The overhauling of textile speciality chemicals

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An attempt has been made to look at the textile speciality chemicals industry from the grassroot level. The transition in the fibre-mix processing is changing the textile chemical scenario constantly and with this back-drop the textile chemicals are reviewed with a peep into the wonder moieties which go into the making of these speciality chemicals.

Keywords: Enzymes, Silicone surfactants, Textile speciality chemicals, Waterless processing

1 Introduction

The textile industry in India has been hit by most of the changes which have been witnessed in a short span of few years only. Not only has globalization and liberalization of the economy brought about the changes in textile speciality chemicals (TSCs) but also the change in fibre-mix has thrown out the conventional TSCs and brought in a series of wonder molecules to satisfy the 'global minded' customer. The liberalization of the mind has set in along with the opening up of the markets and one sees the end consumer of textiles and markets being responsible for the overhauling of TSCs.

The entire spectrum of TSCs including dyebath chemicals, sizing chemicals, synthetic fibre production additives for spin finishes, topical additives, bleaching chemicals such as resins, softeners, wetters, flame retardants and optical brighteners have started to look for a change in the formulations for their existing range of products. These initiatives catalyzed by demands from the fashion-conscious consumers have already overhauled revolutionary trends in product design, manufacturing and packaging in this core sector. Thus, what is visualized is the stagnating of the conventional TSCs whereas environmentally benign products become a top priority in recent years.

The overhauling of TSCs have brought in phosphated amine oxides and salts which are to replace sodium hyrosulphite for reducing dyes. Such products are biodegradable and use a foam developer which allows the product to access most parts of the equipment.

To maintain the competitive edge, the TSC manufacturer has to align with the spurt in the textiles for the automobile sector and other growth areas. In this GATT era, the answer to the 'world-class' textile will come from the TSCs which will integrate into the global needs and conform to the standardized labels and parameters.

In the present treatise, an attempt has been made to look at the textile speciality chemicals industry from the grass-root level. The transition in the fibre-mix processing is changing the textile chemicals scenario constantly and with this back-drop the textile chemicals are reviewed with a peep into the wonder moieties which go into the making of these speciality chemicals.

2 The Fibre-Mix

It has been forecasted1 that the total world fibre consumption will grow at the rate of 2.72% per annum to the year 2000. Table 1 gives some of the global textile fibre consumption data2.

The fibre consumption data per head reveals high levels in the developed countries of North America, Western Europe and Japan and lower consumption in Asia and Africa. However, the

<table>
<thead>
<tr>
<th>Table 1—Global textile fibre consumption</th>
<th>Consumption in million tonnes</th>
<th>Annual growth rate, % (1986-95)</th>
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<tbody>
<tr>
<td>Total textile fibres</td>
<td>36.2</td>
<td>45.5</td>
</tr>
<tr>
<td>100% cotton (excluding viscose)</td>
<td>15.4</td>
<td>18.3</td>
</tr>
<tr>
<td>Polyester-cellulose blends</td>
<td>4.4</td>
<td>7.0</td>
</tr>
<tr>
<td>100% polyester (excluding blends)</td>
<td>2.9</td>
<td>4.0</td>
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expansion in textile processing within Asia may well stimulate the economics of the region and increase the fibre consumption per head in these countries including India. The consumption figures for India are given in Table 2.

The change is tremendous in the synthetic sector in India as can be seen from Fig. 1. The total output of 1,90,000 MT in 1980-81 has moved on to nearly 7,16,000 MT in 1992-93.

With the tremendous growth of man-made fibres, the fibre-mix is changing and the formulation chemist is left with no other choice but to give the changed chemical-mix to suit the end-use. The thrust is going to be on speciality chemical finishes which are safe environmentally and by the use of which higher levels of comfort and performance may be obtained. The development in the textile chemicals sector will have to conform to the achieving of ecologically sustainable industrial development. Like others, the textile industry has to maximize profits by increasing efficiency while at the same time keep on maintaining environmental concerns. Pollution prevention is to be practised by the processors as it is more environmentally effective, technically sound and economical than conventional controls. The emphasis will be to develop and utilize clean production processes and produce ‘green’ products. The full cooperation of all concerned is needed to avoid irreversible adverse effects on human development. The concern for environment-friendly molecules is so important that an ecologically balanced approach is to be taken in the development and changes to be witnessed by the textile speciality chemicals. A broad outline emphasizing the thrust in this overhaul could be summed up as follows:

