Ecofriendly textile production

H T Deo
18 Safalya, 19-20 Nath Pai Nagar, Ghatkopar (East), Mumbai 400 077, India

It is no longer adequate to have a finished product to be safe only to human beings, but the product has to be environmentally safe during its entire life cycle and even beyond. This paper discusses the aspects of ecofriendly textile production in terms of use of ecofriendly chemicals, generation of lighter pollution load, effluent and gases, and drastic reduction in the use of resources like water, oxygen, land, energy, manpower, etc. Futuristic eco-scenarios, leading to the total eco-revolution philosophy, have also been discussed.

Keywords: Eco-revolution, Waste water treatment, Green textiles, Natural dyes

1 Introduction

The early-recorded history of textiles all over the world is the same. Every single step of preparing a textile item was manual. There was no mass production for commercial purposes. The textile items were, however, given in a gift to show respect, love, affection and concern for the dear ones. This brought about social changes conducive to create a healthy social life. This situation remained unchanged till the industrial revolution took place in the 18th century in Europe when the era of mass production arrived. The worst casualty of this revolution was the environment. Man has now realized this fact at the cost of wasting more than two valuable centuries.

Excessive use of chemicals has resulted in pollution of environment and slow deterioration of soil health. The All India Federation of Organic Farming (AIFOF) has demanded a total ban on the use of chemical fertilizers, pesticides and fungicides on agro-products including cotton and other natural fibres.

'Think globally, act locally' is the slogan of tomorrow for the world textile industry. Mackie and Geerdes reviewed the evolution of the textile industry during the last century. This paper discusses, among other issues, the consequences of World War II in terms of production and consumption, considers the factors that will reshape the industry over the next few years, and anticipates the 21st century with initial reference to the impact of environmental and population issues. With the further increase in population in future years, the authors predict a large increase in textile consumption than ever before and fewer employment posts. Consequently, the industry will be forced to find ways of reducing the burden on the world resources.

1.1 India's National Textile Policy 2000

In November 2000, Government of India announced the new textile policy (National Textile Policy 2000), de-listing the Garment sector from its Small-Scale Industry (SSI) reservation list. India started exporting garments in 1969-70 at a modest level of Rs. 9 crore. This sector performed well over the years and is expected to meet or surpass the export target of Rs. 10,000 crore (equivalent to US$ 2.13b approximately) in the year 2000-2001. WTO offers good opportunities for garment exporters after January 2005 when the quota restrictions will end.

Vishwanath opined that textile is such an important sector of Indian economy that steps must be taken to ensure the industry's survival after trade protection is removed. There is considerable apprehension that China will flood the country with cheap goods, while Indian spinners may import superior Egyptian cotton rather than using home produced cotton. Government of India is to support three main export areas: ready-made garments (RMG), cotton yarn and man-made textiles.

The entire textile sector is now open for Foreign Direct Investment (FDI) so that it can be at par with the new economy information technology (IT) sector. Even today, the foreign exchange earning from the textile sector, which is US$ 11b a year, is about 35%
of the total foreign exchange earned by the nation. This amounts to approximately Rs. 51700 crore per year (at Rs 47 per dollar). This figure is to be raised 5-fold at US$ 50b per year (Rs. 2,35,000 crore per annum) by the year 2010, a level projected for the Indian IT sector by 2008. The new textile policy of India is aimed at promoting a vibrant and dynamic Indian textile sector, able to compete internationally and withstand the pressure of imports into the domestic market.

In this paper, the elements of ecofriendly concepts have been discussed by reviewing a relevant recently published textile literature that highlights the contemporary research efforts. Futuristic eco-scenarios, leading to the total eco-revolution philosophy, have also been discussed.

2 Modern Thinking on Ecofriendly Textiles

2.1 Ecofriendly Preparatory Processes

A method for sizing and desizing yarns with liquid and supercritical carbon dioxide solvent has been described to produce a clean yarn. Calorimetric determination method of D-galacturonic acid in reverse micellar solution has been investigated to monitor bio-scouring of cotton in organic media. Quick removal of cotton wax must be taken into account in the bio-scouring process to obtain effective results.

Wrzalski described a bio-preparation process for cotton using pectinase enzyme. It gave environmental and economic advantages when compared with the conventional preparatory process based on kiering. The new process saved considerable energy and achieved better handle and reduced pilling tendency of the prepared fabric. Prochimica Novarese has developed a new range of surfactants, Biotex, to meet the need for technologically efficient but rapidly biodegradable products.

A process for bleaching of a substrate, which includes adding a molecular oxygen activating system to aqueous wash liquor, is disclosed. The molecular oxygen is obtained from air, which results in significant bleaching of a substrate obviating the use of the conventional oxygen-generating compounds like perborate or percarbonate. Sclavos S A of Greece has developed the Aqua-Chron system enabling to use a continuous rinse process, which consumes less water than that consumed in conventional drop/fill rinsing process. Here, the rinsing process takes place without stopping either liquor or the fabric circulation. Feasibility of a one-step process for desizing, scouring, bleaching and mercerizing of cotton fabric followed by dyeing with direct dyes has been discussed. Closed loop dry cleaning machine and a solvent have been developed. A closed loop dry cleaning machinery using a cyclic-organo-silicone-based solvent allows the process to be environment-friendly, which is more effective in cleaning fabrics than any known prior systems.

