

8 Scouring, enzymes and softeners

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8.1 Introduction

Scouring is probably the single most important process in the wet processing of textile materials. Effective scouring is essential for the subsequent processing of any textile substrate, regardless of type. In early textile processing, soap, often in combination with soda (sodium carbonate) was the universal agent for cleaning textile substrates. In many cases its use persists to this day, particularly for the processing of natural fibres where its gentle action is of some benefit. However, the majority of cleaning now employs manufactured detergents, specially formulated for particular purposes and applications.

In general, the same principles apply in all scouring operations, that is the effective removal of oils, waxes, fats, sizes, etc., prior to further wet processing such as dyeing, bleaching, resin application, softening or shrink-resist processing. If such materials are not properly removed from the substrate, this will inevitably lead to problems such as patchy, uneven dyeing or bleaching, or failure of shrink-resistance, for example. Scouring may in some instances be the only wet process applied, when its use is to prepare the article to make it acceptable to the consumer.

It is not unusual for a material to be scoured more than once during its progression from raw fibre to the final made-up article, as many finishes must be applied for a particular process, and then removed again once their job is done. This is especially true of the natural fibres, and of wool in particular. For example, wool destined for woollen spinning will be scoured in its raw state to remove the natural oils and waxes present in the fleece as well as general soil. The scoured loose wool will be blended and carded, and a spinning lubricant applied to aid the spinning process and the cohesion of the yarn. Typically (in the UK), around 5–8% oil will be applied, although this can vary greatly depending on the quality of the wool being processed. Once the yarn is knitted, the oil must be readily removable for any subsequent processing of the article.

There are two means by which textile substrates may be scoured, namely in wet (i.e. aqueous) processes or in solvent processes ('dry cleaning'). Both should achieve the same end result, that is, a clean article prepared for subsequent processing or sale, but the choice of which process may depend on factors such as:

Cost—dry cleaning is generally more expensive than aqueous scouring;

Ease of removal—in many cases, dry cleaning is only used as a last resort on particularly difficult jobs;

Subsequent processing requirements—there are some processes which are carried out entirely in solvent;

Machinery availability—the machinery requirements for aqueous scouring and dry cleaning are specific and are not interchangeable.

There are additionally some aqueous systems which incorporate a solvent, sometimes even a dry-cleaning solvent such as perchloroethylene, but these are essentially aqueous scouring agents where the solvent has been added to boost the effect.

8.2 Aqueous scouring processes

As has already been mentioned, soap is the traditional material used in the aqueous scouring of textile substrates; before the introduction of synthetic detergents, its use was universal. Indeed, soap has been known for more than 2000 years. However, the major drawback with soap as a scouring agent is the tendency to form insoluble calcium salts or 'scum' in hard water. Synthetic detergents were first developed to overcome this particular problem.

Since soap is manufactured by the reaction of a fatty acid with an alkali-metal base, it could be regarded as 'synthetic'. However, it is customarily accepted that soap is not classified with modern synthetic detergents, which were first introduced in the late nineteenth century.

In a sense, the chemistry of both soap and synthetic detergent molecules is very similar, and certainly the basic principles underlying their action are the same. Synthetic detergents are, however, much more effective in their action, and their chemical structures can be substantially altered to achieve a variety of effects in a way that is not possible with simple soap molecules. Some understanding of basic surfactant science is necessary to appreciate why scouring agents are effective in the removal of oils and other materials from surfaces. In this discussion, no distinction is made between soap and synthetic detergents, since other than their chemistry, their modes of action are considered to be similar.

Surfactants—or surface-active agents—are materials that act at the interface between two (or more) immiscible substances. In the widest sense, the immiscible substances may be solids, liquids or gases, in any combination. In textile processing, of course, there is most often a bicomponent immiscible system, being, in the large majority of cases, water and an oily material. However, liquid–solid and liquid–gas interfaces are also important in textile processing, for example in the wetting-out or de-aeration of materials. The role of a surfactant can most simply be described as overcoming such natural

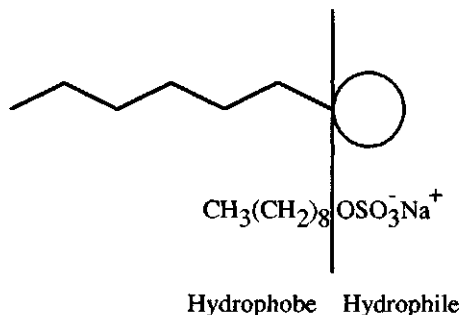


Figure 8.1 Schematic representation of the structure of a surfactant molecule.

immiscibility and allowing the two substances to come into close, intimate contact. In order to achieve this, all surfactants have a characteristic type of structure, although the exact structures employed depend upon the requirements of a particular application. Since we are considering aqueous processes, it can be assumed that the surfactant molecule will, in general terms, have one portion which is hydrophilic and one which is hydrophobic. For use as a scouring agent, the structure will be designed such that the water molecule has a high water solubility.

8.2.1 *The surfactant molecule*

The characteristic feature of all (aqueous) surface-active agents is the possession of a hydrophobic 'chain' and a hydrophilic 'head' (Figure 8.1). This is true of the simplest soap molecule right through to the most complex synthetic detergents. In the majority of cases, the hydrophobic portion is a long-chain hydrocarbon, while the hydrophilic portion is a highly polar or charged (ionic) group that will confer water solubility. When one considers the potential pairings that might be possible in designing such a molecule, the number of possibilities is almost limitless, and indeed the number of commercially available surfactants is very large. However, for practical purposes, there are limits on the structures which are useful; for example, the solubility of the molecule in the desired medium must be considered, and this may place a limit on the length of the hydrocarbon chain.

It is most convenient to consider the two distinct components of the surfactant molecule separately, namely the hydrophile (or lipophobe) and the hydrophobe (or lipophile). Surfactants are customarily classified on the basis of the nature of the hydrophobe, this classification relating to the ionic charge carried by the hydrophobe. There are only four classes of surfactants, using this classification scheme, that is anionic, cationic, nonionic and amphoteric. Notice that the term 'anionic' (and similarly 'cationic') refers to

the charge carried by the hydrophobe on the surfactant molecule itself, not to the (non-surface-active) counterion. There are, of course, both anionic and cationic components in any charged, electrically balanced molecule.

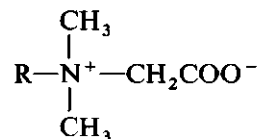
The hydrophobe portion can vary widely, and though most are based on linear hydrocarbon chains, the actual number of structures possible is immense.

8.2.1.1 *Anionic surfactants.* Soap can be considered as an anionic surfactant, but there are many examples of synthetic anionic surfactants. Indeed, the first synthetic surfactant — Turkey Red Oil, a sulphonated castor oil — was an anionic material. The characteristic feature is the possession of a group carrying a negative charge, the most typical examples being carboxyl ($\text{RCOO}^- \text{M}^+$), sulphate ($\text{RSO}_3^- \text{M}^+$) and sulphonate ($\text{ROSO}_3^- \text{M}^+$).

8.2.1.2 *Cationic surfactants.* The hydrophile carries a positive charge, the most common examples being quaternary ammonium compounds ($\text{R}_4\text{N}^+ \text{Cl}^-$). Cationic surfactants are rarely used in textile scouring. They have a pronounced germicidal/bactericidal activity which is particularly important in personal-care and hard-surface cleaning products.

