10 The environmental impact of the textiles industry

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10.1 Introduction

Current concern over environmental issues is reaching fever pitch to the extent that it affects most of the working population to some degree, even in financial and banking circles. In particular, the level of emphasis given to the environmental agenda in school curricula in many countries of the Western World is predicted to produce a new generation of consumers and employees with a considerably heightened level of awareness over environmental matters. This will inevitably fuel consumer demand and influence national and international political agenda, producing a general demand on industry and commerce to deliver ever-improving environmental performance (Elkington, 1990; Good Housekeeping, 1990).

As a major world industry, textiles will increasingly be forced to respond to this rising concern. A thorough knowledge of the basics on environmental matters will therefore become as much a prerequisite for technicians qualifying in the industry as the technology of coloration, construction, manufacture or design that they have chosen to study. No textile technologist qualifying today will be able to avoid becoming involved with environmental concerns during a career in the industry. Whilst this chapter will seek to identify some of the major issues likely to be of concern to the textile technologist, full justice cannot be done to such a broad subject. It is therefore essential that reference is made to specific works on the subject, and in particular that current developments are monitored through the trade journals. This is important in a subject area which is experiencing such a rapid rate of change.

10.2 The environment

In any logical study of a subject area, a clear overall definition of the scope of the subject is a prerequisite. Unfortunately, whereas the dictionary defines the term 'environment' as "the circumstances surrounding an organism or group of organisms", it has been and is being used in so many differing ways, consciously or otherwise, that one definition suitable as a basis for study proves difficult to find. An evaluation of the various contexts in which the term has relevance is useful in gaining some understanding of the scope of the subject. The term 'environment' can usefully be considered as relating to various areas, approximate in scope and even overlapping considerably, but nevertheless giving rise to particular sets of issues dictated by the nature of the area involved. These may usefully be described as: immediate, local, regional and global.

10.2.1 *The immediate environment*

This use of the term may best be described as relating to all situations where there is a direct interaction between an individual and his or her immediate surroundings. In this respect, it could also be called the 'personal' environment. Issues arising through this interpretation of the term stem from such concerns as hygiene and health, safety, comfort, etc. Concern is therefore created through a perceived threat to the individual.

The most immediate personal environment is that normally generated by an individual's clothing, and it is in this area, where the textile technologist is most directly involved, that the perception of threat is clearest. Whilst issues such as comfort and fit are the obvious concerns of the textile technologist, increasingly the health or hygiene issues will need to be taken into account.

The prominence of this type of issue in the consumer's mind can be seen in the publicity given to the issue of residual amounts of manganese compounds present in 'stonewashed' denim articles which had been subjected to a bleaching process using potassium permanganate. This was given particular prominence in the USA and Germany. Similarly, the amount of formaldehyde released by articles treated with crease-resist resins has become of concern and even subject to legislative regulation in Japan. There is no doubt that other such issues will become important in the future.

Beyond the individual, immediate environmental concerns relate to the workplace or the home. In both cases health issues are central. Any textile technologist becoming responsible for production will have to deal with the work-related aspects directly, as is already the case—for example: noise-related hearing impairment; allergies such as dermatitis and asthma; and the abandonment of solvents and dyestuffs suspected of being carcinogenic.

One market-related illustration of direct relevance to textiles involves the purchasing pattern for floor-covering in the Scandinavian countries in the early 1990s. Originally this area was a good market for traditional tufted or woven carpet. Studies were then produced to imply that textile floor-coverings could harbour dust mites. The droppings of these minute creatures were associated with asthma and other respiratory conditions. This, together with the potential for release of chemicals into the room atmosphere created a strong consumer reaction and the market for textile floor-coverings in that area collapsed.

10.2.2 *The local environment*

Whereas the immediate environment involves issues arising from effects on or concerns of an individual, the local environment involves issues effecting groups of people concerned with their locality. Whilst there may still be health risk issues involved, these are likely to be bound up in the most common concern: quality of life.

Increasingly in the Western World people are becoming much less tolerant of the effects of industrial activity in their vicinity, and may well take action to correct what they perceive as irresponsible behaviour. This does not have to be permanently damaging, or even externally harmful. For example, in the UK, regulation of the amount of colour being discharged into the river system is becoming stricter, even though it may not be permanently damaging as such, but is nevertheless very visible pollution. Other local issues may relate to unpleasant noise, odour, smoke or steam emission, to level of traffic to and from a factory site, or even an unsightly or badly maintained factory site itself.

10.2.3 *The regional environment*

Regional issues arise where the activities of a group, factory, industry, etc., produce effects in another location, possibly at some distance from the original action. Some examples of this type are fairly well known, such as the effects of acid rain on the forests of Norway and Sweden as a consequence of fossil fuel burning in other Western European countries, or the effects of radiation fallout in Western Europe from the Chernobyl disaster.

A more directly textile-related example of this type of issue relates to the Aral Sea on the border of Kazakhstan and Uzbekhistan. The river system feeding this lake was partially diverted and used to irrigate cotton fields. As a consequence, this lake, the fourth largest in the world at one time and home to a prosperous fishing industry, shrank to a fraction of its size and increased in salinity, to the point where all fishing ceased as a result of the virtual disappearance of the fish population.

10.2.4 *The global environment*

Although generally less perceptible to the individual, changes in the global environment affect every human being ultimately, and arise out of the activities of the human race as a whole, or large portions of it. A number of truly global environmental issues exist, of which ozone layer depletion and the greenhouse effect are two of the best known.

Although to the casual observer most of the environmental movements are motivated by threats to the global environment, many of the issues which concern them may not be global except by extrapolation. Environmentalists argue that local or regional environmental issues may have a globally cumulative effect, and therefore are more important than they appear at first sight. This makes a rational response all the more difficult as industry tries to respond positively to the environmental challenge. Support for this attitude may be found in James Lovelock's 'Gaia Hypothesis'.