2.2 Dyeing, Printing and Finishing

Bradbury et al. have advocated the adoption of controlled coloration principles that lead to right-first-time (RFT) performance and reduction in costly and wasteful re-processing in dyeing industry. Smart rinsing systems and ultra-low liquor ratio (ULLR) machines have been described.

Non-conventional methods for dyeing and finishing of wool, such as use of ultrasonics, dyeing from supercritical media, plasma treatment and use of enzymes, have been reviewed. Liquid ammonia mercerization of woven and knitted cotton fabrics has been described. The alternatives for chlorine-polymer combined processes, e.g. enzymatic treatment processes and low-temperature plasma (LTP) treatment, have been discussed.

Consumers prefer natural feel and comfort of garments made from cotton fabrics. However, direct and fibre reactive dyes, the dye classes that provide cotton with a full colour range of bright shades, have only a moderate affinity for the fibre. This lack of affinity is overcome during batch dyeing by the use of electrolytes such as sodium chloride and sodium sulphate and by extended dyeing times at elevated temperatures. Multiple rinses and after washes are required to remove unfixed dyes and often a polymeric fixation agent is applied to improve the wet fastness properties of the dyed fibres. Overall process is extremely energy and water intensive and leaves significant amount of chemical waste in the dye house effluent. Acid dyes, another dye class with a wide range of bright colours, have very little affinity for cotton and are used primarily with amide containing fibres. Chemical pretreatments or modification of the substrates could improve the affinity of fibres. In 1973, Lokhande reported the development of sensitization process of cotton which increases the dyed shade ten times, giving near zero-dye and zero-salt effluent with reactive dyes (Table 1).
Table 1—Saving of reactive dyes consumption during industrial bulk trials

<table>
<thead>
<tr>
<th>Dye</th>
<th>Quantity of dye used for matching shade on 65 kg fabric, g</th>
<th>Net saving of dye</th>
<th>Per cent saving of dye</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>Treated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amaryl Brilliant Red 8BX</td>
<td>1400</td>
<td>450</td>
<td>950</td>
</tr>
<tr>
<td>Amaryl Turquoise Blue 2GX</td>
<td>2000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Reactofix Turquoise Blue 2GFL</td>
<td>1200</td>
<td>400</td>
<td>800</td>
</tr>
<tr>
<td>Procion Red M8B</td>
<td>1200</td>
<td>400</td>
<td>800</td>
</tr>
<tr>
<td>Procion Red M5B</td>
<td>500</td>
<td>175</td>
<td>325</td>
</tr>
<tr>
<td>Reactofix Golden Yellow GX</td>
<td>3518</td>
<td>1320</td>
<td>2198</td>
</tr>
<tr>
<td>Reactofix Turquoise Blue 2GFL</td>
<td>598</td>
<td>325</td>
<td>273</td>
</tr>
<tr>
<td>Amaryl Yellow RX (H/C)</td>
<td>1200</td>
<td>500</td>
<td>700</td>
</tr>
<tr>
<td>Amaryl Turquoise Blue 2GX</td>
<td>85</td>
<td>45</td>
<td>42</td>
</tr>
<tr>
<td>Amaryl Orange RX</td>
<td>100</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

* red, *green, and *Mehandi (Hena) compound shades.

Dyeing behaviour of cotton, that was rendered cationic by reaction with 2,3-epoxypropyltrimethylammonium chloride, was examined. The excellent dye yields and fastness properties are reported for direct, reactive and acid dyes with the modified fibre without the electrolytes, multiple rinsing and fixation agents normally employed.

Chavan and Jahan recommended the use of organic bases as substitutes for sludge-forming caustic soda to maintain dye bath pH during dyeing of indigo on cotton. Apart from making more eco-friendly substitution, 25-30% increase in colour yield was also achieved. Multiple dip method was adopted for increasing colour yield of indigo on cotton by replacing HERCOSETT 57, a polyamide-based synthetic resin which acts as a cationizing agent for cotton, with ferrous sulphate. The six-dip six-nip method gave 28.6% increase in the colour yield, making the process more eco-friendly.

Reduction in the use of chemicals without affecting the fabric characteristics approach has been employed to reduce the pollution load; sodium carbonate was substituted with much less quantity of sodium hydroxide for the dyeing of reactive dyes on cotton.

Cotton was dyed with a natural colouring matter extracted from canna using ecofriendly mordents with good fastness properties of shade specific with different mordents.

Leary studied and revived naturally coloured cotton. Nearly all the varieties in commercial use today are derived from the stocks created by the native peoples of South America, despite all advised attempts to standardize cotton varieties and cultivations during this century. The environmental benefits of cotton, which is grown organically and does not require bleaching or dyeing, have led to renewed interest in its cultivation and marketing.

Absorption behaviour of acid dyes in multiple layers of modified wool was studied. The data shows that the affinity has a direct bearing on dye absorption by the woolen substrate. Economical aspects of dyeing treatments have been discussed. Sulphur dyes were treated as ecologically unsafe. Much has changed over the past 15 years, as the modern sulphur dyes are no longer inferior to other classes of cotton dyes in terms of odour and ecological profile of simplicity of application. Now, the dyeing with modern sulphur dyes represents the best ecological and economical alternative for many specific fields of application.