8.2.1.3 *Nonionic surfactants.* As their name implies, these carry no electrical charge, and water solubility is conferred by the presence of highly polar groups. By far the large majority of nonionic surfactants contain a polyoxyethylene chain $-(\text{OCH}_2\text{CH}_2)_n-$ of varying length. An increase in the value of n tends to increase the water solubility, but solubility is also influenced by the nature of the hydrophobe group.

8.2.1.4 *Amphoteric surfactants.* These contain both negative and positive charges within the same molecule, although the particular ionic charge under given conditions will be influenced by solution pH. Thus, under alkaline conditions the molecules act as anionic species, while under acidic conditions they behave as cationic species. Between these extremes of pH lies the isoelectric point, where the ionic charges are balanced and the molecule carries no charge. The most simple examples of amphoteric are the alkylamino acids ($\text{RN}^+\text{H}_2\text{CH}_2\text{COO}^-$). Other common examples include the betaines, trisubstituted alkylamino acids:



8.2.1.5 *Hydrophobes.* The range available is very large, but is substantially limited to the straight-chain hydrocarbons of chain length from eight to eighteen carbon atoms in the majority of cases. The chain may be saturated

and unsaturated, and of natural (animal or vegetable fats and oils) or synthetic (crude oil) origin. The naturally occurring oils and fats contain carbon chains with an even number of carbon atoms only; chains with odd numbers of carbon atoms must be manufactured.

Other more or less common hydrophobes include:

- Branched-chain alkyl groups
- Alkylphenols of various configurations, which includes the important nonylphenol derivatives
- Polyoxypropylene derivatives
- Polydimethyl siloxanes
- Fluorinated derivatives, generally partially or fully fluorinated alkyls

8.2.2 *The nature of surface activity*

Surface activity is a highly complex field of study, and is of great significance in a surprising variety of aspects of our daily lives. However, we can confine ourselves to a very brief description of the most basic principles of surface activity, and its importance in understanding wetting and detergency. For those requiring a more detailed description of surfactants, there are a number of excellent reference books available, such as Myers (1992).

Surface activity is concerned mainly with the behaviour of materials at interfaces, that is, at the boundary between two or more immiscible phases. It should be clearly understood that the bulk properties of each individual material may be quite unaffected by such surface effects, but that the properties of a system as a whole (i.e. of the two or more immiscible materials) are governed entirely by the behaviour at such an interface. The principal feature of a surfactant is the ability to modify the behaviour of materials at such interfaces. The most obvious example of this is of course the use of a detergent to emulsify water and oil. The surfactant acts as an agent for overcoming the natural tendency for the boundary to be minimised; in aqueous systems this is governed by the relatively high surface tension of water. The net result of emulsification is a vast increase in the mutual surface area of the two phases as the oil is dispersed as small droplets of water (or *vice versa*). A surfactant molecule is able to achieve this because it contains within its structure an oil-soluble portion and a water-soluble portion. As such, it can act as a bridge at the interface of two phases, where the hydrophilic end of the surfactant is oriented towards the water while the hydrophobic end is oriented towards the oil phase. It is thus able to bring two immiscible phases into intimate contact.

In an aqueous system this orientation of the surfactant molecule between the aqueous and oil phases is controlled by the balance between the hydrophobic and hydrophilic components. Thus, the balance determines the characteristics of a surfactant, and hence its usefulness in a particular situation.

Although there are a number of schemes for relating a surfactant's properties to its physical structure, the most commonly used, and perhaps the most useful, is the hydrophile-lipophile balance (HLB) first proposed by Griffin (1949). Although they are of an empirical nature, in many ways HLB values can be used quantitatively for determining the characteristics of a surfactant.

Within this classification, surfactants are assigned an HLB value between zero and twenty or higher. Low values indicate surfactants with high lipophilicity (i.e. oil solubility), while a high HLB denotes a high water solubility. The HLB classification is especially useful for the nonionic ethoxylate surfactants, where the degree of ethoxylation readily identifies a surfactant as being of low, medium or high HLB. Thus, low degrees of ethoxylation result in low water solubility/high oil solubility and hence a low HLB. Increasing the degree of ethoxylation increases the water solubility (and subsequently decreases oil solubility), and hence the HLB increases. Table 8.1 lists typical applications related to HLB range for nonionic surfactants, while Table 8.2 gives the approximate behaviour in water of surfactants of varying HLB. From this behaviour, an estimation of HLB can be gauged for an unknown surfactant.

It is possible to calculate the HLB of a pure surfactant of unknown HLB. For example, the HLB of an ethoxylated nonionic surfactant is calculated from the formula:

$$\text{HLB} = \frac{\% \text{ by mass of the hydrophilic group}}{5}$$

which gives a value in the range 0–20.

Table 8.1 Approximate HLB values *versus* surfactant characteristics

| HLB range | Application |
|-----------|-----------------------|
| 3–6 | W/o emulsifier |
| 7–9 | Wetting agent |
| 8–18 | O/w emulsifier |
| 13–15 | Detergent |
| 15–18 | Solubiliser/disperser |

Table 8.2 Approximate HLB from water solubility

| Behaviour in water | Approx. HLB |
|-----------------------------------|-------------|
| No dispersibility | 1–4 |
| Poor dispersion | 3–6 |
| Unstable milky dispersion | 6–8 |
| Stable milky dispersion | 8–10 |
| Translucent/semi-clear dispersion | 10–13 |
| Clear solution | 13+ |

For fatty esters derived from polyhydric alcohols, e.g. glycerol monostearate, the following relationship applies:

$$\text{HLB} = 20[1 - (S/A)]$$

where S is the saponification number of the ester and A is the acid number of the fatty acid.

Table 8.3 gives the HLB values of typical nonionic surfactants.

The most valuable use of HLB values is in determining the effectiveness of a surfactant to stabilise an emulsion of either oil-in-water (o/w) or water-in-oil (w/o). In order to make a stable emulsion it is necessary to match carefully the HLB of the surfactant to that of the oil, bearing in mind the requirements of the application. However, when choosing surfactants for a particular situation, it is not always necessary to match the HLB of the oil with that of a single surfactant, and indeed in many instances it is preferable and more effective to choose a blend of two or more surfactants. The HLB of a mixed surfactant system is simply the algebraic mean of the individual HLBs. For example:

$$\text{HLB}_{\text{mix}} = F_a \times (\text{HLB})_a + (1 - F_a) \times \text{HLB}_b$$

where F_a is the weight fraction of component a in the blend and HLB_a , HLB_b are the HLB values of components a and b respectively.

It is of course possible to use such a relationship to calculate a precise blend given the individual HLBs of the components and the desired HLB of the blend.

When designing an emulsification system for an oil of unknown HLB, the most convenient method is to take two surfactants a and b of widely differing

Table 8.3 HLB values for typical nonionic surfactants

| Surfactant | HLB |
|---------------------------------|------|
| Cetyl alcohol, 10-ethoxylate | 12.9 |
| Cetyl alcohol, 20-ethoxylate | 15.7 |
| Tridecyl alcohol, 6-ethoxylate | 11.4 |
| Tridecyl alcohol, 12-ethoxylate | 14.5 |
| Tridecyl alcohol, 15-ethoxylate | 15.4 |
| Nonyl phenol, 1-ethoxylate | 4.5 |
| Nonyl phenol, 6-ethoxylate | 10.9 |
| Nonyl phenol, 9-ethoxylate | 12.8 |
| Nonyl phenol, 12-ethoxylate | 13.9 |
| Sorbitan trioleate | 2.3 |
| Sorbitan mono-oleate | 4.6 |
| Glyceryl monostearate | 4.4 |
| PEG 200 monostearate | 7.9 |
| PEG 300 monostearate | 10.2 |
| PEG 400 monostearate | 11.5 |
| PEG 400 mono-oleate | 11.3 |
| PEG 400 monolaurate | 13.1 |

HLB values and combine them in such proportions as to give a range of HLB values, using the calculation above. The stabilities of the emulsions produced from these various surfactant blends are compared visually, and the most stable indicates the effective HLB for that particular oil. Further tests can then be carried out to optimise the HLB around this value, perhaps using blends of differing surfactants to achieve the same HLB value.