10.2.5 *The Gaia Hypothesis*

The geologist James Hutton in the late eighteenth century proposed to the Royal Society of Edinburgh that the world was, or could be considered as, a superorganism, and that the flow of nutrients and water through the environment paralleled the recently discovered circulation of blood in the human body. This idea was largely discarded as science grew in the nineteenth and twentieth centuries, but was revived by James Lovelock in 1972.

That the world may be considered to be alive seems absurd when the biosphere, or living part, effectively forms a thin layer over a large sphere of inert rock. Proponents of the theory point out that a giant redwood tree largely consists of an inner core of dead woody matter, and only the thin outerbark is actually alive: 1% living matter superimposed on 99% inert material. Lovelock has continued to develop his hypothesis and provide data and theoretical studies in its support (Lovelock, 1986a,b).

The implications of the Gaia Hypothesis are considerable, in terms of both public opinion and the environmental effects of the activities of the human race. Both are important for the textile technologist concerned with environmental matters, since public opinion may affect consumer behaviour in complex ways, and hence alter purchasing patterns from an industry of global proportions.

The Gaia Hypothesis suggests that the planetary conditions suitable for life, and in particular the highly unstable combination of gases in the atmosphere, are maintained by a complex series of mechanisms involving all the living species on the planet. Any imbalance in climate or atmospheric composition results in an enhancement of the appropriate mechanism (or species activity) to compensate for the change. This is not a conscious act by the planet but a natural consequence of the unconscious behaviour of the multitude of living organisms which make up the biosphere.

One example of how humankind may be affecting this mechanism lies in the destruction of the large rain-forest belts throughout the world. It is considered by environmentalists that these act to recycle carbon dioxide to oxygen in the atmosphere and also act to control weather patterns on a global scale. In addition, they harbour a wide variety of plant and animal life whose value to and interaction with the global environment can only be guessed at (Allen, 1980; Woodward, 1989).

This view, which is widely propagated, leads to public concern that may be evidenced in complex ways. Strong lobbying against the use of valuable hardwood timber produced by such rain-forest areas is a very direct effect. More subtle effects may occur; for example, the rumour that certain fast foods were produced from land made available by rain-forest clearance has required the companies in question to mount a strong campaign to allay fears in a volatile mass market.

10.2.6 *Environmental complexity*

All the foregoing serves to illustrate the vagueness and complexity of the environmental debate. There are few clear boundaries or well-defined issues, though many vested interests on both sides would assert differently. A rational and commonsense approach is required to deal with the many technical problems which are produced from this arena, with a clear understanding of the true facts of the situation as a primary requirement.

Such a framework is now being developed and applied in industry, with some degree of success, by the pioneers of this approach. Before considering this in detail, it is first necessary to address some of the major technical issues in question.

10.3 Environmental impacts of the textiles industry

Although industrial activity has many effects on the environment, these may be divided into two main groups: use of resources, and the production of waste. In both groups, a number of aspects are important to the environmentalist. A clear appreciation of these issues is necessary before embarking on an environmental programme.

10.3.1 *Resources*

There are two main types of resource, renewable and nonrenewable, though the category into which some resources fit may be a matter of dispute. Renewable resources are those which may be replaced as they are used up, and in large part are the product of living things, such as cotton, wool and silk for example. Nonrenewable resources are those with a finite supply on this planet, and are largely mineral in origin, such as coal, copper and diamonds. In some cases, nonrenewable resources as so defined might be regarded as renewable because they exist in such great abundance on the planet, like water for example. Even here, water can be regarded as renewable in an area with abundant rainfall, but nonrenewable in a more arid region where it is always at a premium.

10.3.1.1 *Renewable resources.* Renewable resources cannot be regarded as being in infinite supply. Being produced by living organisms, the amount of any resource available will be dictated by the lifeform capable of producing it, and the timescale and the yield from the resource base. For example, to produce equal amounts of wool and cotton fibre in the same time will, it has been estimated, need some 33 times more land area for wool than for cotton. In the case of the more exotic fibres such as cashmere and angora, where yields are even lower than for wool, the ratio is even more extreme. Attempts to enhance the production rate to give higher yields do not automatically do so for very long, and may even suppress the long-term viability of the existing production rate.

Two concepts are important in this respect: sustainable development, and biological diversity. Sustainable development is the discipline of production of the required resource, cotton for example, at a rate and on land types which secure the long-term maintenance of the crop yield without any adverse environmental side-effects. Since this rate may not be that realisable by the best modern technique, sustainable development is much less widely practised than is advisable for the long term.

Biological diversity has only recently been recognised as being of vital importance in the sustainable development of world crops. Earlier, it had been thought that the important factor in agriculture was maximisation of crop yield by development of super-strains of plants and animals giving high yields, and the widespread use of these in preference to locally used strains. This leaves the crop wide open to predators and disease and has, in a number of cases, led directly to a drop in yields until new strains could be produced. This can only be done if sufficient differing strains of the species have been preserved to provide a suitable gene pool.

10.3.1.2 *Nonrenewable resources.* Although the exact extent of the amount of any mineral on the planet may not be known at present, reasonable estimates are available, from which by extrapolation it is possible to project an approximate date by which they will be depleted at current rates of exploitation. Whilst only the most pessimistic of such estimates predict that this is in imminent danger of happening within the next ten years, the vast majority agree that a number are destined to run out or become severely depleted within the next 20–50 years, that is, within a generation or two from now (Myers, 1986).

