Chemical processing of synthetics and blends—Impact on environment and solutions

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Chemical processing of synthetic textiles and blends generates significant air/water pollution. Through judicious selection and optimum usage of inputs (energy, water and substances) in processing, it is possible to minimize waste/pollution substantially. This will reduce the pollution load of an effluent to such a level at which it would be feasible to effectively operate the effluent treatment plant (ETP) and satisfy the norms of Pollution Control Boards (PCBs). Judicious selection of inputs will also take care of ecofriendliness of finished textiles to meet the eco-label requirement and tackle environmental problems. Waste minimization is achieved by pre-care and care during processing. Unavoidable minimum waste generated is then treated in after-care step to remove colour, toxicity and heavy metal ions to reduce the levels of total dissolved solids (TDS), COD/BOD, etc by primary/secondary/tertiary treatments before recycling the treated water. Sludge (solid waste) is disposed off by either land-filling or incineration depending on the extent of toxicity. The solutions offered aim at decreasing the hazardous character of sludge by eliminating the use of banned, red-listed chemicals/dyestuffs which have carcinogenic, allergic and toxic characteristics.

Keywords: Environment protection, Pollution control, Waste minimization

1 Industry

Processing of synthetic textiles and blends is now carried out in several parts of the country such as Bhilwara, Ichalkaranji, Hyderabad, Surat, etc. However, the three-tier decentralized man-made textile industry of Surat is the biggest single growth area for synthetic textile industry in the country and it is essentially a composite set-up. This industry engages in all activities necessary for converting fibres or filament yarns into finished product. The problems due to impact on environment in this growth area will, therefore, more or less cover the problems faced by similar industry in the other parts of the country as well.

In yarn preparatory and fabric formation sectors, the impact on environment is mainly concerned with the solid fibre/yarn waste management, i.e. collection and recycle/disposal, of 10-12 tonnes per day. Moreover, at times, if excess of antistatic/conding oils are used to gain weight, this creates an added problem as oil finds its way into the drain when the fabric is later on scour ed or it may sublime and pollute surrounding air when the fabric is heat-set for dimensional stability. The manufacturing sector may also create some noise pollution³.

In chemical processing of synthetic textiles and blends, the following activities are mainly carried out in around 400 process houses located in and around Surat city²:

- Reactive dyes dyeing/printing of viscose fabrics.
- Disperse/reactive dyes dyeing/printing on PET/cotton blends.
- Acid dyes dyeing/printing on nylon fabrics.
- Disperse dyes dyeing/printing on PET fabrics.
- Khadi/pigment printing on nylon fabrics.
- Brasso style printing on nylon/viscose and PET/cotton union fabrics.
- Discharge printing of synthetic textiles.
- Dyeing/printing of PET/CDPET union fabrics.

These process houses process, at the peak time, 4,000 million metres of fabrics, mostly dhotis, sarees, dress materials, shirtings and furnishing materials made from nylon/polyester/CDPET and viscose yarns. Besides these, in some process houses situated in other parts of the country, PET/cotton blend is also sized and desized and causticization/mercerization is carried out, whereas in other set-up of process houses, PET/cotton blend carbonized varieties are processed. Such process houses face the problems associated with the disposal of concentrated solutions of caustic soda and sulphuric acid and of sizing materials. These fabrics are processed for local as well as export markets and even niche markets and hence, the industry is expected to take utmost care of both quality and quantity of pollution load in effluent, solid waste management, and ecofriendliness of finished

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product. These fabrics will have to be toxin-tested and free from the presence of certain red-listed chemicals/dyes depending on the end-use or market.

In the above activities, the chemical processing industry of South Gujarat alone consumes dyestuffs/chemicals/auxiliaries worth crores of rupees—about 10,000 tonnes of dyes (mostly acid, disperse and cationic dyes) and 50,000 tonnes of chemicals/gums/auxiliaries and finishing agents. It also consumes significant quantities of oils and lubricants. Besides, it burns about 5 lakh tonnes of coal (including imported steam coal), equal quantity of lignite and natural gas as boiler fuels. It also uses about 10,000 million gallons of water, of which fair quantity is from bore wells with high total dissolved solids (TDS), Ca/Mg hardness and taste of salinity. The rough estimate is that Surat process houses consume 25,000 tonnes of salt every year for regeneration of ion-exchange softening plants. This is bound to increase the salinity of sub-soil water in the area due to seepage.

1.1 Water Effluent
All the above chemicals/auxiliaries/residual unfixed dyestuffs go down the drain in effluent. Some of these are carcinogenic, allergenic and toxic. It is estimated that each gallon of water drained by these process houses may contain as much as 5 g of chemicals/auxiliaries/dyes. The far reaching effects on environment due to the character of such waste water from textile effluent are highlighted in Table 1.