Ecofriendliness and several economic advantages of cellulase in finishing of cotton goods have been highlighted. Technological and ecological demands of pigment printing systems have been discussed. More and more ecofriendly alternatives are being developed by AATCC in clothes care, cleaning and dyeing. Auladel discussed the use of energy in textile finishing with reference to correct environment management. Points for consideration are Agenda 21, climate change and EMAS certification. A check-list of the key elements in an environment review include an environment policy, supplies and material, products, residues, emissions and spills, transport, ground and installations, control and feedback, emergencies and special cases, water management and the reduction of residues. It was pointed out that
non-toxic, non-pollution and low price should be the development direction of the anti-static and fire-retardant technologies in the future. A robust diagnostic test, soon to be adopted as an ISO test, has been developed that indicates which dyes will exhibit excessive fading. This will help avoiding such dyes, thus preventing the possible water pollution.

The enzymatic treatment of cotton is compared with kiering, and the environmental and financial advantages are discussed. It is shown that treatment with pectinase results in considerable energy savings and better cotton properties. The fabric has a better handle and tends to pill less. Handle of jute fabric was improved by more than 15% by biopolishing using cellulase enzyme.

2.3 Effluent Treatment Process/Plant

Reife and Freeman gave a summary of pollution prevention through waste minimization and source reduction, successes and ideas in the production of dyes and pigments. Examples presented include process optimization in the synthesis of azo disperse dyes and pigments, substitution of toxic metals and genotoxic dye intermediates in the synthesis of metal complex dyes for polyamides, direct dyes for cotton, and replacements for toxic inorganic pigments containing cadmium, lead, nickel and copper. A method of reusing valuable pollutants, such as waste aniline and phenols, and hydrolyzed reactive dyes has been discussed. Energy savings, safety and recycling opportunities using reverse osmosis, ultra-filtration and hyper-filtration methods have been given to generate recyclable water.

Absorption capacity of five low-cost ecofriendly absorbents, namely bagasse pith, orange peel, saw dust, Eichhornia roots and Eichhornia shoot, was compared with that of activated carbon at ordinary conditions of dyehouse effluent containing Methylene Blue. 95-100% decolorization was achieved in this process. Kos and Perkowsk described an advanced oxidation process of textile waste water treatment and have shown that the most efficient method for degradation of pollutants is the simultaneous application of ozone, hydrogen peroxide and UV radiation. The bisidiomycetous fungus Phanerochaete chrysosporium excretes extracellular lignin peroxidases (LiP) which were used in decolorization of different commercial dyes. The decolorization was non-specific and hence could be useful for decolorizing a large number of dyes of diverse structural classes. Decolorization and degradation kinetics of reactive dye waste water by a UV/ultrasonic/peroxide system has been investigated. Enzymatic decolorization of effluents containing azo, triarylmethane and indigoid textile dyes was efficiently achieved by enzyme preparations from seven types of enzymes. Lignin peroxidase and/or manganese peroxidase in combination of the specified enzyme preparations showed synergistic influence, giving 25% higher decolorization. Ferrero studied the oxidative degradation of dyes and surfactants in Fenton (iron sulphate and hydrogen peroxide) and photo-Fenton treatment of dyehouse effluents in presence of UV irradiation and showed that the residual total organic carbon (TOC) is a function of the initial TOC concentration and temperature.

Perkins highlighted the importance of pollution prevention vs end-of-pipe treatment of waste water in textile wet processing industry. Ozone, hydrogen peroxide activated by UV light, and Fenton’s reagent were shown to be powerful oxidants that were effective for the destruction of dyes in aqueous medium.

2.4 Recycle and Reuse Practices

The vinyloop process, patented by Solvay of Brussels, Belgium, for which Ferrari Textiles of La Tour du Pin, France has worldwide exclusive license in the composite textile field, separates the elements of composite PVCs so that they could be reused. It is an environment promoter process. A feature of this process is that the additives in the initial product to provide flame retardancy or UV resistance remain in the recycled PVC.

It is possible to reduce water consumption and waste water generation by 30% in a typical textile unit processing cotton and viscose rayon knit fabric and generating 750 m³ waste water per day by adopting the recycle and reuse principle.

2.5 Ecofriendly Machinery

A textile fibre recycling machine has been developed for reprocessing hard thread waste, woven and nonwoven fabrics, carpets, rugs, etc. The machine outputs open usable fibres which can be used in subsequent conventional textile processes. Kyungwon Enterprise Co. of South Korea has developed a washing machine which does not need detergents to clean cloths. The new technology has
developed a device which is able to transform water into an electronically charged liquid that cleans goods with the same power as that of a conventional synthetic detergent powder. It will make washing easier, cheaper and more environment friendly. The system would cut water and electricity consumption by two-thirds and one-half respectively\(^{47}\). Yanghal Carpet Yarns of Cork, Ireland, producers of large amounts of spun and dyed wool, have installed an ultrafiltration plant supplied by Koch Membrane Systems of Stafford, UK. The process pre-filters the waste water to remove any stray fibres after scouring, and then passes it through membrane treatment plant. Once the filtration is complete, the permeate is diluted with a large volume of dye bath waste water, pH balanced and discharged into the sea\(^{48}\).

