9

Environmental protection

Now that we have examined the way in which textile production and use can harm our planet, it is time to look at the steps we are taking as a society to minimise that harm. In this chapter, we will look at the ways in which governments attempt to compensate for the damage caused within their jurisdiction, how successful they are and how we can evaluate their success (or lack of success) in stopping environmental damage. We should not forget that other industries, besides the textile one, are guilty of causing the same pressures on planetary health, but this book must concentrate on how textile manufacturers and ourselves, as textile consumers, should be judged. In particular, what steps are being taken by the industry to minimise the onslaught that textile production makes on the health of the planet and how effective are these steps?

9.1 Commitment

The most critical point is a distinct lack of commitment on the part of many governments to do anything but pay lip service to the environmental lobby. There are plenty of examples to support this admittedly pessimistic viewpoint. The most recent one, at the time of writing, is the refusal of the USA to ratify the Kyoto Accord, on the grounds that it is likely to be ineffective. It seems to the author that any move towards restricting toxic emissions, even if ineffective, is better than agreeing to permit virtually unlimited pollution by industry to continue unabated, presumably because curbing the polluting activities would be economically harmful. The Earth Summit in Rio de Janeiro in 1992, too, is looking more and more like a waste of time as the years pass by without any tangible action on its recommendations. The ready availability of weapons of destruction to both sides in a war, as long as there is money to pay for them, also appears to reflect a somewhat cynical attitude to preserving our planet unharmed. So does the willingness to ship oil to every part of the globe without much long-term concern whether a tanker is wrecked and spews its polluting cargo over pristine beaches. Environmentalists are regarded as antisocial creatures determined on a course of action intended to wreck the economy, rather than as conscientious citizens trying to save their planet. The time has surely come for governments to be more responsible in investing for the future welfare of the Earth, rather than in trying to maintain high living standards for a favoured few citizens.

9.2 Protective applications

There are many published references in the area of environmental protection in the textile context, including some general ones dealing with the need for the industry to attack pollution problems. Germany establishes regulations[1] to limit or eliminate environmental and health hazards for textile and leather processing industries. Japanese textile firms[2] emphasise harmony with the environment, mentioning, for example, the possibility (well known for many years in the West) of recycling used clothing. They also introduce industrial consumers to the ideas of producing environmentally friendly products, saving energy and reducing water pollution. Orzada[3] carries out a survey to discover the degree of development of environmental responsibility regarding products and processes in the USA apparel industry, looking at types of environmentally friendly products, environmental policies, fabric waste disposal and reduced packaging waste. Cunho *et al.*[4] carry out research relevant to environmental aspects of textile materials, such as the impact of some environmental parameters on fibre properties and the evaluation of products on the basis of their environmental safety. Muirhead[5] considers the development of environmental awareness, touching on emission controls, water charges, landfill tax and packaging regulations as opportunities to increase profits and reduce costs.

9.2.1 Ecologically beneficial practices

Benisek[6] reports on a conference in which ecologically beneficial practices are one of the major areas of focus and on a later one[7] with a strong emphasis on the ‘green’ future of textiles, including replacement of harmful catalysts or other reagents and improved dyeing or finishing conditions. Smith[8] discusses the greening of the textile supply chain, noting that cleaner products and better waste management are essential. Gale *et al.*[9] produce a regular column dealing with environmental matters and include in this particular one reports or suggestions such as (a) water pollution should be limited by water quality, not individual discharges, (b) some new dyes and pigments may change in classification regarding toxicity and (c) benign chemicals (in a wet processing stage, with special procedures to prevent dimensional changes in fabrics) are being sought as an alternative to perchloroethylene in dry cleaning. In another general review article of environmental issues, Gale and Bide[10] report a recommendation to limit the ammonia content in effluent ***(* W-3)*** (see Table 1.1 for an explanation of codes) with reference to early life stages of fish. They mention, too, concerns about tributylin as an antibacterial agent that, even though it is not supposed to be used because of its hazard to health, has nevertheless been found on certain football shirts that have now been withdrawn from the market; it is entirely possible that other examples of this kind of irresponsible manufacturing may exist. In the same article, the authors also summarise work dealing with dye decolourisation with oxides of zinc or titanium, or with hydrogen peroxide in conjunction with ultraviolet radiation, then discuss the aerobic treatment of dye waste water. The same two authors, in yet a further article,[11] record the move towards replacing regulatory control of pollution with voluntary responsibility based on incentive, an apparently dangerous precedent in view of the tendency of many manufacturers to ignore environmental concerns totally until forced to take them into account. They also note revived interest in low-wet-pick up techniques in dyeing (such as the use of foams) to reduce the amount of water needing to be removed in drying, so decreasing costs. The recycling of water, they feel, is becoming more attractive as disposal costs rise and they mention water-saving techniques such as filtration and the use of membrane, biological or ozonation procedures, as well as a new method to allow recycling of solvents by low-pressure steam. Barton[12] examines the rise of the 'organics' market, especially as it pertains to textiles. She discusses the establishment of units to influence development and marketing of the technology in an effort to achieve sustainable solutions. However, she notes that banned compounds can still be found in clothing, possibly lowering safety levels. As a kind of compensation, she then reports a new initiative to produce organic textiles for clothing and household uses at prices comparable to those of standard (i.e. non-organic) goods.

9.3 Legislation

It is true that some legislation to reduce planetary harm exists. Arias[13] describes the criteria that a manufacturer must meet in order to use the European Union's ecolabel. There are 34 separate standards to be considered, relevant for all types of fibres, processes, chemical products and suitability for end use. The objective of the programme is to reduce air and water pollution and increase both human health and public awareness of the problems existing, as well as lowering water and energy consumption. McCarthy and Burdett[14] introduce details of an ecolabelling production chain, discussing the effluent issue. They describe product disposal and review label types, including in their article a consideration of the relevance of the labelling regulations to the textile industry and the benefits of environmental awareness. Achwal[15] feels that the ecolabel guarantees environmentally friendly production. He discusses background use and criteria for its adoption and provides a list of banned azo and carcinogenic dyes, plus a list of permissible limits of other harmful chemicals, with each process hazard criterion identified. McKenzie[16] warns of the dangers of assuming that natural fibres are less environmentally harmful than synthetic ones.To support her contention, she provides a comparative analysis of the ecologically relevant steps in the production of natural, regenerated and synthetic fibres. In a later paper,[17] she observes that, although the demand for organic cotton has grown recently, consumers are not prepared to pay higher prices for the benefits of environmental conservation. She also notes[18] that ecofashion costs more until mass production output is attained, but there can be no mass production until demand rises, which will only happen when cost decreases. Consumer education is needed, but she remains adamant in her conviction that natural fibres cannot automatically be assumed to be inherently ecologically friendly.

Elsasser *et al.*,[19] in a paper dedicated to clear processing in the recycling of textile waste, include many legal aspects of shredded fibre use. European Union directives on integrated pollution prevention and control are reviewed by Shaw,[20] who also provides a prediction of the effects they might have on wet processes in wool production.

9.4 Future prospects

Future prospects in an age of environmental concern are also considered by Dixit,[21] who feels that there may be a risk of some companies being closed because of an inability to meet the ecological challenge. He emphasises the need for safer and better treatments for reducing pollution to satisfy the newly emerging regulations. Shaver[22] stresses the need for companies to enhance their management of environmental responsibilities because of the projected increase in costs and liabilities. He recommends an environmental management system as a cost-effective way to establish level of commitment, developing plans, programmes, or controls and correcting problems. By its adoption, he feels, the environmental effects of production will become obvious and a reduction in costs will be accompanied by a gain in recognition for the company.

9.5 Financial benefits

Financial benefits of ecological responsibility are also predicted by several other workers. Battersby[23] suggests that the expenditures for environmental protection may be of great advantage to a company, because they can give major tax deductions, a nice surprise at the fiscal year end. More tangible benefits are reported by Moore *et al.*[24] who find that environmentally driven action can actually improve production and that more than three-quarters of the companies they investigated made changes to their production techniques with environmental conservation in mind, often surpassing government regulations. Wakeling[25] suggests that water recycling, currently regarded as a burden by manufacturers trying to meet environmental standards, can be an opportunity for saving money. He calculates that annual operating costs for water recycling are about £104 800 (after meeting capital costs of £300 000, but that savings amount to some £248 700, so that capital payback time is only 25 months, a period that should be regarded as better than merely acceptable. Hohn[26] outlines ecological and environmental methods for waste water treatment, comparing and contrasting several techniques, and finds that the most ecologically beneficial one is also the most profitable. An anonymous author[27] describes a new energy-saving stenter capable of reducing consumption by about 20% as a result of using a redesigned chamber and preheating incoming air with heat recovered from exhaust gases in a manner that also cuts emissions significantly.

9.6 Costs

There are, though, costs that cannot be ignored. Russell[28] discusses the proposed EU tax on energy consumed, noting that textile producers will be heavily penalised in comparison with those from other industries because the processes are energy intensive, so the industry is likely to suffer high increases of up to 15% in fuel costs. Phillips[29] brings to light a little-known source of both environmental and financial cost in the form of steam traps. Failure of one of these can involve a loss of about US $2000 and, with 100 to 200 in use in a typical textile plant, with a failure rate that often reaches 20%, total annual cost can approach $80 000. He advises manufacturers to select steam traps carefully, paying special attention to their suitability for the purpose intended, the condensate loads that each one is expected to sustain, any relevant safety factors and the differential pressure under which they will operate in comparison with their maximum allowable pressure.

9.7 Drawbacks

Despite all the regulations and the interest in them, however, it is my belief that they can never be satisfactory in providing environmental protection, simply because they are neither effective nor severe enough. It is true that there are many laws, differing in each jurisdiction, about what can and cannot be done in releasing compounds, or engaging in activities with ecologically undesirable effects, to the environment. These, for instance, usually set quantitative limits for each harmful substance or activity, regarding how much can be tolerated in a specific time period. They include laws about such matters as emission of air or water pollutants, and display of advertisements, signs or other types of visual pollution, as well as specifying the intensity of a sound level that may be released. A particular example of the noise pollution laws is the legislation that limits exposure of workers to ambient noise levels, summarised in Table 5.1 of Chapter 5. All of these laws are excellent in their intention but there are, unfortunately, five drawbacks that make them considerably less than ideally effective in practice. These are the non-uniformity of standards, the lack of enforcement of standards, the relatively insignificant penalties for flouting the law, disagreement on what is considered to be pollution and the lack of quantitative measures applicable to pollution violation assessments.

