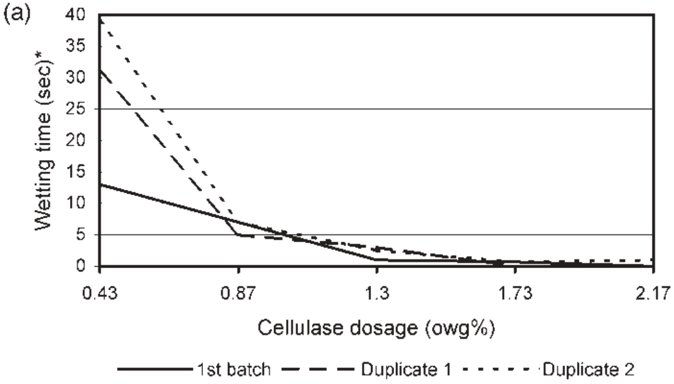
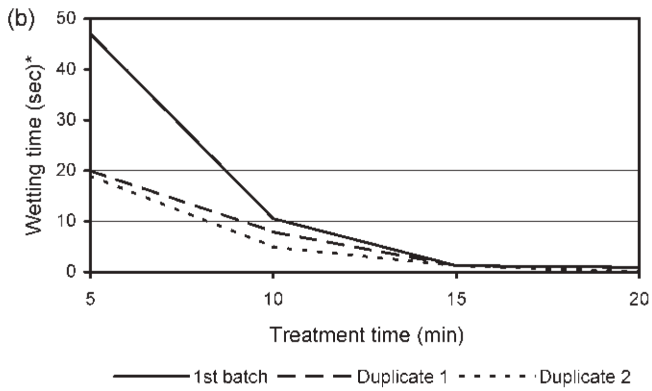
Appendix

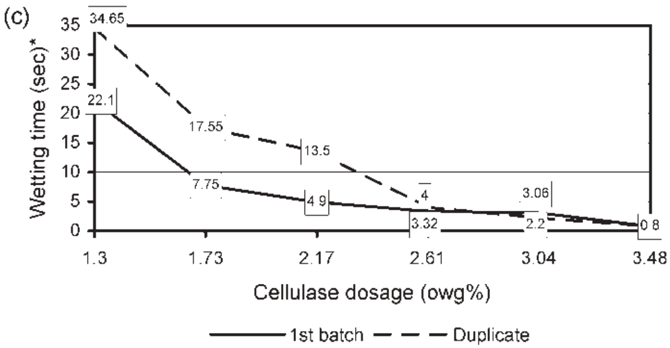
Section 1 Cotton scouring with enzymes

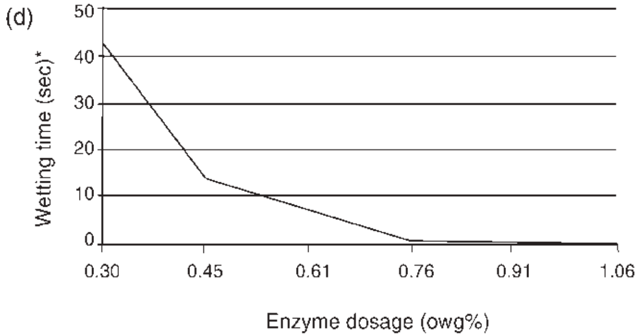
The addition of enzymes to enhance the effectiveness of scouring operations while minimising the environmental load, as mentioned in Chapter 5, occurs under conditions such as those specified by Li and Hardin.[1] These include the use of a surfactant with mechanical agitation and require careful selection of the optimum enzyme for commercial success. Figure A.1 gives comparative data on the effects on wetting time of dosage and treatment time for various enzymes. Calafell *et al.*[2] specify optimum temperature, pH and surfactant conditions to reduce the use of raw materials, pollution production and energy consumption, all important and desirable traits. Manian[3] recommends fine tuning of the time and temperature of a scouring bath to give the optimum wetting and scouring conditions for removing products of enzymatic hydrolysis. Traore and Buschle-Diller[4] scour cotton with enzymes instead of sodium hydroxide as an environmentally friendly step. They investigate several enzymes, alone or in combination, under different conditions, and include the effects of agitation as a variable. They then measure absorbency, whiteness, mechanical properties and the level of impurities remaining, obtaining optimum results with the best combination of enzymes, pectinase with lipase and cellulase. Agitation is not important, subsequent dyeing is uniform in all cases, whiteness is slightly enhanced and all trials yield a softer fabric except when cellulase is present.

Sawada *et al.*[5] propose bioscouring using pectinase enzyme with a multiple mixture of surfactants and D-limonene as assistants, for cotton scouring that is as good as, or better than, that resulting from the conventional alkaline scouring process. Figures A-2 and A-3 give an indication of the weight loss and changes in methylene blue value as a function of scouring time, with and without enzymes and surfactants. Subsequently, Sawada *et al.*[6] express the belief that scouring in a non-aqueous medium using a pectinase enzyme has great potential. They find that enzyme activity is still excellent in the absence of water and that the results are equal to or better than those obtained in an alkaline scour. Figure A.4 provides a