- Adoption of pollution prevention—an approach that prevents pollution at its source in products and manufacturing processes rather than removing the same after it has been created.
- Integration of environmental responsibility in decision-making at all management levels; introduction of waste minimization and environmental compliance auditing; establishment of emergency, risk and safety management systems; and establishment of training programmes.
- Adherence to voluntary environmental codes for conduct of industrial investment and production.
- Increase in research and development activities with emphasis on cleaner production technologies, giving priority to technologies that offer potential for improved efficiency and reduced pollution and provision for training facilities to developing countries for that purpose.
- Consideration, where feasible, of the use of substitute materials and products reformul-

### Table 2—Textile fibre consumption in India

<table>
<thead>
<tr>
<th></th>
<th>1983-84</th>
<th></th>
<th>1989-90</th>
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<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>%</td>
<td>Quantity</td>
</tr>
<tr>
<td></td>
<td>× 1000 MT</td>
<td></td>
<td>× 1000 MT</td>
</tr>
<tr>
<td>Cotton</td>
<td>1361.00</td>
<td>82.05</td>
<td>1650</td>
</tr>
<tr>
<td>VSF</td>
<td>100.00</td>
<td>6.63</td>
<td>145</td>
</tr>
<tr>
<td>VFT</td>
<td>41.01</td>
<td>2.47</td>
<td>47</td>
</tr>
<tr>
<td>NFY</td>
<td>35.01</td>
<td>2.11</td>
<td>39</td>
</tr>
<tr>
<td>PSF</td>
<td>43.77</td>
<td>2.64</td>
<td>100</td>
</tr>
<tr>
<td>PFY</td>
<td>57.57</td>
<td>3.47</td>
<td>150</td>
</tr>
<tr>
<td>ASF</td>
<td>20.47</td>
<td>1.23</td>
<td>32</td>
</tr>
<tr>
<td>Wool</td>
<td>N.A.</td>
<td>N.A.</td>
<td>30</td>
</tr>
<tr>
<td>Silk</td>
<td>N.A.</td>
<td>N.A.</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>1658.83</td>
<td>100</td>
<td>2203</td>
</tr>
</tbody>
</table>

*Fig. 1—Man-made fibres/yarns production in India*
ations, process modification and redesigning of equipment, renewable sources of energy and raw materials, and recycling and reuse of waste materials.

- Assumption of a 'cradle-to-grave' approach to textile speciality chemicals.
- Application of cleaner industrial production processes and more rational use of natural resources.
- Transfer and adoption of environmentally-sound technologies, knowhow and skills to meet the need and thus mobilization of resources properly.

3 Textile Speciality Chemicals

A casual glance at the inputs of the textile processing chemicals gives a totally 'mind-boggling' impressions. However, the details show the overlapping of certain usages and the multiple effects obtained with certain key molecules. Formulation is the key to the correct level of success in the textile speciality arena. The current emphasis on process integration and on right-first-time processing will only reinforce the necessity of the correctly formulated product to obtain the right fabric processing. In fact, a blend containing a sequestrant, a pH buffering system, a dispersing agent and a wetting agent in a carefully formulated proportion will give optimum performance during the processing of textiles.

Thus, the trend in the future will be only in this direction. The chemicals used would be biodegradable and will be engineered for the specific process requirements in the form that provides ease of handling, storing and dispensing while providing a high quality of performance during processing. It is clear that there is still a great scope for the introduction of novel chemical finishes with superior performance, greater ease of application along with multifunctional properties. However, the influence of the environmental issues is clear and environment-friendly products will be preferred in 1990s. While many new chemicals, particularly polymeric systems, will be studied to provide durability to washing, there is still scope for improvement by the traditional formulation approach in which products are blended on a cost-performance basis. Integrated finishing treatments will be preferred because of the necessity to provide a quick response to market demands.

The growth of textile chemicals has been achieved with the growth of textile fibres and the stringent demands laid down by the environment-friendly lobbyists. Tremendous capacities created for man-made textiles, production of regenerated cellulosics and steady crops of cotton have all taken the demand of textile chemicals upwards.