Natural alternatives\(^{49}\) such as flax and kenaf fibres and new machinery for processing of such fibres were exhibited in ITMA '99. Monforts new stenter having special feature of 'explosion-proof' top meets the demand by British health and safety laws\(^{50}\).

The Spanish firm MCH SA produces dyeing machinery to save water, energy, products and time in the dyeing cycle, and matches the machines to customer requirements\(^{51}\). Kleinewefers Textile Machinery has extended the Raco-Yet concept to include the Pre-Yet unit. This allows textile processors to implement multi-phase processes continuously in the shortest possible time, using jet spray technology for processes such as desizing and scouring\(^{52}\).

Babcock has designed new finishing machines to meet environmental performance. It comprises wash compartments, impregnation compartments, reaction accumulators and machines for the cold pad batch process. These units allow treatment of knitted goods at low fabric tension and result in substantial savings in water and energy consumption\(^{53}\). Viviani\(^{54}\) highlighted the changing processes in dyeing while describing the Balco-Thermo Eco Flash process, the Power-tex intensive washing unit, Noseda's Flex 10 beam dyeing models, EVS computer vision systems, cold plasma treatments and electrolysis technologies.

2.6 Genome Research to Impart Ecofriendliness to Textile Products

Modification of bacterial cellulose was studied by Ciechanska et al\(^{55}\). The modified bacterial cellulose, characterized by unique properties such as bioactivity, biodegradability, biocompatibility and non-allergic action, connected with good mechanical tenacity, was found to be an excellent material for biomedical applications such as dressing of wound healing and artificial skin.

Genetic markers, mainly microsatellites from the sheep linkage map, were used to search for Quantitative Trait Loci (QTL) for wool traits using a Marino x Romney backcross flock. There was evidence for the segregation for fibre diameter at one marker locus with a difference of 1.7\(\mu\)m between the progeny groups\(^{56}\).

Nuclear polyhedrosis virus (NPV) infection is the most common and severe disease in silkworm, (*Bombbyx mori* L) which accounts for more than 15% loss in cocoon yield. Japanese scientists succeeded in breeding a strain of silkworm resistant to NPV by means of cold treatment and selection through thirteen generations. The induction of tolerance in bivoltine silkworm (*NB* 4\(D_2\)) to *Bombbyx mori* nuclear polyhedrosis virus (Bm NPV) infection by selecting pressure applied through generations has been studied\(^{57}\). The cocoon shape is an important parameter from the standpoint of silk production, evolution as well as evaluation of commercial hybrids. Some Japanese and Indian researchers found that cocoon shape is related to the size of the larva and the length of each part of the body. Uniformity of cocoon shape helps to get uniform filament size in semi-automatic and automatic reeling machines\(^{58}\).

Biotechnology, which is an emerging theme and has practical applications to textile field, offers the opportunity to reduce costs, protect the environment, address health and safety, and improve quality and functionality\(^{59}\).

2.7 Miscellaneous Aspects

Kearns of Waterfoot has recently implemented a number of cost-cutting environmentally effective changes as part of the Environet 2000, an UK government-backed scheme aimed at making cost-effective environmental improvements\(^{60}\). Cotton industry in Thailand went through the characteristic sequence leading from subsistence farming to a disaster phase because of the increasing reliance on chemical pesticides. Therefore, the integration of biophysical and socio-economic aspects of cotton production has now allowed an evolutionary path for its survival\(^{61}\).

A heat recovery system, reducing 35% oil consumption in dye house, was commissioned in a
typical dyehouse. The concept of ecological balance is useful for systematically monitoring the impact of a product on the environment, e.g. cotton.

Preventive approach to lower the emissions is being adopted recently. New methods of cutting emissions of dyestuffs and chemicals from carpert and textile plants are being investigated in Holland. In a programme supported by the Dutch Agency for Energy and Environment (NOVEM), a number of projects have been carried out to investigate the prevention of emissions as a preferred alternative to end-of-pipe methods such as waste water treatment. The work has been spurred on by new regulations that oblige firms to reduce their dyestuff emission in water by 90% by 1999. They are also seeking to combine this with overall reduction in energy consumption bringing economic as well as environmental benefits.

A newly recognized respiratory illness among workers at nylon flock and nylon-flocked upholstery fabrics producing plant in USA has been investigated by the National Institute for Occupational Safety and Health (NIOSH), USA. Assessing risks and damages, fire and explosion protection, the use of new medium frequency regulation techniques for flock processing and plant safety in the flock industry have been discussed. Noise reduction in textile mill was a subject of a recent study.

Cargill and Dow Chemicals have agreed to fund the construction of a commercial scale facility to develop polymers from renewable resources such as corn. These polymers could become a basic raw material for many textile applications, including fibres used in nonwoven hygiene products such as diapers. The polymer, NatureWorks PLA, is composed of chains of lactic acid which is produced by converting cornstarch into sugar followed by fermentation. Water is then removed to form lactide, which is then converted into polyactide resins using a solvent-free polymerization process. Such resins can run on existing spinning and downstream fabrication equipment. Cargill Dow Polymers have a manufacturing facility in Nebraska where they plan to produce 140,000 tons of the products.