9.7.1 Variation in standards

The first of these arises from the fact, noted above, that different standards are adopted in different areas. It is not too long ago, for instance, that North American textile producers were shipping goods to Mexico or south-east Asia, where laws were much more lax, to have finishing carried out there that would have been illegal in their own countries. The finished goods were then returned to the original manufacturer to be sold as 'domestically-produced'. It is true that some authorities are trying to improve the situation; the example given above is no longer applicable, mainly because the changes in laws in the former 'dumping' countries make it economically not worthwhile to pay the transportation costs involved, even though the standards there are still lower than in the host countries. Legislators are slowly responding to pressure from constituents to enact laws that enhance ecological responsibility, but changes tend to be of the 'too little, too late' variety.

The attitude of many otherwise responsible scientists, who discuss endlessly whether the Earth is actually suffering from the presence of human activities, or whether the disturbances we observe are merely the result of natural climate cycles, is not helpful. What is clear (but often ignored) is that, even if the cyclic explanation is the true one, our behaviour will add to, rather than reduce, the ecological burden placed on the planet.

The example of air pollution is probably the best known and several workers are active in carrying out research to improve the situation in an effort to meet more and more stringent laws. Baker *et al.*[30] summarise air quality research in relation to cotton production, with special reference to ginning, discussing the removal of trash and potential means of improving the situation by the use of preseparators, modifications and improvements to equipment or procedures before emission to the atmosphere in the cyclone method. Rey[31] provides guidelines on the technology available for controlling smoke and odours from textile finishing. Holme[32] recommends a three-faceted method (considering emissions, efficiency and economy) for pollution reduction or prevention. In it, he looks at processes, identifies potential for improvement and assesses the effects (in comparison with other techniques), finding that cost reduction, lower emission and higher efficiency can result.

The main objection to these lines of approach is that they are applied unevenly in specific regions. Smoke stacks still pour out noxious fumes, but the traditional solution that is still tolerated has always been to build the stack higher to allow the toxic effluent gases to be discarded further into the atmosphere and thus become dissipated. Legislation tends to accept this compromise, yet it is not an effective means of lowering pollution, as is becoming more and more obvious, as the number of stacks and the amount of gas discharged from them increase steadily. Air pollution is not localised; harmful gases are carried by wind or air currents to other regions and, eventually, to all parts of the world. Thus, a toxic reagent released into the air in one country can eventually bring harm to people in other locations. The most familiar instance of this kind is perhaps the Chernobyl disaster, in which a nuclear power station released harmful radiation into the air in the Ukraine; animals as far west as Great Britain were subsequently deemed unfit for consumption because they had ingested radioactive airborne particles.

There are many other, less famous, examples of this kind of global dissipation of environmentally dangerous substances. Dioxins and furans, arguably the most toxic types of chemical known because they can bring about poisoning or adverse genetic mutations in extremely small concentrations, can be emitted ***(* W-3)*** from textile finishing treatments. Their discharge is, in theory, strictly forbidden in most developed countries, yet there are frequent reports in these very countries of their appearance in waste streams; it is cheaper to discard them, as long as the source of this crime is not detected, than to deal with them effectively and responsibly, simply because their destruction is, technically speaking, relatively difficult and hence costly. Sedlak *et al.*[33] find that they arise mainly after treatment has been carried out, forming in chimney depositions. Carroll et al,[34] on the other hand, estimate that textile treatments involving chlorinated organic compounds (the most important source of these toxins) only account for about 1% of the total dioxin and furan emissions in the USA. The industry, then, is by no means the only or even major culprit in this dangerous activity.

Notwithstanding this assurance, the emission of any compound as harmful as these is undesirable and the lesson to be learnt from such comments is a simple one. Because emissions may not be different in different regions of the earth, standards of safety or of environmental protection need to be harmonised over the entire planet if they are to be effective. If there is a difference, then unscrupulous manufacturers will merely move their ‘dirty’ production activities to a part of the world where standards are less severe, if they can take advantage of the lax laws there by so doing, and will thus continue to pollute the planet excessively rather than clean up their production methods. The lower standards may arise because a country is eager to attract manufacturers to its territory and will offer greater latitude in environmental standards for the sake of financial gain, but the net effect on the planet is an adverse one that will harm the original country of the manufacturer in two ways; first, in the economic loss of the production and second because the pollution may eventually reach that region of the Earth anyway. As this pollution has the potential to be far greater because of the lax laws, the entire planet clearly suffers as a direct result of the differing standards in different locations.

9.7.2 Lack of enforcement

The second problem is the lack of enforcement of standards even where they exist. There are several underlying reasons for this failure. First, there may be too few inspectors to carry out an effective policing operation, usually as a result of shortage of money. A manufacturer can pollute for a considerable period of time before there is any risk of being caught and, if the visit of an inspector is predictable, can take steps to ensure that laws are not being broken on the specific day when an inspection takes place. This lack of funding can only be rectified if society accepts that environmental protection is a vital feature of its continued healthy existence and applies pressure to its government to reflect this fact in providing adequate monitoring of potentially polluting activities.

Lack of enforcement, however, can arise from other causes. The manufacturer may be part of a political lobby that threatens withdrawal of essential support if a government is too diligent in providing ecological protection, or there may be a system of 'financial encouragement' in operation that convinces inspectors to turn a blind eye to contraventions of the law. There may also be conflicts of interest, where the manufacturer's activities are profitable for specific legislators, who thus have no wish to curb the harmful proceedings and can persuade their colleagues to agree with or accept their own lenient judgement. For all of these reasons, the planet will suffer if enforcement is neglected.

9.7.3 Penalties

Even where enforcement is evident, though, there is still another reason why planetary damage continues to take place. In many cases, the penalty applied for flouting pollution laws is a relatively minor one that amounts to little more than a slap on the wrist. If manufacturers know that, even after being prosecuted successfully, they will only be assessed with a small financial penalty, they will continue to pollute and pay the insignificant fine on a regular basis. If the frequency of conviction is low, the fines can be written off as a business expense to be added to production costs and passed on to the end purchaser of the goods.

9.7.4 Non-standard definitions

A further problem is the lack of agreement on what should actually be classed as illegal pollution. In most Western nations, heavy emissions ***(* A-1, A-2, A-3)*** from motor vehicles or from factories are regarded as unacceptable. The owner of the offending source of pollution is fined or, in the limit, forced to cease operation of the vehicle or plant. At the same time, the authorities in many countries of Eastern Europe, Africa, South America or Asia exhibit a total disregard for this type of source of harmful chemicals. Some cities in these developing nations are almost invariably shrouded in a toxic layer of fumes that would close down an entire municipality in the less tolerant countries. The excuse usually offered is that such nations are still catching up with their Western trade competitors and will not be able to afford the extra cost of dealing with the problem until their economies are considerably stronger.

9.7.5 Emissions

Emissions to water are the most obvious example of harmful substances released into the environment during textile production. Their importance can best be judged by the amount of work focused on this particular subject. A report[35] confirms that textile mill effluents that are waste water discharges from wet processing such as scouring, neutralising, desizing, mercerising, carbonising, fulling, bleaching, dyeing and printing are indeed toxic ***(* W-2, W-3)*** and are likely to have immediate or long-term harmful effects on the environment. As a consequence of publication of this report, mills will face tighter effluent control regulations in Canada. Bradbury *et al.*[36] suggest that 'smart rinsing' with careful attention to the location of inlet and outflow water in kier (a type of vat) dyeing can reduce rinsing times and provide more effective use of waste. Care in the selection of volume, flow rates and temperature is also needed. Reife and Freeman[37] summarise the possibilities of pollution prevention by waste minimisation and source reduction in producing dyes or pigments. They include process optimisation, the substitution of toxic metals by less harmful ones and the replacement of toxic inorganic pigments containing calcium, lead, nickel or copper by other substances, then recommend the reuse of pollutants (such as aniline or phenols). Included in their article are comments regarding energy saving, safety and recycling opportunities that take advantage of reverse osmosis, ultrafiltration or hyperfiltration to produce reusable water.

Other research papers tend to fall into one of two categories, the majority dealing with purification before release into streams or rivers and others in which the water is purified for reuse in processing operations. Frangi[38] includes both areas from the viewpoint of environmental health and economics, noting four separate factors (management of reserves, quality of cleanliness for textile use, industrial treatment techniques and purification of waste) in the context of European Union regulations and the specific needs of particular processes. Peralta-Zamora *et al.*[39] feel that extensive use of organic dyes is the main cause of textile environmental problems because they are recalcitrant carcinogenic ***(* W-2, W-3)*** materials. They study three processes for degradation of an anthraquinone dye: ozonation, enzyme and photocatalytic degradation with oxide of zinc or titanium. Ozone use produces complete decolourisation quickly, but no mineralisation; enzyme treatment gives quick decolourisation, but is limited to about 30% mineralisation. Photocatalysis produces complete decolourisation and mineralisation in about 60 minutes. Alho[40] describes seven steps that can improve colour control in dyeing, thus avoiding unnecessary retreatments or premature discarding of goods. Holme[41] suggests decreasing emissions at source by process optimisation. Kearns[42] feels that tighter effluent controls must be adopted, while Porter[43] recommends process automation as the key to waste water recycling and conservation of water and energy.

Purification before discharge is attempted (often with only partial success) by using mechanical, chemical or biological treatments, alone or in combination.