Whilst the textile industry is not so directly dependent on mineral resources as, for example, the engineering industry, minerals are needed to produce the many complex machines used extensively in textiles. In addition, certain metals are essential components in some dyestuff types, and in some dyeing techniques. However, the textile industry is very dependent indeed on fossil fuels, in common with all other world industries.

The use of fossil fuels, especially oil and gas, is a major world concern, since much of our industrialised society depends upon these resources. Whilst predictions vary, it is generally accepted that the oil supplies available are unlikely to last very far into the twenty-first century (Myers, 1986), and will certainly cost more in real terms to extract as the easily depleted sources are used up. Fossil fuels impact widely in the textile industry, through heat energy, electrical energy and motive power for transport, and therefore any environmental audit must carefully examine energy and fuel usage.

10.3.2 *Production of waste*

All living things produce waste in some form in order to continue living, and this waste is released into the environment, where it is generally dealt with by an appropriate biological mechanism. If the waste is produced in too great a quantity, this mechanism can break down from pollution overload. Should the production of waste nevertheless continue beyond this point, serious disruption of the population of living creatures in the area affected by the waste will occur, and in the extreme, most of the higher life forms will die. In nature, there is often a self-regulating mechanism, since the lifeform producing the waste is also killed and the source of the pollution is removed. Gradually the pollution load will then dissipate and the affected area will be restored.

The pollution produced by humankind is usually carefully channelled away from the population that produces it and is deposited elsewhere. The amount of care given to the disposal of this waste will dictate what happens in the area where the disposal occurs. The nature of the waste is also relevant. Basically, waste can take three physical forms: solid, liquid and gaseous. It may also fall into one of four categories:

(a) Nontoxic, biodegradable
(b) Toxic, biodegradable
(c) Nontoxic, nonbiodegradable
(d) Toxic, nonbiodegradable

No biodegradation mechanisms exist for gases, and therefore waste released in this form must first be taken into solution in rainfall and deposited on to the land or into the sea before any biological mechanism can come into play. The physical form of the waste largely dictates the means by which it is released into the environment, whilst the category of the waste will dictate its environmental effects. In general, these become more severe as toxicity increases and biodegradability decreases.

10.3.2.1 *Biodegradability.* Waste materials that are biodegradable are broken down into simpler molecules by the digestive action of micro-organisms that are capable of using them as food. These simpler molecules are then excreted as waste, which may form a food source for another organism, be converted into yet simpler molecules which are excreted, and so on. For biodegradation to occur, moisture and a suitable population of micro-organisms must be present. Usually, the micro-organisms also need an adequate supply of oxygen to survive and digest the waste. This is aerobic digestion or biodegradation. Anaerobic digestion occurs in the absence of air or oxygen, and is often associated with the production of toxic and unpleasant gases such as hydrogen sulphide. If there is an oversupply of the material to be aerobically degraded, the population of micro-organisms grows rapidly and so does the oxygen consumption until all the available oxygen is used up. At this point, anaerobic digestion takes over, and all the oxygen-breathing life in the area of oxygen depletion dies. In rivers, lakes and seas this process is referred to as eutrophication.

Whilst biodegradation of waste products results in the production of simpler molecules, this in itself is not necessarily desirable if the simpler molecule has undesirable properties. It may be that the new molecule is not readily degraded further for example, and a 'biodegradable' molecule has been traded for a nonbiodegradable one. Alternatively, the products of biodegradation may be toxic to other higher life forms, again an undesirable result.

In considering biodegradation, it is therefore important to distinguish between primary and ultimate biodegradability. Primary biodegradability is the degree to which the initial molecule is removed from the environment, whereas ultimate biodegradability is the readiness with which, and degree to which, the material is finally converted to the simplest molecules such as water and carbon dioxide. Clearly, the ease with which a material undergoes ultimate biodegradability, and the amount of oxygen used up by the micro-organisms in this process, are the most important factors in evaluating the environmental impact of a material.

Some materials are more rapidly removed from the environment than others, the rate also being dependent on a wide variety of factors for any given material. It is therefore important to have some quantified measure of biodegradability in order to compare materials and to set legislative standards. Measures of biodegradability are widely quoted for many textile chemicals, but great care must be taken in the use and interpretation of the information before conclusions are drawn.

These tests all measure the biodegradability of the product in solution in water. The measure is usually of primary degradation, being based on the disappearance of the target molecule, or some property associated with it, in a controlled experiment using a culture of suitable bacteria. These tests have their origins in the work done to provide indications of the environmental persistence of detergent materials in rivers, the original intent being to avoid the generation of unsightly foam banks in waters receiving treated sewage outfall. These tests do not provide information on the rate or degree of ultimate biodegradation. An example of this is found in the comparison between alkylphenol-based nonionic detergents and those based on linear fatty alcohols. Whereas both pass the primary biodegradability tests, alkylphenols are much more resistant to ultimate degradation than linear alcohol ethoxylates (Kravetz, 1983).

The situation becomes much more complicated when the materials evaluated by these tests differ greatly in their physical properties, by being emulsions in water rather than solutions, for example. The results from standard OECD tests may be highly unreliable. More specialised test regimes are being developed for oily materials, such as the CEC Method L-33-T-82 (Co-ordinating European Council for the Development of Performance Tests for Lubricants and Engine Fuels, London). For this reason, biodegradability data quoted without reference to the test protocol used should be viewed with caution, especially when compliance with legal limits is being considered. It should furthermore be borne in mind that biodegradation produces a large population of bacteria which must be withdrawn from the treatment plant as a slurry or wet filter cake, and disposed of in landfill or by limited spraying on agricultural land (provided that the toxic metal content meets statutory limits).

