittedly, a beneficial asset to the planet. Not only does it provide us with the warm fabrics that have kept out cold climates since time immemorial, but it is also a source of meat. Unfortunately, the animals that provide the best wool tend to produce poor quality meat, and vice-versa. Sheep can thrive on marginal land where virtually nothing else will grow; the moorlands of northern England where these hardy beasts make their home have only to be seen in order to appreciate just how useful they actually are in converting scrub grass into vital end products. They also provide manure to fertilise the ground on which they graze or for sale to avid gardeners.

Harvesting the wool consists of shearing the animal on a yearly or twice-yearly (depending on climate) basis. Hand shearing has virtually disappeared today, to be replaced by the use of electric shears. These do not consume a great deal of power, so are not too costly in environmental terms. But perhaps the most significant aspect of sheep growth, from the point of view of this book, is the use of sheep dip, an antiseptic agent, to prevent infection or to remove insects and other pests from the animal’s coat, which (depending on the exact formulation used) may seriously contaminate ***(* W-3)*** water supplies.

4.3 Artificial fibre production

The discussion so far of types of production has given a brief overview of most of the natural fibre concerns. However, natural fibres currently represent less than half of world textile production and we must turn our attention to the other major source, artificial fibres. These can be classified into three types, true synthetic polymers, regenerated materials and modified natural ones. Production figures for synthetic fibres during the year 2000 were quoted at 31.3 million tonnes,[34] a figure that has been more or less constant in recent years; this should be compared with the world total of about 45 million tonnes if natural fibres are also included[35] to give some indication of the disproportionate amounts of the two types in use nowadays.

In the first two classes of artificial fibre types, the true synthetics and the regenerated ones, there are three main production techniques, dry (or solvent) spinning, melt spinning and wet spinning, details of each of them being found in standard books of textile technology. All of these have an impact on the planet that can be appreciated readily by an examination of what happens in each case. Before we look at these processes, though, we should consider the way in which a polymer is created.

4.3.1 Polymer preparation

The usual, almost exclusive, source of raw material for polymer preparation is oil. As mentioned in Chapter 3, the extraction of this raw material is environmentally very costly and the production of polymers from it is not much less so. The oil is first ‘cracked’ (separated into various segments of a limited small range of molecular weights), usually with the aid of specific gravity or boiling point as indicator. The appropriate segment for making polymers is then converted into a form able to produce the starting material for the polymerisation step. This involves a chemical reaction between two precursors, often with heat, to produce a white solid that is then chopped up into chips for convenience in handling. The entire operation, as can readily be envisaged, uses large amounts of energy, produces waste in the form of gas, liquid or solid by-products ***(* A-2, W-3, L-2)***, and may often be quite a messy activity for the people engaged in it. Thus, the actual acquisition of the precursor for polymer manufacture is environmentally costly before any further processing is carried out. The chips that emerge are relatively clean and easy to handle, however, and can readily be passed on to the next stage, the actual fibre production step.

4.3.2 Dry spinning

In dry spinning, a solution of the polymer in a suitable solvent is extruded, or forced, through a spinneret, a disc containing many fine holes through which the jet of polymeric liquid passes. The result is a set of multiple strands of filament, which are then drawn to strengthen them by means of a godet, a device exerting a force of traction on them. As the solution emerges from the spinneret and falls away from the solidification zone under the influence of gravity and the tension exerted by the godet, a stream of heated air is allowed to flow upwards around the newly formed filaments. This warm air increases the rate of evaporation of the solvent, ensuring that the filaments are stable enough to be drawn without breaking. The evaporated solvent is drawn upwards by the air stream, for collection and recycling. A paper[36] describing the production of acetate from wood indicates that better absorbency and a closer approximation to the properties of silk can be achieved in this way; the paper describes in detail many aspects of the machinery needed and summarises the properties that are inherent in the fibres.

Apart from the usual concerns regarding energy and complex equipment, there is an obvious pollution problem inherent in this method of production. No matter how carefully the operator may adjust the rate of air flow, it will be almost impossible to contain all the evaporated solvent within the system. In order to allow the filaments to pass down to the godet, there must be an exit aperture. If it is big enough to allow a solid filament to pass, then it will not prevent a gas from escaping. Even if the rate of input of air is very high, diffusion will ensure that not all the solvent vapour is swept along by the air stream. In the limit, the rate of flow of air needed to attempt to control vapour loss would have to be so great that the filaments would be blasted out of existence before they even reached the exit from the enclosed space, thus defeating the entire object of the technique. As solvents consist of harmful vapours from chemical agents such as acetone ***(* A-2)***, there is clearly a need for concern regarding the safety of the nearby workers, as well as that of the ambient surroundings in general.