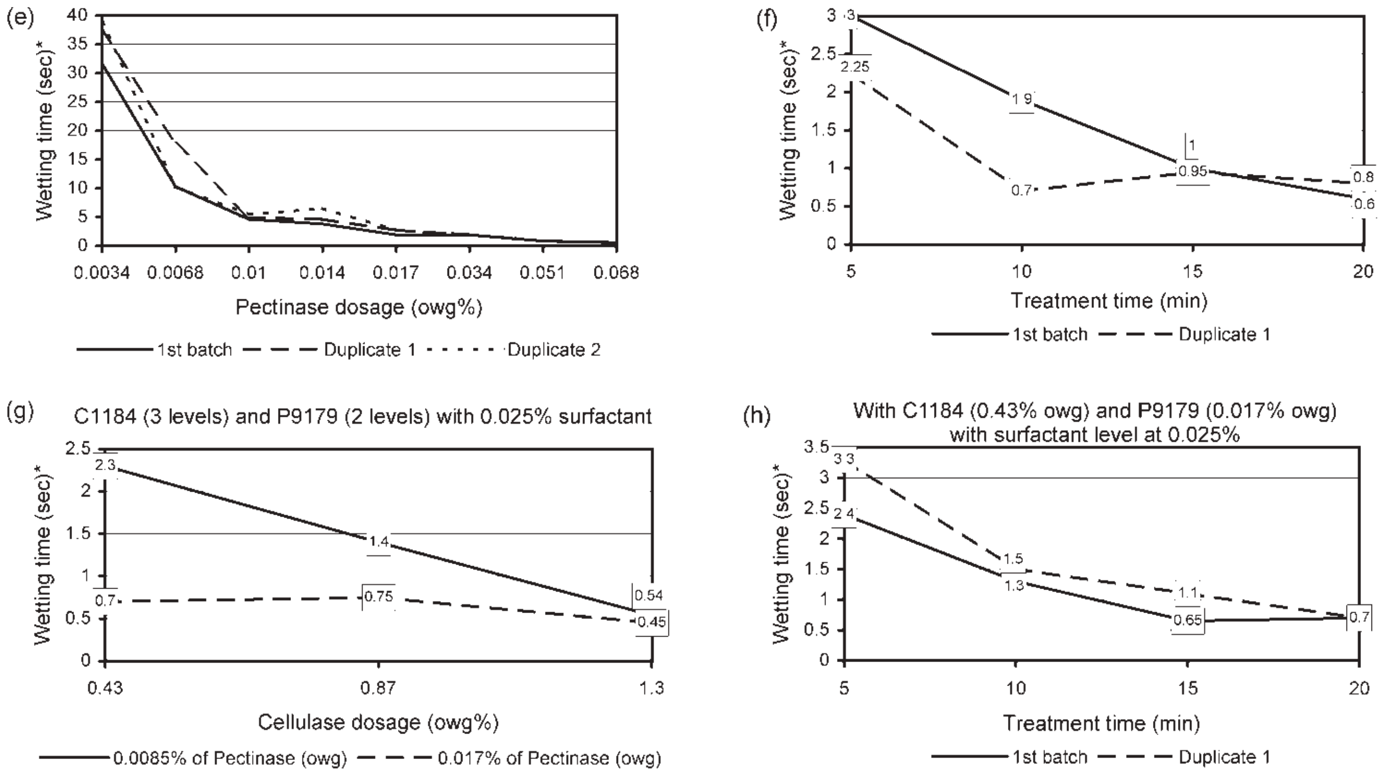






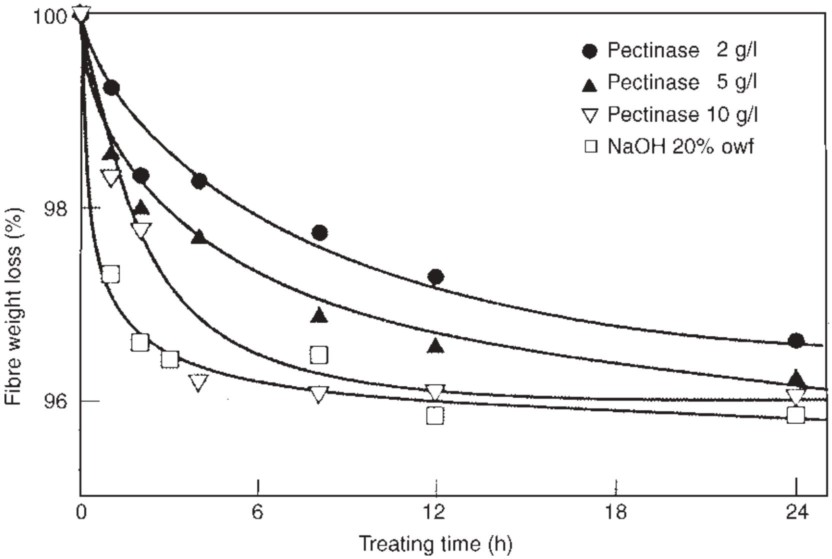


*The average wetting time of the controls is about 10 minutes

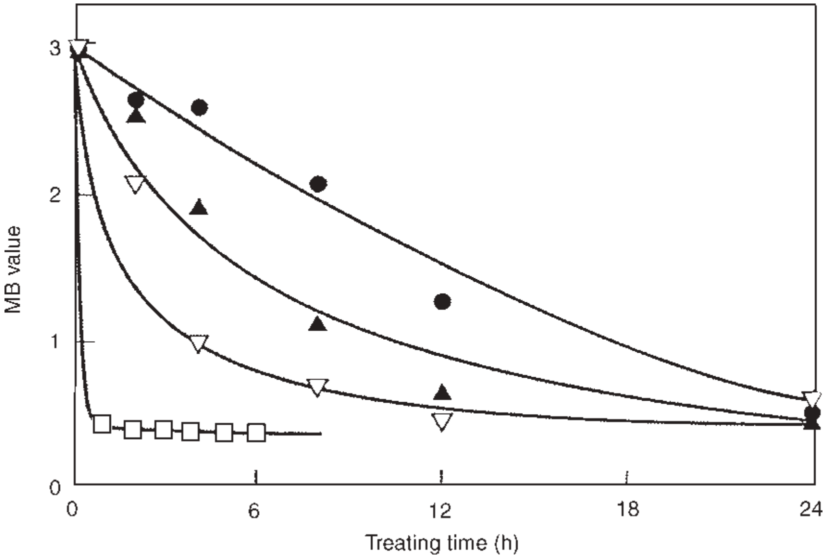


*The average wetting time of the controls is about 10 minutes

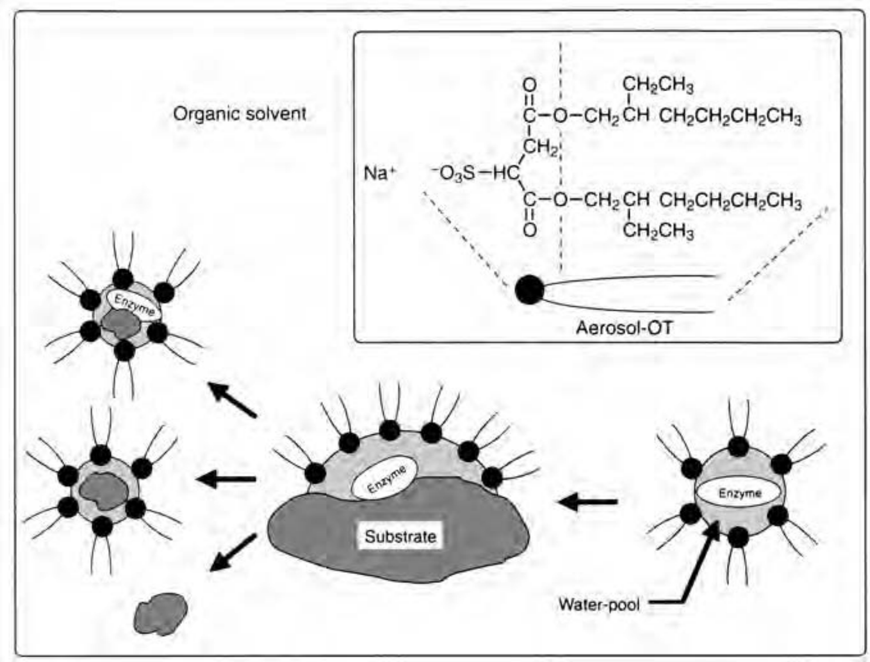
A.1 Effect of enzyme dosage and treatment time for various enzymes on wetting time of knitted fabrics; owg = onweight of goods (source: *Textile Chemist and Colorist*, Vol **30**, No 9, September 1998, pp 23–29; reprinted with permission from AATCC).



A.2 Comparison of weight losses in conventional and enzymatic scouring of raw cotton; owf = onweight of fibres (source: *JSDC* **114** (1998), p 334. Reprinted with permission from the publisher, the Society of Dyers and Colourists, Bradford, UK).



A.3 Comparison of methylene blue values in conventional and enzymatic scouring of raw cotton. For key see Fig. A.2 (source: *JSDC* **114** (1998), p 334. Reprinted with permission from the publisher, the Society of Dyers and Colourists, Bradford, UK).