Knowledge of biodegradation of solid materials is at a much more elementary stage even than that of materials in solution. Biodegradation in the solid state occurs in soil or some mixture of solid wastes with a bacteria source and a supply of air and moisture. This process is composting, as used over many generations to turn domestic and animal waste into usable manure. However, though such a process may occur quite readily in the controlled environment of the compost heap, it has been shown that it does not follow that degradation will occur in municipal refuse tips. Virtually unchanged samples of vegetables, meat and newspaper have been found by excavating old municipal rubbish facilities, even though the material has been buried for over ten years.

From the foregoing, it can be seen that biodegradability is no panacea for the environmental problems facing the textile chemist. The picture is complex and highly technical. Where simplistic claims of 'environmental friendliness' based on biodegradability are made, the claimant is wide open to attack from sophisticated and well-informed environmental pressure groups.

10.3.2.2 *Toxic materials.* Not many of the chemicals used in textile production and processing are highly toxic, though some materials may have long-term toxic effects. For example, some dyestuffs based on benzidine were withdrawn on the basis of their suspected long-term toxic effects on users in the dyestuff industry. Toxicity in environmental terms is a very different consideration. Substances which may be harmless to humans can be very toxic to other species. Surfactants, widely used in industry, are often toxic to the more sensitive varieties of fish, such as rainbow trout, for example. Properly treated in an effluent plant these materials present a relatively low threat in the environment, but if a substantial accidental spillage directly into a watercourse were to occur, substantial loss of aquatic life would be likely.

This damage would nevertheless be localised in nature, since the material would be diluted in the water flow and biodegraded by freshwater organisms. More serious effects are possible when the material is not biodegradable. In such cases, toxic effects from accidental releases into the environment are prolonged and can generate substantial adverse publicity. Further, the toxic material may be deposited in the sediment along the stream or river bed, being released periodically by disturbances such as storms or dredging.

Concern is now being focused on a more insidious problem than the foregoing. Low-level release of non-degradable toxic materials may occur for a great many years with no obvious effects. This material is, however, gradually concentrated through the food chain. It is first ingested by detritus eaters who live on sea and river bottom deposits. These are in turn eaten by their immediate predators, who are in turn eaten by larger predators, then small fish and so on. At each stage, if the toxin cannot be easily metabolised or excreted, the concentration of toxin in the body of the creature in the food chain is substantially higher than that in its predecessor until, in the higher carnivores, the concentration reaches the point at which serious toxic effects are evident.

These materials are often referred to as micropollutants, since they may not be discharged at levels of more than parts per million or parts per billion in effluent, but are suspected of being accumulated in the food chain (bioaccumulation). The risk of bioaccumulation is at its most severe in landlocked seas such as the Mediterranean and the North Sea. Political action has been taken to deal with this pollution issue on an international scale. In the case of the Mediterranean, this began with the Barcelona Convention in 1976. In the subsequent protocol in 1980, two lists of offending substances were drawn up. A 'black list' of highly toxic substances specified materials, such as mercury, cadmium and DDT, which were totally banned from release, and a 'grey list' specified materials where release was strictly controlled. Similar arrangements exist for the North Sea.

Micropollutants present substantial difficulties for the textile industry. The chemicals used are purchased either for their primary chemical composition, such as formic acid, sodium carbonate, etc., or for the effects they produce. There is therefore no requirement or predisposition to disclose the complete chemical analysis of products used in textile wet processing. When manufacturers are pressed, basic chemical analysis data may be presented, but would not necessarily deal with trace components. However, if trace amounts of nonbiodegradable toxic substances are present in the products, these may be sufficient to render the effluent 'over limit' for this material.

As an illustration of the problem, sodium hydroxide (caustic soda), which is widely used in the textile industry, has been produced by the mercury cell process for many years. This results in trace amounts of mercury in the final product, as used by the unsuspecting textile processor. This trace contaminant is passed through the system and into the factory effluent. Only at this stage may it be picked up in analysis of the effluent by the monitoring authority.

A lengthy process of backtracking is then required to pinpoint the source of the contaminant from the wide range of dyestuffs and auxiliaries that may have been used. This is no easy matter if the production routes of the chemicals are not known to the textile chemist seeking the answer to the effluent problem, as is usually the case. In the case of sodium hydroxide, the level of mercury in the product is very low, and can vary between manufacturers. Fortunately, in this case, there exists an alternative, in material made using a new, mercury-free diaphragm cell process, and the problem has been identified with manufacturers who are working hard to reduce mercury levels with immediate effect, prior to switching eventually to the new process.

A more complex problem is presented by the introduction of various toxic, nonbiodegradable organic materials into the textile process, and hence into the effluent, via the textile goods being processed. These are materials such as pentachlorophenol and a variety of insecticides. In a situation of this nature, the source of the micropollutant must first be identified, and proof obtained that the source is none of the chemicals used by the wet processor.

Although pentachlorophenol is applied to cotton as a rotproofing agent, and various insecticides, such as permethrin (actually one of the more biodegradable of such materials) are applied to wool as moth-proofing agents (Shaw, 1990), this is only carried out in a small number of the processing plants with these materials in their effluent. In the remainder of the cases, the pollutant is introduced into the effluent by the dry goods being processed. The pollutant may have been introduced on to these goods at an earlier stage in processing, perhaps as an antifungal agent for cotton goods to prevent rotting during storage in hot, humid climates, or as a preservative agent in a processing oil or sizing agent, for instance.

To complicate matters further, the source of the pollutant may lie at an even greater remove from the wet processor, being applied to the natural fibre during its growing stage to protect the plant or animal from attack by insect pests. The textile technologist has then to become detective to try first to pinpoint the source of pollutant in the factory, and then to ascertain the point of introduction on to the goods, to find means to obviate the problem. The easy answer of issuing an outright ban on shipment of goods bearing this material may not be practical, if the use of the undesirable chemical is widespread, and at the very least requires a method to be developed for detection of the offending chemical on shipments of goods being received by the factory.