4.3.3 Wet spinning

In wet spinning, used most often in conjunction with regenerated fibres, a chemical reaction is carried out on the starting material to create a solution viscous enough to allow it to be extruded without disintegrating on leaving the spinneret. Immediately after extrusion, a second chemical reaction is carried out on the emerging liquid to convert it into a solid that can be drawn, as before, to form the polymeric filament. In this system, the presence of the chemicals, which may include acids, alkalis, reducing or oxidising agents and bleaches, may well pose a threat ***(* W-3)*** to environmental safety. In addition, the initial chemical reaction is likely to be a source of toxic or otherwise harmful agents ***(* A-2)***. All these chemical compounds need to be manufactured, again at ecological cost in terms of equipment, energy, raw material extraction and the various other cumulative factors encountered earlier.

4.3.4 Melt spinning

Melt spinning, the final spinning method to be considered here, uses heat to melt the polymer, extrudes the resulting liquid through a spinneret, then immediately cools it to a solid form by means of a stream of cold air. Because the melting point of most polymers is not too far below the decomposition temperature, great care must be taken to avoid overheating the material. As these polymers are almost invariably poor thermal conductors, it is a difficult task to arrange for uniform melting to take place at a reasonable rate, without finding a mixture of still-solid chunks and blackened waste product in the apparatus. The risk is compounded if the rate of extrusion is not exactly right, since the polymer will then spend too long or short a time in the heating chamber, and may well clog the spinneret if production is halted to adjust anything. A further difficulty that may subsequently be encountered, applicable to all three of these production methods, is the need to dispose of a large quantity of waste if a careless operator makes a mistake and ends up with a mound of nasty stuff that cannot be used for anything.

4.4 Alternative fibre sources

One development is the idea of using alternative sources for the starting point of manufacture instead of oil. An anonymous author[37] describes the production of polylactic acid, a fibre that has the advantage (unlike virtually all other synthetic ones) of being biodegradable. This matter of biodegradability is extremely important, as will be discussed shortly, and the capacity to exhibit such a property has inspired other fibre research workers. Another anonymous writer[38] suggests using a blend of natural cellulosic and thermoplastic polymers to yield a new fibre that can be blended with cotton, while a second paper[39] in the same vein claims that a biodegradable polyester can be produced as a block copolymer with other units to give a material that can be used for most practical purposes. In both cases, though, the examples listed do not seem to belong to the type of compound that disappears into the Earth without trace. The usual problems with synthetic fibres that are supposedly biodegradable is that, when they break into tiny pieces, toxins resulting from their breakdown remain in the soil contaminating the surrounding land and hence water ***(* L-2)***. Better 'biodegradability' usually implies a faster rate of disintegration, but the increased surface area thus produced increases the rate of release of toxins and so makes the presence of these materials even more undesirable. The act of trying to recycle polyester, to be mentioned later, is suggested as an environmental cure, with a note that the efforts to carry out this type of operation for producing fibres are increasing rapidly.

4.5 Inorganic fibres

Another type of fibre that is becoming more important is in the inorganic category. Fibres of this type are produced from materials that are present in the Earth's crust (or can easily be made from naturally occurring materials there) and that are inorganic rather than polymeric. Examples currently being used or considered as sources of fibre include glass, metals, carbon, asbestos and ceramics.

4.5.1 Glass fibres

Glass, existing in a wide range of types for various end uses, is usually made by melting silica (the material of which sand is constituted) at very high temperatures and adding to the melt the necessary materials (oxides of various metals, etc., that impart the desired characteristics to the glass) before extruding the molten glass through a spinneret. Uses of the material are summarised by an anonymous author[40] together with a description of the special machinery needs and mechanical properties. High temperatures always incur large energy costs. The extraction of the metal oxides from the ores in which they are present in the ground (plus their purification) is a matter for concern regarding the use of energy, the need for heavy extraction or refining equipment and the production of large quantities of pollution

(* L-2). The process itself is obviously environmentally expensive and the slag heaps remaining after the metal oxides have been extracted can leave scars ***(* V-1)*** on the surface of the Earth that may take years to be assimilated back to provide any semblance of a harmonious landscape. The same factors also have to be taken into account in the production of metal fibres, since ores are essential as their starting materials. In addition, problems can be more serious, because their purification is usually more difficult than that of the oxide. Metals, too, need high temperature manipulation by complex heavy machinery that is environmentally difficult both to make and to operate.

4.5.2 Basalt fibres

Basalt fibres made from rock solidified from volcanic lava are suggested by one author[41] as an alternative to glass. Until recently, they were used solely in the form of basalt 'wool' for thermal insulation purposes, but the article describes new technology for making them into filaments. In comparison with glass, they are more stable to strong alkali, but less resistant to strong acids and can be used in the temperature range of – 200 to + 800°C. The filaments produced are apparently even enough to be used in normal textile structures. One suggested application is as sewing threads for fabrics exposed to high temperatures or adverse chemical environments. Thus, the ecological expense of producing these fibres, stemming mainly from the high temperatures needed in their production, is partly offset by their ability to resist heat, imparting a more extended existence in thermally degrading situations.