Bischefberger *et al.*[44] provide an overview of the possibilities of waste treatment, avoidance and utilisation. Perhaps the simplest techniques for purifying effluents are represented by the work of Canziani and Bonono,[45] who merely use a sand filter to achieve decolourisation, filtering and denitrification of dye effluent and work by Ibrahim *et al.*,[46] who use a composite made from cross-linked wood sawdust for the same purpose. Papić *et al.*[47] use a coagulation/flocculation process to treat reactive dye waste water with ferric chloride as coagulant. They observe colour removal greater than 99.5% and determine that there is an optimum pH, in each case, which depends on the amount of coagulant added and the type of dye, but is within the range pH 2.55 to 2.70 for the conditions used in their test. Gonçalves *et al.*[48] remove colour from waste by using an upflow anaerobic sludge blanket reactor, commenting that some azo dyes are readily reduced (with an average removal efficiency of 80 to 90%) but that the technique is ineffective for disperse dyes. Baughman[49,50] finds that 91% of the copper ions from 12 direct dyes are removed from solution in 4 hours by sorption on a suitable sludge. Slater and Barclay[51] investigate the possibility of using inorganic clays with other materials to absorb dyestuffs and other environmentally harmful substances from dye discharge liquors before discharge. They test 20 to 30 combinations and establish removal efficiencies from very low to over 90%. Although such chemical and biological techniques are relatively more common, there are, nevertheless, also a few miscellaneous instances of attempts to remove pollutants before discharge. All of these are described in Section 9 of the Appendix.

Air emissions should also be mentioned briefly. These can arise from many segments of the industry and are dealt with to some extent elsewhere in this book, but their removal is often attempted before discharge to air or water takes place. One author[52] describes an exhaust clearing system that provides recovery of waste process heat, reducing the need for fuel and hence lowering production costs. Another anonymous author[53] reviews the needs for a satisfactory air cleaning installation for use in filtration, waste handling and air conditioning requirements. Freiberg[54] notes that, until recently, it was impossible to operate air cleaning systems efficiently because they suffered either from external high energy consumption, or from high water consumption, or from considerable maintenance needs. He claims that it is now possible to operate modern cleaners efficiently and at lower costs, because they include an option to omit exhaust air cleaning where it is not needed. He then describes three types of successful cleaners.

9.8 Recycling

A contemporary preference in many industries is to try to minimise resource depletion and pollution production as much as possible by reusing or recycling materials. Several efforts in this direction are described in Section 10 of the Appendix. As may be seen there, the matter of recycling can be extended beyond water treatment to all materials used by the industry. Benisek[55] reports a conference in which a separate section is devoted to recycling, emphasising the importance of environmental concerns in textile processing. Papers presented include those dealing with biological treatment of waste water, digestion techniques, neutralisation of alkaline effluents, reduction of mothproofing effluents, spray dyeing and fibre identification.

One of the current aims in the attempts at cutting down pollution is to recycle (or remove from another recycling operation) chemical agents, many of which include compounds that are notoriously difficult for the environment to handle. The recycling of actual fibre or fabric materials is also being regarded as a useful course of action. Kohler *et al.*[56] report that there are 127 000 tonnes of waste generated by the German textile industry annually, then deal with the topic of recycling edge strips, or the whole article, from quilted goods. Raje and Rekha[57] review work carried out on the regeneration of silk polymer from waste or otherwise unusable silk fibres, while Diounn and Apodaca[58] even suggest using the internet to arrange for exchanges of cotton waste, thus reducing disposal costs. Polyester seems to be of interest, too, as several papers are devoted to the fibre. One possible reason is the report, publicised by Methner-Opel,[59] that old clothing is to be treated as refuse in proposed German legislation, which means that manufacturers will either be required to 'pay' (meaning pass on to the consumer) the cost of future disposal or establish a returns policy. Roberts[60] also states that second-hand clothing might possibly become designated as waste and laments the potential loss of exports and jobs as well as the overflowing landfills, the absence of cheap clothing for developing nations and the revenues lost by charity shops.

Mannhart[61] gives details of the technology for recycling polyester bottles into filament yarn and Hansler[62] notes that the recycling of polyester containers in Europe increased by over 40% in one particular year. Goynes[63] describes a process of recycling polyester fibres and, after blending them with greige cotton, using them to manufacture non-woven blankets by needle-punching. Measurements of air permeability, thickness, weight, stiffness, bending and compressive rigidity, tensile strength and flammability are carried out, as also are evaluations of thermal conductivity or transmission, differential thermal analysis and thermogravimetric analysis. The results confirm that the technique can yield a low-cost lightweight blanket with good handle in a heather shade that can be deepened by dyeing if desired. The blend used, of 30% cotton and 70% reprocessed polyester, produces an acceptable cover for military, medical or recreational use on a short-term basis. One report[64] indicates that yarn-dyed fabrics from recycled polyester bottles can be made into uniforms. Biodegradation, also mentioned in the Appendix (Section 9), is currently in the ascendancy as a means of combating pollution. However, the main thrust in the recycling effort currently appears to revolve around the idea of recovering new raw materials from carpets. This is reportedly a big issue;[65] it is obvious why when one considers the magnitude of the problem, because the rate of disposal is reported[66] at four billion pounds (that is, about 1.8 million tonnes) per year in the USA alone. Again, Section 10 of the Appendix should be consulted for further details of research taking place in this topic area.

9.9 Pollution measurement problems

An important reason why environmental efforts may not be as effective as we would like is the fact that the inability to measure pollution accurately may lead to lenient sentences. It is a fundamental tenet of the justice system of most countries that innocence is to be assumed until guilt is proved. If the legislation depends on a quantitative assessment of the amount of pollution produced, and this amount cannot be measured precisely, there is no point in taking an offender to court unless the amount of pollution occurring is so far in excess of the legal limit that there can be no possibility of a mistaken measurement being used as a defence. Thus, pollution that exceeds considerably the amount permitted may well be overlooked, rather than risking losing a case on insubstantial legal grounds.

9.10 Environmental auditing

In an effort to minimise the difficulty mentioned above, the technique of environmental auditing has been developed. The major benefit of this action is that it enables changes that were unexpected to be detected and, once the difference has been explained, it can pinpoint a part of the process where pollution is being produced or undesirable additives are being taken up by the textile goods. An investigation can then be carried out to detect the source of the problem, which can subsequently, it is hoped, be corrected. There are, however, some difficulties that can arise.

9.10.1 Theory

In theory, the environmental audit process measures (by weighing) every component that enters a process and every one that leaves it. Thus, if (say) six raw materials are used to make some type of product, then the weight of all six materials entering is compared with the weight of product obtained. There will, in general, be a difference in the two readings. It represents the occurrence of one or more of several possibilities. If there is a negative difference (i.e. the weight of the product is less than the sum of the weights of the components), then an unexplained loss of material has taken place. This could be accounted for by an evolution of a by-product (an undetected gas, liquid or solid that has escaped the measurement process) resulting possibly from burning of fabric, evaporation of water or a difference in atmospheric conditions at the times the two sets of measurements were taken, or fibrous material that has been lost in the form of fly. If, on the other hand, there is a positive difference (i.e. the weight of the product is greater than the sum of the weights of the components), then an unexplained gain of material has taken place. Possible reasons for this include (as before) a change in measurement ambient conditions, a chemical reaction with the air or with moisture or the accumulation of foreign matter (such as dirt or an adsorbed chemical) on the fibres. Smith and Lee[67] identify trace impurities that can cause pollution, such as fibres, metals, volatile organic compounds (VOC) or toxic organics. The determination of trace impurities is difficult and one important outcome of the work is the evaluation of analytical methods for cotton, wool, polyester, acetate and nylon 6 to determine how effective they are. Kalliala and Nousiainen[68] develop an environmental index model based on life-cycle assessment to determine the total environmental impact for a comparison that includes energy in laundering a range of fabrics. They find that, for instance, 100% cotton needs 20% more energy in laundering than does a 50/50 cotton/polyester blend.

9.10.2 Eco-balances

Schmidtbauer[69] recommends the increased use of eco-balances as a tool for comparing the environmental impact of regenerated polymers, using viscose rayon as an example. He demonstrates its usefulness by tracing the impact of rayon production from beech trunk to fibre, thus achieving a life-cycle balance for rayon from its forest origins to the final product and establishing the ecological aspects of rayon manufacture. He describes special processes to reduce pollution and protect the environment and notes how waste can be converted to valuable secondary materials. In his presentation, he includes a material and energy balance for pulp and viscose production, quotes emission parameters (such as chemical or biological oxygen demand, adsorbable organohalides, sulphur dioxide and hydrogen sulphide emission) and discusses the environmental impact of forestry. He concludes that viscose production is relatively clean in comparison with that of natural or synthetic fibres.

9.10.3 Accuracy

The first drawback of the practical aspects of an environmental audit process concerns the matter of accuracy. The technique demands very precise measurement of the various components to ensure that the materials present in all parts of the process are detected. If an operator fails to note the existence of one type of material, or fails to measure its presence accurately in a quantitative assessment, then an error is introduced that indicates the presence of pollution in the form of lost or acquired mass. Much time can then be wasted in the effort to find this non-existent pollution, adding to the cost of production. It is possible, too, for workers to falsify the results in the belief that management representatives want to hear good news, or may blame the workers for the existence of a large quantity of pollution. The discrepancy may not come to light until an inspector checks the audit figures, finding that unreported defects are in fact present. He is then likely to levy on the company a fine or other penalty that may cost them more than would have been needed to pay for fixing the problem in the first place if they had been made aware of it.

9.10.4 Inevitable pollution

There may also be situations where, no matter how good the audit may be, the detected presence of pollution cannot be rectified. If, for example, a vital process inevitably produces large quantities of an undesirable by-product, the government (or society) may be faced with the choice of either accepting the harmful substance or agreeing not to need the actual product. If the consumer or society stipulates that the product is indeed essential (as in military or space applications, for example), then no amount of auditing or imposition of fines will be able to solve the problem.

9.10.5 Pollution quotas

It is for situations of this kind that the idea of trading or buying pollution quotas has been developed. The principle of this activity is that a company producing less than its permitted quota of pollution can 'sell' the remainder of its unused quota to a company with excessive pollution. The latter company is then allowed to exceed its own pollution quota and is thus paying for the privilege of producing this excess pollution. This arrangement exempts the 'dirty' company from prosecution and enriches the 'cleaner' company, but does little or nothing in the way of helping the environmental overload. One of the worst aspects of this trade is that, as more companies are developed, there is a need for added pollution permits to be issued; we never think of compensating for the extra load by reducing the quotas issued to existing companies to ensure that the overall level of pollution does not increase. The effect on the planet needs no amplification; a sane society would abandon without hesitation this sacrifice of ecological preservation in favour of economic gain.