"Chicken and egg" situation in case of organic cotton, "eco-fashion" has been discussed. The author states that consumers are not prepared to pay a premium for eco-fashion, while the prices will come down only when there is high production and growing demand. Eco-performance method to assess and improve eco-performance in the lifecycle of a consumer goods was developed and implemented.

The European LIFE Regulation—a financial instrument for the environment—is a far-reaching concept in the field of eco-science. LIFE is a financial instrument introduced by European Regulation 1973/92 of 21 May 1992 and modified by regulation 1404/96 of 20 July 1996, which concluded its second phase on 31 December 1999. The European Commission is preparing to launch the third phase from 2000-2004. LIFE is divided into three sections: LIFE-environment, LIFE-nature and LIFE-third world countries. LIFE-environment is aimed at encouraging innovative techniques and productive methods by financing pilot schemes and projects with the following objectives: (i) to reduce to a minimum the environmental impact of the economic activity by a strategy of prevention; (ii) to prevent, reuse, recover and recycle, and manage refuse laws rationally; and (iii) to reduce the environmental impact of products by an integrated strategy of production, distribution, consumption and after-use treatment, including the development of products with respect to the environment.

In Netherlands, the environmental policy for the textile and carpet industry is primarily focussed upon the emission of dyestuff and additives to water or energy consumption through preventive approach. Prevention is achieved by increasing the fixation rate of the reactive dyestuff on the textile or carpet, replacement of harmful additives by more environmentally-benign additives, and application of enzymes in the pre-treatment of textiles as desizing agents (amylase). Currently, further research is being conducted to evaluate the possibility for enzyme technologies (cellulases) in the functional finishing of textiles. Future developments in environment related technologies and the current Japanese Government policy have been discussed.

Kimberley-Clerk Corp. (USA) has introduced a new product into the adult incontinence market. Called Depend, the underwear is disposable and absorbent and is designed for adults who experience incontinence. The company is also launching a new incontinence pad called Poise as well as improved Kotex feminine pads, pull-up training pants, Huggies diapers and GoodNite disposable underpants. New demands on sizing technology due to environmental considerations as well as future developments in spinning and weaving technologies have been discussed. A reduced effluent pollution coupled with
a marked drop in size pick up and improved weavability has been described by Sherrer. SaveSizecombi of Benninger offers prime benefits of prewetting – impregnating the warp with hot water while washing.

3 Some Ecofriendly Concepts

Lokhande advocated the "Preventive Environmental Policy" to prevent harmful emissions through improved recycling of raw materials, to use low emission technologies, and to substitute harmful products and harmful processes with ecofriendly ones. He showed that investments made to protect environment are, in fact, quite attractive paying propositions. Ecofriendly concepts of Lokhande and his group in the last three and half decade's research are summerized below.

3.1 Morpholine as a Swelling Agent for Cellulose

It was recognized that the production of viscose rayon by the xanthation process is highly polluting process and hence be replaced by an ecofriendly technology. Lokhande was the first to show that morpholine is a very powerful swelling agent for cellulose while piperidine has no action on cellulose even though both have almost identical structure and very similar solubility parameter (δ) (Table 2).

Due to the formation of soda cellulose, the viscose production is obtained through conversion of cellulose I into cellulose II which is more stable polymorph of cellulose and hence difficult to be dissolved in a solvent of cellulose. To dissolve cellulose in carbon disulphide-containing xanthate solution, the chain length of cellulose molecule has to be brought down to 300-400 DP level by hydrolysis. This induces inherent weakness in the viscose structure, especially in the wet conditions. Morpholine brings about the same extent of swelling (200%) as achieved by caustic soda treatment, while keeping the cellulose I structure intact. This allows dissolution of cellulose of much higher chain length, say 500-600 DP. Manufacture of Tencel or Liocell, which is regarded as the fibre of 21st century, is perhaps based on these considerations. The unlimited swelling, i.e., dissolution of cellulose, is brought about by N-methylene oxide of morpholine. It is, therefore, not surprising that its wet modulus (3.8–4.2 g/den) is much superior to that of viscose rayon (0.5–1.5 g/den) in fact, it is even higher than that of polyester fibres.

Electron microscopic study, absorption characteristics and dyeability studies of morpholine-treated cotton fibres brought out significant data to suggest that the extent of swelling of fibres was so high that it could be almost entering into the dissolution stage by replacing morpholine with one of its suitable derivatives. It is significant that Tencel/Liocell manufacturing processes are based on N-methylene oxide of morpholine.

3.2 Water-Superabsorbent Polymers

Superabsorbent polymers (SAP) find many applications in diapers, tissue papers, cosmetics and in agriculture. The early SAPs based on synthetic raw materials were failures as they were non-ecofriendly and found to damage soil quality. SAPs, developed in UDCT laboratories, gave excellent results in absorbency and in sustained release of absorbed fluids such as water, moisture and saline solution. They were biodegradable and totally ecofriendly being based on natural polymers. These products were prepared from non-wood based cellulose as well as textile loom waste containing cellulose and starch. The soil mixed with the products gave comparable growth of plants even in the absence of water as compared to the one which was watered in the normal way.