Textile speciality chemicals have been showing good growth rates, keeping in tune with the growth of the fibres. The market is quite large, encompassing a wide spectrum of products. In India, the textile speciality chemicals business is in excess of Rs 1000 crores per annum with a constant shake-up of conventional moieties along with the regular introduction of newer specialities. Looking at the various volumes of textile specialities world-wide and projecting them with the estimates of Frost & Sullivan Market Intelligence, a mountain view, California based research firm, the percentage share of the different classes of textile specialities in dollar terms or rupee value for Indian market has been deduced:

<table>
<thead>
<tr>
<th>Textile Speciality Chemicals</th>
<th>% Share</th>
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<tbody>
<tr>
<td>Chemicals used at the fibre level including antistatic treatments, spin-finishes and other topical additives like lubricants</td>
<td>22.39</td>
</tr>
<tr>
<td>Sizing chemicals</td>
<td>7.46</td>
</tr>
<tr>
<td>Preparatory chemicals including scourers, enzymes, stabilizers and surfactants</td>
<td>6.72</td>
</tr>
<tr>
<td>Dyeing and printing additives</td>
<td>11.19</td>
</tr>
<tr>
<td>Finishing chemicals including resins, softeners, wetters, finishing lubricants, flame-retardants, soil repellents, aid and washing preparations</td>
<td>52.24</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

With a lot of restrictions coming up on the usage of a series of textile chemicals, the textile chemical manufacturers are gearing up to meet the challenges of producing biodegradable products which will have lesser and lesser environmental damage problems. Such a shake-up can be viewed as a challenge to give correct value-added products to cater to the ever changing needs of the users.

Textile speciality chemicals can be precisely engineered for specific end-purposes. As the theoretical knowledge of textile processing is becoming clearer, the practical evaluations and the number of concoctions of textile chemicals available are becoming increasingly higher. This presents a danger because it becomes difficult to differentiate such textile chemicals which are promoted purely for commercial reasons from those which serve a purely technical need. Some chemicals offer cost savings by improving reproducibility and
minimizing reprocessing. Nevertheless, it is all too tempting to incorporate too many products without critically evaluating their efficacy, thus inevitably and unnecessarily increasing processing costs. Consequently, it is more important than ever that the processors understand the function of these chemicals and are equipped to evaluate their use realistically and monitor it continually.

Quite a few factors dictate the areas of satisfying consumer demands and process demands and finally providing satisfactory solutions to the environmental issues. The range of issues to be covered by the specialty chemicals is very wide and complex, encompassing ecological and toxicological considerations, health and safety during storage, application and use, and safe disposal of chemicals on land, and into water and air.

4 The Overhauling of Textile Speciality Chemicals

As indicated earlier, the exacting demands laid down by the customers have led to a serious look into the ecological considerations. The future thrust is going to be in the direction of such environmental protection policies. Total ecological consideration involves preservation of working atmosphere, minimum pollution in waste streams, no hazard to the health of workers and users, and no problems during the disposal after use. Even in our country, new regulations will make it obligatory for companies to have ecological audits in their annual reports.

The important and urgent problems have to be systematically studied and the following three-state strategy can be followed:

- **Avoiding:** Replacing the chemical wherever possible by a permissible equally effective and economical chemical, which may involve process modification.
- **Minimizing:** The quantity used, where replacement is not possible.
- **Recycling:** After isolation from the waste baths/wash waters involving ultrafiltration/reverse osmosis techniques.

Some of the textile speciality chemicals which are witnessing overhauling are grouped under the following four heads:

4.1 Growth of Natural Fibres

Pests and pathogens growing on a highly pest-prone crop like cotton can be controlled with the choice of an environmentally-acceptable preservative. Well, initially it would be helpful if the pretreatment formulation could effectively inactivate any pesticide residue before the onslaught of any chemical processing. At a later stage, one could shift towards the cultivation of ‘green’ cotton without the use of any pesticides. In the case of wool, contamination of wool greases with preservatives should be looked into and the correct choice product need be used. To minimize local pollution and also meet the export requirements, permissible available pesticides based on neem, fenvalerates, permethrin, cypermethrin, decamethrin, etc. should be used. Such permissible products are being developed in many countries including India.