9.10.6 Vigilance

A further difficulty is the need to maintain constant vigilance on processing to ensure that new problems (or the same ones) do not crop up at a later date. This monitoring tends to be an expensive activity and one in which there is seldom, if ever, any payback to add to the profit side of the books. If detection of a problem leads to a solution that saves money for the manufacturer, then the results are welcome. If, on the other hand, all that is found is a need to remove the pollution (at a cost, naturally) without any financial benefit, then the manufacturer is likely to be much less willing to participate in the altruistic activity of helping to save the planet!

One point that is never made, however, is the fact that the cure for an environmental problem may in fact be environmentally harmful in itself. If, for instance, a specific machine or reagent is needed to remove a pollutant, then the cost of manufacturing that machine or reagent provides an ecological burden that is usually ignored. The result of its use, too, may leave a pollutant of a different kind; absorbing an acid gas in a mill chimney stack by means of scrubbing through a water trap, for instance, leaves an acidic solution to be discharged to the local water system. If an alkaline medium is used to absorb the acid gases, or to neutralise this solution, then a salt is produced, to be deposited on the land. In other words, we are not removing the pollution, but merely changing its form by disguising it, usually to meet some form of restrictive legislation. Thus, because the total effect on the planet is undiminished by this change in form, many of the efforts put forth are ecologically useless. This is true at all stages in the manufacturing process; wherever a problem is 'solved' by any method other than reduction of consumption or production, the 'solution' adopted leaves behind a residue that often creates an ecological nightmare when disposal is attempted.

Another aspect needs to be considered. The fact that a short life expectancy for a textile product can add to the pollution load for which the textile is responsible has been mentioned several times. In the remainder of this book, the ways in which such a reduction in usable life can occur are examined. Once again, environmental factors are of crucial importance.

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10

Effects on textiles of natural exposure

10.1 Influences

If this were a work of science fiction, the remainder of the book would have a title like *The Revenge Of The Planet* to express its focus. Until now, we have seen how the production and use of textiles affect the environment. This section is intended to illustrate the way in which textiles and their production are influenced, in turn, by the environment. The first survey will involve the degradative effects impinging on a textile used under normal circumstances in the natural environment. This will include exposure to air or moisture in the atmosphere, radiation striking the fabric from its surroundings, mechanical stresses and combinations of two or more of these effects.

10.2 Degradation

When a textile product is placed into service, it has a specific set of attributes, designed for its intended end use. From that point on, however, it is subjected to the effects of the ambient conditions under which it is used. In virtually all cases, these conditions bring about adverse changes in the product, a process usually classed under the general term of degradation.

All textiles (and almost all other materials) are victims of this type of change. The normal course of events includes a decrease in properties, which may be gradual or sudden, depending on the circumstances, to make the material less suitable for its intended purpose. This process continues until, after a period of time during which the changes occur sporadically as a result of the continuing presence of the sources of degradation, the material reaches a state of unsuitability at which it can no longer be used at all for that purpose.

There are so many feasible reasons why the changes might occur that it is almost impossible to allocate any specific change to one source of harm. What has to be recognised is the fact that a variety of degradative mechanisms, all operating in conjunction, will always be present in a particular situation and will bring about the loss of properties that results in failure of the textile product. All that can be done is to examine in turn each of the potential sources of harm and establish how its effects are produced, then decide which combination of mechanisms is present in each specific situation and predict what the overall effects of exposure to the combination will be.

We should also not forget that degradation may affect the equipment used to produce the textile product, not merely the product itself. Environmental factors can be harmful to all materials, not just textile ones, and some of those affected may indeed be a part of the production process.

10.2.1 Molecular characterisation

Degradation occurs because of the destruction of a part of the molecule of which the structure is made. In general, the region in which change takes place is governed by the level of energy applied to the structure. If a small amount of energy is absorbed in the molecule, the effect observed will most probably be in the side chains. These may be modified chemically to alter, for instance, the type of end group present in them. The molecular structural consequences may or may not be detected as a loss of a specific property, but there will normally not be too major a change observed. If higher energy levels are encountered by the structure, then the entire side chain in which the end groups are located may be split off from the rest of the molecule, with a more obvious loss of property. Finally, if the impinging energy level is even higher, there may be a scission of the entire main chain, with a massive loss of properties that automatically renders the product useless. The actual level of energy that governs where changes occur and what their magnitude is likely to be will naturally depend on individual circumstances, with an energy level that would bring about total decomposition in one type of molecule causing only minor loss in another, more tightly bonded one.

10.2.2 Time dependence

We have to recognise that textile degradation can take place at many different points in the lifetime of the material. Even during the manufacturing process itself, there may be adverse changes that occur. Once the textile is made, losses in property can be evident merely as a result of storage. It is, though, during use of the product that the most significant changes are brought about, mainly because the textile would be rejected as a failure if too much degradation had resulted from the former two stages (production and storage) of its life. Whenever and wherever degradation happens, it should be stressed that, if a major loss of property occurs prematurely, the product will be discarded prematurely, thus bringing about an early load on the environment, leading squarely back to the same situation of an adverse ecological effect being created once more.

10.3 Atmospheric influences

10.3.1 Oxygen

The first and most obvious source of potential harm is the atmosphere to which a textile product is exposed. There are two crucial components that are always present, air (especially oxygen) and water in the form of moisture vapour. Both are omnipresent and likely to impinge on the textile goods no matter where they are used (unless their function is in a space application). For the textile product to be a successful one, the effects of exposure to atmospheric air should be negligible. If oxygen is going to have any effect at all, it must be by the process of oxidation, in which a change in structure takes place. There are many examples that can be quoted to illustrate the type of reaction that could occur. The change may be one in which an oxygen atom is added to the molecule (e.g. when an aldehyde side chain in a molecule is oxidised to an acidic one) or in which a valency state is changed (e.g. when a ferrous ion in a side chain is converted to a ferric one) or in which a side chain undergoes scission (e.g. when combustion also takes place).

10.3.2 Moisture

Somewhat surprisingly, oxygen at normal concentrations in the atmosphere has virtually no effect on textile products, or on the machinery used for their manufacture as long as moisture is absent. In the presence of water, though, the situation can change drastically. We should accept without question that moisture is almost always present in textile (or other biological) products; the exceptions are those in which the structure is completely hydrophobic, textile examples including such fibres as carbon and polyolefins. For those fibres that are hydrophilic, excess moisture can enter the structure from an atmosphere of high humidity and cause molecular bonds to break open. Even fibres with very low moisture regain can be affected, because moisture can be adsorbed (i.e. held on the surface of the fibres) so that its presence is potentially able to bring about changes.

There are two common types of effect in textiles that can occur as a direct result of moisture in the atmosphere. If relative humidity is high, the added moisture within the structure can cause dimensional changes. Cockling and swelling may take place, adversely affecting the shape of a fabric and rendering its use in making garments or other products limited. Conversely, in conditions of low humidity, some of the natural moisture within the structure may be lost, leading to possible brittleness or cracking of fibres during mechanical handling. Other effects associated with water in non-textile materials, such as loss of water-soluble components or the freeze–thaw phenomenon, can occasionally arise in textile products, but the frequency and importance of these unusual occurrences are so small that it is safe to ignore them in normal use on the Earth's surface. In some applications (protective clothing for space, fire-fighting or marine oil-rig uses, for instance) they may possibly become crucially important and so should not be forgotten completely.

The type of effect that results from atmospheric exposure depends, as always, on the situation. There may be a loss of colour, manifested as fading, or a spoilage of colour as a consequence of the running of dyestuffs not intended for exposure to large quantities of moisture. There may be watermarking of a fabric as a result of salts or other chemical reagents present that are allowed to stain it by the sequential evaporation and rewetting of the textile surface. Weakening of the structure, or swelling to distort a fabric, are also possible consequences.

In textile production machinery, the combined effect of air and moisture can be drastic. Corrosion of metals is one of the most pervasive and troublesome problems that structural or mechanical engineers have to face. The most usual example, the rusting of iron, is a leading cause of forced early scrapping of machinery which then despoils the land. In an effort to prevent corrosion, literally millions of pounds are spent annually in making special materials, such as alloys that can resist the effects of air and moisture, as well as in developing and using protective coatings such as paint, varnish or other agents of surface isolation.

Even before rejection as a result of corrosion is necessary, problems can be encountered. The existence of machine rust can bring about staining on a textile product, staining that may be difficult or impossible to remove; even if the soiling can be eliminated, a considerable cost is added to the goods by the removal process. Corrosion can also bring about dimensional changes as a result of a metal axle or shaft warping and wear on a bearing or other component. This flaw will cause defects to arise in the material being processed, thus bringing about the need to discard or scrap it.

10.3.3 Chemical substances

There are other chemical substances present in the atmosphere in addition to oxygen and water. Nitrogen is the main constituent of air, carbon dioxide is universally present, and there are various gaseous, liquid droplet or particulate impurities derived from human household or industrial sources that can affect materials exposed to them. Nitrogen is an inert gas and has little or no effect on non-reactive materials like textiles. Carbon dioxide and the impurity materials are generally of a type that falls into one or other of the substances to be covered in the remainder of this book (such as acids or solvents), so can be omitted at this stage.

We should not forget the simple matter of dirt present in the air. Grime from industrial air pollution or from coal-burning fires has long been the bane of many a washing day, when clothes are hung out to dry and come into contact with air that is contaminated by tiny particles. These may also gather on the skin near an air/fabric interface, especially where garments come into contact with the body tightly, and produce soiling of the cloth there. Chrobaczek *et al.*[1] note that the interaction between soil and textile depends on many physical and chemical properties. They discuss the processes involved, the various parameters influencing soiling behaviour and the topic of antisoiling finishes, including the classic ones with fluoropolymers, the application of silicone-based softeners and the use of combinations of the latter two types of substance.