1.2 Air Emissions
The oxides of nitrogen, carbon, sulphur, etc. are emitted into the atmosphere through 500 odd boiler chimneys, and fly ash also shows up as suspended carbon particles in the atmosphere. The ash content of Indian coal is as high as 20-25% and the calorific value is low at 4000. As a consequence, a number of process houses have switched over to imported steam coals from Indonesia/Korea which have calorific values of about 5500. These air emissions pollute atmosphere of entire South Gujarat and affect fruit gardens and plant/animal life and even human beings.

1.3 Pollution Control Measures
It is now well accepted that civilization, urbanization and industrialization has increased the comfort levels and prosperity but then the same has also aggravated problems of pollution. It is, therefore, extremely important that, side by side, steps are taken to minimize the generation of waste/pollution and the hazardous chemicals are substituted, wholly or partially, by the harmless ones having lower BOD/COD values and which are non-toxic. Some examples of lower BOD/COD substitutes are given below:

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Substitute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>Formic acid</td>
</tr>
<tr>
<td>Citric acid</td>
<td>Citric W</td>
</tr>
<tr>
<td>Phenol</td>
<td>Eliminated</td>
</tr>
<tr>
<td>Non-ionic detergent</td>
<td>Ginasol 6836</td>
</tr>
<tr>
<td>DFT</td>
<td>Hicoleveller BJD</td>
</tr>
<tr>
<td>Hydro</td>
<td>Diosyn HF(Thiourea dioxide)</td>
</tr>
<tr>
<td>Oxalic acid</td>
<td>Catalyst D</td>
</tr>
</tbody>
</table>

Such substitutions will certainly reduce BOD/COD levels in effluent by more than 50%.

In spite of all such efforts, some waste is bound to be generated and this must be suitably treated (end-of-the-pipe treatment) to reduce the hazards to plant and animal life. It is noteworthy that entrepreneurs, technicians and consumers are now aware of the problems of pollution, more so to improve the profitability and marketability. Several phrases like ecofriendly textiles, cleaner technology/production, safer atmosphere, environment management.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine and caustic alkali</td>
<td>Affect crop and aquatic life</td>
</tr>
<tr>
<td>Suspended matter (organic and inorganic)</td>
<td>Cause choking of pipes and gutters</td>
</tr>
<tr>
<td>Dissolved solids (TDS)</td>
<td>Clog porous structure of soil</td>
</tr>
<tr>
<td>Salinity (salt deposits)</td>
<td>Obstruct air and plant growth</td>
</tr>
<tr>
<td>Colour</td>
<td>Lead to anaerobic fermentation</td>
</tr>
<tr>
<td>High sodium content</td>
<td>Alleviate osmotic pressure balance and hinder plant growth</td>
</tr>
<tr>
<td>Metal ions (iron, copper, lead, chromium)</td>
<td>Prevent penetration of light and hamper photosynthesis</td>
</tr>
<tr>
<td>Bacteria and chemicals</td>
<td>Lead to ion exchange and reduce permeability of soil</td>
</tr>
<tr>
<td></td>
<td>Affect taste and appearance</td>
</tr>
<tr>
<td></td>
<td>Destroy useful bacteria</td>
</tr>
<tr>
<td></td>
<td>Affect metabolism of body</td>
</tr>
<tr>
<td></td>
<td>Lead to depletion of oxygen and increase BOD/COD</td>
</tr>
</tbody>
</table>

Table 1—Impact of waste water characteristics on environment
systems (EMS-14000), waste minimization at source, green audit, polluter-must-pay and so on are being debated now. Carcinogenic or allergenic nature, fish toxicity and safety data sheets of inputs are being considered and words like reuse, recycle, optimum/just required quantities and optimum process parameters are given full weightage. In this context, process ecology, human ecology and disposal ecology all three are considered equally important to protect environment. Two approaches advocated are: 

Batnee — best available technology not entailing extra cost. 

Bat — best available technology. 

It is argued that all justifiable costs must be incurred and recovered and no compromise made on quality (ecofriendliness).

2 Impact on Environment

There is no doubt that impact of industrialization on environment is far reaching and even disturbing. The three basic requirements of human beings are food, clothing and shelter. Human activities for these requirements more or less disturb the ecological balance. The toxic effects of chemicals and physical agents on living organisms and their interactions with the environment lead to phenomena like acid rains, depletion of ozone layer and global warming due to green house effect. These have become the main concern of the Scientific Committee on Problems of Environment (Scope). Consequently, the effects of hazardous chemicals are being highlighted and use of safe alternatives advised. Eco-labelling for ecofriendly textiles insist that textiles are not processed using banned azo dyes and other chemicals such as pesticides, pentachlorophenol (pdp), formaldehyde resins, kerosene oil emulsions, nonylphenol ethylene oxide condensates, heavy metal ions (chromium, copper, zinc, tin, etc) which are either carcinogenic or allergenic and toxic. Extremists say that what is good for stomach must be only acceptable for textile processing. Everything is harmful—some even in small doses and others in long runs. The best approach to the problem is to minimize/avoid usage. Through systematic study, it is possible to reduce wastage of inputs from 30-50%. Pollution load of the effluent must be daily monitored and controlled. Reuse/recycle wherever it is possible and dispose off the remaining unavoidable solid/liquid/gaseous waste safely. In general, it is suggested that 90% of the effluent or more of it must be biodegradable in a reasonable time span.