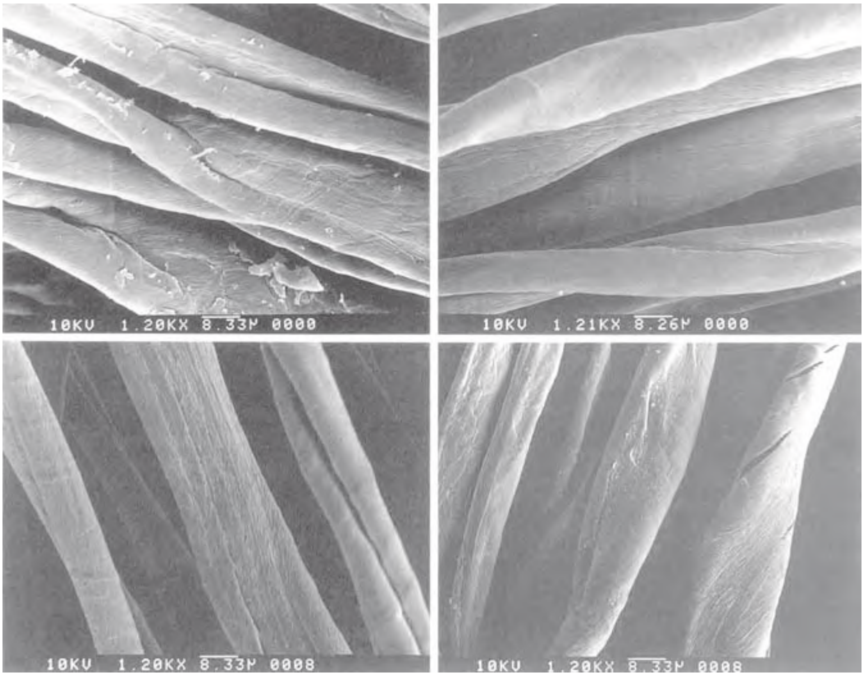


A.4 Principles of operation of enzymatic scouring (source: *JSDC* **114** (1998), p 356. Reprinted with permission from the publisher, the Society of Dyers and Colourists, Bradford, UK).

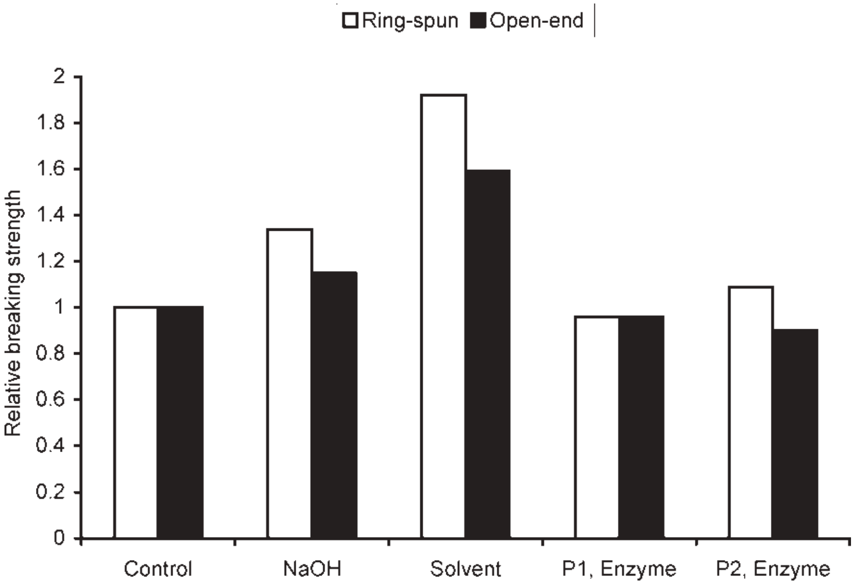
schematic diagram illustrating the principle of operation of enzymatic scouring. Buschle-Diller *et al.*[7] compare the scouring methods (sodium hydroxide, organic solvent and pectinase), finding that the first gives best whitening, the second highest tensile strength, and the third the softest yarns. They also note differences between open-end-spun and ring-spun yarns, concluding that yarn structure may have some effect. Figure A.5 allows a comparison to be made between the surface features induced by caustic, solvent and enzymatic scouring, while measurements of tensile strength given by the authors to justify their conclusions are illustrated in Fig. A.6. Etters *et al.*[8] extend the above findings to some extent, because they find that alkaline pectinase gives a softer fibre, better water absorption, cleaner effluent and lower costs in the cotton preparation process overall.

Section 2 Wool scouring with enzymes

The alkaline treatment of wool for cleaning purposes, also discussed briefly in Chapter 5, is described by a number of authors. Gacen and Cayuela[9] bleach merino wool tops with hydrogen peroxide in acid and alkaline media at various concentrations of the peroxide, finding that the alkaline conditions produce wool that has better whiteness but is more easily attacked chemically. In recent years, the ability



A.5 Effects of caustic, solvent and enzymatic scouring on scanning electron microscope (SEM) surface features of cotton fibres (source: ref. 7).



A.6 Tensile strength changes induced by various types of scouring of ring-spun and open-end-spun cotton yarns (source: ref. 7).

of enzymes to improve this situation, by eliminating (or lowering the quantity of) the alkali needed has been noted. Heine *et al.*[10] are in the process of testing whether enzymes can reduce the mechanical stability of vegetable matter, such as cellulose, pectin or lignin, to enable its removal to be accomplished merely by shaking, without damaging the wool or lowering dyeing quality. Other suggestions to improve the cleaning operation are reported. They include one by Neyers *et al.*[11] to adapt complexing agents to compensate for the greying of wool by the presence of iron ions from contact with machinery. In a second one, Schafer *et al.*[12] suggest different types of adsorbents (such as silica gel, diatomaceous earth, zeolite, alumina, Fuller's earth, sodium carboxymethylcellulose and bentonite) for the removal of residual dirt. Kasztelnik[13] compares the advantages and costs of solvent scouring of wool with the conventional alkaline one. Lennox-Kerr[14] describes a new system of wool scouring with much lower water usage, based on partial liquefaction of contaminating greases, with their subsequent absorption and separation. An anonymous writer[15] reports an environmentally sound scour in which there is total recycling of effluent, with no pretreatment; a heat exchange arrangement is used to evaporate liquid and the effluent itself is converted to a high-solid state by forced-circulation passes. Another writer[16] reports a scouring process that can remove pesticides, as well as dirt and grease, from waste water, in a system without the need for halogen-containing compounds.

Section 3 Bleaching with peroxide

Chapter 5 mentions the need to stabilise peroxide as a bleaching agent to enhance its effectiveness and this topic receives the attention of a few research workers. Chakrabarty *et al.*,[17] working with knitted fabrics and noting that stabilisers can be used to improve peroxide bleaching of cotton, find that non-silicate ones are preferred to silicate ones because they yield a softer yarn with no adverse effect on dye uniformity. Sekar[18] reviews developments in peroxide bleaching, noting that some fibre damage can occur with this reagent, and proposes the use of peracetic acid for bleaching cotton. Chattopadhyaya *et al.*[19] agree, recommending substituting this reagent for conventional peroxide or hypochlorite ones, because it is so much more ecofriendly and favour the use of a non-silicate organic stabiliser once more. The net effect is improved whiteness, with less loss of tensile strength and abrasion resistance, accompanied by increased softness, but the product is still susceptible to photoyellowing on exposure to sunlight. Deo and Wasif[20] suggest changes in the formulation to allow bleaching of polyester/cotton blends in a manner that can save steam, energy and water while being more ecofriendly and avoiding the production of toxic compounds from chlorine bleach decomposition. The advantages include lower consumption of chemicals, lower effluent load and hence a reduction in biological and chemical oxygen demand.