10.3.4 Other sources

Textiles in the normal atmosphere almost inevitably encounter other sources of degradative stress besides the ones mentioned above, the most notable being that of radiation, first from the sun and then from other sources. Exposure to heat can occur, either accidentally or as a deliberate part of the function of the textile use, as also can contact with chemicals. Each of these subjects will therefore be considered separately in the remainder of the book.

10.4 Radiation

Radiation is a term given to electromagnetic energy emanating from various sources (light, sound, ultraviolet, etc.) over a wide spectrum of frequencies. Not all of them have an effect on textile materials or on other materials used in the production of textile goods, although we are beginning to suspect that some relatively small-scale effects may exist where none were believed to do so by former investigators.

10.4.1 Frequencies

The range of frequencies that can be attributed to radiation extends from about 10^{23} Hz (i.e. at a wavelength of about 3×10^{-15} m) to about 1 Hz (a wavelength of about 3×10^{8} m). In this range, the regions of most importance to textile degradation are approximately in the middle of the range, including the optical (at frequencies of about 4.3×10^{14} to 7.5×10^{14} Hz), ultraviolet (at frequencies of about 7.5×10^{14} to 3.8×10^{17} Hz) and infrared (at frequencies of about 1.5×10^{11} to 4.3×10^{14} Hz) frequencies. The mechanisms of change are similar in all cases; the radiation impinges on the object and its energy is absorbed by the latter, bringing about some kind of degradation. The amount of energy contained within a unit particle (a photon in the case of electromagnetic radiation) is given by the expression

$$E = h.\nu$$

where E is the mean energy of a photon in electron volts (eV), ν is the frequency of radiation in hertz and h is Planck's constant, with a value of 6.63×10^{-34} J-s.

It follows that energy is proportional to frequency, so that an ultraviolet photon has higher energy than an optical one, which in turn has higher energy than an infrared one. Therefore, we can expect that ultraviolet radiation will be more damaging than optical radiation, other things being equal, and this is generally borne out in practice. There are two additional considerations to take into account. The first of these is the amount of radiation falling on the textile material. Clearly, if a fabric is exposed to a higher dosage of radiation (of whatever kind) it is likely to experience higher degradation than it would if it were exposed to a lower level of the same radiation. A piece of cloth stored in the dark, for example, is likely to deteriorate less rapidly than one exposed to bright sunlight. Millington[2] compares the effects of ultraviolet and gamma radiation on wool keratin. At high gamma radiation levels, burst strength is decreased by about 15%, but no change is evident with comparable high levels of ultraviolet exposure. There is a complex colour change with gamma radiation, but an easily explicable one with ultraviolet exposure. In addition, gamma radiation causes yellowing that is difficult or impossible to remove with peroxide bleaching and produces, as Millington expects, no permanent set (irreversible change of shape or form). With ultraviolet radiation, peroxide bleaching brings about an increase in colour yield on printing. The author suggests as explanation for these phenomena the fact that gamma radiation causes damage to the whole fibre, while ultraviolet rays cause damage only on the surface.

10.4.2 Resonance

The second contributory factor is more complex. Energy absorption takes place at specific sites within the molecule, these usually being identifiable as certain bonds. All bonds are in constant movement at temperatures above absolute zero and these movements occur at fixed frequencies. If the frequency of oscillation of a particular bond happens to coincide with the frequency of the radiation falling on the material, then the bond will be forced into enhanced oscillation (a process known as resonance). This is because the ‘kick’ caused by the arrival of every photon of energy will coincide with the beginning of a period of oscillation and each ‘kick’ will add some impetus to the motion. This situation is analogous to the way in which a child’s swing can be made to go higher by means of a small push applied at the crucial moment when the swing begins to reverse its direction. By chance, the frequency of oscillation of many carbon–carbon double or triple bonds happens to coincide with the natural frequency of radiation in the optical or ultraviolet region of the electromagnetic spectrum, so that energy at the characteristic frequency of this portion of the radiation is absorbed heavily and is likely to to be very damaging. Textile materials tend to contain a lot of carbon–carbon bonds, many of them (especially in the structure of dyestuffs) being compound bonds. Thus, in essence, the total energy level absorbed by a textile product may often be greater than the molecular structure of the fibre or dyestuff molecules can tolerate without suffering some bond breakage.

In general, the three types of radiation mentioned above occur in nature, since they are all derived from sunlight. The amount of solar energy falling on our planet[3] (taking into account the fact that there is some loss by absorption in the atmosphere) is about 1 kW/m^2 over the entire surface of the earth, averaged on an annual basis. Bonding energies generally lie[4] in the range from 600 to 1500 kJ/mol for molecules commonly found in textiles, so exposure to solar radiation (assuming all the energy falls uninterrupted on the fabric) might be expected on average to break all the bonds in a mole of material every second. Obviously, this does not happen, or textiles would disintegrate at a rate almost as fast as we could make them. The explanation is simple; the energy does not all impact exclusively on the bonds, but is absorbed by all parts of the structure, including those regions where there are no bonds that can be broken by the specific radiation falling on them. Nevertheless, the concept does give some indication of the high rate at which damage can potentially be done by incident radiation.

10.5 Changes occurring

10.5.1 Visible

In practical terms, the changes can be categorised in two different types of observation, a visible one and a mechanical one. When bonds break, the first indication that damage has occurred is often a colour change. A dyestuff may fade, for example, or a fabric may turn yellow. These symptoms arise because the chemical substance that has been damaged has undergone a change in bonding type. Bonds that originally absorbed a particular region of the optical spectrum (and hence gave rise to a colour representing the portion of the light not absorbed) have been destroyed, so the preferential absorption no longer occurs and the material's colour is lost. Rastogi *et al.*[5] study the photofading of reactive dyes on silk and cotton, finding that fading depends on the interaction between fibres and dye molecules, in that better interaction produces better fastness. They propose explanations in molecular terms for the fact that reactive dyes are better for cotton but poorer for silk in comparison with unreactive ones. Oda[6] tries to improve the light fastness of natural dyes with nickel sulphonate complexes used as singlet oxygen quenchers, which he finds to be much more effective than conventional ultraviolet absorbers, especially in the presence of hydroxyl groups.

Alternatively, the change may produce new types of bond that absorb preferentially in other regions of the spectrum. If absorption is greatest in the blue region, for example, the remaining non-absorbed colour, yellow, is emitted and can be seen in the shade of the fabric viewed.

10.5.2 Mechanical

The second type of change is usually representative of more intense bond destruction, as discussed earlier in this chapter. When a bond breaks, the material loses a minute amount of its mechanical integrity and, if enough bonds are destroyed by the incident radiation, the strength imparted to the structure as a whole by the bonds can deteriorate. In consequence, tensile, tear or burst strength can be reduced, so that the material breaks if a load is applied to it. In general, textile goods tend to wear out most frequently under the influence of abrasive force, as a result of the lowering of abrasion resistance resulting from the accumulation of small fabric integrity losses over an appreciable surface area. The fabric may also become brittle as a consequence of the molecular changes induced by the radiation, again causing it to disintegrate, this time by a cracking process.

10.6 Infrared radiation

The third type of radiation (in addition to visible and ultraviolet) emitted in large amounts by the sun, infrared, tends to be much less damaging to textiles. This is for a combination of two reasons: first, the frequency (and hence the energy) is much lower and second, it does not coincide with the natural vibration frequencies of bonds present in the molecules, so the material is much less susceptible to destruction from this source. Infrared radiation, in fact, is used as a source of drying energy for textiles; it is, though, not entirely harmless, as will be shown in detail later in the book.

10.7 Other types of radiation

These are not, however, the only types of radiation present in the output from the sun that falls on the Earth. Evidence is slowly accumulating to show that there are many other different types of radiation within the solar electromagnetic spectrum that are a constituent of the overall emission output from our star. They include (in descending order of frequency and hence of energy) γ-rays, X-rays, microwaves and radiowaves; the former two are at higher frequencies than the three common solar ones already mentioned, while the latter two are at lower ones. There are also present minute nuclear units such as α-particles, neutrinos and other exotic products of nature, currently of interest only in the realms of high energy physics. Fortunately for the long-term stability of terrestrial materials (and hence for a healthy environment) all of these occur naturally only in insignificantly small amounts, or are of frequencies not causing major damage to materials, or pass through all objects (including the earth itself and even its human inhabitants) without leaving any trace of their passage or bringing about any detectable change. They would not be worth a mention in the context of this book at all if it were not for the fact that they have been harnessed by human beings in textile usage and thus become less insignificant. Microwaves are used, for instance, in drying equipment, and will be discussed again later, while X-rays, α-rays, β-rays and γ-rays are finding applications as diagnostic tools for elucidating textile structures. Ultrasonic vibrations, too, though not usually defined as radiation, are used to disintegrate fibre samples into fragments for analytical purposes. To date, radiowaves and neutrinos have not been harnessed by the industry, but this situation could change as knowledge about their production, properties and control is accumulated.

10.7.1 Diagnostic uses

The diagnostic uses of some of these types of radiation can be mentioned briefly at this point. X-ray diffraction is a familiar means of identifying crystal structures in polymers, while γ-rays are eventually likely to take over this function completely, in view of their higher frequencies (and hence energy capabilities and higher resolving power) at some time in the not-too-distant future. One of the uses of α-rays and β-rays is to bring about radioactive labelling of goods and there are some devices (such as textile thickness testers, electrostatic measurement equipment or evenness monitors) that have found application, at least in experimental situations, by dint of such labelling.