8.2.3 Critical micelle concentration (CMC)

In aqueous solution, all surfactants tend to agglomerate in small particles. At low concentrations, surfactants will tend to orient themselves at interfaces, resulting in effects such as the lowering of surface tension. As the surfactant concentration is increased, these interfaces become saturated, and the surfactant molecules tend to form discrete clusters, called micelles, in the bulk of the solution. This concentration is called the critical micelle concentration or CMC (see Figure 8.2). Above this concentration there is no further reduction in surface tension and other properties of the surfactant solution, such as wetting power or foaming, are unchanged. However, as we shall see below, the formation of such micelles is crucial to the usefulness of surfactants as detergents in scouring operations.

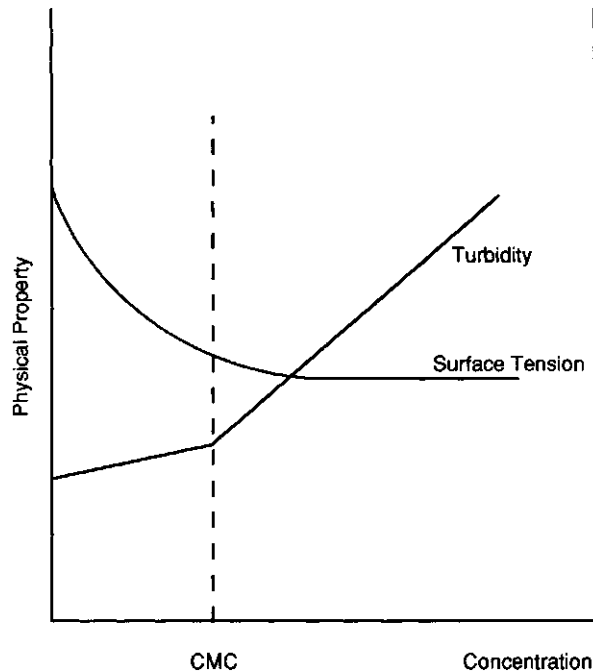


Figure 8.2 Critical micelle concentration.

The CMC of most surfactants is low, of the order of 0.2–0.5 g/l, the exact value depending upon the chemical structure of the surfactant. As a general rule, it can be said that the CMC increases with hydrophobe chain length and that nonionic surfactants have a lower CMC than ionic surfactants. The CMC is also very sensitive to temperature, with many ionic surfactants showing a minimum around 60–70°C. This is believed to be related to the ordering of water (hydration) around the ionic head group. Nonionic and amphoteric materials do not show such predictable CMC minima, but many polyoxyethylene nonionic surfactants do exhibit a cloud point.

8.2.3.1 *Cloud point.* Nonionic polyoxyethylene surfactants show an inverse temperature–solubility relationship, that is as the temperature of a solution is increased, the surfactant may become less soluble in water. The cloud point is the temperature at which a surfactant (measured as a 1% solution) becomes cloudy as a result of a decrease in water solubility. At this temperature it may no longer perform as a surfactant in some or all respects. For a given hydrophobe, cloud point increases with degree of ethoxylation.

8.2.4 *Scouring of textile substrates*

As has been said, the purpose of scouring is to remove all extraneous matter from the textile substrate, either as a preparation to further processing or as a final treatment prior to sale of the goods. The scouring agent must perform a number of functions, including wetting out of the goods, emulsification and suspension or solubilisation of the removed material. As has been indicated, the precise action of a scouring agent will depend to a large extent on its HLB, and how it is matched to that of the material to be removed. There are also other considerations, such as the type of soil and the nature of the textile fibre. In addition, the use of a ‘builder’ or other auxiliaries such as sequestrants may be necessary, depending upon the conditions. Still further consideration must be given to the processing machine type, especially where there is a need for low or zero-foaming products, such as in jet machines with a high-shear action.

It was indicated in Table 8.1 that the characteristic performance of a surfactant is defined by its HLB value, to an extent. For example, surfactants which show good wetting properties are likely to be poor detergents and *vice versa*. In order to create a balanced product which is able to wet the goods effectively and remove and suspend soil, a blend of surfactants is the ideal. Commercially available scouring agents range from simple single-component systems to complex blends able to fulfil many functions more effectively than the simple systems. Where there are particular constraints on the scouring systems, these can usually be accommodated by careful formulation, perhaps by use of suitable surfactants, or by the use of additives

in the blend. The free rinsing of surfactants after the scouring operation is important in many situations, where the presence of surfactant residues may interfere with subsequent processing. The printing of fabrics is a good example where surfactant residues lead to a loss of definition at the colour edges of designs, due to bleeding from one area to another. Low foaming is of vital importance in jet machines, where excessive foaming can impede or even stop the free movement of the fabric around the machine.

The use of co-agents with the scouring agent may be necessary. Certainly the use of a 'builder' improves detergency significantly, and the most widely used builders are alkalis. In industrial processing this is most likely to be sodium bicarbonate, carbonate or hydroxide. Although alkaline phosphates are also used, their chief application is in the domestic product laundry market. Alkalis improve scouring operations by saponifying oils, waxes and fats, in essence making 'soaps' from these materials, increasing their water solubilities and hence their removability from the textile substrate.

Sequestering agents may be employed in areas where hard water is a problem. Where alkali is added to form an oil soap, the presence of calcium or magnesium may lead to scum formation. Sequestrants act by forming soluble complexes with metal ions, preventing their reaction with other species. They are not formulated into the surfactant system, but are added as separate auxiliaries to the scouring bath. Some of the materials used as sequestrants may have other properties useful in a scouring operation; for example, polycarboxylic acids have high dispersing powers, and help to prevent the redeposition of solid materials onto the substrate.

Solvents are sometimes added to enhance the scourability of particularly difficult, greasy substrates. Typical solvents are perchloroethylene, xylene, white spirit, terpenes and pine oils. Most formulators tend now towards the less hazardous solvents, and the use of chlorinated and aromatic solvents is much reduced.

Oily materials are removed from textile surfaces by two mechanisms, these being emulsification, which is an entirely surface (interfacial) phenomenon, and solubilisation by micelles. In addition, we should first briefly consider the removal of solid soils. In order to remove a solid soil from the surface, it is necessary first to wet the surface and by so doing reduce the affinity (interfacial forces) of the soil for the surface. Often little more than wetting and mechanical agitation are required to remove solid soils. The surfactant must then be able to disperse the solid particles effectively and prevent their redeposition. In many cases, solid particles are attached to the substrate not by mechanical or electrostatic forces, but by an oily deposit, and this first must be emulsified, freeing the solid soil particles from the surface.