Section 4 Sizing and desizing

Work on sizing and desizing operations, introduced briefly in Chapter 6, is described by a number of authors. Sizing attracts the attention of Thomas,[21] who focuses on the reduction or disposal of waste chemicals and provides lists of undesirable sizing materials. He also reviews important relevant topics, such as alternative sizing methods, yarn tension control, warp preparation and quality issues. Perkins[22] describes the basic principles of the sizing and desizing stages, including details of recent innovations. Hyrenbach[23] stresses that new demands on sizing for environmental constraints, new fibres and new spinning or weaving technologies mean that some evolution in the process of sizing is critical. Trauter *et al.*[24] survey sizing work, including prewetting, pretreatments, chimgel sizing and expert systems that provide potential savings in size use, then recommend the use of starch/PVA (polyvinyl alcohol) blends of size. New compositions are reported by Vasil'eva *et al.*[25] that enhance mechanical properties by combining the size with easy-care and shrink-resistant finishing to save energy and materials. Chen *et al.*[26] assess the effects of CPI (corn-protein isolate) starch on the mechanical properties (size penetration, tensile strength, elongation and bending flexibility) of sized yarns critical to weavability, in comparison with those resulting from the use of commercial starch or PVA sizes. They show scanning electron microscope pictures of the way in which the three reagents penetrate into yarns and fibres. Penetration into yarns is virtually 100% for PVA and 27% for the commercial starch, but only about 17% for CPI. Nevertheless, because fibre penetration is higher for CPI than for the other two starches, the bending rigidity with the CPI (though less than that for the PVA-treated material) is greater than that achieved with the commercial starch. The authors find that their new formulation produces yarns that, in addition to being stiffer than those with starch (but comparable to PVA-treated ones), suffer less impairment of elongation than in the current treatment methods, with improved yarn surface properties. Frontczac-Wasiak *et al.*[27] propose using casein grafted with ethyl acrylate as a size for rotor-spun cotton, wet-spun linen, silk and woollen yarns. This combination can be used without auxiliary agents and tests carried out before and after sizing indicate the strong possibility of its potential usefulness in commercial applications.

When attention is turned to desizing, there are again some interesting papers in the literature. Jakob[28] describes the process, giving a range of variables and some possible ways of improving its effectiveness. Patra and Chattopadhyay[29] mention enzymatic desizing in an article dealing with the benefits of various treatments, including also pectin removal and silk degumming, with information on acidic, neutral and alkaline conditions for the elimination of cellulases. Nalankilli[30] feels that the use of an enzyme for desizing is more effective and economical than using inorganic acids or alkalis, as well as being much safer. The article describes uses in defuzzing apparel knits, scouring cotton fabrics and biowashing denims.

An anonymous author[31] lists a range of new sizes, including some operating at low or high temperatures, with special mention of a subgroup for the vital (to today's consumers) process of stone-washing jeans. Mention is also made of dyebath lubricants that prevent creasing and abrasion while lowering the need for washing off in cellulose reactive dyeing. In two papers, Jakob[32,33] describes the advantages of oxidative removal of starch-based sizes, listing types of removal, such as peroxide or oxidative alkaline cracking, currently available. Kuo[34] describes low-temperature plasma desizing for polyester and polyester/cotton blend fabrics, noting that the efficiency of the process depends on the gases selected as well as the pressure and power level used. Efficiency increases with pressure, but cloth quality diminishes if pressure is too high and removal is increased if the fabric is prewashed in a hot bath before the plasma treatment is carried out. Huang[35] investigates the possibility of carrying out desizing, scouring and dyeing of cotton in one bath, and feels that his laboratory studies confirm the validity of this suggestion. The possibility of recycling sizes also receives some attention. Stegmaier *et al.*[36] investigate the feasibility of such a beneficial environmental advantage, finding five acceptable formulations at the time of their enquiry. Brusa[37] describes the technology of ultrafiltration necessary in the recycling operation, associating these needs with the desirable properties of the sizing agent and provides examples of sizes that he feels are suitable.

Section 5 Pollution reduction in dyeing

The reduction of planetary loading in dyeing, as mentioned in Chapter 7, is attempted in a number of ways. Schramm and Jantschgi[38] assess dye technologies from the viewpoint of their tendency to cause environmental damage, finding that the methods adopted at the time meet regulations but still leave a lot to be desired. Writers review a conference on the science and art of dyeing,[39] new dyeing machines[40,41] to reduce cost, energy use and environmental impact, dyeing carried out simultaneously with cross-linkage in finishing[42] and novel means of applying traditional dyeing technology.[43,44] Lomas[45] points out that, despite all the new applications of science, colourfastness during laundering is still a major unresolved issue, as is fibre damage, as reported for wool dyeing by Naithani *et al.*[46]

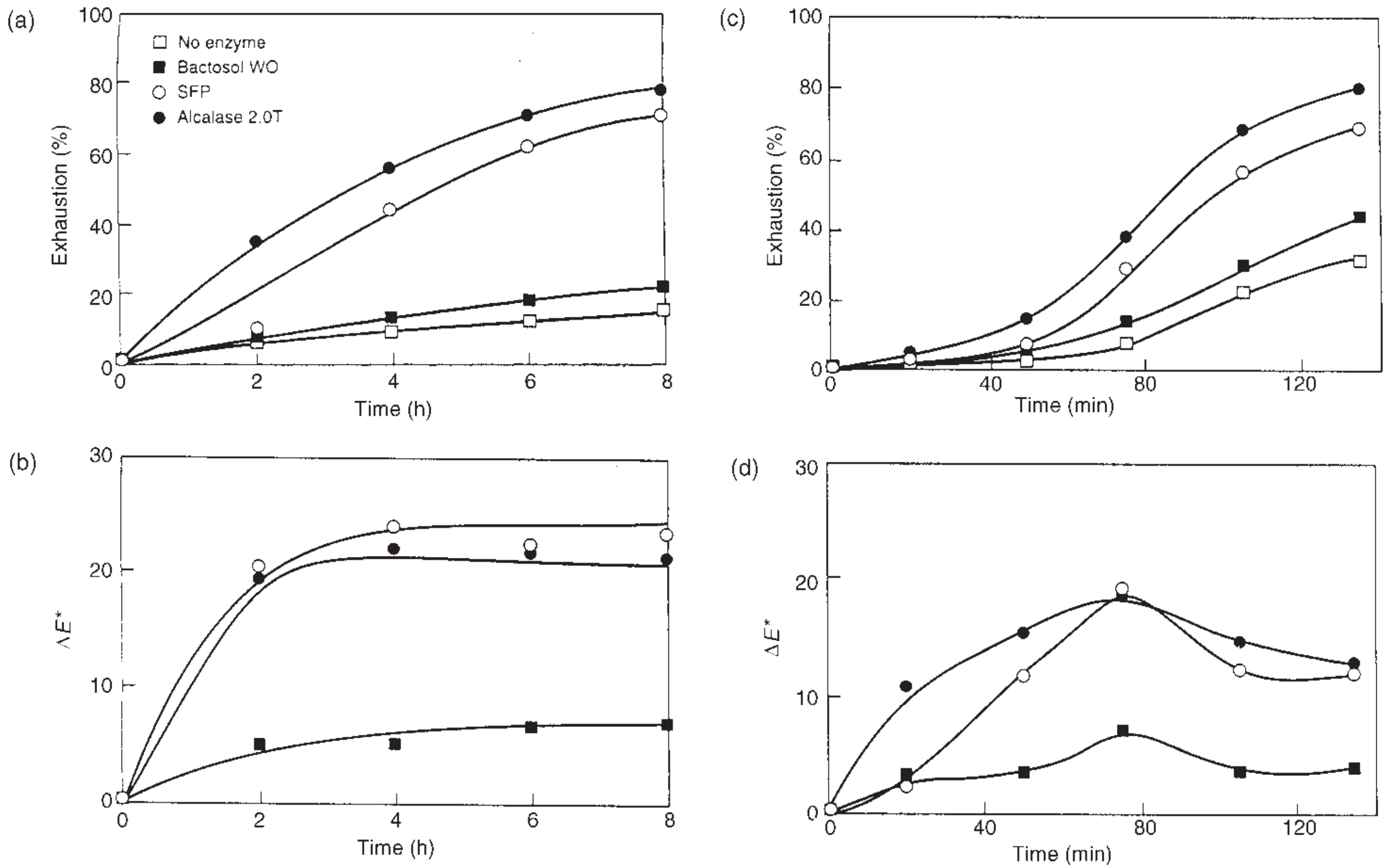
Azo dyes, long regarded as stalwarts in the industry, have also been viewed with less favour in recent years. These versatile dyes, as noted by Yadav,[47] constitute some 60 to 70% of the world dyestuff market, but contain carcinogenic components, typified by the four identified by an anonymous writer,[48] who explains the German legislation relating to them. Singh and Parmar[49] suggest that the harmful effects of azo dyes are so bad that a return to natural ones should be considered seriously and, after reflecting on their health, safety, yield and quality criteria, affirm the wisdom of such a step in spite of their admitted drawbacks. Ammen[50,51] recommends a return to sulphur dyes, rejected in the past for their unpleasant odour, ecologically undesirable nature and unsafe components, because he feels that recent work has converted them into the best choice on both ecological and economic grounds.