3 Solutions

Waste minimization and ecology preservation/protection are the two complimentary activities. Waste minimization people concentrate on waste-in-totality whereas the ecologists consider banning or minimizing the use of hazardous substances. In either case, the philosophy remains of pollution reduction at source.

Quality of all inputs and check of quality in-process through optimization of parameters will automatically ensure/guarantee quality of output. Even the quality of water effluent or air emissions will also come under control and help preserve ecology.

The ultimate goal of processor is to provide “Quality Assurance” to consumer. The quality may bear on Eco-mark or Eco-label. The processor aims at right-first-time, right-every-time, right-on-time (quick response) coupled with ecofriendliness of textiles.

For this, the industry will have to follow the following few principles:

• Judicious selection of inputs that are biodegradable and acceptable to buyer.
• Process suitably modified to save energy, water and chemicals, e.g short sequence operations, pad-batch processes, continuous dyeing, etc.
• Machinery modified and properly maintained to save energy, water and chemicals, e.g low material:liquor ratio, Roberto rolls, etc.
• Stop the use of banned red-listed chemicals and substitute the ones having higher BOD/COD by those having lower values.
• Wherever possible, reuse/recycle and recover the input, e.g reuse of dyebaths, used print pastes for dark shades, etc.
• Adequate effluent treatment and safe reuse/disposal of waste—gaseous, liquid or solid.

In this context, the obvious targets are (i) energy conservation, (ii) water consumption, and (iii) safety data sheets of inputs. These can be achieved through the optimum utilization of existing facilities and upgradation of technology by modernization. Ecofriendly textile
concept is dynamic/market-oriented and demands not an adhoc but a systematic proactive approach.

Cleaner technology advocates new dyes and processes, e.g. high exhaustion dyes, low-metal content dyes and auxiliaries, low-formaldehyde finishes, easily biodegradable sizes, enzyme processing, mechanical finishes (decating, emerising, zero finish, calender), and fibres like Lyocell which are environment friendly. Such steps enable to reduce waste, cost of waste treatment, inventory and energy cost, and cost of handling.

3.1 Waste Minimization

The objective of waste minimization is to produce minimum air, water and noise pollution. Waste minimization is both economically sensible and environmentally responsible. Accordingly, a chemical used should be effective at low concentration level, at low level of pollution load and must ensure performance optimization. It automatically conserves all inputs by eliminating wasteful practices and thus ensures cleaner environment for workers, consumers and for future generation too. The motto is to conserve water and substances that are exhausting (depleting) fast.

The importance of textile industry in the country’s economy has been well accepted due to export achievements. To sustain the level of exports and to improve it, there is an urgent need to create awareness amongst entrepreneurs to produce eco-friendly textiles as many developed countries have banned entry in their countries of textiles in which presence of toxic and hazardous substances is detected even in minute ppm quantities. One of the objectives of waste minimization is also to reduce the cost of pollution treatment (end-of-pipe treatment).

It is estimated that every year Indian textile industry produces roughly 3.5 million tonnes of textile fabrics and consumes, in chemical processing, about 250 million cubic metres of water, most of which is drained. This industry uses a lot of electrical energy as well as steam and hence the fossil fuels like coal, lignite, diesel oil, furnace oil, etc. Energy conservation is also an environment-friendly activity and the efficient use of electricity and steam is waste minimization. For textile industry, however, process waste water is more important. It is necessary to fix consumption norms for each machine, each process and water consumed per kg of fabric. It is necessary to (i) quantify and characterize water inputs for boiler and various other processes, and (ii) quantify and characterize waste streams (effluents) from various processes as well as composite effluent (Table 2).

It must be emphasized that due to worker's negligence and absence of good practices, 15-20% water is wasted. By proper water management alone the industry can save lakhs of rupees. Waste water treatment cost will also be drastically reduced. Industry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scouring/bleaching</th>
<th>Dyeing</th>
<th>Printing</th>
<th>Composite effluent</th>
<th>Bore water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>I</td>
<td>II</td>
<td>I</td>
</tr>
<tr>
<td>pH</td>
<td>11</td>
<td>11</td>
<td>4.0</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Hardness, ppm</td>
<td>60</td>
<td>160</td>
<td>1440</td>
<td>120</td>
<td>2740</td>
</tr>
<tr>
<td>Total solids, mg/L</td>
<td>17120</td>
<td>9192</td>
<td>8744</td>
<td>2370</td>
<td>6844</td>
</tr>
<tr>
<td>Suspended solids, mg/L</td>
<td>2512</td>
<td>1026</td>
<td>1384</td>
<td>200</td>
<td>1240</td>
</tr>
<tr>
<td>TDS, mg/L</td>
<td>14608</td>
<td>8166</td>
<td>7360</td>
<td>2170</td>
<td>5604</td>
</tr>
<tr>
<td>COD, mg/L</td>
<td>1169</td>
<td>776</td>
<td>426</td>
<td>206</td>
<td>328</td>
</tr>
<tr>
<td>BOD, mg/L</td>
<td>351</td>
<td>233</td>
<td>128</td>
<td>62</td>
<td>98</td>
</tr>
</tbody>
</table>

*Figures in parentheses are for print wash and those without parentheses for blanket wash.