4.2 Manufacture of Man-made Fibres

Viscose and modified fibres warrant spinning of xanthogenate dopes. These processes consume a lot of water and toxic chemicals. Strict control is needed in the processibility of the same. A lot of newer modified processes are reported, e.g. with the use of N-methoxymorpholine oxide and other solvents. Shifts are not easy but total implications have to be worked out. In the area of man-made fibres, the trend is towards incorporating suitable additives in the spinning dope to impart desirable properties such as fibre repellency, hydrophilicity, antistatic, etc. This will avoid the use of those harmful chemicals which lead to subsequent pollution. During production of texturized filaments, selection of oils has to be done so as to avoid volatile harmful chemicals.

4.3 Mechanical Processing

The conversion of yarns to fabrics by weaving or knitting falls under this heading. Warp yarns are strengthened by sizing and the future thrust in this area would dictate products with quick drying properties and uniform film-forming capabilities. Acrylic and their blends are the formulated polymers preferred for this use. Preservatives should be the ones taken from the ‘green-line’ of products. Some success has been reported with quaternary ammonium compounds with some synergistic permissible bromonitro additives.

4.4 Chemical Processing

First and foremost, in the pretreatment, the future will rotate around the right type of synthetic detergents, enzymes for desizing and bleaching with oxidizing agents. Bacterial α-amylases are the enzymes of choice in desizing but developments would be needed to make them alkali-resistant. Anionic wetting agents act as poison and so should be carefully eliminated. The synthetic de-
tergents of choice would be the fatty alcohol ethoxylates. The major bleaching agent to emerge as the dominant player will be the hydrogen peroxide. This would push up the market for organic stabilizers. Magnesium salts with carefully selected molecules from the so-called 'green list' would provide answers to this problem. In the area of dyeing and printing of textiles, TSCs will have to be carefully selected keeping the environment implications in mind.

In the years to come, developments in this field will continue with emphasis being on biodegradability and superior dispersing properties at higher temperatures. In the area of dye carriers, severe pressures will be on because of lack of biodegradation, odour and the fact that they are absorbed by fibres during dyeing and can only be effectively removed by high temperature treatment. In fact, recent developments have centred on the use of mixture of carriers and also on the use of chemicals which have been termed 'non-carrier' carriers and which function essentially by aiding the immigration of disperse dyes. The future thrust in this direction would visualize incorporation of green-line molecules and would have to preferably be made more effective at a lower concentration in the fibre and must be more readily removed by after scouring rather than in the post heat-setting treatments.

The wash fastness of direct and reactive dyes has been improved by the use of cationic after-treatments. The development of bi-, tri- and tetra-functional agents containing reactive group capable of forming covalent bonds with suitable groups in the dye and/or hydroxyl groups in cellulosic fibres have been reported. The use of multifunctional crosslinking agents based on 1,3,5-triacylhexahydro-s-triazines is reported, the highest colour fastness of washing being obtained by the use of tetrafunctional reactant resins. Typical molecules are made by the reaction of an amine (e.g. diethylenetriamine) with cyanamide, guanidine or biguaniamide and especially dicyandiamide (Fig. 2).

The mixing of such products liberating catalyst with N-methylol based reactant like DMDHEU and an acid liberating catalyst enables such cationic reactant resins to be applied to fabrics by the pad-dry-cure technique, conferring high levels of colour fastness and superior dimensional stability. The development of such treatments to yield lower levels of formaldehyde release would be the step forward in the right direction. Multi-functional cationic fixatives are also of interest for reaction with unfixed and hydrolyzed reactive dyes. Tri- and tetra-functional fixatives are used which can covalently bind such dyes to the fibre (Fig. 3).

Future possibilities will be development of such products without sacrificing the hue and the light fastness of dyeings. In the area of softeners and lubricants, the field has been dominated by both organic softeners and silicones.

Modifications of silicones have given rise to a series of organomodified commodities wherein the altered functional groups serve different end purposes. The beauty of the silicone backbone is that it has lower surface tension not only in aqueous medium but also in various solvents. Modification of the functionalities of silicones can give
various ethoxylated and propoxylated derivatives with silicones ranging from water soluble to dispersible to insoluble. This has given birth to the so-called silicone surfactants where one can see the behaviour of these silicones as general purpose surfactants serving as emulsifiers and de-emulsifiers. The degree of solubility can be varied with the levels of ethoxylation/propanoylation to give various surfactants conforming to varied HLB values. In the overhaul being witnessed, one will see a lot of silicones as emulsifiers in the future because of the promise they hold of being totally inert and show better properties at lower concentrations.