The use of plasma treatments, also mentioned in Chapter 7, is yet another method of approach to the thorny problems of environmental conservation in dyeing. Thomas *et al.*[52] use scanning electron microscopy and X-ray spectrometry to examine the surfaces of wool, cotton, polypropylene and polyester to determine what changes have taken place there as a result of plasma exposure and also study the effects on dyeing properties. Hocker[53] and Schafer[54] propose using ultrasound as a dyeing assist, with Schafer noting that evenness and diffusion are improved without damage to fibres. Hocker provides an overview of modern techniques, mentioning what is perhaps the most notable development, the use of supercritical fluid dyeing. This consists of using a gas (almost invariably carbon dioxide) in its supercritical state, under extremely high pressure and at an elevated temperature, to act as a solvent for the dye molecules. The fluid is very mobile and can penetrate the fibres easily, carrying the dyestuff with it. Once it has achieved this aim, a reduction in pressure immediately turns the solvent liquid back to gas, which escapes into the air, leaving the dye molecules in place on the fibres.

Sekar[55,56] reviews various uses, including sizing and desizing as well as dyeing, while Watanabe *et al.*[57] find that polyester dyed in this way acquires a much deeper colour. Holme[58] also recommends its adoption in conjunction with reactive disperse dyes (with their sulphonyl azide group) for polyester, polyamide, polypropylene and wool dyeing. In Fig. A.7, Riva *et al.*[61] show the effects of dyeing time on percentage exhaustion and colour difference. Giehl *et al.*[59] agree, because of the ecological advantages conferred by the method, but point out that new solvents and dyes should be sought and that a modifier is needed with reactive disperse dyes to give optimum results. Smota and Zupper[60] find that slight changes in fibre orientation can occur, depending on the temperature and pressure during treatment, but they feel that these are not major and are probably caused by the equipment used. Despite the optimism engendered by this new technique, however, it should not be forgotten that carbon dioxide has to be manufactured before it can be compressed (at relatively high energy costs) and is a problematic greenhouse gas when released.

Yet another suggestion is the adoption of enzymes, in place of chemicals, for various wet processing treatments. Riva *et al.*[61] compare the effectiveness of three enzymes, in terms of absorption rate, colour depth and washfastness, finding that absorption and diffusion are both enhanced and, perhaps more importantly, dyeing can be carried out at a considerably lower temperature. Etters[62] notes the reduced environmental stress resulting, while Karmaka[63] investigates the effects of enzymes on various other treatments on cotton or wool.

Chapter 7 also deals with the reduction of harmful emissions in textile dyeing. Dong *et al.*[64] attempt to dye and finish (durable press) cotton in a single bath with a reactive dye and citric acid. Factors influencing the success of the operation include the concentrations of dyestuff, citric acid, catalyst or alkali, together with the temperature. They evaluate colour, crease recovery, tensile strength and fastness, finding that the single-step process imparts satisfactory results with



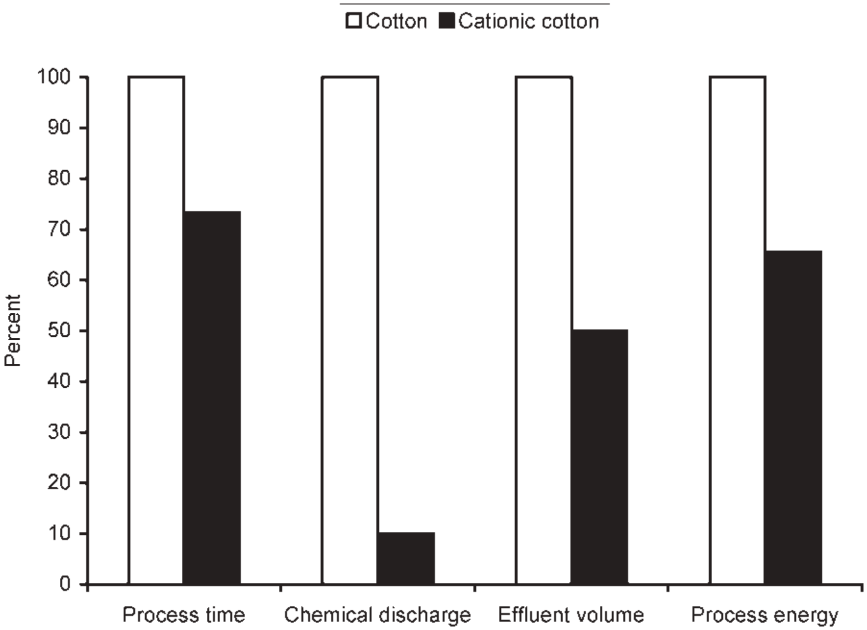
A.7 Effect of dyeing time on percentage exhaustion and colour difference; (a) contains key to all parts (source: *JSDC* **115** (1999), p 126. Reprinted with permission from the publisher, the Society of Dyers and Colourists, Bradford, UK).

careful adjustment of conditions, but suggest that further study would be beneficial. Hauser and Tabba[65] improve economic and environmental aspects of cotton dyeing simultaneously by adding cationic dye sites to the fibre, using a specific quaternary ammonium compound. Excellent dyeing results are achieved without using any of the electrolyte, multiple washings or fixation agents normally needed. The testing is carried out with direct, reactive and acid dyes, taking a shorter time than usual, but acid dyes are not as washfast on the cotton as they are on nylon. Phillips *et al.*[66] compare chromium and cobalt compounds for their effectiveness as metal complex additives in dye fastness. They wash dyed fabrics in detergent containing an oxygen bleach, finding that both compounds give acceptable results at 50°C, but that some of the cobalt-containing ones fail a washfastness test at 60°C while chromium-treated dyes pass. They conclude that cobalt-complexed dyestuffs are more sensitive than chromium-complexed ones. Hauser[67] introduces cationic dye sites into cotton to allow dyeing to be carried out in a more energy-efficient, low-polluting manner by improving the affinity of dyes. This step eliminates rinsing and after-washing steps while increasing productivity. The usefulness of the suggestion can be envisaged from Fig. A.8, in which the time, chemical discharge, effluent volume and energy consumption are all seen to decrease significantly as a result of the cationic treatment. The large savings obtained in effluent, chemical use and energy are quantified in the paper.