Oily materials may be removed by emulsification with a surfactant of a suitable HLB value. While it is true that emulsification is the probable first step in most such situations, in fact the surfactants used as detergents are not very effective emulsifiers, and the emulsions so formed are likely to be

unstable and may coalesce and redeposit on the substrate. The solubilisation of oily materials is perhaps of more significance in textile scouring. It is found that oil removal is most effective only at surfactant concentrations significantly above the CMC, particularly for nonionics. At concentrations above the CMC the surfactant molecules form structures (micelles) of varying complexity and configuration, depending on the structure of the surfactant, its concentration and the bath temperature. Fairly simple spherical structures might be formed at relatively low concentrations (above the CMC), while at concentrations significantly above the CMC, large, complex structures are formed with the capacity to solubilise a large amount of oil. In typical scouring operations, however, the surfactant concentration is not generally significantly greater than the CMC, and hence large amounts of oil cannot be solubilised; emulsification may play a significant role in such situations. Another consideration is the temperature of the scouring bath, particularly when using nonionics. The efficacy of nonionics increases with temperature and is at its maximum when the cloud point is approached.

8.2.5 *Choosing the surfactant for a fibre type*

The complexity of processes carried out in various substrate preparations makes different demands on the surfactant. Also the relative cleanliness of the substrate has an impact. Raw wool, for example, may contain 20–60% of extraneous matter, while the synthetic yarns, by the nature of their manufacture, contain only small and relatively consistent amounts of oil or waxes. Cotton scouring agents must be able to withstand strongly alkaline conditions during processing. Obviously no single scouring agent is able to cope with all these situations. To follow is a brief summary of the requirements of different fibre types and the typical scouring agents which might be employed.

8.2.5.1 *Wool.* Generally nonionics are used, largely replacing the traditional soap-based methods. Nonionics have the advantage that they are highly effective in neutral solutions, resulting in less damage to the wool. They are stable to hard water, and of relatively low cost. Scouring consists of a series of bowls containing surfactant and alkali; the concentration and temperature decreasing from the first bowl, 0.8% surfactant and 0.3% sodium carbonate at 50°C, to just water at 40°C.

8.2.5.2 *Cotton.* Like wool, cotton contains a significant proportion of extraneous matter, up to 12%, composed of waxes, protein, pectins, hemicellulose and ash. Cotton is, however, remarkably stable to strongly alkaline conditions, such treatments being an essential part of the preparation processes. Scouring treatments vary according to the equipment used but follow the general regime of 2–4% sodium hydroxide, 0.2% surfactant, 100–140°C and 2–360 min. Surfactants must be stable to such conditions, and fatty alkyl sulphates or

sulphonates are generally employed, often formulated to give both wetting and detergent characteristics. Sulphosuccinates, although excellent wetters, are avoided, since they readily hydrolyse under strongly alkaline conditions. The hydrophilic nature of a cellulosic surface also means that polar or hydrogen-bonding interactions with nonionic surfactants may result in an orientation of the surfactant on the fibre surface, thereby decreasing the soil-removing capability; in order to be effective a surfactant must orient itself with its hydrophobic tail in the oil phase and its hydrophilic head in the aqueous phase.

8.2.5.3 *Synthetic fibres.* Nylon and polyester are typically scoured with an alkyl ether sulphate-based products, although nonionics may be equally effective. Where a fibre is to be subsequently dyed with disperse dyestuffs, it is essential to scour with anionic surfactants, since nonionics, if carried over into the dye bath, may affect the stability of the dye dispersion. Acrylic fibres must be scoured with nonionic surfactants, and never with anionics, since any carry-over of anionic surfactants will affect the uptake of basic dyestuffs used on this fibre.

8.3 Enzymes

8.3.1 Introduction

There is a common misconception about the nature of enzymes, and this is perhaps reinforced by some of the terminology used when describing their action. Enzymes, despite their derivation from living materials, are not living organisms themselves. They are protein structures, of varying complexity, based on chains of amino acids linked by peptide linkages. There are a number of factors that may distinguish one enzyme from another, and these include the particular amino acids present, the order in which they are linked together, and the presence or absence of metal ions. Most important, however, is the conformation or shape of the protein structure. All enzymes are water-soluble; the amino acid chains are coiled in such a way that the hydrophobic portions are oriented inwards, allowing maximum hydrogen bonding intramolecularly and with water or other molecules. Indeed, water is an essential medium for the proper functioning of all enzymes. Enzymes are enormously effective catalysts which permit reactions, that under normal conditions would simply not occur, to proceed and at a greatly accelerated rate. They are true catalysts that are not consumed in the reaction, but provide a low-energy path for that reaction to proceed, and can then catalyse further reactions. Enzymes are highly specific and will catalyse only one reaction, without having any effect on the other components of a system.

Enzymes are present in all living organisms, where they serve to promote the reactions which are essential for life. They catalyse only very simple

reactions, which proceed in a stepwise fashion towards the final objective; no single enzyme is able to catalyse highly complex, multistage reactions. In this sense they can be likened to computers, which carry out complex mathematical operations by breaking them down to their most simple operations, and then carry these out at lightning speed. Thus, an enzyme will catalyse only a particular reaction, and the reaction path from A to B may involve a number of enzymes, each catalysing a particular step in the sequence.

The working environment of an enzyme is very important to its functioning. Most have very specific requirements for temperature and pH, for example; all require water. This is probably where analogies to living organisms creep in. Enzymes, for example, are said to be 'killed off' by extremes of heat or acidity/alkalinity, in the way that bacteria might be killed. However, this is simply not the case, and the enzyme is often only deactivated when encountering an environment outside of its normal working range. When conditions are brought back within this range, enzyme activity may well recommence. There are means of permanently disabling enzymes, but these involve destroying the structure itself, for example by removing the central metal ion from certain types of enzyme molecules.

Since enzymes are present in all living organisms, there is, in theory, a plentiful supply. However, the economics of extraction may be prohibitive, and nowadays enzymes are specially produced from bacterial or fungal species in large fermentation vessels, from which they are subsequently extracted. These micro-organisms produce their own enzymes, for example cellulases to enable them to live on cellulosic materials such as wood. In the past many enzymes were extracted from animal pancreases, a rich store of enzymes, but now too expensive. Another useful source is plant material, for example malted barley.

Enzymes can be classified according to their action, the important classes of which are listed below:

- Lipases, which hydrolyse fats and oils into alcohol and organic acids
- Proteases, which split protein molecules, and in the extreme may break the protein down into the component amino acids
- Amylases, which convert starch to shorter chain sugars
- Cellulases, which break down cellulosic materials
- Pectases, which hydrolyse pectins.

It should be remembered that enzymes are highly specific in their action and that, for example, there is not one amylase enzyme, but a variety each of which has a different part to play in the conversion of amylose to simpler compounds. For example, malt extracts contain at least two enzymes, α -amylase and β -amylase, which each have different functions.

An enzyme is very rarely, if ever, a pure material, and the classification given to an enzyme is often of necessity simply no more than the activity

ascribed for a particular application. Bacteria and fungi must produce a whole range of enzymes, for example cellulases to break down cellulose to glucose, each specific cellulase differing in its mode of action. An extracted 'cellulase enzyme' may contain from a few percent to eighty or more percent of various cellulases, and will undoubtedly have many other side-activities, for example, amylase activity. However, it is common practice to describe an enzyme preparation by the activity for which it has been assayed, even if it might equally be described as an amylase in different situations and for other applications.