Current trend in the fibre softening is visible in the enzymatic biopolishing field. Enzymes are available for treatment of cellulosics and woollen substrates. Future holds a lot of promise for enzymatic treatments of textiles. In future, integrated finishing treatments will be visible wherein depending on the chemical nature of the softener, other properties such as bactericidal, antistatic and soil-release may be incorporated. Some of the softening compositions of tomorrow will have the following chemical moieties:

- Tetrahydropyrimidinium salts
- Quaternary ammonium salts with reactive ester groups
- Quaternary aminoboric acid mixtures and amine oxides
- Distearyl(dimethyl)ammonium chloride and ethoxony quaternary salts
- Di-isostearyl(dimethyl)ammonium chloride
- Aliphatic amine and quaternary ammonium compounds
- Quaternary ammonium derivatives of bisimidazole compounds
- Quaternized melamine derivative
- Polyethylene glycol modified triazine compounds
- Fatty, methylolated polyoxyalkylylcarbamates

Super soft results can combine the weight loss effect of enzymes with low add-ons of silicones. Such softening will have to be exploited. In fact, commercial products are often complex mixtures and contain along with the conventional softener the hydrodilutes, solvents, exhaustion aids, antistatic agents, lubricants, bactericides, perfumes and antifoam agents. In the changing scenario to be witnessed by TSCs the future shrink-resistant and wool treatments will have to be totally brought in line with the prevailing environmental issues.

Chlorination will be on its way out. Alternative oxidative or even reductive treatments may have to be sought after in the short and the medium term. It would be desirable for the polymer shrink-resist treatments to form extremely uniform hydrophilic coatings that swell in water washing the scale structure of wool. These polymers should be capable of wetting the wool surface without chemical pretreatments.

The easy care and durable press finishes have taken a lot of beating with toxicological studies, revealing obnoxious properties associated with formaldehyde. BTCA type of polycarboxylic acids are recommended.

Among the novel finishes a further development would be the incorporation of UV absorbers for sunlight protection for natural fibres of the silk type and some synthetics like polyesters. It is reported that the use of fluorinated products will increase as the demands for soil-release and stain-release finishes will grow. Mineral spirits have already given way to synthetic thickenings in the printing areas. Fig. 4 indicates the trends in the changing scenario and overhaul of TSCs.

Most of the synthetic fibres are known to undergo photodegradation in the presence of sunlight. This may hamper the use of a fibre depending on the photosensitivity of the fibre and the intended end-use, and therefore protection against or prevention of photodegradation is essential. For this purpose, chemicals known as ultraviolet absorbers (UVA) have been found to be useful. UV absorbers are organic compounds which absorb UV radiations mainly responsible for causing

**PRINTING SPECIALITIES**

**TRENDS TOWARDS ELIMINATING HYDROCARBON SOLVENTS FROM THE THICKENINGS**

Synthetic thickeners gaining importance, viz.

![Fig. 4](image-url)

Examples: (1) Copolymers of acrylic acid (1 mole) with divinyl benzene
(2) Maleic anhydride alkene copolymers cross-linked by a diamine

Defects—Sensitivity to electrolytes including anionic dispersing agents
degradation and give protection by dissipating the energy as heat. Other materials used for protection are screening agents such as pigments and energy-transfer agents which deactivate the degradation process.

For heat stability of modacrylic fibres, various chemicals are reported such as organo tin compounds either alone or mixed with oxalic acid, as well as triethyl phosphate. Such finishes will resume greater importance in future. Pilling is an unpleasant phenomenon usually associated with spun yarn fabrics, especially when they contain synthetics. Fibres are released from the yarn by bending and abrasion, and they combine together at the surface of the material to form knots known as pills. These little knots contain fibres that are still partially embedded in the yarn so that they are secured to the surface of the fabric. Synthetic fibres are more easily brought to the surface of the fabric than cellulosic fibres because of their smooth surface and circular cross-section.