3.3 Eco-friendly Bleaching

Several formulations and eco-processes were developed in UDCT laboratories with a view to make

<table>
<thead>
<tr>
<th>Sample</th>
<th>Accessibility, %</th>
<th>Extent of swelling cm²/100g</th>
<th>Microfibrillar dimensions, Å</th>
<th>Swelling %</th>
<th>Increase in dyeability with reactive dyes %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid hydrolysis Formulation</td>
<td></td>
<td></td>
<td>Width Thickness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>17.5</td>
<td>30.59</td>
<td>17.2</td>
<td>110</td>
<td>25</td>
</tr>
<tr>
<td>Morpholine-treated cotton</td>
<td>18.9</td>
<td>30.76</td>
<td>33.5</td>
<td>205</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 2—Changes in fine structure of morpholine-treated cotton fibres

(Morpholine conc., 40%; Treatment temp., 20°C; and Treatment time, 1 h)
chemical processing totally ecofriendly coupled with substantial earnings through saving time, water, steam, electricity, dyes, chemicals and other costly inputs and services. By reducing the number of steps in bleaching, about 72% time saving, 59% water saving and 42% cost saving was achieved in bleaching of cotton goods on the industrial scale. The bleaching process was made more ecofriendly by substitutions and process modifications (Table 3).

A new method of bleaching of cotton yarn, which doubles the production with overall saving of 58% without sacrificing the bleached yarn quality, has been reported by Deo and Chintal. As no chlorine-based bleaching agent or chemical is used, the new method is ecofriendly. It virtually obviates the need of costly effluent treatment plants and can be particularly useful to the cottage industry in yarn dyeing sector.

3.4 Ecofriendly Dyeing and ETP Systems

Several ecofriendly research projects in dyeing were completed with good promising results. Over 90% saving in water consumption and very substantial reduction in pollution load of the dyehouse effluent (COD reduction by 57%, BOD by 26% and TDS by 37%) were achieved during dyeing of cotton and polyester fabrics on industrial scale coupled with a substantial cost reduction in dyeing (Table 4).

To reduce the load on ETP system, a maximum amount of dyestuffs should be removed from the dyehouse effluent before it is lead to the ETP plant. A novel process of using very cheap waste materials that are natural products and available in plenty at very cheap rates was used for comparison. A single product was used in a column and the effluent also contained a single class of a dye to see the effectiveness of the absorbent vis-a-vis the class of the dye present in the effluent. Absorption of at least 80% of the dye was taken as a criterion to evaluate a particular absorbent for a given dye (Table 5). A blank in the table means that less than 80% of dye was absorbed. Results indicate that the selected natural absorbents are very effective in removing almost entire amount of dye present in an effluent giving a colourless waste water to be treated subsequently by the ETP system at ease and at much lower cost.

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**Table 3—Effect of different bleaching sequences on process parameters**

<table>
<thead>
<tr>
<th>Process</th>
<th>No. of steps required</th>
<th>Total time required (h)</th>
<th>Saving in time (%)</th>
<th>Quantity of water required (litre)</th>
<th>No. of washings required</th>
<th>Savings in water consumption (%)</th>
<th>Cost of bleaching per kg (Rs) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>14</td>
<td>18.0</td>
<td>-</td>
<td>110</td>
<td>8</td>
<td>-</td>
<td>2.54 (-)</td>
</tr>
<tr>
<td>Formulation I</td>
<td>09</td>
<td>5.5</td>
<td>69.44</td>
<td>67</td>
<td>5</td>
<td>39.09</td>
<td>1.69 (33.5)</td>
</tr>
<tr>
<td>Formulation II</td>
<td>09</td>
<td>5.5</td>
<td>69.44</td>
<td>67</td>
<td>5</td>
<td>39.09</td>
<td>1.69 (33.5)</td>
</tr>
<tr>
<td>Formulation III</td>
<td>09</td>
<td>5.5</td>
<td>69.44</td>
<td>67</td>
<td>5</td>
<td>39.09</td>
<td>2.48 (2.4)</td>
</tr>
<tr>
<td>Formulation IV</td>
<td>09</td>
<td>9.5</td>
<td>47.22</td>
<td>67</td>
<td>5</td>
<td>39.09</td>
<td>1.48 (41.8)</td>
</tr>
<tr>
<td>Formulation V</td>
<td>06</td>
<td>5.5</td>
<td>69.44</td>
<td>45</td>
<td>3</td>
<td>59.09</td>
<td>2.59 (Nil)</td>
</tr>
<tr>
<td>Formulation VI</td>
<td>06</td>
<td>5.0</td>
<td>72.66</td>
<td>45</td>
<td>3</td>
<td>59.09</td>
<td>2.87 (Nil)</td>
</tr>
</tbody>
</table>

* Bleaching of cotton fabrics

**Table 4—Analysis of waste water generated by different eco-processes and saving in water consumption during dyeing of cotton with reactive (R), sulphur (S) and vat (V) dyes**