8.3.2 *Enzymes in textile processing*

Although enzymes have been employed in textile processing for many years, there is currently renewed interest in the possible benefits offered by enzyme processing, and not just for the traditional desizing of cotton. Enzymes are becoming a relatively cost-effective, pollution-free means of treating cellulosic fabrics for dehairing, pill-preventing and handle modification (collectively, the so-called 'Biopolishing' technology, a trade mark of Novo Nordisk), as well as the well-known stonewashing applications. For wool fabrics, somewhat different enzymes can be used to dehair processed fabrics, and even to render wool shrinkproof. For the consumer, there are the 'biological' laundry powders and liquids which rely, in part, on the action of enzymes for their effectiveness.

The applications of enzymes in textile processing can now be considered in more detail.

8.3.3 *Desizing of cotton*

Desizing is an essential preliminary stage in the processing of cotton fabrics. The size itself may be natural (starch based) or synthetic (commonly poly(vinyl alcohol), PVA) in origin, and may be present with other materials such as paraffin waxes on the substrate. Waxes and synthetic water-soluble sizes are relatively easily removed from the fabric by scouring in warm water, and indeed would not respond to enzyme treatment alone.

Starch-based sizes are most frequently removed by enzymes, which have the advantage of not causing any physical chemical damage to the cotton. Although starch and cellulose are both composed of long chains of glucose units linked together, they are sufficiently different in the way that these units are linked that amylases have no effect on cellulose and cellulases no effect on starch.

Starch is a mixture of two similar carbohydrates of differing molecular size and shape, amylose and amylopectin. Amylose comprises about 20% of starch and is water-soluble; amylopectin, a branched, high molecular weight molecule which is largely responsible for the thickness of starch pastes, is insoluble. By mechanical action or treatment with hot water, starch can be

made to swell in water to form gel. Thus, in order to remove starch effectively from a fabric, it must first be rendered completely water-soluble. This may be accomplished by the action of bacterial amylases, which hydrolyse the starch molecules stepwise to dextrin (a polysaccharide), maltose (a disaccharide) and finally to the monosaccharide glucose, the simplest unit in the starch molecule. The progress of size removal can most conveniently be followed by iodine coloration; the unhydrolysed starch gives an intense purple–blue colour, while glucose gives no colour.

8.3.4 Biopolishing and stonewashing of cotton

Originally devised as a means of introducing a clean, smooth surface appearance and soft handle to woven cotton fabrics, biopolishing is now a widely promoted technology in all areas of cellulosic fabrics. The process is essentially a degradative action, resulting in a loss of both weight and strength of the fabric, although these losses are only moderate, and are kept under control by proper operation of the processes. Stonewashing is a specific, more severe form of cellulase treatment that is restricted to vat-dyed fabrics, particularly denim. The general principles underlying each treatment are essentially similar, however, and they are considered together.

Cotton is composed almost entirely of pure cellulose, an insoluble linear chain made up of linked glucose units, of at least 1500 units length. It differs from starch in the way that these units are linked together. The cellulose chains also show hydrogen bonding between the chains to form fibres. Cotton forms both highly ordered, crystalline regions and amorphous regions.

Most commercial cellulases are derived from the fungal *Trichoderma* and *Penicillium* species. They may be produced both in powdered forms (often adsorbed on a support medium) and as concentrated liquids, typically 25% active in brine, for stability. It has already been said that there are many highly catalytic actions within a 'single' enzyme preparation. For cellulases, there are four main actions, each of which may be represented by a number of individual cellulases:

- Endocellulases cleave the long cellulose chains randomly to produce two shorter chains
- Exocellulases attack one end of the cellulose chain, cleaving one glucose unit at a time
- Cellobiohydrolases similarly act on one end of the cellulose chain, producing a cellobiose molecule
- Cellobioases degrade cellobiose molecules to the simplest glucose unit.

These actions are illustrated in Figure 8.3.

Because of the highly specific nature of enzyme activity, the effectiveness of enzyme preparations may vary widely, and it is essential to carry out proper dosage trials with any product. It should always be remembered that 'cellulase' is a collective name for a whole host of activities within a single

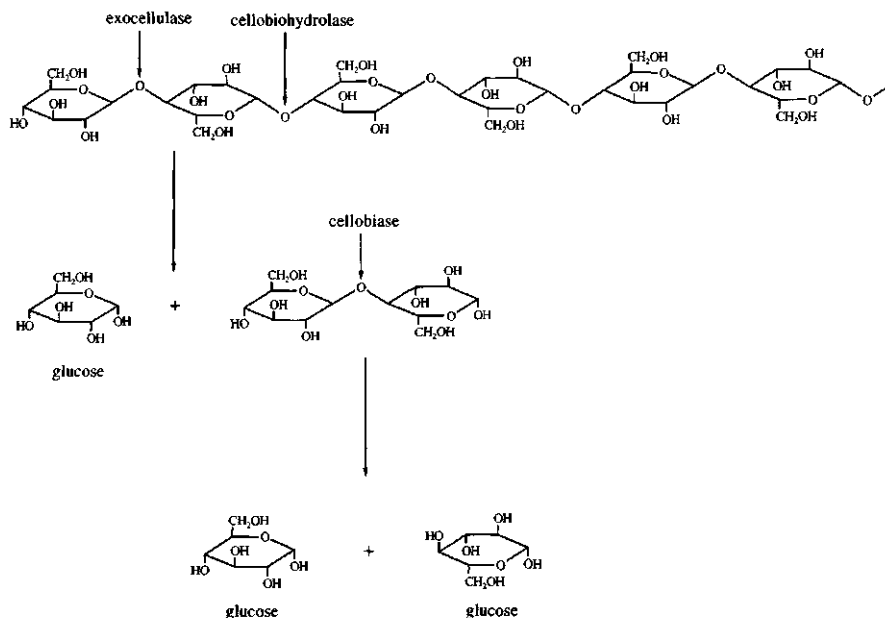


Figure 8.3 The actions of cellulase enzymes on a cellulose molecule.

preparation. Claims of total cellulase activity should always be closely scrutinised since the activity may relate to degradation of carboxymethylcellulose, a water-soluble derivative, quite dissimilar to cotton. To be meaningful for cotton processing, the enzyme should be assayed for activity on a substrate which more closely resembles cotton, such as filter paper or avicel, or preferably cotton itself.

The mechanisms of cellulase degradation of cotton are still not fully elucidated, but it appears that the first step involves attack by an endocellulase, which attaches itself to the cellulose surface, forming a complex. After cleaving a glucose unit the enzyme molecule may detach itself and move to another site, or may remain to degrade the same site further. Whether it moves to a fresh site or not may be governed by the nature of the cellulase, and even the fibre structure. The cellulase molecule itself has been found to be comprised of three identifiable regions: a *binding domain* which facilitates attachment to the cellulose molecule, a *core* which is the catalytic centre and a *linker*, which bridges these two regions.