While the man-made fibre manufacturers can offer low-pilling synthetics with reduced strength there is also a possibility of counteracting the pilling tendency with an appropriate finish which will form a polymer film such as polyvinyl propionate, polyacrylates, etc.

Resin finishing fundamentally reduces pilling, but there are also the antipilling synthetic resin dispersions that have proved highly satisfactory and their wash fastness is improved by the presence of crosslinking agents. Man-made warp and weft threads in loosely woven fabrics are particularly prone to slip because of the surface smoothness of filaments. As a result, the structure of the fabric is disturbed and the appearance is no longer attractive. Attempts have been made recently to give filaments a rougher surface by finishing with silica gel dispersions. The effect can be made more permanent by using silicic acid colloidal solutions along with acrylate film formers.

With synthetic textiles and especially with knit goods the abrasion experienced during use can cause individual filaments to work themselves out of the yarn and veil over the knit pattern as a kind of a pile of varying densities. The term picking is used for this effect, which produces a fluffy, unattractive appearance on the garment. Even less pleasant is the drawing out of filaments or yarn loops on the surface of the materials made of filament yarns when the garment catches on to pointed or rough objects. Such drawing out of threads is known as snagging, and it can make the garment worthless. Picking and snagging arise all the more quickly; the more open the weave, the bulkier the yarns. Knit goods made of textured filament yarns are therefore most exposed to the danger of picking and snagging. Thus, the finisher is faced with the task to cementing the fibres within the yarn with a finish so that the dragging out of fibres or filaments is made more difficult, but the handle of the goods must not suffer thereby. This can be achieved particularly well with special polyacrylates which:

- produce a film with good adhesion and do not render the surface of the fibre tacky so that it does not soil readily,
- are sufficiently hydrophilic so as not to be the source of additional electrostatic charges, and
- do not adversely affect the general handle of the goods.

These properties have been successfully combined in a polyacrylate dispersion that is compatible with most finishing agents. The amount applied depends on the substrate and fabric structure, and is usually between 40 g/L and 100 g/L. Impregnation is carried out on the padding machine and it may be done at the same time when other finishing agents are applied. It is fixed fast to washing and dry cleaning by drying at a temperature of at least 110°C. Although the product is not decomposed even under the temperature conditions of heat setting and thermosoling, a temperature of over 130°C during drying should be avoided in order not to impair the rubbing and perspiration fastness properties of disperse dyes on polyester materials.

5 Enzymatic Biopolishing

Enzymes are naturally occurring proteins capable of catalyzing the chemical reactions of nature. Fermentation of micro-organisms produces industrial enzymes. Industrial applications of enzymes include household and industrial detergents (proteases, amylases, lipases, cellulase), desizing of textiles (amylases), enzymatic stone washing (cellulases), and others. Moreover, as enzymes are natural proteins, they are easily and completely biodegradable. It has been found that “cellulase” is the enzyme having cellulose degrading capabilities. Cellulase treatment of textiles made from cotton and cotton blends is carried out for a particular length of time, pH and temperature conditions so as to ensure only softening and no eventual degrading. Virgin cellulosic fabrics resulting in a weight loss of 5-7% give satisfactory
softening results. Abrasion of the material is also a pre-requisite condition for enzymatic biopolishing. The reaction is stopped at the required juncture so that no further degradation results because left to itself, cellulase can completely eat up the cellulose polymers to give sugars and alcohols. In terms of action of the enzymes, it has been established that cellulose-destroying enzymes can be sub-divided into four groups regardless of which living organism they come from.

There is one group of endoenzymes wherein the enzyme attacks the chemical bonds removed from the ends of a long polymer molecule. Further, there are two groups of exoenzymes viz. exoglucohydrolase and exocelllobiohydrolase, which attack polymer substrate when a short end group is cleaved off, and finally there is a fourth group consisting of cellobiases.

These enzymes can be characterized as soluble organic bio-catalysts produced by a living organism to act specifically on a determined substrate. Their action consists in lowering the activation energy of a reaction. The speed of reactional kinetics of enzymes can be multiplied by a factor of $10^{12}-10^{10}$.