*After softening.

I — Regular printing. Uses stain remover and sequestering agent in scouring besides hydro, detergent and caustic soda.

II — Brasso printing.
must keep watch whether the profits are going up in smoke, down the drain or in the waste bins. Sincere efforts in waste minimization can help reduce COD/BOD values of composite effluent by 30-35% and thus help reduce cost of maintaining effluent treatment plant (ETP).

3.1.1 No Cost Options
- Switch of fans/lights when not required.
- Repair leaks for water and steam. Install water flow meters.
- Train workers through newsletters or by word of mouth.
- Prevent overflowing/overfilling vessels; use level marks and low material-to-liquor ratio machines.
- Weigh all chemicals and dyes correctly and accurately.
- Use timers and temperature controllers to improve machine productivity and save time/energy.
- Avoid unnecessary boiler blow down.
- Maintain steam traps.

Major pollutants in a typical composite waste water stream are pH, TDS, COD/BOD, colour, toxicity, heavy metals, sodium absorption ratio, etc. The environmental impact of surfactants or dyestuffs depends on their concentration, biodegradability/ bio-eliminability and toxicity. If a substance is biodegradable, the hazardous levels do not build-up. Biodegradability is assessed by (i) the amount of O₂ used, (ii) CO₂ produced, and (iii) calculating the removal of dissolved organic carbon (DOC) from the sample.

3.2 Three-pronged Attack
To minimize pollution of air and water, a three-pronged attack is suggested.

3.2.1 Pre-care
It minimizes waste at source by judicious selection of all inputs taking into consideration the BOD/COD values and toxicity. Insist for “safety data sheet” for inputs. Take steps to control inventory.

3.2.2 Care during Processing
In-process care will involve following measures:
- Optimize usage of all selected inputs and if it can be avoided, do not use.
- Follow short sequence operations, e.g. single-step scouring and bleaching.
- Optimize time and temperature for fixation of prints.
- Reduce heat losses by proper lagging of agers and steam pipes, employ heat recovery systems and return condensate water to boiler house.
- Follow strictly preventive maintenance to reduce down times and improve machine productivity.
- Direct gas firing in hot air stenters and loop agers conserve energy. It is observed that direct gas firing in loop ager also improves colour yield and the brightness of prints, probably due to the presence of flue gases in chamber. It also reduces downtimes in attaining temperature.

Energy/water/substances (inputs) conservation directly controls air/water pollution loads. In South Gujarat, water has become scarce and good quality water (Table 3) for dyeing/printing costs as much as Rs.250/- for 10,000 litres. Bore water in Sachin/Pandesara (GIDC) is not usable in critical operations.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Tolerance limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour (hazen units)</td>
<td>0.5</td>
</tr>
<tr>
<td>pH value</td>
<td>7.5</td>
</tr>
<tr>
<td>Total hardness (in terms of CaCO₃)</td>
<td>10-25 ppm</td>
</tr>
<tr>
<td>Alkalinity to methyl orange</td>
<td>35-65</td>
</tr>
<tr>
<td>Iron</td>
<td>0.02-0.10 ppm</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.003 ppm</td>
</tr>
<tr>
<td>Total dissolved solids²</td>
<td>65-150 mg/L</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>Nil</td>
</tr>
<tr>
<td>Chloride</td>
<td>0-30 ppm</td>
</tr>
<tr>
<td>Sulphate</td>
<td>0-30 ppm</td>
</tr>
</tbody>
</table>

²Due to bicarbonates, carbonates, chlorides and sulphates of Ca and Mg.

Table 3—Quality of water required in textile process house - tolerance limits

<table>
<thead>
<tr>
<th>Unit</th>
<th>Temporary hardness (As CaCO₃) ppm</th>
<th>Permanent hardness ppm</th>
<th>Total hardness ppm</th>
<th>Suspended matters mg/L</th>
<th>TDS mg/L</th>
<th>Total solids mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80</td>
<td>700</td>
<td>780</td>
<td>11</td>
<td>2460</td>
<td>2471</td>
</tr>
<tr>
<td>B</td>
<td>230</td>
<td>1690</td>
<td>1920</td>
<td>9</td>
<td>5881</td>
<td>5890</td>
</tr>
<tr>
<td>C</td>
<td>290</td>
<td>2910</td>
<td>3100</td>
<td>14</td>
<td>7985</td>
<td>7999</td>
</tr>
<tr>
<td>D</td>
<td>240</td>
<td>4680</td>
<td>5100</td>
<td>20</td>
<td>13337</td>
<td>13357</td>
</tr>
<tr>
<td>E</td>
<td>400</td>
<td>6800</td>
<td>7200</td>
<td>9</td>
<td>18482</td>
<td>18491</td>
</tr>
</tbody>
</table>
as it has very high TDS and tastes saline due to proximity of sea (Table 4).