8.3.4.1 Operating conditions. As with all enzymes, cellulases exhibit optimum properties within fairly narrow limits of pH and temperature. With regards to pH, there are two classes, the 'acid cellulases' which operate at pH around 4.5–5.5, and the 'neutral cellulases' which operate around pH 5.5–8.0. The acid cellulases also tend to have a slightly lower temperature range (45–55°C)

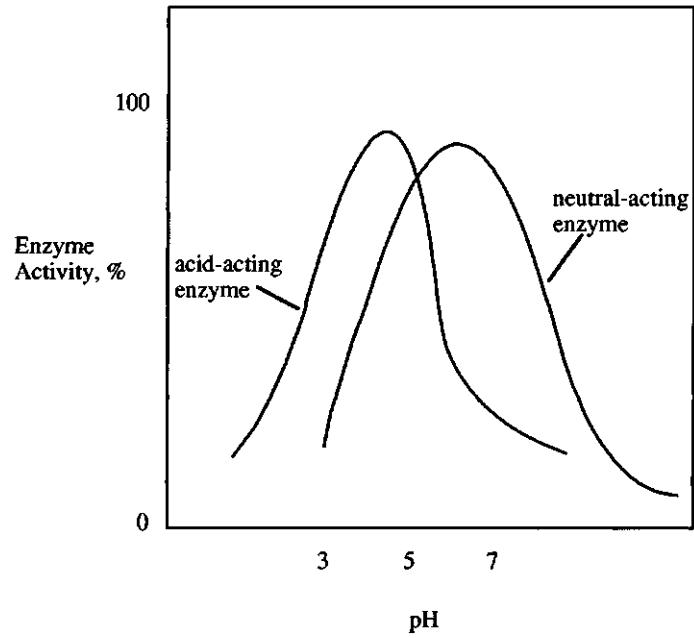


Figure 8.4 The influence of pH on the activity of cellulase enzymes.

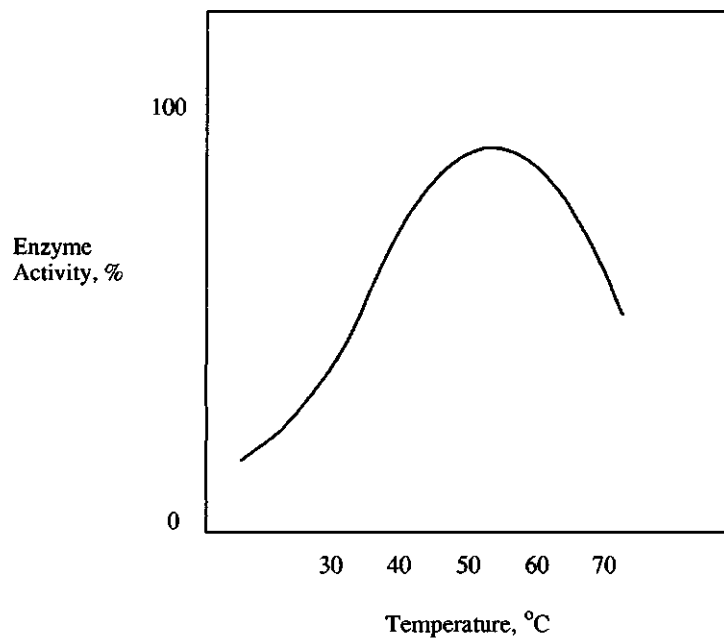


Figure 8.5 The influence of temperature on the activity of a cellulase enzyme.

than the neutral acting cellulases (50–60°C) (see Figures 8.4 and 8.5). The acid enzymes are available from a number of producers using various fungal strains, and will thus vary in effectiveness; neutral enzymes are currently produced exclusively by one manufacturer.

In stonewashing, the type of enzyme chosen has an important bearing on the process. Stonewashing effects as achieved by pumice stones can be duplicated by the action of cellulases which artificially 'age' the fabric by chemically degrading the cotton and thereby releasing indigo dye particles, giving an abraded, washed-out look. Cellulases may be used either in conjunction with a reduced load of stone or alone in a stoneless process. Acid enzymes are faster acting, and more aggressive, resulting in more chemical abrasion and resultant loss of fabric strength. Since the process is carried out under acid conditions, dyestuff redeposition is likely, giving backstaining on the reverse side of the fabric and less defined 'pinpoints' on the face side. By contrast, neutral enzymes are less aggressive, require longer cycle times, but give no backstaining.

8.3.5 *Wool processing*

One of the primary end-uses for enzymes in wool processing is to render the fibre shrink-resistant. Wool fabrics, both knitted and woven, have a natural tendency to shrink irreversibly unless treated; all current large-scale commercial anti-shrink processes for wool rely on a chemical modification of the wool fibre, in the majority of cases by the use of chlorine or permonosulphuric acid. This aspect is discussed in greater detail in chapter 6. Over many years a great deal of research has been directed toward the use of enzymes as anti-shrink treatments, these being seen as environmentally much cleaner than chemical processing, but to date the success in conferring worthwhile levels of shrink-resistance has been low.

Enzymes which act on wool (and proteins in general) are known as proteases. Like the cellulases, proteases are members of the class of enzymes known as hydrolases, that is, they catalyse hydrolysis reactions. As with cotton processing using cellulases, there are highly specific requirements for temperature and pH when processing wool with enzymes. Proteases attack polypeptide (protein) chains at the peptide (amide, CONH) linkage, giving rise to an organic acid and an amine. Again, as with cellulases, there are endoproteases which attack any peptide linkage in the chain and exoproteases which act only on the terminal linkage in each chain. However, in comparison with cellulose, proteins are relatively resistant to enzyme attack, and complete degradation to a protein fibre such as wool must usually be preceded by some form of denaturing.

Of course, there is a significant difference in the structure of wool compared with that of cotton. As mentioned above, cotton is composed solely of glucose molecules joined in a specific manner; wool, on the other hand, is composed

of many amino acids in varying proportions depending upon both histology and the source of the wool fibre. Whereas cellulases always act on the β -1,4-glucosidic linkage between glucose molecules in the chain, proteases are much more selective in the exact linkage attacked. This is related to the spatial requirements of the enzyme protein—it was previously said that the conformation or shape of an enzyme structure is important to its functioning, and indeed enzymes can be thought of as acting like a key in a lock.

The specificity of proteases is seen in the hydrolysis of only those peptide links which satisfy the exact conformation of the enzyme. Indeed, by choosing proteases of closely controlled specificity it is possible to cleave a protein molecule effectively, and this has been used as a standard method of protein characterisation for many years. Thus, proteases for wool can be classified according to their action on particular peptide linkages, for example:

- Trypsin acts on lysine and arginine sites, at pH 7–9
- Chymotrypsin acts chiefly on tyrosine, phenylalanine, tryptophan and leucine, at pH 7–9
- Pepsin acts on linkages with an aromatic side chain at a much lower pH in the range 1.5–2
- A number of other less specific enzymes have activities in the pH range 5–8.5.

Enzyme attack on wool fibres results in loss of strength and weight; in extreme cases, up to 15% weight loss is seen. It is important therefore to select enzyme activity carefully, and to optimise reaction conditions (temperature, pH, enzyme concentration) such that the desired effect (for example, shrink-resistance or dehairing) is achieved without undue damage. However, one of the main considerations in the use of enzymes for the shrink-resist processing of the wool is the levelness of the treatment. Electron microscopic studies of wool fibres treated with enzymes show that some fibres are poorly treated while others are massively overtreated, with visible damage to the fibre cortex. In general, attack is related directly to enzyme concentration.

8.4 Softeners

8.4.1 Introduction

The processing of textiles to achieve a particular ‘handle’ or softness is one of the most important aspects of finishing technology. Very few fabrics with which people have contact are left in their natural state, and this includes not only apparel, but also, for example, furnishing fabrics. The exact nature of the finish to be applied may depend on any one of a number of factors, such as function, fashion or individual preference, and of course what is acceptable to one customer may be unacceptable to another.

The measurement of softness or handle is still largely a subjective decision on the part of the assessor, although there are some systems that are able

to give some objective measure of the performance of a softener (these are described in section 8.4.3). The terms used when evaluating a softener tend therefore to be rather descriptive, attempting to convey an impression rather than hard fact; for example, 'dry' or 'greasy'; 'crisp', 'natural', 'warm'; and so on.