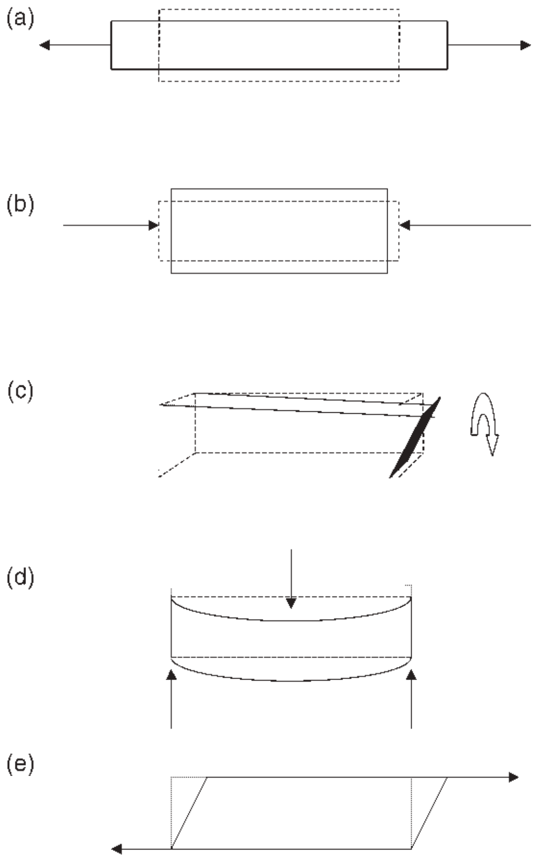
All of these energy sources are artificially augmented above their naturally occurring levels, simply because the sensitivity of the apparatus making use of them would not be sufficient otherwise. As a result, there are precautions that have to be taken to prevent damage to the textile goods exposed to all of them, as well as (in some cases) to the human beings working in the local environment. Any exposure at too high a level would tend to degrade the textiles, in the same kinds of way as those discussed above in connection with the more conventional forms of radiation, because bond disintegration could occur, if the material happened to be susceptible to the amount of energy falling on it.

Finally, it is vital to note that exposure to radiation is virtually inevitable for textile materials, even where they are not placed into service. Fabrics cannot easily be isolated from natural sources, except by sealing them into a light-proof chamber, and degradation cannot be avoided in any other way. In all other forms of degradative decomposition (thermal, chemical, mechanical, microbiological) to be dealt with in this book, it is necessary for the textile goods to be placed into service in some way before changes occur; radiation is thus unusual in this respect and should be recognised as such. In fact, this is an almost impossible situation to envisage; textiles are seldom, if ever, encountered in total isolation from their surroundings and everyday use normally subjects them to other stresses, of which the most obvious is mechanical action.

10.8 Mechanical action

10.8.1 Mechanical stresses

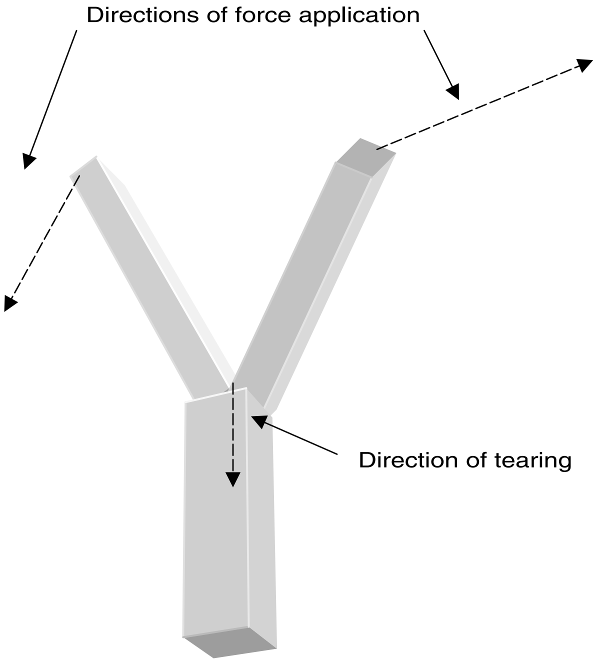
Textile materials are subjected to mechanical stresses throughout their lives, during production as well as during use. Stresses may be imposed in any of several modes, as shown in Fig. 10.1; in all the diagrams, the manner of application of the force changes the object under stress from its initial (shown by dotted lines) position to its final (full lines) one. The application of tensile force (Fig. 10.1a) stretches the fibres or fibre assemblies in a lengthwise direction. Compressive force (Fig. 10.1b) pushes them together in a crushing manner. Torsional force



10.1 Modes of mechanical stress application. (a) Tension, (b) compression, (c) torsion, (d) bending, (e) shear.

(Fig. 10.1c) applies a twist that causes rotational movement to take place. Bending force (Fig. 10.1d) brings about a bowing of a component which had previously been linear. Shear force (Fig. 10.1e) causes a distortion in the plane that deforms a material sideways.

These forces are seldom, if ever, applied in isolation. Most mechanical action involves the presence of two or more stresses, or even types of stress. In the tearing process, illustrated in Fig. 10.2, possibly the simplest example of compound force application, tensile forces are applied in a non-collinear manner to a fabric, with the result that the direction of deformation, and hence destruction, is perpendicular to the line of application of the two forces. In bursting, there are many forces involved, the main ones being tensile ones applied sideways to the surface of a fabric under stress combined with compressive forces normal to this surface, possibly with the addition of shear, tear and bending ones as well, so resulting in its near-violent collapse.



10.2 Mechanical forces present in tearing.

Abrasion is a more complex, but very common, mode of mechanical action. In it, a textile material in contact with the surface of another material is gradually or rapidly destroyed by having fibres dragged out or broken as a result of frictional resistance to movement. As is obvious by elementary consideration of the process of abrasion, the types of force applied can be any of the five listed in the opening paragraph of this section. A fibre may be snagged on the foreign surface and be pulled out of the structure by tensile force. It can be squashed between the foreign surface and the body of the textile. It can be subjected to torsion, bending or shear as the textile twists, bends or is pulled sideways in a specific zone during its passage across the surface.

It should always be remembered that, when mechanical action destroys a fabric, the mechanism is the familiar one we have already encountered earlier in this chapter. Minor application of small levels of force will cause a distortion of the structure, but the latter will recover its original state on relaxation of the stress. If the applied force is somewhat larger, then changes in the end-group chemistry are potentially able to occur, with atoms or groups being released from the molecule. Still more stress can cause loss of the entire side chain and very high-level stresses can bring about chain scission in the carbon–carbon backbone of the fibre molecules.

One important factor not usually present in other methods of degradation, however, is the matter of rate of application of stress, as opposed to the level of stress. When a force is applied gradually, the stress is distributed evenly throughout the structure, so that breakage may be resisted or take place at a low level in a gradual manner, to leave a weaker area in the fabric that is not actually a physical break. If stress application takes place at very high speed, however, there is not time for the forces to be distributed, so that all the stress is borne by a single small area of fabric and catastrophic failure occurs virtually instantaneously. A large hole or rupture results, even though the force is only of the same magnitude that caused a relatively small weakening of the fabric in the low-speed application. Thus, rate of application of the source of potential harmful change is of much greater importance in the case of mechanical action than in that of other types of degradation.

10.8.2 Force application

In considering the manner in which the forces are applied to textiles during production, it should first be noted that literally millions of fibres are being moved, often at very high speeds, by machinery that changes the position of the fibres relative to each other and to the surfaces with which they are in contact. Again, it is much more common to impose a variety of types of force, rather than merely a single one, on the fibres. During the opening of bales, tensile forces are used to separate individual fibres, but there is a certain amount of compression, bending, torsion or shear also implicit in the process as the opening device forces its way through the bale. Similarly, in carding, the card clothing that applies tensile force (as it removes clumps and dirt) also squashes, twists or bends the fibres as it passes through their grouped masses. Drawing by means of rollers teases out the fibre assembly into a finer strand, but does so only by squeezing the individual fibres against the rollers or against one another. The twisting action of spinning inevitably applies a torsional force to fibres while drawing them out against the surfaces of neighbouring fibres to reduce the cross-section of the strand.

10.9 Mechanical stress in manufacture

Even after the yarn is made, its individual fibres are still subjected to mechanical action. In weaving or knitting, the strand must pass through the small holes present in the healds or the needles, so that the outer fibres are compressed and abraded. The yarn is subsequently forced to move against adjacent yarns as the process continues, with the same effect on the outer fibres. In any winding operation, a yarn is bent, pulled and abraded as it is passed around or over guides, through rollers, or onto the cone or spindle on which it is being wound, so that the fibres are again subjected to various forces.

10.10 Mechanical stress in use

Mechanical action continues to occur after the fabric is manufactured. As cloth is pulled through various types of machinery for finishing, dyeing, printing or drying, tensile force is frequently applied to maintain the forward motion of the fabric. In other types of cloth transport mechanisms, rollers are used to carry the goods forwards, and frictional force (which automatically involves compression and at least some slight amount of abrasion) must be present for the motion to occur successfully. In cases where mechanical force is a necessary part of the cloth treatment process, such as in felting or some types of dyeing and printing, then compressive stress, often at high rates of application, will be experienced by the fibres. In a tenter, the drying operation is accomplished by drawing the fabric through the heated zone by means of a pin feed, so that small holes are made as the pins penetrate through the cloth. In this step, then, burst force is present at the same time as the fibres are subjected to the lateral tensile force that draws the material through the machine. Again, guide rollers are often an essential part of the dryer, applying compressive and abrasive actions to the surface fibres. At different stages in the fabric manufacture, too, there will be a variety of rolling or folding operations, all of which impart some type of mechanical stress to the cloth.

The stresses imposed during manufacture, however, are more or less controlled and known. Usually, their magnitude is taken into account in setting up the process conditions. Calculations are carried out to ensure that the amount of force imposed is not sufficient to cause any significant damage to the material. The same cannot be assumed during use of the textile goods made from the fabric, since there is no means of controlling or, in many cases, even predicting the way in which external forces are applied to an article.