It is relevant to mention at this juncture that poor water quality can create following problems in wet processing:

- Hardness of water affects colour yield and dye dispersion. It causes deposits on fibre surface, formation of scales, corrosion of heat transfer surfaces, and decrease in cleansing efficiency.
- Heavy metal salts (Fe/Cu/Mg) chelate and form metal-dye complexes which cause uneven dyeing, dulling of shade, reduction in colour yield, change in tone, and poor rub fastness.

It is also observed that the hardness of water and more so TDS can very significantly affect the brightness of shade as well as dye bath exhaustion in case of ionic dyes such as acid/basic dyes. This is evident from the data given in Table 5.

Even when the water softened by ion-exchange process is used, the relative dye strength is significantly and adversely affected as TDS in softened water still remains high. Addition of Metaclaw CL to dye bath for chelation also does not help as TDS increases further due to Metaclaw CL and the relative dye strength decreases proportionately.

3.2.2.1 Water

Synthetic textile industry of South Gujarat has taken up a challenge to minimize water use per metre of fabric processed by at least one third. This will be achieved by:

- Using lower M:L ratio machines and optimizing parameters like mangle expressions and moisture content at stenter delivery end.

- Using standing baths in processes of weight reduction, optical brightening and dyeing of synthetic fabrics on jet dyeing machines. This will enable save chemicals and auxiliaries. Use of standing baths for optical brightening and certain self shades in dyeing of polyester with disperse dyes has enabled savings of up to 75% in chemicals and 65% in water. It has also helped reduce COD levels in effluent up to 85-90%. Bath is reused from 3 to 6 times.

- Storing and reusing the water used for hot and cold wash after scouring or dyeing. This enables energy saving also.

- Reusing, after sedimentation, the water used for blanket washing which contains thickeners in small quantity.

- Recirculating the cooling water on jet dyeing machines and zero-zero machines.

- Following the counter current washing principle on washing machines.

- Reusing/recycling treated effluent water in appropriate processes (after-care).

- Recharging of bore wells during monsoon by collecting rain water from roofs and terraces and diverting into borewell to improve quality of bore water even after monsoon for 2-3 months.

The treatment of effluent water for reuse/recycle in Surat process houses is carried out by the standard procedures such as equalization, neutralization, settling and flocculating, aeration, decolourization, softening, etc. For this, the activated carbon filter beds and biotowers are made use of. Although the reverse osmosis membrane technology is not yet exploited, there is a growing awareness for the same and many

<table>
<thead>
<tr>
<th>Water hardness (As CaCO₃) ppm</th>
<th>TDS mg/L</th>
<th>Relative dye strength, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Disperse dye on polyester</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disperse Blue 36</td>
</tr>
<tr>
<td>780</td>
<td>2460</td>
<td>103 (104.2)</td>
</tr>
<tr>
<td>1920</td>
<td>5880</td>
<td>102.6 (103.9)</td>
</tr>
<tr>
<td>3100</td>
<td>7985</td>
<td>99.7 (99.1)</td>
</tr>
<tr>
<td>5100</td>
<td>13335</td>
<td>99.9 (98.1)</td>
</tr>
<tr>
<td>7200</td>
<td>18480</td>
<td>97.3 (97.6)</td>
</tr>
</tbody>
</table>

Figures in parentheses are for 3% depth of shade, [1% depth of shade dyed under identical condition in distilled water is taken as 100% dye strength].
are convinced that it can be economically viable as good quality water is scarce and expensive.

3.2.2.2 Substances

The textile processing involves the use of numerous chemicals/auxiliararies/dyestuffs. All these contribute to the total pollution load of the effluent as measured by biodegradability/bio-eliminability, aquatic toxicity, COD/BOD values, and metal ion concentration.

Most waste water treatments simply convert the waste water into sludge which is then disposed off by either land-filling or incineration. This may end up finally in the ground water. It is, therefore, important that waste generation is minimized at source by adopting stringent controls, as stated below, to reduce sludge:

- Right-first-time, right-every-time and right-on-time philosophy will go a long way to help minimize waste. To achieve the goal, the first requirement is a well-equipped quality control laboratory for dyes/chemicals/auxiliaries. This must be equipped to assess pollution load too. Reprocessing increases waste and decreases profit.
- Inventory management is equally important. Use only if required, use optimum amounts, and buy in just required quantities. Control inventory by using computer colour matching system. Judicious selection and optimum use can very effectively control pollution load of an effluent. Always use environment-friendly substances. Insist for “safety data sheets” of products.
- Use safer/green products in colouration of textile fabrics.