The basic function of a softener, then, is to impart a particular handle to a textile surface. This may be required to overcome the naturally harsh feel of the fabric (for example, linen), or to disguise harshness imparted by chemical processing of the fabric (for example, application of crease-resist resins to cottons). Alternatively, a softener may be applied simply to alter the handle for reasons of fashion. The range of materials that can be used as softeners is vast, but a relatively small number of basic chemical types are commonly in use. These are described in more detail in section 8.4.2.

It should be remembered that the performance of a softener will be altered by the nature of the substrate to which it is applied. This does not simply mean that, for example, the same softener will have a different feel on cotton and nylon; even on the same fibre, the handle may be different. The fabric construction is obviously important, and factors such as yarn fineness, yarn density, etc. in the fabric will play an important part in the overall impression of the feel of the fabric. In addition, the mechanical finishing of the fabric may alter the handle to a greater extent than will the application of a softener.

The durability of the softener should be taken into account. It is common to use fabric conditioners in the rinse cycle of domestic washing machines, therefore a durable effect from the mill-applied softener is perhaps unnecessary. What is then important is the point-of-sale handle; the softener is applied in order to make the garment or fabric feel more appealing, and so to encourage customers to make a purchase. Perhaps the most extreme example of this is the use of silicones in towels. Silicone softeners give a very soft, luxuriant handle to even the cheapest towel, but by their nature are hydrophobic, rendering the towel almost useless until the softener has been removed by washing.

The handle of a fabric may not be the only consideration in determining the 'comfort', particularly for fabrics which are in direct contact with the skin. In this category we can include underwear, sportswear and bedlinen. The most important properties a softener can impart to these fabrics is hydrophilicity and an ability to wick moisture away. Although not strictly concerned with the softness of the fabric, the softener plays an important role in maintaining the correct, comfortable environment close to the skin. A hydrophobic fabric of extreme softness is of no value in these situations, since moisture is allowed to build up as a film between the skin and the fabric, making the wearer sweaty and uncomfortable.

Softeners often have a multifunctional nature, depending upon chemical type. All quaternary ammonium containing softeners will show a degree of antistatic behaviour, for example; long-chain fatty acid-based materials may show yarn lubricating properties. Softeners may yield hydrophilic or hydrophobic

finishes, either of which may be beneficial in different circumstances. Others may show some anti-soiling behaviour.

8.4.2 Softener types

Softeners can be grouped under a number of general headings. Each of these chemical types will be considered separately.

8.4.2.1 Oils and waxes. Although oils have largely been replaced as softeners for fabrics, they were once widely used, in the form of water-dispersible emulsions. Waxes are, however, still widely used, most commonly paraffin- or polyethylene-based. The waxes are manufactured and sold as emulsions in water, containing a proportion of surfactant. Paraffin wax emulsions tend to be sold as anionic formulations, and, as such, must be applied by padding techniques, since they will not exhaust. These materials will also act as effective lubricants during processing.

Polyethylene waxes may be produced as cationic, nonionic and anionic emulsions, although only the cationic and nonionic forms are encountered in textile processing. They also give good lubricating properties, and are often incorporated into formulations specifically to improve sewability of fabrics. They impart a rather greasy, full handle to fabrics, and are widely used on cotton and cotton-blend fabrics, especially twills and poplins. The durability of these waxes is not high, but can be improved by using a higher molecular weight wax.

8.4.2.2 Cationic softeners. This probably comprises the largest and most important group of softeners currently in use. Whilst many softeners have a cationic nature (for example, certain silicones and cationic polyethylene emulsions, mentioned in section 8.4.1); included in this group are the true cationic materials which contain a positive nitrogen atom in the structure. Perhaps the simplest, and certainly the cheapest and most widely available of this type, is dimethyldistearylammonium methosulphate (Figure 8.6).

Some of these types are based on the ethosulphate ($\text{SO}_4^- \text{CH}_2\text{CH}_3$) or chloride (Cl^-). The ethosulphates are less common, while the chlorides are not favoured in industrial use because of the more corrosive nature of the chloride ion. These materials are hard waxes with relatively low melting points and can be dissolved in water. Because they contain a quaternary

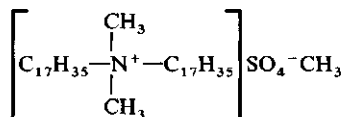


Figure 8.6 Dimethyldistearylammonium methosulphate.

ammonium ion, they show mild antistatic properties, and tend to be fairly hydrophobic as a consequence of their waxy nature.

The properties of these materials can be improved by modifying the structure, most commonly by replacing one or more of the methyl groups by ethoxylate chains, and/or by altering the nature of the fatty chains. Any such change will increase the cost of the material, but does give rise to a softener more suited to industrial application than the simple structures, which tend to be used for domestic softeners. The hydrophilicity of the softener on the fabric increases as a result of the presence of the ethoxylate groups, and the antistatic behaviour may also increase because of the molecule's ability to retain moisture, and so conduct static electrical charge. The use of 'hardened' fatty chains (that is not containing an unsaturated C=C group), gives rise to a less waxy, stiffer handle. In addition, the length of the fatty chain can be increased, although this tends to lead to a decrease in solubility (Figure 8.7). These types also show a moderate durability to domestic laundering. It is common to prepare an emulsion of these softener types, using a nonionic surfactant as emulsifier.

Lastly in this group are the imidazoline softeners (Figure 8.8), although these are less common than the above types.

Under the heading of cationic softeners are also grouped the wax emulsions based on the condensation of a fatty acid and an amine. The reaction between an acid and an amine results in an amide (Figure 8.9). Often a polyamide

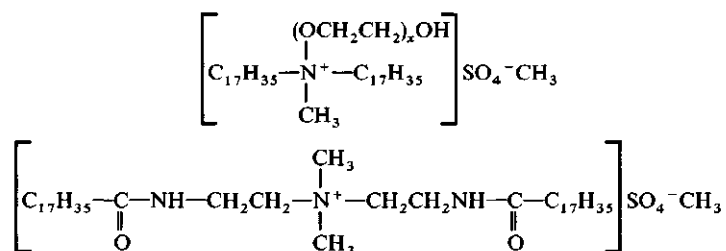


Figure 8.7 Increase in the length of the fatty chain of ethosulphates leads to a decrease in the solubility.

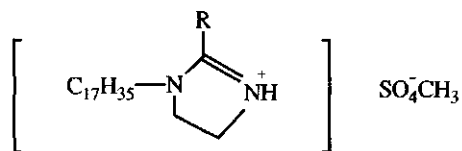


Figure 8.8 Imidazoline softener.

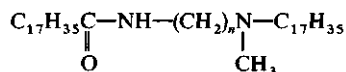


Figure 8.9 Amide softener.

such as diethylene triamine is used, resulting in a higher molecular weight. These materials are made cationic by virtue of their manufacture as acidic solutions, as which they are more stable. Wax emulsions tend to be hard waxes of relatively high melting point, which are dispersed in water with a suitable surfactant. They give a very lofty, waxy handle to many fibre types, and are the real workhorses of industrial softening. They are relatively hydrophobic and show no durability, being readily removed on laundering.