10.10.1 Apparel

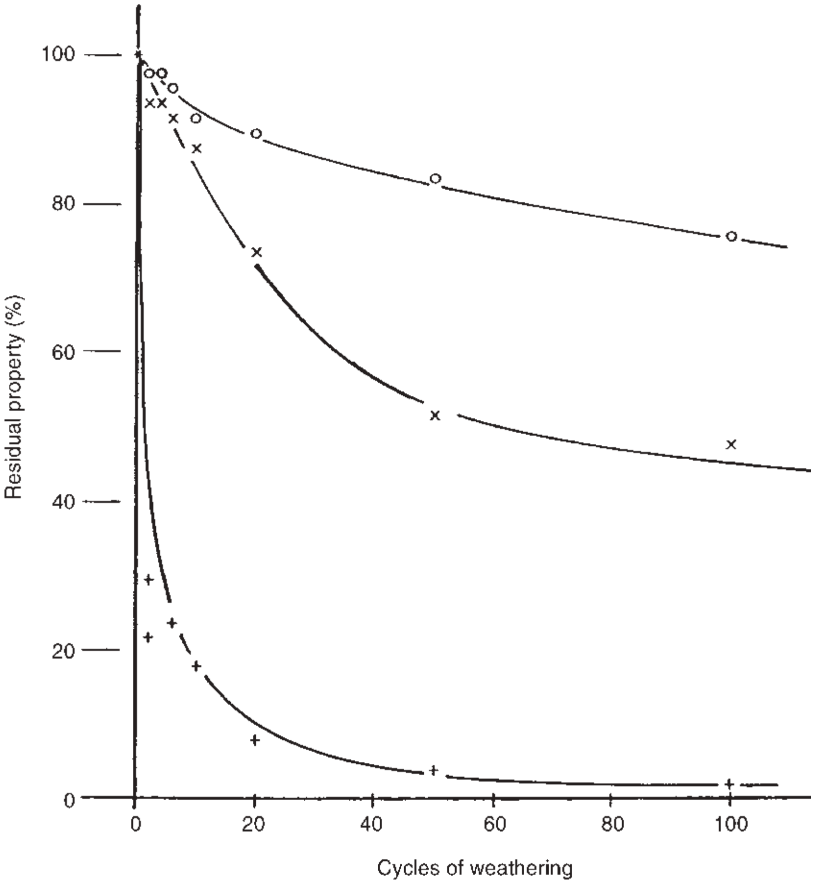
An apparel item, for instance, is subjected to force every time it is used. As the body moves, the garments fitted to it will rub against the surface of the skin, or against another garment, or against an external surface (a chair or a wall, etc.), thus experiencing compressive and abrasive forces. As a garment is pulled off, it will be subjected to a tensile force until the resistance caused by frictional contact against some other part of the body is overcome. Compressive and abrasive actions will again occur at the same time, especially if the shape of the part of the body across which it is being pulled is of such a nature that impedance to movement is high. Contact with another surface can cause pilling, the phenomenon by which short fibre lengths are broken within the structure but in which the force applied is insufficient to pull the broken portions out of the yarn immediately. Zarens[7] deals with the subject in some detail, describing pilling as taking place in three stages. The first of these is the formation of fluff, after which balls (the pills) are produced and, finally, detachment eventually occurs. Early discard speed and intensity are governed, he feels, by many factors and he discusses in outline the effects of fibre type, yarn construction, knitting or weaving parameters and finishes. Even the storage of clothing, on hangers or in drawers, needs the application of some force to get the article into place or to remove it in readiness for wearing.

10.10.2 Non-apparel uses

Commercial, industrial or sporting goods fabrics are notoriously prone to mechanical action. A tarpaulin or other covering material is blown about, often while in contact with sharp edges, so that tensile, compressive, torsional, shear, bending and abrasive forces are all being applied to it, at different times, as the cargo it covers is transported at speed on a road or rail vehicle. A conveyor belt is compressed at the region of reversal and abraded or compressed where it contacts the drive mechanism or, in a moving staircase application, by the feet of the people walking over it. Tents and sails are stressed constantly as the wind blows them, again with the potential for all the different modes of application of force to them. A rope used for climbing, or harness, or mooring purposes, will be under tensile stress, and may also be compressed or abraded against the surface of a dock or cliff or metal mooring ring. Cushions and curtains in the home, or in commercial space, are frequently in contact with a wall or a sofa or chair, and may be handled roughly by people moving them. Carpeting in the same location will endure the abrasion of shoe soles carrying particles of grit that increase the wear. Tyre cords on a vehicle are invariably subjected to high compression forces as the tyre bounces on the road and to tensile force as the rotational effect is imposed on them. Geotextiles are abraded by soil particles as rain washes over the fabric surface, or subjected to the stress of wave motion if they are in use as tidal barrages, or to the action of wind if they are part of a roofing system. Flags waving in the breeze are similarly abraded against the pole and pulled as air currents move them about.

10.11 Prediction of effects

In many cases, efforts are made to predict the magnitude of the forces applied, in an attempt to design fabric properties to ensure satisfactory life. Cloth used for most purposes, for instance, is tested in laboratories to make sure that it will not fail when used or handled in a reasonable manner. Industrial, sporting and commercial fabrics are designed with a healthy margin of error to provide a reasonable life expectancy even under extreme conditions. Unfortunately, conditions of use are not always reasonable and testing cannot always be carried out in a way that will simulate every stress to which the cloth will be subjected. A rough child (or a bad-tempered adult) may subject a fabric to extreme forces that the manufacturer cannot reasonably assume will be present. A storm or high wind can impose on a material forces that cannot possibly be withstood, given its structure. Carpets or



10.3 Effects of weathering time on O, tensile strength; ×, tear strength and +, abrasion resistance of nylon (source: ref. 8).

upholstery treated with the utmost disrespect will wear out far more rapidly than might be expected in a normal household situation.

One major difficulty is the fact that inappropriate testing may be carried out. If, say, a rope needs to be tested, its resistance to tensile force is often measured. In use, though, the tensile mode may not be the critical one that is likely to cause failure. A nylon climbing rope, for example, will be subjected to high abrasive force at the edge of rough surfaces. Figure 10.3[8] indicates the possible unpleasant effect of assuming that a tensile test is adequate to predict rope safety. As is obvious from the graphs relating the change in resistance to tensile, tear and abrasive forces to the time of use, tensile failure is still unlikely to take place even after prolonged use, but resistance to abrasive failure, as a result of molecular changes brought about by exposure to the ultraviolet radiation in sunlight, is lost very quickly. Thus, the poor climber will plunge to his death because of the failure of a rope that could still appear to be satisfactory and safe by tensile stress measurement standards.

The problem, of course, is an economic one. Higher quality goods are likely to withstand stresses better than inferior ones, but they cost more to produce. Manufacturers must therefore aim to provide their customers with goods of a quality that will give satisfactory service, for a reasonably lengthy period of time, at a reasonable cost. Dishonest manufacturers can disguise poor quality goods (e.g. by heavy raising of a fabric to hide a sleazy weave) but will not keep their customers long if a practice is made of this, and the conscientious manufacturer who eschews such fraudulent treatments will eventually outlast the cheating one. As long as the stresses imposed on the material are not excessive, an article of good quality will last in a manner that satisfies the customer. Indeed, in clothing, it is often a change in fashion that makes a garment redundant, rather than any mechanical failure. If a fabric does fail prematurely, though, there is the economic cost of replacing it, either for the manufacturer or, if the guarantee is not valid for the treatment it has received, for the consumer. In addition, no matter who pays financially for the loss, it is our long-suffering planet that once again has to deal with the extra environmental load when the article is thrown away before its intended date of disposal.

Finally in this section we should recognise that isolated stresses are virtually unheard of, because a textile material is always simultaneously subjected to more than one type of degradative effect. Combinations of stresses should be considered next and, since there are so many potential permutations of the various effects present, it will be possible to select only a few representative samples of the more obvious ones to examine.

10.12 Degradative combinations

It is relatively rare for any textile product to be exposed only to one single type of environmental challenge. Far more common is attack by two or even several different potentially degradative mechanisms at the same time. In practice, there is often a synergistic effect, where the combination of attack methods leads to a more rapid loss of properties than would be expected from a summation of the changes occurring in each case separately. As a result, it is usually impossible to allocate specific levels of the change taking place to any one type of attack and hence to predict exactly how a fabric will actually behave when it is put into service. All that can be done is to assume that the changes occurring will be at least the sum of those that would be expected from laboratory tests of individual types of environmental attack, and to design properties with a wide safety margin that, it is hoped, will allow the goods to function satisfactorily.

10.12.1 Maintenance

The most familiar common example of combination degradation, at least in terms of clothing, is regular maintenance. When a garment is dirty, it is washed or dry cleaned. In the former procedure, the textile is subjected to the action of water and chemicals in the form of detergent or fabric softener. At the same time, it undergoes mechanical stress as a result of the agitation given by the machine and, normally, a thermal loading. Afterwards, it is usually dried, either in a machine (with mechanical action and heat again) or in the open air, with exposure to ultraviolet radiation, movement as a consequence of wind and (on a *really* bad washing day) water and chemicals from acid rain. In dry cleaning, which is less severe on the textiles, only agitation and a chemical, the dry cleaning solvent, are involved, though elevated temperatures may occasionally be present.

10.12.2 Outdoor clothing

Clothing used outdoors in adverse conditions may suffer the consequences of enhanced attack. The simplest example of this is the existence of sweating during hard work, which brings about chemical or microbiological attack in conjunction with ultraviolet or water (possibly acidic) exposure. There is, too, an increased chance that mechanical degradation caused by abrasive force will also occur, since hard work frequently involves vigorous activity, such as climbing or fast movement. In such cases, less care of clothing is also common and contact with abrasive surfaces can be expected to result.

10.12.3 Weathering

Outdoor applications are also notoriously likely to subject other types of fabric to a range of mechanisms. Indeed, perhaps the most common and widespread of the possible cases of combinations of degradative mechanisms is the process of weathering. This will take place in any article that is used outdoors, whether as clothing, as industrial fabric or as sporting goods.

Oxygen in the air and water in the form of solid snow, liquid rain or moisture vapour make contact with the material. So too do any chemical substances dissolved in the water, such as acidic material like carbon dioxide (also present as free gas) or, especially in industrial regions, components of acid rain. Together, these represent a combination of oxidation, water and chemical attack, but to them must be added ultraviolet degradation from sunlight. Sunlight (except on the above-mentioned bad laundry day) is always a potentially damaging agent and will add to the burden caused by the air and acid rain, subjecting the fabrics also to ultraviolet degradation. In addition, the textile may be subjected to mechanical stress if it abrades against a nearby surface. This may be a wall, the ground, trees, metal railings or any similar obstacle, but it may also be a human body or another textile product. These will add mechanical stress to the aqueous, ultraviolet and chemical ones already present.