It is observed that the chemicals/auxiliaries used in a process house such as printing gum, acetic acid, oxalic acid, non-ionic detergent, ethyl acetate and sodium hydrosulphite contribute more than 75% of the total pollution load and, therefore, must be used judiciously and substituted wherever possible. In case of printing gum, the monthly consumption can be considerably decreased by using higher viscosity gum thickener.

Process-wise steps taken by ecofriendly processors are as follows.\(^7\)\(^-\)\(^13\).

3.2.2.2.1 Sizing/Desizing

Starch-based size mix is responsible for high BOD in effluent and hence use of recoverable synthetic polymers such as acrylates and polyvinyl alcohol with ultrafiltration recovery systems for reuse is suggested.

Pentachlorophenol as preservative must be replaced by benzothonoxol or neem-based product. Coning oils must have also lower BOD/COD values.

3.2.2.2.2 Scouring

- Use of alkyl polyglucosides, α-olefin sulphonate, fatty alcohol ethoxylates or anionic polyacrylates as wetting agents and detergents in place of alkyl phenol ethoxylates is recommended as these are readily biodegradable. Alkyl phenol ethoxylate have high aquatic toxicity.
- Do not use CCl\(_4\) based stain removers as these affect ozone layer. Perchloroethylene and trichloroethylene are also potential carcinogens and must be avoided.
- Avoid use of oxalic acid as it has high BOD/COD values as well as high aquatic toxicity. Substitute for the same is catalyst D which also takes care of rust stains.
- Hydrosulphite of soda causes substantial depletion of dissolved oxygen in water. Replace it by thiolourea dioxide at least partially in all processes.

3.2.2.2.3 Bleaching

- Hydrogen peroxide with non-silicate stabilizers such as phosphonates to be used instead of hypochlorite.

3.2.2.2.4 Mercerizing

- Use non-cresylic type wetting agents such as salts of sulphated lower fatty alcohol like octyl alcohol. Recovery of caustic soda must be done.

3.2.2.2.5 Dyeing

- Substitute acetic acid by formic acid as it has much less BOD/COD load. Acetic acid alone is responsible for about 15% pollution load in a typical process house. Combination of formic acid and oxalic acid (1:1) can be also used.
- Carriers based on chlorobenzenes are highly toxic and carcinogenic and their use must be discontinued. Instead, carriers based on N-alkylphthalamide or N-alkylphthalimide may be used.\(^\text{14}\)
- Castor oil ethoxylated based levelling agent used widely has high BOD/COD values and can be replaced by Hicolever BJD type levelling agents.
- Sequestering agents like TSPP and sodium hexametaphosphate are not easily biodegradable and end up in downstream river waters where these are converted into orthophosphates which promote growth of algae having high oxygen demand. EDTA
and NTA are also not biodegradable. Recently introduced phosphonates are more effective and form more stable complexes. These are used in lesser quantities and do not promote algae growth.

- Azo dyes which give harmful aromatic amines must be eliminated. Select dyes which contain heavy metal ions or require use of chromium/copper salts as mordants or for improving fastness must not be used.
- Use hydrogen peroxide or sodium perborate as oxidizing agents in place of bichromate.
- Replace sodium sulphide or hydrosulphite of soda by other safer reducing agents such as hydroxyacetone, alkaline organic carbohydrate or other glucose-based reducing formulations.
- Avoid or reduce the use of urea in reactive dyeing/printing by pre-sensitising the fabric. Use of salt must also be eliminated or reduced. Use newly developed dyes which require much less salt for exhaustion.
- Dye-fixing agents containing formaldehyde to be substituted by non-formaldehyde ones such as tetra-functional reactant resin.

3.2.2.6 Printing

- Use environment-friendly photoemulsion which does not contain any formaldehyde in screen making.
- Reuse water in blanket washing after proper coagulation and sedimentation.
- Pentachlorophenol used as preservative in gum thickeners is known to cause dermatitis. It is a potential carcinogen and chronic exposure can damage liver and kidney. It is a banned item, still used blatantly. Use benzothiazol as a substitute.
- Use of phenol in nylon printing must be stopped and substituted by diethylene glycol.
- Citric acid adds to COD/BOD levels of effluent. Citric W and other substitutes have much less BOD/COD.
- Zinc sulphotylate formaldehyde and tin chloride used in discharge printing increase the metal ion concentration in effluent. These can be replaced (up to 50%) by less objectionable sodium sulphotylate formaldehyde. This will reduce the cost also.
- Replace kerosene oil emulsions by synthetic thickeners like polycarboxylic acid or aqueous acrylic products in pigment printing. Also use low BOD thickeners and reuse scraped and collected print pastes in dark tertiary shades.

3.2.2.7 Finishing

- Use formaldehyde-free resins. Scavengers for formaldehyde can be also used during application.
- Cationic softeners based on quaternary ammonium compounds are toxic to aquatic life.
- A pre-polymerized long-chain macromolecule based on non-ionic urethane is recommended as eco-friendly finishing agent.
- Replace chlorofluorocarbons by safer fluorochemicals.
- Reactive softeners based on methylol stearamide must be replaced by safer silicons or acrylic emulsions.
- Existing flame-retardant finishes based on THPC, THPOH, PBB, etc. are non-eco-friendly. Replace these by FR finish using safer chemicals developed and patented.
- Reuse leftover finish baths.