4.5.3 Carbon fibres

The use of carbon fibres has only become widespread over the past couple of decades or so, but their growth has been rapid since their inception. Gurudett[42] traces the development of a type of recently produced, activated carbon fibres, summarising their advantages over earlier ones and lists applications that depend in many instances on an improved adsorptive ability. Again, the complex series of processes and the inert atmospheres needed for carbon fibre production tend to make them expensive from the environmental standpoint.

4.5.4 Ceramic fibres

Ceramics are the latest in a series of new materials earmarked for use as fibres. Many of them are oxides, with the same properties and drawbacks as mentioned above, but they usually have a very high melting temperature, which increases the difficulty of manufacture and hence the ecological impact. Others are chemically more complex, requiring difficult techniques of manufacture that are again unlikely to improve the Earth's chances of recovery from their impact if production becomes as commonplace as is generally predicted by their proponents. A typical modern ceramic is silicon carbide, produced in one case[43] by melt spinning of chlorine-containing polysilanes under an argon atmosphere, followed by cross-linking with ammonia as a curing agent, then subjecting this precursor to pyrolysis. This produces an Si–N–C system, with properties which the authors compare with those of the simpler Si–C fibre system. A second method of production[44] involves infiltrating liquid silicon into carbonised wood at 800 to 1800°C. At 1600°C, rapid liquid infiltration occurs and the resulting ceramic fibre takes on the pore structure of the original wood, so that different properties are obtained when different types of wood are used as starting materials.

From the descriptions of these two processes, it is clear that silicon carbide is an environmentally expensive fibre to produce. Apart from the high temperatures required, the need to produce polysilanes or silicon demands complex chemical reactions that place a huge demand on the planet's capacity to recover from environmental stress, as also does the establishment of an inert gas atmosphere. Indeed, all these new fibres are ecologically very damaging in comparison with the more traditional ones. Their production is deemed to be necessary because of their highly unusual properties, such as heat resistance or their inert nature, which find invaluable applications in satisfying the demands of the space industry or the military that could not be met in any other way. Once again, it seems that the environment is being sacrificed to meet a need that would not be regarded in many quarters as strictly essential.

4.5.5 Asbestos fibres

The fourth example of modified natural fibres, asbestos, has a special place in the environmental debate. Long regarded as a wonder material for its good thermal and electrical insulation abilities, it has been recognised as a dangerous substance because of its tendency to cause lung cancer ***(* L-3)***. It differs from the other materials in this group in that it does not need any heat or chemical reactions to produce it, merely a sequence of crushing and cleaning operations after it is dug out from the ground. At first sight, then, it would appear to be a desirable product, apart from its carcinogenic nature. Nevertheless, the equipment needed for these purposes is heavy, so that its use, even without its inherent danger, should not be regarded as wholly desirable. In 1999,[45] acrylic sulphide was touted as a replacement for asbestos, because it is tough, resistant to alkalis, non-flammable and has high tenacity. It can thus be used as a filter medium for hot gases, as a reinforcing medium for concrete and in other applications where asbestos has been considered to be the only suitable material, as in firefighters' uniforms, foundry clothing and similar protective garments.

4.6 Microbiologically stable fibres

One direction in which research is making progress is in the attempt to produce fibres that are resistant to microbiological agents, thus prolonging their life and benefiting the planet. Jou and Liaw[46] set down the conditions for a successful fibre of this type, pointing out that it should be non-toxic, non-allergenic, durable and non-carcinogenic and, if the antibacterial action is effective, it should reduce odour to make a safe, comfortable and healthy garment. Takeda[47] claims to have developed such a fibre, with the incorporation of a tetravalent metal phosphate (such as titanium or zirconium), a divalent hydroxide (usually of copper or zinc) and a photo-semiconductor like titanium dioxide. Service[48,49] describes Amicor, another new material based on an acrylic fibre, with the same type of behaviour, noting that the antimicrobiological agent can resist a wide range of bacteria, fungi and larger pests, such as dust mites, because it is incorporated into the matrix and can migrate from there to the surface to replace any agent lost by abrasion, weathering, and so forth during use. Stevenato and Tedesco[50] make use of a new organic substrate with very fine particle size to provide effective antimicrobial activity without affecting fibre properties adversely. Rhovyl[51] add an acaricidal (mite- and tick-destroying) agent to their fibre before extrusion to give long-term action in a fabric that not only destroys dust mites but also prevents subsequent reinfestation. Ward[52] also suggests the premanufacturing insertion of an agent for mattresses and other bedding products.

4.7 Effects on the planet

Despite these attempts to increase longevity and safety, however, fibre production of any type is likely to be harmful to the planet in the long term. Costs of producing the fibres must include costs of making the chemical agents or precursors that are needed for growing or manufacturing them, costs of the chemical activity necessary for their production and costs of their handling or transportation around or away from the plant where they are made. These auxiliary costs are seldom, if ever, recognised, yet they exert a considerable influence on the planet that cannot be ignored in any comprehensive consideration of its long-term survival prospects.

After the fibres are produced, of course, their adverse influence on the planet does not magically cease. There are still ecological costs that have to be paid. The next two chapters will consider what happens when they are made into further textile products in the form of yarns or fabrics.

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