8.4.2.3 Silicone softeners. Probably the most widely used softener types in recent years are the silicones. The structures available are diverse, yet are all based on the same Si—O backbone. The simplest silicone softener is polydimethylsiloxane (PDMS, Figure 8.10), which is available as an oily material in the molecular weight range from about 1000 to 1 000 000 or more. These materials are emulsifiable in water and can then be applied to fabrics where they give a characteristically soft but greasy handle. They are also used as lubricants applied to sewing threads. The softeners have no real affinity to textile surfaces, and so must be applied by non-exhaustive techniques. Since they are not reactive materials, they have no durability to fabrics, and are readily removed by laundering. Better durability can be obtained by incorporating reactive groups on the simple molecules; most commonly, the silicone contains a terminal hydroxyl or other reactive group which reacts readily with a silane catalyst (Figure 8.11). The catalyst acts as a crosslinking agent between siloxane chains, so giving rise to an elastomeric structure, which might advantageously offer other benefits as well as softness. For example water and soil repellency are common features of these elastomeric finishes.

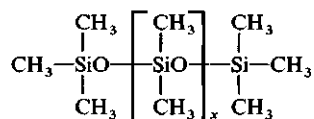


Figure 8.10 Polydimethylsiloxane (PDMS).

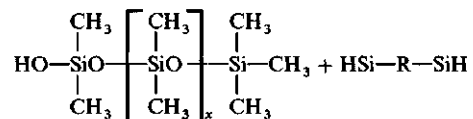


Figure 8.11 Incorporation of a reactive group on to a silicone softener using a silane catalyst.

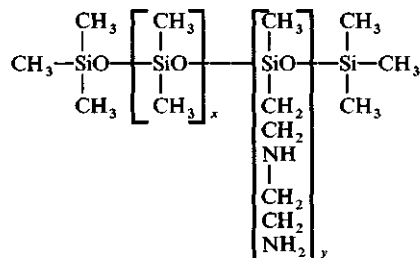


Figure 8.12 Aminofunctional softener.

Of the silicone softeners available, perhaps the most common in current industrial usage are the aminofunctional types (Figure 8.12). These materials offer a range of handles depending on the relative size of x and the ratio of $x:y$. They may be supplied as surfactant-stabilised emulsions in water, either mechanical or microemulsions. Mechanical emulsions contain large droplets which tend to coalesce on the fabric, giving surface effects. The microemulsions, of much smaller droplet size, will tend to migrate into the yarn and give an overall softness to the whole structure.

The aminosilicones may give a relatively dry handle where the $x:y$ ratio is high, and a typically greasy handle where the $x:y$ ratio is low. Because of the presence of the amino group, they tend to be of a mildly cationic nature (in acidic solutions for stability) and will therefore readily exhaust on to fibre surfaces. The amino group also results in a propensity to yellowing, particularly during curing or drying, and the likelihood of yellowing increases with increasing amino content.

A recent development is the introduction of related silicones containing not an amino group but an amide group (Figure 8.13). The benefits of these softeners are that they are essentially non-yellowing, and that the handle is very dry when compared to even the low-amine aminosilicones.

8.4.2.4 *Miscellaneous softeners.* The structures described in the previous sections form the majority of softener types in common usage in the textile

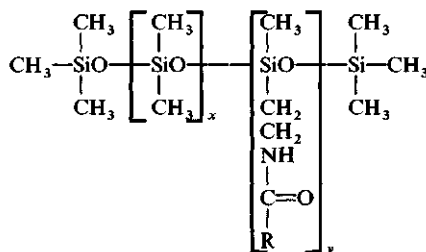


Figure 8.13 Silicone softener containing an amide group.

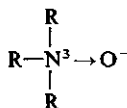


Figure 8.14 Long-chain amine oxide softener.

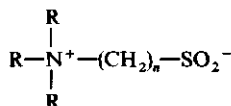


Figure 8.15 Sulphobetaine softener.

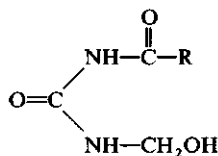


Figure 8.16 Softener for use with crease-resist resins.

field, but other types are also available. These other types tend to be more expensive, however, or are used only in specialised fields. Amongst these miscellaneous softeners can be included the amphoteric types, such as long-chain amine oxides (Figure 8.14) and sulphobetaines (Figure 8.15). There is also a class of reactive softeners useful in combination with crease-resist resins on cotton (Figure 8.16). These are essentially of similar chemistry to many crease-resist resins, in that they contain the *N*-methylol group, which requires an acid catalyst and baking to effect a crosslinking reaction. They are, however, conveniently applied with crease-resist resins via a padding operation. At higher application levels these reactive hydrophobes impart water repellency.

8.4.3 Mechanical measurement of fabric properties

The physical properties of a fabric are relatively easy to measure; the tensile strength, tear strength, bursting strength, etc. are all conveniently measured by various mechanical testing machines. However, while these methods have their value in determining fabric quality, they are all destructive methods, and represent extremes of wear. When evaluating fabric handle, we are largely dependent on the subjective opinions of the assessors, although the human fingers are remarkably sensitive to the small nuances of 'feel'.

Fabric handle may be considered to be related directly to factors such as the compressibility and frictional behaviour of a given fabric type. Other

properties of the fabric are related to the tensile properties (extensibility) and shearing and bending properties (drape), for example. It would therefore be convenient to be able to compare such fabric characteristics by these readily measurable properties.

Extending this idea further, it would be useful to be able to measure the performance of a fabric under conditions more typical of actual wear. Such a system would measure the response of a fabric surface to small stresses, far lower than those imposed in traditional destructive testing, and more typical of the stresses normally encountered. The Kawabata KES-FB system (actually a series of four different instruments) measures six different fabric properties. From these, sixteen different parameters, relating to fabric processibility and wearability, may be measured or derived (Table 8.4). The biggest drawback with this system, however, is the extreme complexity and cost. Other systems are available, for example, the FAST (Fabric Assurance by Simple Testing) system developed by CSIRO, which is a simpler system than the Kawabata. A recent development is the use of an Instron universal testing machine, such as is commonly available in textile testing laboratories for measuring similar properties. These alternative systems provide similar information but by reducing the number and type of measurements, they are perhaps better suited to more routine use.

Table 8.4 Fabric properties and parameters measured by Kawabata

| Property | Parameter |
|-------------|--|
| Bending | Bending rigidity Hysteresis of bending moment |
| Surface | Coefficient of friction Geometrical roughness Mean deviation of MIU |
| Tensile | Linearity of tensile curve Tensile energy Tensile resilience |
| Shearing | Shear stiffness Hysteresis at 0.5° Hysteresis at 5° |
| Compression | Linearity of compression curve Compressional energy Compressional resilience |
| Thickness | Fabric thickness |
| (Weight) | (Fabric weight) |

Note: Fabric weight is measured on a balance, not on the Kawabata system.

With careful interpretation of the results obtained, all of these systems can yield useful information on the characteristics of a fabric, clearly defining differences resulting from yarn type (natural or synthetic, staple or single filament), construction (fabric weight, yarn count, weave) and the application of various finishes.

8.5 Mercerisation

In 1850 John Mercer discovered that cotton immersed in sodium hydroxide swelled and shrank. The alkali treatment converts the fibre's crystalline structure from cellulose I to the cellulose II form (see section 1.2.1.2). The commercial benefits of mercerisation are improved lustre through a more circular fibre cross-section; improved softness, strength and dyeability; and easy care properties. Typical processing conditions are 200 g/l sodium hydroxide, 10–20°C, 30–180 s immersion and tension to enhance lustre. Liquid ammonia can also be used to mercerise cotton.

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