The enzyme, being a biological catalyst, is a molecular worker offering an answer to the desire for a cleaner, more gentle, less polluting, non-aggressive and hypoenergetic chemistry, with minimum damage to textile substrates and environment. Today, we are witnessing an explosion of biotechnology that is revolutionizing the textile industry. Continuous scientific leaps forward are establishing a new state-of-the-art and permitting spectacular progress to be achieved. Through the use of enzymes, for example, with their apparently magnetic or “intelligent” properties, it is possible to metamorphose linen fibre to cotton, viscose to silk or wool to cashmere. In the case of enzymatic treatment, the substrate fits into the enzyme like a key in a lock, producing an intermediate complex filled with the enzyme's energy, which then decomposes into a final converted product. The enzyme plays the role of molecular pair of scissors. This action proceeds in a chain-like fashion so that one single enzyme is capable of catalyzing several million molecules. The action of cellulase is given earlier. However, in the case of wool and silk, three distinct groups of enzymes come into play. They are:

- The proteases, with the sub-groups of peptidases and proteinases. These split up the proteinic or polypeptide molecules into organic acids and amines. They act as endopeptidases, i.e. they attack the CONH groups, not just at the extremities of the chains but also in the interior of the molecule. The exopeptidases only act on the terminal links of the chains. The origin of these proteases may be pancreatic, vegetable, bacterial or fungal.
- The lipases which act on the lipids of fatty substances, hydrolyzing the triglycerides into glycerol and fatty acid by their exo- and endo-lipase sites. These lipases are specific and cut the ester linkages at positions one and three of the triglycerides. They are found among moulds (Rhizopus, Aspergillus), yeasts (Candida) and bacteria (Bacillus).
- The lipoprotein lipases which act selectively on the lipoprotein liaisons by breaking the hydrophobic barrier.

The enzymes used in today's textile treatments are 'selective' in their action, thus becoming 'intelligent'. In the case of wool, laboratory tests have confirmed that a sliver of ultrafine wool can be completely dissolved by a devouring enzyme. The enzyme infiltrates itself into the molecular interstices between the scales and can, therefore, consume the entire endoscale without even altering the exoscale. This mechanism indicates that it is necessary to be able to stop the action of an enzyme at the surface by a keratinophilic enzyme (by a keratinolyses) or subtly immobilize an aggressive enzyme so as to prevent it from penetrating into the endoscale.

In the case of wool, enzymatic pretreatments represent a very interesting alternative to chlorine. An intelligent enzyme for this purpose is discovered, which produces a significant increase in the antifelting property of the wool. This antifelting effect is obtained by the enzymatic filing of the scaly epi-cuticle of the wool fibre. Enzymatic treatments of the proteinic fibres such as wool and silk are already being applied on an industrial scale in the processes of bio-washing, bio-bleaching, sandwash, partial bleaching, degumming, etc. At the same time, scientific studies are continuing to obtain a better knowledge of the reaction mechanisms, search for new processes and application techniques, study enzymes that are still little known, and continue the search for 'super-intelligent' enzymes. It appears that at the dawn of the coming century, biotechnology will play a decisive role even in textile finishing.

6 Certain Home-Truths

Textile production encompasses three main
stages including fibre production, dry processing (spinning and weaving) and wet processing and any future projection or change has to visualize the current scenario and accept the home-truths. What are they?

Wet processing uses approximate 100 litres of water and 15-20 kWh of energy for every kilo of finished textile, which, in turn, consumes around 5 kg of oxygen and releases nearly 7 kg of carbon dioxide. In addition to these, the manufacture of textiles and tending of garments also adds to the pollution loads. Heavy metals are present in buttons, fasteners, zips and some azoic and chrome dyes are known to carry potent allergens. Some of the risks directly linked to various processes are shown in Table 3.

Against this backdrop is developed the process of dying in supercritical fluids. The initial reactions to such a phenomenon is simply termed "Dream Cum True". Initial trials have been done with disperse dyes on polyesters with no water, no chemicals and have shown a lot of excitement. All what is desired is the polyester substrate, the dye (free from dispersing agents and adulterants) and the supercritical fluid, viz. CO₂.

Supercritical CO₂ is CO₂ above its critical point, viz. 31°C and pressure of 74 bar. This property is meaningful because CO₂ displays solvent properties similar to those of liquid hydrocarbons. Hence, dyeings with polyester have been successfully tried at 80-160°C for 5-20 min with pressures going up to 250 bar with supercritical CO₂ in an autoclave where only the dye and the substrate are kept at the beginning of the dyeing to see the dyed material at the end of the dyeing cycle.