Textiles that will clearly be included in this category, apart from clothing,

10.4 Effect of weathering on a nylon flag.

include tents, sails, tarpaulins, geotextile roofing or ground fabrics, flags or bunting, and garden plant protective materials, all of which inevitably involve outdoor exposure as a part of their useful existence. In addition, other marine uses (e.g. hammocks, sails and ropes) may also expose the textile fibres to salt water or to water that is contaminated with other chemicals. Figure 10.4 shows the flag that has been flying at the farm of the author's daughter in Canada for only two years; the way in which it has been severely attacked and degraded in that relatively short period is clearly visible.

Fabrics used in gardening applications will be especially likely to degrade rapidly, as a consequence of coming into contact with soilborne micro-organisms at the same time as abrasive, chemical and radiative contacts occur. Typical of this use is the grass-catcher bag attached to a lawn mower, or the fabric placed over tender plants as rainwater falls on them or wind blows across them. A piece of sacking used for this purpose is shown in Fig. 10.5 after outdoor exposure for about six months in the author's garden, where it was used to protect tender plants against winter damage. There may also be some chemical attack arising from the presence of garden chemicals, such as fertilisers, weedkillers or insecticides, that enhances the risk of overall property loss when this type of degradative source is added to those already inherently present in the situation.

10.12.4 Indoor hazards

In indoor situations, multiple environmental hazards can also exist. Upholstery, curtains or carpeting in the home, at a workplace, or in a vehicle, are subjected to

10.5 Effect of weathering on a jute garden fabric.

abrasion by contact with human beings, or by movement of furniture or drapery across the fabrics. At the same time, light falling on the textiles and liquids or fumes from sources inside the home (such as heating gas, cooking effluent, spilt foodstuffs and cleaning solvents or animal activities) likely to cause fading will add their contribution to the overall change in properties of the materials. It should also be remembered that the initial application of chemicals (such as dyes or finishes) to the materials may, in time, cause chemical attack to take place as a result of long-term changes in the substances used for such treatments; the same consideration holds true for many of the other examples provided in this chapter.

Some fabrics, such as towels, tea towels or dishcloths, will inevitably suffer damage from abrasion as well as from the presence of water (and heat in many cases) during normal use, apart from that arising from their frequent laundering. Towels and bedding textiles will also be exposed to microbiological challenges as a result of their contact with the human body. Fabrics used in lamp shades are subjected to thermal stress as well as some of the ones already mentioned.

10.12.5 Tyre cords

A well-known instance of inevitable exposure to more than one type of degradative source occurs with tyre cords. These must be designed to withstand high temperatures during use at normal road speeds, as well as abrasion from movement of the wheels and should be resistant to burst tendencies arising during use, as a result of contact with nails or bouncing on uneven roads. In summer and winter conditions, they will undergo changes in dimension arising from expansion or contraction and must retain their adhesion to the tyre body despite this movement.

10.12.6 Other sources of degradation

More esoteric examples of degradation can be identified. A filter fabric may be exposed to chemical attack as well as mechanical force when it functions as part of a chemical process. Acoustic or thermal insulation material may come into contact with abrasive dust in the walls of a house (or even in the air itself), or with oil in the engine compartment of a vehicle. Protective clothing of the body from biological or chemical hazards, deep space exposure, deep sea diving hazards or merely from contact with oil or dirt, will suffer abrasion because of movement of the body at the same time as degradation from exposure to the element from which protection is sought.

It should be noted particularly that virtually all of the examples given in this chapter involve normal operating conditions. The exposure of the textile goods to different types of attack is, indeed, expected as a result of the specific intended end use. This points up sharply the fact that environmental attack is a pervasive phenomenon, one that cannot often be avoided. It therefore becomes necessary to accept its existence and to try, as far as possible, to minimise its effect. This aim is demanding, and the ways in which attempts are made to accomplish it are the subject of the next chapter.

10.13 Magnitude of textile environmental damage contributions

Before embarking on this survey, though, an effort will be made here to estimate just how large the actual problem of environmental damage related to textiles might be. We have seen how the production of fabrics or secondary products can be accompanied by ecological damage and how the industry tries to reduce the harmful effects as far as possible. We have also seen how degradative changes to textiles in manufacture or in use can lead to their premature discard, so that they contribute a further load on the environment that may merely be unsightly or may be toxic as well. How does this damage fit into the overall planetary harm we are causing as a species?

10.13.1 Assumptions

One way in which to estimate this parameter is to try to discover what place textile production and use take in the overall consumption of goods by humanity. In this approach, several assumptions will be made. The first is that the environmental harm caused by any process is directly proportional to the amount of product yielded by that process. Thus, if we double the production of a material in the second year of a two-year development stage, we will also double the ecological damage caused. This is not strictly true; the initial environmental costs of setting up the operation are not taken into account, nor is the fact that economies of scale can have an ecological, as well as economic, effect. Nevertheless, as will shortly be seen, the assumption is accurate enough for our purposes here.

The second assumption is that the activities involved in making textiles are not the most highly damaging ones that humans can effect, nor are they the least damaging ones to the planet. The action of extracting metal ores from the Earth's crust or that of launching a spacecraft, for example, will probably bring about much more profound changes (especially on an individual event basis) and lead to more environmental harm than does making a textile fibre or finished product. On the other hand, growing foods would be expected to be less damaging per unit of product than the manufacture of a textile article. The net effect of this assumption is that we need not make any special allowances (in the form of abnormally high weightings) in allocating an environmental harm figure to textile activities. The third assumption is that, if a product is made, it will be consumed or used and will contribute to ecological damage. Again, this may not be strictly accurate, because products may be kept in storage, but a large production base will render such exceptions relatively insignificant.

10.13.2 Statistics

With these three assumptions provisionally taken as valid, it is time to examine the facts. In the United Nations (UN) statistics for world production figures[9] for the latest complete year available, 1999, it is possible to discover what quantities of a wide variety of products are actually made. Table 10.1 is a summation of what may be classed as raw material production, in which category fibres may be included. There is a discrepancy between the UN statistics and those reported in the textile literature, so the latter (larger) figure has been taken as the more accurate one to avoid biasing the conclusions drawn here favourably towards a reduced textile contribution to environmental harm. Even with this handicap, the textile contribution is minuscule, a mere 50 million tons out of almost 19 billion tons, or less than 0.3% of the total figure.

Table 10.1 Annual production: raw materials (× 1000 tonnes)

Chemicals (organic)	5000 431
Coal and lignite	4880 720
Metal ores	3777 868
Petroleum and gas	3510 180
Non-metallic minerals	1014 344
Chemicals (inorganic)	382 487
Fertilisers and agricultural chemicals	217 971
Plastics and polymers	105 977
Textile fibres	50 872
Total	18 940 850

Table 10.2 Annual production: secondary materials (× 1000 tonnes)

Fuels	3093 962
Refined metals	2166 451
Non-metallic products	2096 727
Food	1521 504
Paper products	503 423
Painting materials	53 485
Wood products	36 455
Hardware	22 557
Textile products	10 114
Total	9504 678

Fibre production is not the only factor to be taken into account. Textile products must also be included in our calculations. Table 10.2 summarises the production figures for goods manufactured from raw materials. The secondary products of the textile industry, which can logically be included in this category, constitute an even lower proportion, 10 million tons out of over 9 billion tons, or just over 0.10% of the total.

Finally, we must not forget that equipment used in making textile goods, or their end products, can have a large effect on the environment. In Tables 10.3 and 10.4, the annual 1999 production figures of heavy machinery and light equipment, respectively, are summarised. From the former table, it can be seen that textile production equipment, at 30 million tons in over 17 billion tons, is dwarfed by other machinery (agricultural, industrial and construction units, for instance) of comparable size to less than 0.2% of the total. Similarly, Table 10.4 shows that sewing machines are only responsible for some 0.05% of the total, or about 0.3% if very small items (notably writing instruments) are removed from the total to make a fairer size comparison.

Thus, the average contribution of the textile industry and its products to world production figures is something like 0.25% of the global total. This estimate, of course, cannot be regarded as an accurate one. There are, for example, agricultural machines used for cultivating or harvesting cotton, and these are included in the agricultural category of the listing, not as textile machinery. In addition, the life expectancy of textile machines may be greater or less than that for other ones, leading to a higher or lower, respectively, effect on the planet per machine. Finally, the production of textile machinery appears to have declined markedly since the early 1980s, so the 1999 figure quoted may not accurately represent the current environmental impact of textile processing. Even allowing for this kind of error and even if the various other assumptions are faulty, however, the deduction that the entire textile industry represents a total of well below 1% of world commodity production figures is a very reasonable one to make. Thus, it is not fair to allocate more than about 1% of the world's total environmental impact to the industry, a figure which is highly satisfying given the enormous contribution made by textile

Table 10.3 Annual production: heavy machinery (number of units)

Agricultural machinery	11227 126
Industrial engines	4776 276
Construction and load-moving equipment	994 252
Transportation machines	237 092
Printing machinery	672 666
Textile production machinery	31 526
Total	17 938 938

Table 10.4 Annual production: light equipment (thousands of units)

Writing instruments	9540 651
Small consumer goods	1136 033
Entertainment equipment	589 229
Domestic appliances	
(large)	416 304
(small)	114 462
Metal and wood working machinery	39 251
Office machines	23 560
Sewing machines	6805
Musical instruments	4651
Electrical distribution	745
Total	11 871 691

goods (and summarised at appropriate places elsewhere in this book) both to human survival or comfort and to environmental protection.

So we can continue to use textile products with reasonable certainty that we are harming our planet far less than is the case with the application of other consumer goods. The best means of minimising adverse planetary effects, though, is to be careful about how we handle materials, taking good care of products to avoid any premature need to discard them and so cause pollution. This is to some extent an idealistic view, though, because textiles are not always restricted to normal conditions of everyday use and are, indeed, often intended for applications in which stresses far greater than those discussed in this chapter are present. The most crucial factors relevant to textile exposure, but not normally encountered under natural conditions of use, will be considered in the next two chapters. These are, respectively, devoted to the effects of high levels of heat and to chemical or microbiological agents.

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