This may well prove to be a recurring problem for textiles, as raw materials are sourced from new Third World countries with little previous experience. Since the polluting materials are generally cheaper than more environmentally acceptable alternatives, there is strong commercial pressure to use the former.

Further complications exist when chemical reactions occur during the textile processing route, thus producing molecules in the effluent which were not introduced into the system directly or indirectly on the goods to be processed. Processes using highly reactive chemical species do exactly this. For example, chlorine is used in the bleaching of cotton and other fibres to modify the coloured impurities in the grey goods chemically and produce a whiter fibre. Alternatively, it may be used with wool as part of a process aimed at imparting shrink-resistance (Shaw, 1990). The exact chemical reactions involved are generally not known, are definitely complex, and undoubtedly follow various pathways. Recent work has shown that these processes produce new, chlorine-containing molecules in the effluent stream. This mixture of materials of unknown composition has an unknown environmental impact.

The regulation of such materials in effluents is therefore based on the 'precautionary principle'; where there is evidence to suggest that some material might possibly have an adverse environmental effect but no studies have been done, the emission of the material into the environment is regulated as if the material is proven to be undesirable. For regulation to be possible, some accepted test method is required.

In this particular case, measurements are made in terms of AOX (adsorbable organic halogen) and EOX (extractable organic halogen), with AOX being the more common measurement. The test methods are based on detection of halogen in the combustion gases from samples isolated out of the substrate being examined following a specified isolation procedure. This gives an estimate of the amount of organohalogen compounds being carried into the environment from the process. In no way, with this technique, is any attempt made to evaluate the environmental impact of the organohalogen compounds.

10.3.2.3 *Nontoxic nonbiodegradable materials.* Some chemicals, for example silicones, used by the industry are not broken down by the usual biodegradation systems. If tested for biodegradability in the usual procedures, even where these have been properly modified to be suitable for the form of the material to be examined, the chemicals will be shown to be poorly degradable. A simplistic approach based on the precept that all chemicals used in wet processing should be readily biodegradable would result in an immediate ban on use of the product. This would not necessarily be the most desirable course of action in true environmental terms. Firstly, no adverse effect on the environment may exist. If the chemical has no known or suspected effect on flora and fauna in streams and rivers, its release into the aqueous environment could be seen as neutral. Secondly, if the material is nonbiodegradable, it will probably not participate in eutrophication, and may well be preferable to an alternative, rather more degradable, material that does. Thirdly, a nonbiological route for degradation may exist which is not shown up in controlled laboratory test environments aimed at measuring biodegradation. Such evidence may be beginning to emerge in the case of silicones.

10.3.3 *Air pollution*

Although associated with images of smoking factory chimneys and vehicle exhausts, the most serious air pollution is invisible and therefore not so immediately evident to the general public. Some of the issues created by air pollution have been given considerable prominence in the media in recent years, and therefore issues exist and will continue to arise which the textile technologist must take into account. Although biodegradation mechanisms do not exist to remove airborne pollution, this interacts with the biosphere very directly, in a manner dependent on the type of pollution, giving rise to specific issues.

10.3.3.1 *Acid rain.* In any combustion process, byproducts are formed from impurities in the components. Those giving rise to acid rain are the oxides of sulphur (SO_x) and nitrogen (NO_x). They are produced from the oxidation of sulphur- and nitrogen-containing impurities in the fuel used for combustion and, in the case of NO_x, from oxidation of a small amount of the nitrogen in the air. These oxides are emitted into the atmosphere along with the products of combustion, and eventually interact with water droplets in the atmosphere to produce dilute solutions of the oxyacids of nitrogen and sulphur. This often falls as rain. The low pH value of the rain then alters the natural pH balance of the soil upon which it falls. At first, the alkalinity of the soil will counteract this effect, but this will eventually be exhausted. The alteration of pH, and the action of the weak acidic solution on plants, results in damage to vegetation, especially trees. In addition, the low pH of the water table enables toxic minerals to be released into the groundwater, affecting water supplies and poisoning aquatic life (Pearce, 1987).

All combustion processes will produce these gases to some extent, though the amount produced can be controlled by regulating the quality of fuel burnt and the combustion conditions. They can be removed from exhaust gases by post-combustion cleaning or scrubbing, but this introduces extra cost, may decrease the efficiency of some combustion processes, and generates solid or liquid waste which is not biodegradable and must be disposed of. It is therefore not a viable proposition to regulate this form of pollution in all cases.

10.3.3.2 *Ozone layer depletion.* Chlorofluorocarbons (CFCs) were first developed by DuPont in the 1930s. They are chemically very inert substances which do not dissolve in water, do not burn and are not taken up by any of the usual mechanisms in the biosphere. This led to their being used widely as refrigerants, solvents and propellants for aerosols. However, in 1974, a paper by F. Sherwood Rowland suggested that these apparently harmless gases may pose a very severe threat indeed (Stevenson, 1990).

The biosphere on earth is protected by a layer of ozone in the high atmosphere. This ozone is created by the action of sunlight on oxygen in the

Earth's atmosphere, and results in the removal of much of the ultraviolet light in sunlight before it reaches the earth's surface. Ultraviolet light is inimical to many forms of life, and causes sunburn and skin cancer in humans. Sherwood Rowland showed that, in the conditions prevailing in the upper atmosphere, CFC molecules would be attacked and liberate chlorine atoms. These chlorine atoms would interfere with the formation of ozone drastically, in an approximate ratio of 100 000 ozone molecules destroyed per chlorine atom generated, before the chlorine atom was removed from the process by other mechanisms.