This is showing a lot of promise as other areas of finishing are also being investigated and the claims made are as follows:

- Complete elimination of water pretreatment and pollution.
- Energy savings on drying textiles because drying is dispersed with.
- No need for auxiliary agents, dispersing agents, adulterants, etc.
- No chemicals required, e.g. pH buffers, levelling agents, etc.
- For polyesters, no reduction clearing is needed.
- Considerably shorter dyeing time.
- No harmful air emission because CO₂ is recycled.

| Table 3 – Risks directly associated with textile production and processing |
|-----------------------------|----------------------------------|
| Production activity | Risks                               |
| Man-made fibres | Cancer inducing                   |
| Monomer residues | Cancer inducing                   |
| (vinyl chloride, acrylonitrile) |                                            |
| Synthetic dyestuff | Cancer inducing                   |
| Azoic dyes | Sensitizing                       |
| Chrome dyes | Sensitizing                       |
| Finishing | Cancer inducing, sensitizing       |
| Formaldehyde and flame-resisting finishes | Cancer inducing, sensitizing |
| Antimicrobial finishes | Allergenic, neurotoxic, skin irritant |
| Whiteners | Sensitizing                       |
| Softening and antistatic finishes | Encouraging sensitizing |
| Dyeing/Finishing residues | Cancer inducing, environment damaging, neurotoxic, immunosystems impairing |
| Dye accelerators and halogenate hydrocarbons | Cancer inducing, environment damaging, neurotoxic, immunosystems impairing |

<table>
<thead>
<tr>
<th>Table 4 – Supercritical CO₂ dyeing system</th>
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<tbody>
<tr>
<td>Conventional dyeing</td>
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<td>High volumes of waste water with residual dye chemicals, etc</td>
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<tr>
<td>High energy requirement</td>
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<tr>
<td>Dyeing/washing; drying time, 3-4 h per bath</td>
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<td>Conventional systems</td>
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Thus, in the changing scenario, the chemical specialities should address problems and tackle the same with a hands-on approach. The manufacturer of such chemicals should be clear in formulating the correct input and the user at the mill level should use the correct balance of the product mix so that the textile user gets the fabric within tolerable limits. Some of the limitations are outlined in Table 4.

7 Future Strategies

With the shifting of speciality chemicals manufacturing to the developing countries, countries like India should carefully study the opportunities, look into the social costs attached and not just grab such options from the point of view of earning valuable foreign exchange.
The most important factors for future developments of speciality chemicals are the ecological and toxicological considerations. The ecological considerations require that the eco-system may not be disturbed so as to cause irreparable damage to flora and fauna, geophysical environment and to mankind. TSC industry have to address these issues both at the manufacturing as well as end-use stages. Toxicological safety requirements were never considered as important factors when the first ever direct dye was synthesized. But, today the task of finding safe substitutes for these chemicals is of foremost consideration.

Still there is a great scope for the introduction of novel chemical finishes with superior performance, greater ease of application and preferably with multi-functional properties. In the years to come, integrated finishing treatments will be preferred because of the necessity to provide quick response to market demands. The continued expansion of the leisurewear and sportswear markets for textiles in the west will continue to offer exciting challenges and opportunities for chemical finishes in future.

Future thrust areas will soon take direction from the fermentation biotechnology field. Apart from amylases conventionally being used for desizing, enzymes like cellulase, pectinase, protease and lipase will find more uses in TSCs. Enzymatic biopolishing of textiles of the cellulosic and woollen substrates have already become reality.

However, in the years to come, full-flagdged streamlining of such bacterial fungi will have to be totally exploited to give value-for-money to the textile processor. TSC industry is quick to pick up the advances in science and technology. The streamlining of microencapsulation techniques will present the chemical manufacturers to come out with perfumic capsules, antimicrobial agents, etc., in the near future.

Materials available in abundance in our country should be looked into and exploited fully. In the petrochemical field, abundant natural gas is still open to fantastic manipulations whereas huge guar gum type of agroproducts could be systematically exploited to give better value-added products.

References