<table>
<thead>
<tr>
<th>Process</th>
<th>pH</th>
<th>Total solids (mg/litre)</th>
<th>Biological oxygen demand (mg/litre)</th>
<th>Chemical oxygen demand (mg/litre)</th>
<th>% water savings (R)</th>
<th>% water savings (S)</th>
<th>% water savings (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>10.6</td>
<td>7530</td>
<td>387</td>
<td>1421</td>
<td>37.20</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>Eco-process I</td>
<td>10.2</td>
<td>4832</td>
<td>310</td>
<td>820</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>Eco-process II</td>
<td>10.8</td>
<td>4720</td>
<td>288</td>
<td>610</td>
<td>74.20</td>
<td>88.88</td>
<td>90.90</td>
</tr>
</tbody>
</table>
Table 5.—Effectiveness of dye removal present in a dyehouse effluent by eco-friendly natural absorbents

<table>
<thead>
<tr>
<th>Absorbent</th>
<th>Direct</th>
<th>Reactive</th>
<th>Acid</th>
<th>Basic (Cationic)</th>
<th>Disperse</th>
<th>Vat</th>
<th>Sulphur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated carbon</td>
<td>99</td>
<td>98</td>
<td>95</td>
<td>99.5</td>
<td>99.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Charcoal</td>
<td>93</td>
<td>-</td>
<td>-</td>
<td>96.0</td>
<td>85.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stannous chloride + alum</td>
<td>99</td>
<td>-</td>
<td>-</td>
<td>80.0</td>
<td>100</td>
<td>99.50</td>
<td>-</td>
</tr>
<tr>
<td>Tea waste ash</td>
<td>80</td>
<td>80</td>
<td>-</td>
<td>92.5</td>
<td>80.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wood ash</td>
<td>97</td>
<td>98</td>
<td>92</td>
<td>-</td>
<td>96.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Paper pulp</td>
<td>80</td>
<td>80</td>
<td>82</td>
<td>-</td>
<td>90.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fired clay</td>
<td>96</td>
<td>80</td>
<td>82</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Saw dust</td>
<td>80</td>
<td>80</td>
<td>-</td>
<td>91.0</td>
<td>92.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Flax waste</td>
<td>90</td>
<td>96</td>
<td>80</td>
<td>97.0</td>
<td>97.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jute waste</td>
<td>80</td>
<td>82</td>
<td>80</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sugarcane bagasse</td>
<td>-</td>
<td>80</td>
<td>-</td>
<td>82.0</td>
<td>90.0</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

reduced cost. A universal column could be prepared by taking the appropriate binary or tertiary combinations of absorbents in a column or columns to treat effluents containing any number of classes of dyes. Stannous chloride-alum system is highly effective for vat and sulphur dyes as their mechanism of dye removal is based on coagulation and sedimentation.

Lokhande and Dorugade reported ecofriendly dyeing of jute fibres by replacing the toxic conventional reducing agent CS₂ with more ecofriendly glucose-NaOH reducing system. The new method also gave deeper shades than those obtained in the conventional method.

Heat of dilution of conc. sulphuric acid was used for dyeing of cotton, viscose and wool fibres. The diluted acid was then used for carbonizing polyester/cotton blends.

Deo and Paul developed ecofriendly carbonizing process of polyester/cotton blend fabrics using cellulase enzyme to remove cellulose portion of the blend. Deo et al. were the first to point out that natural dye shades could be built up by multiple dip method of dyeing, making the natural dyeing economically more viable.

Several studies were carried out to dye natural and synthetic fibres with natural dyes. Deo and Desai, and Lokhande and Dorugade were the first to report the use of tea as a natural dye with the excellent wash fastness properties.

Development of ecofriendly non-formaldehyde dye fixative agents for reactive dyes was also reported. Deo and Paul first reported the concept of totally ecofriendly mordents or natural mordents during dyeing with natural dyes, so that dyeing becomes totally environment friendly in the absence of the conventional metallic mordents.

Table 6.—List of forbidden classes of dyes

<table>
<thead>
<tr>
<th>Class</th>
<th>No. of dyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct dyes</td>
<td>77</td>
</tr>
<tr>
<td>Acid dyes</td>
<td>26</td>
</tr>
<tr>
<td>Disperse dyes</td>
<td>06</td>
</tr>
<tr>
<td>Azoic colours</td>
<td>05</td>
</tr>
<tr>
<td>Basic dyes</td>
<td>03</td>
</tr>
<tr>
<td>Oxidation bases and developers</td>
<td>01</td>
</tr>
<tr>
<td>Total</td>
<td>118</td>
</tr>
</tbody>
</table>

3.5 Banned Dyes

German ban initially covered 118 azo dyes spread over several classes of dyes (Table 6). Twenty arylamines including benzidine, suspected to be carcinogenic and toxic, have also been banned. Detailed recommendations were made to the authorities regarding the status of Indian textile industry and to prepare it to face the German ban on azo dyes and other toxic chemicals. Similar ban was imposed in India following the acceptance of the recommendations made in the reports. Several papers on safe alternatives to the banned dyes and chemicals were reported. Subsequently, azo pigments were also banned. Although no reactive and vat classes were affected in the original ban, some dyes of these classes have now been found to be allergens and toxic ones. Apart from the banned dyes of the affected six classes shown in the Table, more and more dyes are being shown to be toxic. Disperse class is now leading the tally.

Hatch and Maibach reported that according to dermatologists' case report, about 79 dyes and 5 dye-related chemicals are contact allergens or sensitzers. About 32 disperse, 33 non-disperse (14 reactive, 8 acid, 3 solvent, 4 basic, 2 direct, 1 pigment, and 1 vat)
and 14 others could not be assigned to any class as a result of lack of sufficient information available for ascertaining their C.I. name. Other chemicals reported to be allergens are Naphthol AS, two azoic diazo compounds, a dye fixing agent and a chromium mordant.