This resulted eventually in the Montreal Protocol in 1987, which aims to regulate and eventually ban CFCs altogether. In the meantime, severe depletion of the ozone layer, especially at the Earth's poles, continues to occur (Gribbin, 1988a).

10.3.3.3 *The Greeenhouse Effect.* The temperature of the Earth's surface is expectedly cold when compared with that of its neighbouring planets. Calculations suggest that the natural temperature if life were absent would be 290°C, instead of the actual mean of 13°C (Myers, 1985). Regulation of planetary temperature is a complex combination of many influences which either reflect some heat energy from the sun back into space, or absorb it through the mechanism of photosynthesis. Some gases in the atmosphere act against this mechanism by absorbing and retaining the heat. The most notable of these is carbon dioxide, produced by all living things. The level of carbon dioxide in the atmosphere is regulated by a number of natural mechanisms such that it forms only a tiny proportion of the Earth's atmosphere, and therefore does not retain too much of the heat (despite the 25% increase in heat output from the sun over the 3.5 billion years that life has existed on the planet).

The situation has been changing since the Industrial Revolution occurred. Humankind now produces vast quantities of carbon dioxide at an ever-increasing rate through the burning of fossil fuels. This is carbon dioxide that has been locked up in the mineral content of the earth from earlier times. Simultaneously, there has been a progressive net destruction of natural forests. These actions result in a gradual increase in the amount of carbon dioxide in the atmosphere, resulting in, it is claimed, a tendency for mean global temperatures to increase through the absorption of more heat by the extra carbon dioxide, the global warming effect. It is not known exactly what the end result will be if this effect proves to be real. Various scenarios have been put forward, all of which involve considerable disruption to humanity and loss of life (Gribbin, 1988b).

Other gases may also contribute to heat retention in the atmosphere. Methane is produced in the digestive tracts of ruminant cattle, generated by rotting waste matter (such as in landfill sites), and accidentally released during the extraction of natural gas deposits in the earth. Methane is thirty times more effective at retaining heat than carbon dioxide. CFCs are even more powerful, being some 17 000 times more effective than carbon dioxide. Carbon dioxide is, however, considered to be the main threat due to the amount being released into the atmosphere each year.

10.4 Approaching the problem

The foregoing has illustrated the complexity of the environmental issue; the vagueness of the meaning of the term itself, the emotional, sometimes illogical, view which may be taken, and the various, sometimes conflicting, issues that are already known. One thing is certain. This is a major issue which will affect humankind through the coming decades, and one which the textile industry must address. Like all business issues, it is best addressed in a logical and ordered manner, with all the various actions defined and an action plan put into place to overcome them. This programme must also be flexible, like all other business strategic planning, to allow for future legislative and consumer pressures.

In the absence of properly structured assessment of environmental issues, there is an inevitable focus on fashionable issues, resulting in false or unsound actions or claims. These serve to mislead public opinion and eventually serve to discredit efforts by industry and commerce to produce a sound response to the environmental issue. Tools are now emerging which enable a rational approach to be taken to these complex issues, so that commercial organisations may act positively and constructively in their activities. These are the environmental audit and life-cycle analysis.

10.4.1 *Environmental audits*

Auditing, formerly a purely financial term, has been widened in definition with the burgeoning quality movement in world industry. The environmental application has further widened its definition. An environmental audit is a detailed evaluation of all aspects of an organisation's activities, in which all the effects, risks and likely outcomes from the organisation's activities are identified and evaluated in terms of their effect on the environment. Degrees of risk may have to be evaluated and effects quantified.

The object of an environmental audit is to determine the environmental performance of the organisation and act as a prelude to the development of an environmental action plan. This action plan will be aimed at improving the performance of the organisation in environmental terms. This may well lead to policy decisions being taken, such as using recycled paper or paper produced from a renewable source of timber, and will certainly result in some form of waste- and energy-reduction programme.

Various programmes exist for environmental auditing, some produced by commercial or industrial organisations, for example the US and UK Chemical Industry Association's 'Responsible Care' programme. Others come from national programmes, such as the British Standards Institute's BS 7750 and the American Textile Manufacturers Institute E3 programme. Whilst they may differ in style, emphasis and complexity, all have a common structure with three main parts.

(a) *Policy and goal setting.* Initially the organisation involved must decide its overall approach to environmental issues in a manner understandable by all its members. This will take the form of a simple policy statement endorsed by the head of the organisation. This may also specify some initial goals which the organisation aims to achieve.
(b) *Auditing.* In this part of the process, the basis of assessment is set, in terms of areas to cover and standards judged acceptable. The actual performance against these standards is then determined, and areas are identified where action is needed to remedy problems or improvements could be made. The audit process should also identify what solutions are available.
(c) *Strategy and implementation.* An action programme is drawn up to make changes to those activities or aspects of the organisation that are judged not to meet the standards set in the first phase. Interim goals or rates of improvement will be set, and investment, product redesign, research or other actions will be required.

This whole process is cyclical in nature, with the strategy and implementation phase followed by a further policy and goal-setting phase, conducted in the light of the knowledge gained through the first cycle. Standards may well be better defined as a result of the clearer understanding gained, and this will result in a more effective audit phase, and so on.

This type of approach is applied to all the aspects of the operation of an organisation, but is focused on the organisation. Another approach, for manufacturing industry in particular, looks at the products made by the organisation, not only whilst in the manufacturing stage within the company, but throughout the whole life of the product. This is termed life-cycle analysis.

10.4.2 *Life-cycle analysis*

Whereas an environmental audit is concerned with an organisation, a life-cycle analysis looks at a product. The process is basically a form of audit in which all aspects of the product are considered. The first step is to consider the raw materials involved in the manufacture of the product and the environmental impact involved in its production. Following this, the production process by which the product is made is then considered, and again the environmental impacts are assessed. The study will then go on to consider the environmental impacts involved in the sale and use of the product, and, finally, the environmental impact involved in its eventual disposal.