Section 6 Medical applications of textiles

Medical applications of textiles, as mentioned in Chapter 8, are widespread today. Hilgers[68] divides them into three types, those external to the body or intended to be transplanted into it, those in the healthcare field and those strictly concerned with hygiene. The author focuses on the second of these types, including protective barrier clothing or drapes, bed linens and towels, with information on how to get the best wear, laundering and reuse of articles by selecting conditions for washing, disinfecting and sterilising properly. Medical clothing includes a new helmet, made from Hytel,[69] to protect from micro-organisms, and new fabrics for barrier clothing in gowns or drapes. Conditions for making satisfactory fabrics for safe surgery are laid down[70] as resistance to liquid water with good moisture vapour permeability (a suggestion put forward[71] some years ago) to allow comfort to be maintained during surgery. Another writer[72] recommends polyimide sandwiched between two layers of fabric to produce a barrier cloth with the required permeabilities, combined with light weight, flame resistance, flexibility and a pleasant handle for extended wear times. Yet another author[73] feels that electrostatic charging of non-wovens, followed by sterilisation in ethylene oxide, can achieve the same desirable properties of breathability and comfort combined with filtration efficiency.

Internal uses of textiles are focused mainly on grafts or implants in modern medical practice and are dealt with in some detail by Ramakrishna[74] in a



A.8 Effect of cationic treatment on process time, chemical discharge, effluent volume and energy used in cotton dyeing (source: ref. 67).

comprehensive survey of the many types of body parts currently being placed into human beings. Kaisha[75] reports a puncture-proof, three-component layer material for use in a dialysis graft or artificial blood vessel. Ellis and Butcher[76] adopt embroidery techniques for implants that have been tested as graft stents and orthopaedic implants for shoulder or neck disc repair, as well as in general implants. Other authors[77] use two threads with different elastic moduli as the basis for a type of graft that can provide good simulation of the biomechanical behaviour of arterial tissue, while Daumer and Planck[78] discuss the development of materials for implants to meet German standards. A new fabric developed for the repair of abdominal aortic aneurysms that can resist long-term changes, even though it has a lower-than-usual wall thickness, is also reported.[79] One interesting suggestion[80] is the use of a woven or knitted fabric made from bioresorbable fibres and treated with a biocompatible film that can be implanted to aid in the regeneration of body damage or in the controlled release of a drug.

Other textile applications in medicine include a novel wound dressing[81] that can provide sustained release of an antimicrobial compound over an extended period of up to eleven days with the preferred agent, chlorohexidine, and use of a silk material,[82] for covering wounds (notably from burns), that can accelerate the growth of new skin while preventing bacterial entry. An ultrafilter made from nonwoven materials with hydroentangled fluoropolymers is devised[83] to provide improved ultrafiltration for liquids (especially blood) or gases that can be used for face masks, diaper interfacings and wound dressings. In this type of hygiene area, too, the requirements of diaper absorbency, together with the similar needs of feminine hygiene products and incontinence pads, are addressed by Daniels[84] and another author.[85] It should be pointed out, incidentally, that the use of disposable diapers is one of the major problems facing the planet today; their ready disposability creates an enormous amount of waste that can rapidly fill up dump sites, and their composition is such that separation into recyclable components, apart from being an extremely unpleasant task, is difficult or even impossible to carry out effectively.

Finally, there is an additional area of work that, though often neglected, is important in many health care situations. The noise levels in hospitals or nursing homes are targeted by Ahuja,[86] who reports the development of new curtains containing acoustic-absorbent panels sandwiched between fabrics as a means of achieving a 7 dB reduction in noise levels.

Section 7 Textile filters

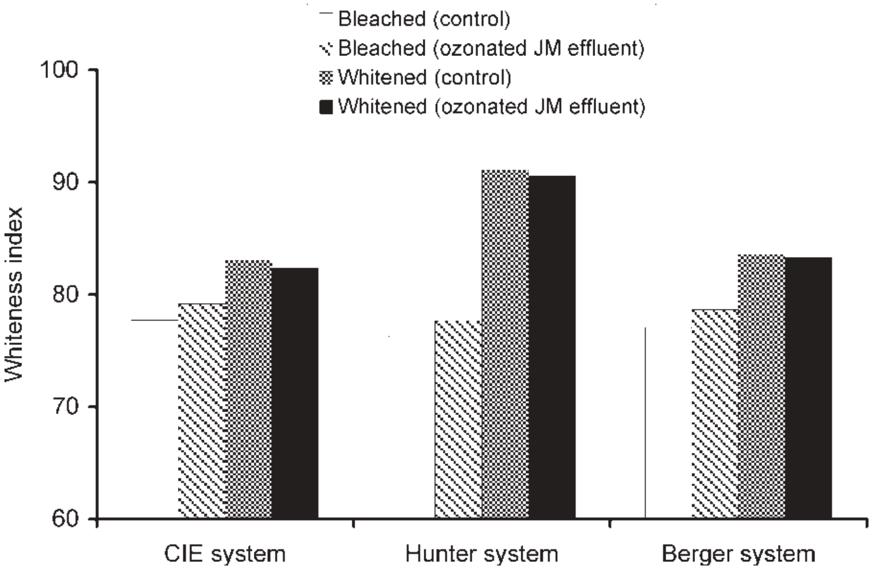
Textiles as filters are frequently found in various types of use. Air cleaning is typified by the work of Reddy and Sastri,[87] who use a geotextile as a filter in the separation of fly ash produced from coal burning at a power plant. They adopt the novel strategy of mixing the ash with water and decanting the slurry through the filter, a procedure that minimises the escape of pollutants into the air. One author[88] describes the production of better filter webs with smaller pore size and improved elasticity, suggesting electrostatic charging as a means of attracting dirt more easily to the filter, while another[89] recommends non-wovens made from thermoplastic microfibres made by a solvent-blowing technique to produce a non-toxic filter that is claimed to be 99.995% effective. Hollow fibres made from polyether ether ketone (PEEK) or (with less effective results) polyphenylene sulphide (PPS) are also suggested by Vorbach *et al.*[90] for use in hot gas separation at up to 200°C to isolate nitrogen from carbon dioxide and argon. Yet another writer[91] suggests that ceramics, metals and glass provide the best options for hot gas separation.

Section 8 Sporting goods and other uses

In sporting goods, there are also examples of textile applications worth noting. Bacskai[92] describes their use for extremely large tents at a tennis tournament, while one industrial manufacturer[93] reports the use of a textile cover for a football pitch. Abend[94] lists various uses of textiles in pleasure boating, discussing developments in this specialised field. A fibreglass-reinforced plastic coating for submarine hulls, to reduce corrosion, also appears.[95] Perhaps the most satisfying use reported[96] is that of a mat with aluminium strips woven into it to deflect solar radiation upwards from the ground in a French vineyard. The energy impinges on the grapes, raising their temperature by a couple of degrees to encourage an early harvest; the need for pesticides and herbicides is said to be dramatically reduced, so we can happily approve of this application on environmental grounds, not just the more obvious hedonistic ones.