3.2.3 After-care

After-care means treatment of polluted air/water\(^5\). This is an expensive proposition but is a must. It is understood that 70% of total pollution created by textile industry is due to waste water. Pollution control norms laid down by Pollution Control Board (PCB) are quite strict and major bottlenecks in effluent treatment are as follows\(^5\):

- TDS reduction down to 2100 mg/litre from levels of 5000-7000 mg/litre in input water. Bore water quality is fast deteriorating.
- COD and BOD reduction down to 100 mg/litre and 30 mg/litre respectively is a difficult task unless all inputs are judiciously selected and used optimally.
- Complete decolourization of treated water for recycling.
- Control of heavy metals in effluent—norms are a few ppm only.
- Drainage of large volumes of treated waste water in overcongested industrial estates.
- Excessive sludge generation, especially where carbonizing is done. Dewatering of sludge and disposal of solid waste is equally challenging.
- Limitations of techniques available such as reverse osmosis, activated carbon beds, incineration and their high costs and questionable economic viability in competitive global market.
- Adequate space for conventional ETP, low profit margin in textiles, and limitations for use of effluent in irrigation.

Industry will have to evolve appropriate novel approach to fulfill the pollution norms. The available
options are multiple effect evaporators, advanced oxidation, bio-remediation/bio-augmentation, synergism of activated carbon and biology, etc. The unit processes involved in current waste water treatment are:

- Pretreatment: segregation of streams.
- Oil/grease removal traps.
- Equalization of various streams enable constant flow characteristics all the time for efficient operation of ETP.
- pH neutralization is also possible by equalising acidic \( \leftrightarrow \) alkaline streams.
- Chemical coagulation: Remove suspended and colloidal impurities as well as reduce colour and BOD to some extent. Lime, alum, iron salts and polyelectrolytes are good coagulants. Steps involved are chemical dosing, flash mixing, flocculation and sedimentation, resulting in sludge separation. In some cases, dissolved air floatation (DAF) process is also employed to reduce TDS, SS, oil, grease, BOD, etc.
- Biological or chemical oxidative treatment by chlorine, hypochlorite or hydrogen peroxide. Textile industry effluent contains adequate amounts of nitrogen and phosphorus besides carbon for biological treatment. Thus, after physico-chemical treatment, it can be subjected to either activated sludge process or trickling filters to reduce COD/BOD. Activated sludge process is more widely used for medium-strength waste water.
- Finally, the activated carbon column is used to remove residual colour and certain refractory chemicals. Ion-exchange method, ozone treatment and reverse osmosis are resorted to in specific cases.

4 Towards Ecofriendly Chemical Processing

In the efforts of textile processor to minimize waste, the dyestuff and auxiliary manufacturers can also help by providing:

- Customerised recipes and colour matchings.
- Technical advise for testing products and optimum usage.
- Safety-data-sheets in terms of ecofriendliness.
- Cost competitiveness.
- Environment compatible green products—elimination of red-listed chemicals.

To tackle the problem of adverse impact on environment, the processor must:

- Identify the process where harmful chemicals are used.
- Avoid use of banned red-listed chemicals by process modification and substitute safe chemicals.
- Minimize use of toxic hazardous chemicals by adequate process controls.
- Reuse/recycle, wherever possible, to minimize pollution load in the effluent and after-care cost (ETP).

4.1 Parameters of Concern

The parameters of concern for waste minimization are given in Table 6. All these parameters have to be checked to satisfy the norms for effluent laid down by Pollution Control Board as well as to meet the requirements for eco-friendly textiles marketed as “Green Clothes”.

5 Future Developments

— Currently the enzymes are widely used in desizing. In future, the enzymes will be used for combined processes of desizing (bacterial amylase) and scouring (lipase). Moreover, for various finishing operations, e.g. to obtain durable aesthetic and specific properties such as soft feel (bio-polishing) and improved surface appearance, and for reducing neps and pilling, the enzymes will find application. Eco-friendly washing of prints to remove thickeners from printed fabrics will be also feasible and “worn-out-look” effect can also be given by enzymes.

— Mechanical finishing of textiles to change the morphology or surface characteristics of fabrics, such as softness, stiffness, fullness, smoothness, drape and handle, will help achieve total ecofriendliness.

— Use of ultrasonic waves, a clean and pollution-free source of energy, can bring in both physical and chemical effects in solid/liquid systems. These will be applicable in chemical processing and besides savings in water, steam and energy, such applications will also drastically cut down chemical requirements. In dyeing, ultrasonics can improve dispersion and diffusion of dyes, resulting in faster dyeing with improved exhaustion and fastness properties. In crease-resistant finishing, the finish quality and durability will improve.