This 'cradle to grave' approach, as it is also referred to, is valuable particularly in identifying the aspects of a product's life cycle with the strongest environmental impact. It is then logical to seek to lessen the environmental impact of a product by addressing this particular aspect first. For example, it has been determined that the major energy and water use in the life of a domestic washing machine occurs largely during its use, not manufacture. The outcome of this study is a new generation of machines that aims to reduce the water and energy consumption during the use period of the product's life cycle. The application of this type of analysis has also resulted in the production of certification schemes in various countries to provide consumer guidance in the form of 'eco labels'. The first types of product to be covered by such a scheme in the EU were washing machines and dishwashers.

In the textile industry, the issues are very complex indeed, and a true life-cycle analysis of a product can be a formidable, if not impossible, task. A simplified example of the problem is provided by considering the relative merits of 'greenness' of articles manufactured from cotton rather than polyester. The simplistic view taken by the average consumer may be that because cotton is the naturally produced fibre, it is therefore better in some way than the artificial version. This is supported by the perception that in the personal environment (when clothing is being worn) cotton is the more comfortable and acceptable fibre. The truth is, of course, much more complex (Van Winkle *et al.*, 1978).

During the use phase, for example, cotton requires more energy when being laundered, often being washed at a hotter temperature, usually requiring ironing, and taking more energy to dry after washing than a comparable synthetic fibre garment. This is due to cotton's ability to absorb moisture. After use, however, cotton is readily degraded by composting in soil, and thus presents no serious long-term waste-disposal threat, unlike the degradation-resistant synthetic fibre garment.

An examination of the production phase reveals more problems for cotton, however. Scouring, bleaching and other wet preparation procedures are required for cotton, while the intrinsically cleaner and whiter synthetic fibre demands relatively little preparation. During dyeing, cotton coloration is relatively difficult technically, with poorer dye yields resulting in wastage of expensive (in both money and energy terms) dyestuffs, and the use of additional dye fixing agents to ensure proper colour-fastness. This contrasts unfavourably with the relative ease with which many synthetic fibres can be dyed to good fastness standards and dye yield. Some fibres such as polyester, however, require dyeing at higher temperatures, thus taking more energy in the process.

Raw-material production presents another set of problems. Cotton may, at first glance, seem to have the more favourable position, since synthetic fibres are in general produced from non-renewable sources. Cotton requires land on which it has to be grown, and there are arguments that allowance should be made for the diversion of this land from food production. In addition, the use of fertilisers, insecticides and fungicides in cotton growing represents another hidden environmental penalty.

In order to obtain a proper picture of the relative environmental merits of the two types of fibre, a very complicated evaluation must take place, comparing identical textile articles in the same market area. All aspects of environmental impact must be looked at, and quantitative assessment of the impacts produced. This process inevitably involves some degree of assumption, and the placing of values on previously nonquantified actions or situations. As a consequence, the results can themselves induce debate. Such evaluations have been carried out by various workers. Van Winkle *et al.* (1978) have itemised early contributions to the debate, which still continues (Greenwood, 1991; Kummer, 1991).

The question of how far back to take a life-cycle analysis is difficult. Purists argue that the process should go back as far as possible, but this can be a very time-consuming and laborious process, as the cotton example ilustrates. It has already been argued in many quarters that the textile industry would be better advised to take a more local view based on the environmental audit approach, to determine what may properly be done to improve the impact of its activities.

10.4.3 *The action programme*

Whatever approach is taken to address the environmental issues raised in audits or life-cycle studies, at some point action must take over from analysis. This can be the point at which mistakes are made if some thought is not given to the action programme. As far as waste and pollution are concerned, a general consensus has been reached about the types of action to take and their order of priority where relevant.

(a) Remove or omit the operation, part or item. Starting from the question 'What happens if you don't do it?', this approach is often the best choice environmentally, but may not always be practicable. It has, however, led to a reduction in the amount of packaging materials used in some textile areas. Whilst some operations such as sizing weak yarns cannot be avoided, others such as prebleaching before dyeing may feasibly be omitted, but may require an alteration of standards or style.

(b) Replace an offending process or product with an environmentally more acceptable one. When seeking to use this approach, it is important to ensure that the issues are properly and fully addressed, and that the alternative is provably better overall. In textiles, there have already been some moves in this direction, such as the switch from chlorine to hydrogen peroxide in the bleaching of cotton, for example (Weck, 1991).

(c) Reduce or minimise the amount of or intensity of some component or process. For example, application of this approach has resulted in the reduction of the amount of polythene used in packaging of textiles by moving to thinner gauge polythene sheeting, with no adverse effects. Significant benefits are also to be gained by using this approach in the development and adoption of low-temperature dyeing techniques.

(d) Recycle materials after their use rather than discard them. In the textile industry, there has been a long history of recycling of textile goods into new textile materials, with extensive technology developed for this purpose (Spangenberger, 1991). New approaches are being developed today (Hoenig, 1993).

(e) Re-use waste or reject material for other purposes or as a lower-grade feedstock in the same process. Again, this is an area with a long history within the textile industry (Hoenig, 1993). Recent developments are centred on the possibilities presented by the conversion of textile waste into nonwovens (Watzl, 1992). Other successful approaches are centred on the use of certain wastes as fuel for energy production, as either heat or electricity or both.

(f) Treat the undesired item or waste. This is the so-called 'end of pipe' approach, and is traditionally the primary reaction of industry to demand to improve effluent to air or water. The weakness of this approach is that 100% removal is very difficult, and therefore the factory is trapped into a spiral of rising cost to meet ever-rising discharge consent standards.