4 Integrated Approach for Eco-balancing

The following integrated approach is required for ecofriendly production:

- Production of raw materials should be ecofriendly.
- Raw material utilization should be with zero-residue.
- Methods for preparing raw materials, intermediates, finished products and disposal of wastes should be ecofriendly.
- Rigid procedures, requiring the use of only specific chemicals and specific methods should be converted into flexible ones to facilitate substitution of non-ecofriendly chemicals by their safe counterparts from time to time.
- Green Technology or Clean Technology, which is totally ecofriendly, should be adopted. This essentially means in increasing the Gross National Product (GNP) of a nation by utilizing substantially reduced quantities of inputs.
- Among the natural fibres, silk is now considered to be non-ecofriendly due to its manufacturing process requiring to kill the silk worms. Research should be directed to get the silk without killing the silk worm to make the process ecofriendly.
- Economic lucrativeness during environmental protection should be used.
- “Prevention is better than cure” – prevention is better than the end-of-pipe methods in ETP.
- Ecofriendly index of a product must include its half life time and the extent of ecofriendliness of degradation products.
- Saving in time, energy, manpower, resources, land, transportation, raw materials are all ecofriendly concepts and should be adopted in industrial practices.

5 Futuristic Projections for Eco-balancing

5.1 The age-old Cross, Bevan and Beadle (England, 1891) method for viscose and the copper-ammonia method (Germany, 1891) for cuprammonium rayon are non-ecofriendly. Research should be directed to replace the carbon disulphide ($CS_2$) used in the xanthation process and copper salts used for the cuprammonium rayon by the safe chemicals, employing ecofriendly methods of manufacturing. Lokhande et al. were the first to demonstrate the tremendous interaction of pure morpholine molecule with cellulose, leading to 200% swelling of cotton cellulose which happens to be equal to the one produced by caustic soda solution of mercerizing strength. They gave mechanism of this unique behaviour of pure morpholine. They also investigated the technological advantages of morpholine as well as its binary mixtures with other aliphatic and aromatic mono and di-amines on cotton cellulose. A major innovation has recently come after the lapse of more than a century in the form of manufacture of Tencel and Liocell rayons, which employs a more ecofriendly solvent, N-methylmorpholine oxide (NMMO) (Courtaulds, UK & USA, 1989 and Lenzing AG, Austria, 1991, respectively). It is heartening to note that these and other similar inventions are essentially based on a member of morpholine family.

5.2 Similarly, after one-and-a-half century, the age-old mercerizing process has undergone change in the form of liquid ammonia mercerizing process in which the conventional caustic soda has been replaced by the anhydrous liquid ammonia at $-35^\circ C$ which happens to be more ecofriendly as it is basically a zero-effluent process.

5.3 Solid (compressed) carbon dioxide ($CO_2$) processing of textiles replaces water, thus making it zero-effluent processing although it is still at the laboratory stage.

5.4 The use of natural dyes on the industrial scale has become possible only due to their ecofriendly characteristics as against synthetic counterparts, whether banned or free and safe or toxic.

5.5 Synthetic dyes, in general, and disperse dyes, in particular, will be a big casualty in future. They are the only class of dyes that sublime and hence are inherently non-ecofriendly. More and more disperse dyes are being identified as toxic, allergens or carcinogens. Research should be directed to replace the entire disperse class by non-subliming dyes for synthetic fibres. Consumers in Scandinavian and other EU countries are welcoming polyester goods dyed with natural dyes. Another casualty will be metal-complex dyes used for wool due to their non-ecofriendly characteristic. Synthetic textile fibres
based on biodegradable non-oil based synthetic polymers will be the future ecofriendly inventions.

5.6 To produce coloured cotton and to cultivate organic cotton will be the right approach. Coloured cotton fibres and the garments made out of them are distinct possibilities now. Genetically, it is possible to introduce colored pigments of desired shades in the natural fibres including jute, wool, silk and cotton by encouraging research in that direction. This may be termed as "natural dope dyeing of natural fibres". Ecologically, this will be a big step forward as no synthetic dyes and pigments will be used, thereby saving the eco system to a great extent. The powerful and rich dyestuff industry and machinery manufacturing corporations in the world at large will be severely affected. In near future, the eco-revolution will be so much intensified that nothing will be able to stop the research efforts in these areas of far reaching consequences to protect the environment.

5.7 The increase in the human population should be accompanied by the increase in population of trees, forests and lakes.

5.8 With a distinct reality of increasing the life span of human being by almost 100%, especially in developing countries, coupled with better health and improved efficiency of working, the GNP of a nation will enhance tremendously. In better environment, the life span of flora and fauna will also be increased, which will have synergistic effect to increase the life expectancy of the humans and other mammals. An excessive increase in population and its negative growth are both non-eco-friendly. The solid block of 1000m population of India, for example, when subjected to eco-revolution, will be a force to be reckoned with in every field of human endeavour. If science and technology has been the buzzword for the past two centuries, the eco-revolution will be the new buzzword of the new millenium for the entire global village.

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