Section 9 Effluent treatment

Techniques for environmental protection by the removal of pollutants before discharge into the air or water are dealt with in Chapter 9. Chemical methods before discharge into aqueous surroundings are typified by the work of Lopez *et al.*,[97] who recommend ozone. Hassan and Hawkyard[98] decolourise spent reactive dye with ozone and reuse the liquor in bleaching, whitening and dyeing, finding that little modification beyond adjustment to the pH is needed. They use the process repeatedly with no difficulties, with application in peroxide bleaching of cotton, whitening cotton with optical brighteners and disperse dyeing of polyester. Figure A.9 compares the whiteness index of cotton treated with the ozonated effluent with that of a control test. Ramasamy *et al.*[99] investigate the effects of temperature on ozonation of textile waste effluents. They find that higher temperatures reduce colour level (71.3% removal at 50°C), chemical oxygen demand (COD) (20.3%) and total organic carbon (TOC) (19.3%), and so recommend that no attempt should be made to dissipate the heat of the effluent

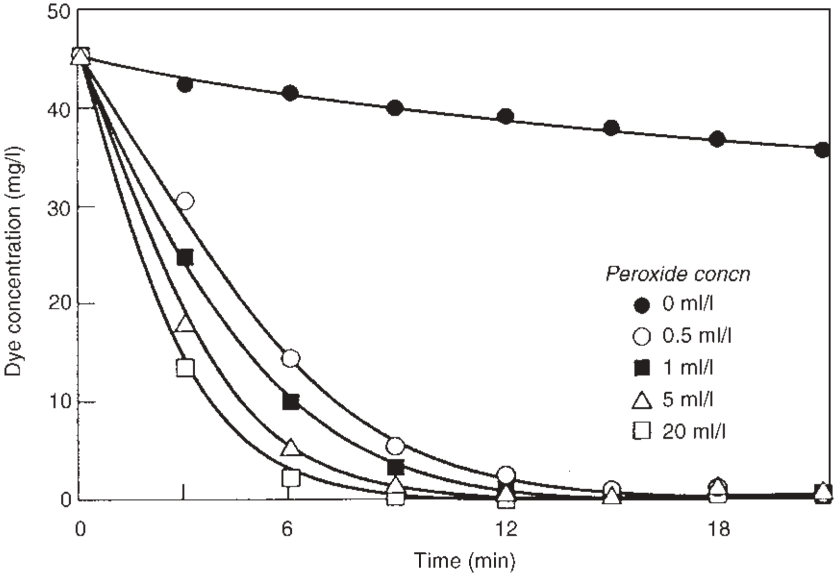


A.9 Effect of repeated use of recycled dye liquor on whiteness index of cotton (source: *Textile Chemist and Colorist & American Dyestuff Reporter*, Vol **32** No 6, June 2000, pp 44–48; reprinted with permission from AATCC).

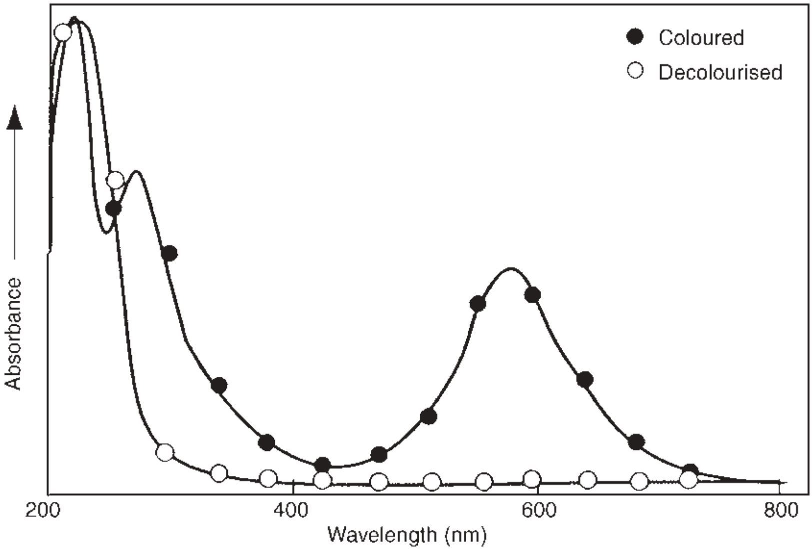
(currently emitted at a temperature of about 45°C) before discharging it to the ozone treatment plant. Mock and Hamouda[100] go so far as to state that ozone is the only viable technology for decolourisation of waste water. Kuai *et al.*[101] disagree, recommending an aerobic/anaerobic sequential treatment of waste water to bring about a reduction of up to 90% in COD and 95% colour removal.

Arslan and Balcioglu[102] try to achieve degradation of dyes in two ways, using either ozone, hydroxide ions and ferrous or ferric ions with hydrogen peroxide or, alternately, titanium dioxide and ultraviolet radiation. They assess TOC, BOD and spectrophotometric measurements, finding that the first technique is far superior to the second one because it gives better decolourisation and better demineralisation. Gregor[103] treats dyehouse waste water with ozone and ultraviolet radiation, accompanied by the use of hydrogen peroxide to produce an effluent suitable for reuse in production processes. Kos and Perkowski[104] use ozone and hydrogen peroxide to treat waste water that is highly resistant to biodegradation and find that, with ultraviolet radiation, the ozone can produce biodegradability. Optionally, both ozone and peroxide can be used simultaneously. Uygur and Kök[105] also report work involving the decolourisation of azo dye waste water by means of ultraviolet radiation and hydrogen peroxide, confirming the logical expectation that decolourisation times are diminished when ultraviolet radiation levels and concentration of hydrogen peroxide are increased. They achieve a 98 to 99.5% removal rate and state that biological oxygen demand (BOD) is increased, while total organic carbon, total inorganic carbon (TOC), total carbon (TC) and adsorbable organohalides (AOX) are all decreased after treatment. These observations are explicable if one assumes that the dye molecules are broken down into carbon dioxide, water and smaller colourless molecules, thus producing more biodegradable products. The authors therefore recommend using oxidative decolourisation before attempting biodegradation treatments, and find that the water/sodium sulphate residue from the treatment is reusable for dyeing. Figure A.10 shows the effect of a change in hydrogen peroxide concentration on the decolourisation rate in the presence of 1500 W of ultraviolet radiation and Fig. A.11 gives the visible and ultraviolet spectra of coloured and decolourised waste water from Procion Blue MX-2R, a reactive dye. The absorption taking place is readily observable in the latter diagram. Hardin *et al.*[106] decolourise waste water without ozone or precipitating agents by making use of white rot fungi. They investigate the effectiveness of nine varieties of fungus on four types of dyes (acid, vat, direct and reactive), finding that colour disappears in five to twenty one days, or faster in a nitrogen-limited situation. Wang and Yu[107] also suggest white rot fungus for extraction of dyes.

Tiedermann and Schad[108] control oligomers from polyester dyeing by reduction under optimum temperature/time conditions, and Krull *et al.*[109] adopt chemical and biological controls in conjunction. In a different approach, Cheng *et al.*[110] suggest the use of soilless culture methods to eliminate phosphorus and nitrogen, claiming that the simple equipment needed is inexpensive, easy to use, flexible in operation



A.10 Effect of hydrogen peroxide concentration on decolourisation of dye waste waters (source: ref. 105).



A.11 Visible and ultraviolet spectra of coloured and decolourised waste water (source: ref. 105).

and economical in energy use. Lin[111] sounds a word of caution, noting that the ion-exchange technique that he prefers is extremely expensive. This is a common problem with all methods if complete colour or dye removal is expected.