(g) Dispose of the waste to landfill. Inevitably this is a course of last resort. Land for this use is rapidly disappearing, and the restrictions on the management of such sites are constantly escalating as regional government seeks to protect the community from the long-term consequences of this activity. In addition, landfill sites are a source of methane, a greenhouse gas, and thus landfilling of waste can generate future pollution.

10.4.4 *Action areas*

These will be highlighted by the environmental audit of the company's activities. A carefully conducted audit will aim to quantify the size of the impact on the environment of all activities, and thus should then make it possible to draw up a prioritised list of actions. It is then necessary to consider how to approach each problem. A multistage programme may be necessary to achieve best environmental performance in an area. The following should serve to illustrate some of the issues which may be involved.

10.4.4.1 *Sizing — an example.* Sizes are used to facilitate the conversion of yarn into fabric, and must then be removed at some stage before the fabric or garments are finally sold. Sizing is considered an essential step in fabric production, to enable yarn to be woven at the higher speeds made possible by modern loom machinery. These are necessary in order for the industry to deliver the large quantities of high-quality, low-priced fabric demanded by modern society. However, this process does present significant environmental difficulties. Stiebert (1975) claims that up to 80% of a textile finishing plant effluent may, in extreme cases, be due to the use of sizing agents. This is further exacerbated by the use of cheap, highly effective sizing materials such as poly(vinyl alcohol) (PVA), which are not very biodegradable. There is thus a direct conflict between the needs of modern industry to become ever more efficient and the demands by environmentalists for cleaner industrial processing. Positive approaches are being taken to address this problem, and these can be divided up into the action types specified in section 10.4.3.

(a) Remove. Although it is not possible in most cases to weave without size, some progress has been made within a limited range of qualities. In the case of linen yarns, where high yarn strengths are available, a switch to specially developed dressings made from biodegradable materials with good water removability has transformed some sectors of the industry, especially in Northern Ireland.
(b) Replace. Becker and Grunert (1980) sought to remove the problem from the effluent by using a size finish which remains on the fabric. This, of course, is technically difficult, because the finish must not interfere with any of the subsequent processes applied to the cloth, and must give a handle and performance acceptable to the final customer.
(c) Reduce. A novel approach to the problem of aqueous size removal has been reported (AATCC, 1973). PVA size is broken down to harmless gases by passing the woven fabric through a low-temperature plasma. In this process, it is reported that approximately 60% of the applied size is removed, leaving only 40% to be removed by conventional wet processing. Unfortunately, this process is therefore additional to those normally used and presents an on-cost to the goods, as well as using more energy in the plasma step. A careful comparative analysis would be needed to ascertain whether there was a net gain in environmental terms, which serves to illustrate the difficulty with which researchers are faced when attempting to develop alternative technology for environmental reasons.
(d) Recycle. Since the polymers used in sizing are effectively unchanged by the process, it is theoretically possible to remove them from the liquor and re-use them in a further sizing operation. A wide variety of methods has been proposed by various workers in this field (Becker and Grunert, 1980). Removal of sizes in aqueous solution is complicated by the high dilution of the retrieved size compared with the concentration required for effective sizing. Various methods have been proposed for overcoming this, using carefully designed removal procedures and/or liquor-

concentration techniques. In all cases, there is an inevitable degradation of the size material by contamination and molecular-weight degradation. Unlimited recycling is thus not possible, though recycling will greatly reduce the amount of load on the environment. A variant of this technique is to use solvent, either solely or in conjunction with water. In the former case special solvent-soluble size molecules must be designed before the process can be used. In both cases recycling is eminently possible, but there is an additional environmental risk introduced: the possibility of organic solvent being discharged into the atmosphere, a risk which must be evaluated and controlled.

An additional drawback of recycling is that it is only really feasible in vertically integrated operations or where special contract agreements are drawn up. It is of little interest to the commission finisher who will have no ready outlet for the recovered size, and little or no control over the type of size used on the goods processed.

(e) Re-use. There are as yet no direct uses of size removal liquors. However, biologically degradable sizes will produce sludge that may then be used as a liquid fertiliser on agricultural land.

(f) Treat. Whilst such materials as PVA are considered to have no ready biodegradability, claims have been made (*Textile World*, 1974) that bacteria capable of degrading PVA can be developed in a purpose-made effluent treatment plant. This is a slow process, but removal rates of over 90% have been claimed. The main disadvantage of this approach is that it is only possible in large vertically integrated plants where sufficient effluent volume of a consistent nature is available, and a large capital plant may be constructed.

Efforts are under way to produce size molecules which are more readily biodegradable than the current materials (Peppmoeller *et al.*, 1992; Habereder *et al.*, 1984). Based on either synthetic molecules, or modified natural products, they are claimed to have similar properties to the traditional materials. They must nevertheless be treated in effluent plant for removal from the environment.

(g) Dispose. Generally, no landfilling of size waste is undertaken, since the liquors are usually too dilute. Where biological treatment is undertaken, sewage sludge is produced, and this may well have to be landfilled if no other disposal route is available.

10.5 Conclusion—the way forward

As the above example of sizing shows, considerable creativity can be liberated when a clearly defined environmental issue is given due prominence in the industry. As the environmental approach of the textile industry becomes more sophisticated, more such issues will emerge. It must be stressed, however, that the best environmental solution may not be achievable without co-operation across the industry. In some cases, environmental problems can be created by a lack of communication between suppliers and customers in the supply chain. It is likely that this will result in the same type of partnership arrangements as are currently being created in the pursuit of total quality management and just-in-time programmes. It is certain that the accelerating pace of internationalisation of both the textile industry and environmentalism will serve as powerful pressures to change the technical face of textile processing in the coming decades.

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