— In future, peracetic acid bleaching will dominate as ecofriendly process with minimum AOX values. At present, due to the special application technology required and high cost, it is not widely
Taste

Toxicity
Total organic carbon
Silica
COD
BOD

Suspended solids
Sedimentable components
Colour

Temperature
Toxicity

• Suspended solids
• Sedimentable components

Chromium
Cobalt
Copper
Nickel
Zinc
Antimony
Tin
Mercury
Fe(Iron)

Heavy metal ions
Metal complex dyes and oxidizing agent
Metal complex dyes
Metal complex dyes & pigments and light fastness improvers
Reduction agents, biocides, catalysts and water pipes
Flame retardants
Biocides and discharge printing
Caustic soda
Water
Brasso style printing

Boiling water
Hydrocarbons
Tensides, grease remover, carrier, chlorine bleach and dyestuffs
Defoamer, de-dusting agents and printing pastes
Preservatives(PCP) and non-ionic detergents
Sequesters and flame retardant
Ion exchange and dyeing process
Chemicals/auxiliaries/dyes
Chemicals/auxiliaries/dyes

Table 6—Parameters of concern

<table>
<thead>
<tr>
<th>Pollutant parameter</th>
<th>Range of tolerance</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.5-8.5</td>
<td>Alkaline: —mercerization —weight reduction of PET —reactive/vat/sulphur dye colouration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acidic: —acid/disperse/ cationic dye colouration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Boiler blowdown, hot water rinses and high temperature processes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemicals/auxiliaries/dyes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dyestuffs</td>
</tr>
<tr>
<td>Temperature</td>
<td>30-40°C</td>
<td>Metal complex dyes and oxidizing agent</td>
</tr>
<tr>
<td>Toxicty</td>
<td>GF&lt;2</td>
<td>Metal complex dyes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metal complex dyes &amp; pigments and light fastness improvers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metal complex dyes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reducing agents, biocides, catalysts and water pipes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flame retardants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biocides and discharge printing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Caustic soda</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brasso style printing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bore water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrocarbons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tensides, grease remover, carrier, chlorine bleach and dyestuffs</td>
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<td>Defoamer, de-dusting agents and printing pastes</td>
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<td></td>
<td></td>
<td>Preservatives(PCP) and non-ionic detergents</td>
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<td></td>
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<td>Sequesters and flame retardant</td>
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<tr>
<td></td>
<td></td>
<td>Ion exchange and dyeing process</td>
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<tr>
<td></td>
<td></td>
<td>Chemicals/auxiliaries/dyes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemicals/auxiliaries/dyes</td>
</tr>
<tr>
<td>Total organic carbon (TOC)</td>
<td>50 mg/L</td>
<td>Metal complex dyes</td>
</tr>
<tr>
<td>Adsorbable organic halogens(AOX)</td>
<td>0.5 mg/L</td>
<td>Metal complex dyes</td>
</tr>
<tr>
<td>Purgeable organic halogens(POX)</td>
<td>0.1 mg/L</td>
<td>Metal complex dyes &amp; pigments and light fastness improvers</td>
</tr>
<tr>
<td>Mineral oils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phenol index</td>
<td>0.1 mg/L</td>
<td>Reducing agents, biocides, catalysts and water pipes</td>
</tr>
<tr>
<td>Phosphates</td>
<td></td>
<td>Flame retardants</td>
</tr>
<tr>
<td>Neutral salts</td>
<td></td>
<td>Biocides and discharge printing</td>
</tr>
<tr>
<td>COD</td>
<td>250 mg/L</td>
<td>Caustic soda</td>
</tr>
<tr>
<td>BOD</td>
<td>30 mg/L</td>
<td>Water</td>
</tr>
<tr>
<td></td>
<td>535/620 μm</td>
<td>Brasso style printing</td>
</tr>
</tbody>
</table>

used. Use of permanganate/oxalic acid system for bleaching also has future prospects.

High exhaustion, almost 100% fixation, minimum salt and urea requirements will be the characteristics of future reactive dyes. Cibacron C of Ciba-Geigy, Procion HE-XL of Zeneca and Remazol EF of Hoechst are new generation dyes[6,17]. These will be marketed as low-dust powders or liquids to keep the environment clean. The application technology is also being revolutionized to eliminate urea, salt and strong alkali.

For synthetic textiles, supercritical carbon dioxide technology is being developed[18] which offers following advantages:

• Complete elimination of water, i.e. zero pollution.
• Energy saving.
• No dyeing assistants such as levelling and dispersing agents are required.
• Percentage exhaustion is much higher and residual dye, if any, can be recovered.
• Recycling of CO2 is possible.

It is an ecofriendly technology.

— Inkjet printing, a revolutionary non-impact printing method now in use for paper printing, will become popular for cloth printing. It is a dry process and hence the pollution problems due to washing of unfixed colour and thickener from the prints will not exist. For environmental reasons, transfer printing can once again come into limelight.

References
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13 Shenai V A, Colourage, 44(10) (1997) 50-64.