Perhaps for this reason, biological techniques appear to be gaining in popularity. Churchley *et al.*,[112] in a series of articles on the bioelimination of dyes, explain the mechanisms involved and note that there is a wide range of bioelimination levels, depending on the molecular structures of the dyes. They find a much lower reduction in dye concentration for reactive dyes (25%) than for direct (95%) or acid (96%) ones. Biolfiltration is recommended by one author[113] to treat a dye/finish effluent, using an activated foam to give high surface area for the support of bacterial activity. Sarsova and Janitza[114] develop an aerobic biological procedure for effluent purification, in conjunction with adsorption on coke, while others[115] prefer a culture that is anaerobic in nature, claiming a removal rate of up to 97% at the optimum state of operation. Jager,[116] in an article dealing with the environmental management of plants, suggests the use of biological assessments for the optimisation of waste water and the development of ecological tests with a selection of dyes and chemicals. Heine and Hoecker[117] provide some discussion of the ways in which enzymes interact with natural fibres and describe various finishing treatments in which these substances are used.

Evaporation technology is used[118] to depollute effluents in wool scouring, and the suggestion is made that there may well be a possibility of extending the approach to dyehouse and flax-whitening processes. Waste water is the subject of a paper, written anonymously,[119] dealing with emissions from a plant where stone-washing and fading of jeans are carried out. Cotton and wool dyeing and fulling of wool are involved, and a wide range and concentration of solvents, organic substances, dyes and surfactants is used. Treatment involves settling to deposit pumice that would otherwise contaminate the fabric, followed by sifting and bio-oxidation in activated sludge, using sedimentation to allow any impurities to settle and, finally, treating the sludge before discharging the waste liquid to the environment. Ströhle and Pröll[120] put forward a new concept for continuous splitting and desizing bicomponent fibre yarns, using continuous desizing with steam and water. Schneider[121] notes that, in the biodegradation of viscose, finishing treatments (with the notable exception of resins) have no significant adverse effect. Halliyal *et al.*[122] evaluate methods of solid waste disposal in silk reeling, finding that there is still no satisfactory method to accomplish this aim.

In examining the possibilities of re-use in processing, an anonymous writer[123] feels that the traditional techniques are unlikely to be completely successful, so recommends others (and especially flotation, in which solids float and are skimmed off) as being more likely to produce reusable water at a lower cost. Broglio[124] also recommends the idea , especially where surfactants are used to assist in processing, while Raikar *et al.*[125] study biodegradation and aquatic toxicity of surfactants. One writer[126] expects that a biodegradable fibre will soon be able to compete economically with polyester. Zhang[127] surveys the quality of waste water from a dye factory, together with the methods available to reuse it and/or reduce the amount of effluent released. Another writer[128] recommends the recycling of waste water from a dye works because waste water represents a large use of a scarce resource. He feels that, because traditional methods cannot be guaranteed, sophisticated ones (such as flotation, with the water then recycled in the production process) are needed. A second anonymous author[129] also favours recycling waste water from dyeing and recommends that, since the traditional methods used to purify water do not represent good energy use, it is advisable to adopt other approaches, flotation again being the one preferred because it can give better quality at lower cost. White *et al.*[130] report an automated analysis system used in automated dyebath reuse for nylon carpets, in order to save water, energy, chemicals and (naturally!) money.

Koh *et al.*[131] reuse the dyebath effluent from nylon dyeing operations for ten cycles by reconstituting it to the original concentrations of dyes, auxiliaries and acid donors after ultraviolet/visible spectroscopic analysis. They measure colour reproducibility, levelness and fastness, finding that hydrolysable organic esters (ethyl lactate is the one they prefer) are superior to the conventional ammonium sulphate or sodium dihydrogen phosphate as acid donors. No deterioration in colour fastness is observed after the ten cycles. Uygur[132] examines the feasibility of reusing waste water from azo dyeing by adopting an advanced oxidation method in which hydrogen peroxide and ultraviolet radiation, at a power level of 1000 W, are applied to the fabric, followed by removal of the excess peroxide. Decolourisation is achieved to a value of 98.3%, but the ability to adopt this treatment is limited to one reuse only. However, Bide *et al.*[133] propose that, although dyebath reuse should be strongly advocated as a means of pollution prevention, the idea has a limited applicability because unevenness of dyeing begins to be evident after about six uses and, even with this limitation, very careful pH control is needed.

Kozlov and Zuikova[134] adopt a membrane method to treat dye effluent and use the treated water successfully as a wash-off liquid in sulphur dyeing, claiming significant reductions in energy and water consumption. Lin and Lin[135] combine ultrafiltration with activated carbon adsorption and ion exchange, at the optimally determined range of all components, to achieve water of very good quality for re-use; the cost can be assumed to be prohibitive and, in view of the number of papers dealing with the subject, it is clear that the solutions proposed to date are not effective enough to satisfy the ecological criteria necessary to preserve the planet unharmed.

Section 10 Recycling

The difficulty of recycling sizes attracts the attention of Stegmaier *et al.*[136] who report that some of the newer ones can be recycled for up to five uses without becoming too unstable to provide satisfactory re-use. Klinkert[137] carries out an investigation of the hydrogen peroxide treatment of starch sizes and other components in mercerisation lye, finding that the flotation principle (in which solid impurities are floated by carbon dioxide generation, to be skimmed off) is an invaluable aid in this work. An anonymous author[138] uses a high vacuum technique to eliminate spin finishes in polyester and nylon recycling, providing a description of the sequence of operations in the process and noting that viscosity loss is reduced.

In aiming to reduce pollution by more esoteric means, Kint and Munoz-Guerra[139] review biodegradation processes for polyester, noting that most of them focus on hydrolysis at high temperatures. They also investigate the application of this type of treatment to copolymers (block and random) and blends. Adanur *et al.*[140] discuss the recovery and re-use of PVC (polyvinylchloride)-coated polyester, noting the stages necessary; these include swelling, separation by the use of a solvent and removal of glue. The resulting material is used to reinforce epoxy resin or needle-punched non-wovens. An anonymous author[141] is able to recycle thermoplastic fibres without the need for a spin finish by the use of high vacuum. It is preferable, though, to ensure that drying and melting are carried out without oxidation to minimise discoloration, and the use of a vacuum during the drying reduces the risk of significant viscosity loss. Artzt[142] sounds a word of caution in making the point that the fall-out fibres from cotton are not economically worth reprocessing, something that may well become applicable to other materials if costs of recycling continue to escalate.

The recovery of recycled components from carpets is currently one of the more interesting developments in the effort to make textile production less ecologically harmful. An overview of the subject is given.[143] Sellers,[144] in reporting the development of a new initiative in recycling carpets, cites as example the conversion of polypropylene carpet backing materials to geotextiles. The range of steps needed is documented[145] and includes collection, identification, sorting and recovery of chemical materials or polymers; the increased energy recovery from, for instance, carpet backing is also noted. Griffith *et al.*[146] carry out the separation and recovery of nylon from carpet waste by supercritical fluid extraction. Solution of nylon is obtained in formaldehyde at 40°C, after which recovery of the nylon powder by antisolvent precipitation at 84 to 125 bar at 40°C can be carried out, then solvent and antisolvent can be recycled. Zhang *et al.*[147] claim that there are many commercial uses for recycled carpet materials, as long as the separate components are dealt with individually, giving compression moulding as their preferred technique for preparing useful recycled units.

Vion[148] proposes the use of a single fibre type, polypropylene, in making carpets to simplify the recovery chemistry and suggests that coating materials should be adopted to enhance the process. Powder coating technology is also recommended by an anonymous writer[149] claiming that floorcoverings in general can provide the environment with increased resources in the form of lower energy consumption or simple recycling. The types of product that can be made by a recycling operation include acoustic panelling (in conjunction with wood chips[150]), new types of moulded products[151] and even caprolactam, the raw material from which nylon is made and from which the fibre can be produced again, by means of an environmentally benign technique using steam at medium pressures.[152]

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