Recycling of textile waste for environment protection — An overview of some practical cases in the textile industry

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Environment protection could be achieved by adopting state-of-the-art technologies to minimize waste generation, effective treatment of effluent so that the effluent discharge conforms to the expected norms, and recycling the waste several times before discharge. The present paper, with the help of typical case studies, such as wool scour liquor disposal, utilization of leftover yarn in spinning and weaving departments, recycling of size, conservation of heat and water in disperse dyeing, recovery and utilization of salt in reactive dyeing, recycling of rags and used garments, and recycling of water in chemical processing, illustrates that the effective way for environment protection is to recycle waste as many times as may be practically feasible. However, the recycling methodology adopted must be economical.

Keywords: Environment protection, Textile waste, Waste recycling

1 Introduction

Necessity is the mother of invention. When there was a shortage of natural fibres, man first recycled cellulose from wood pulp and regenerated viscose fibres. For ages, the old wool garments were discarded as shoddy which were recycled to produce woollen blankets. Today, recycling has become a necessity not because of the shortage of any item but to control pollution. There are three ways to reduce pollution. One is to use newer technologies that pollute less. The other is to effectively treat the effluent so that the final treated effluent conforms to the expected norms. The third and the most practical way is to recycle the waste several times before discharge.

A few examples of recycling that has met with success in the industry are cited here. It has now become a common practice in Europe and in some mills in India to use exhaust dyebath liquor that is difficult to decolourise for cooling boiler ash. By this, not only is the wastage of fresh water avoided, the exhaust dye liquor is also substantially decolourised as dyes are adsorbed by coal and the acidity in water, if any, is also neutralized. This is just one simple example of how the waste from one source can be diverted or recycled for another end use. Another example is the multiple recycling of salt solution from exhaust dye liquor so as to avoid its disposal by treatment with lime while simultaneously facing solid waste disposal problem. SASMIRA has adapted technology to recycle PET bottles into polyester fibres that have ready market as floor coverings for automobiles. Thus, there is plenty of scope to recycle waste and reduce load on pollution in the textile industry.

If one has to export textiles with European Eco-labels to the EU countries, it is necessary to ensure that these textiles not only do not contain objectionable dyes and chemicals but also ensure that they will not be generated during use. Some of the eco-labels also incorporate the clause that the product manufacturing technologies and methods are also ecofriendly so that undue advantage is not enjoyed by the exporters, i.e. the playing fields are level. In view of the above, it has become necessary to adopt newer cost-effective technologies that are ecofriendly, conserve energy and water and more importantly recycle waste to reduce pollution.

Till a few years ago in India, the effluent from textile mills was indiscriminately discharged into rivers, agricultural lands or sea. The primary effluent treatment was also not given by many medium and small industries. Common effluent treatment was not thought of then. The effluent used to be environmentally unfriendly due to high alkali (from mercerizer), acid (after carbonization of cellulose), high temperature (direct discharge from HTHP dyeing machines) or toxic chemicals (chemicals and dyes).
The permissible limits for effluent to be discharged in rivers, sewer, land and sea as per I.S. 2490 (1981) are given in Table 1. The cost of effluent treatment to conform to IS or State Pollution Board norms was enormous. Many plants, particularly in the decentralized sector, closed down or operated clandestinely. This was particularly so in the state of Gujarat since 1995.

In view of the strict enforcement of pollution laws in the world and also in India, the textile industry has started realising that prevention is better than cure. To produce effluent conforming to the norms stipulated in Table 1, the industry will have to install primary and secondary effluent treatment units. The cost and recurring expenditure may be of the order of 35 - 75 paisa per meter of fabric depending upon the location of the unit in India and the impurities in the effluent.

However, it is not that only the processing units which generate waste. Waste is generated at every level, e.g., during manufacturing of the man-made fibres, spinning, warping and weaving, chemical processing and if one takes 'cradle-to-grave approach', even during garment manufacturing and its disposal. Scope, therefore, exists to reduce pollution at each of these stages. One of the ways to do so is to recycle the waste as many times as may be practically feasible. In order that the industry considers the recycling option to control waste, the recycling methodology adopted must be economical. At least, it should cost less than the cost of waste disposal to an accepted level.

This paper presents a few specific examples of how the recycling concept has actually been used in practice. They are typical case studies already adopted by the mills in India and abroad and are listed below:

- Wool scour liquor disposal.
- Utilization of leftover yarn in the spinning and weaving departments.
- Utilization of catch selvedge of weft yarn and side ends from rapier machines.
- Recovery and utilization of size.
- Conservation of heat and water in disperse dyeing.
- Recovery and utilization of salt in reactive dyeing.
- Recycling used garments and cut portions during garment manufacturing.
- Recycling of water in chemical processing.

### 2 Reducing Pollution during Raw Wool Scouring

Wool combing units have a longstanding problem that is related to a very high concentration of wool wax and detergent in the scour liquor. The wool wax content of merino wool is 20-30% and most of it is scoured out. The scour liquor from the first bowl of raw wool scouring unit has the following characteristics:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Surface water</th>
<th>Sewers</th>
<th>Land (Irrig.)</th>
<th>Sea coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.5 - 9.0</td>
<td>5.5 - 9.0</td>
<td>5.5 - 9.0</td>
<td>5.5 - 9.0</td>
</tr>
<tr>
<td>Total suspended solids, mg</td>
<td>100</td>
<td>600</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Dissolved solids (inorg.), mg</td>
<td>2100</td>
<td>2100</td>
<td>2100</td>
<td>—</td>
</tr>
<tr>
<td>Oil &amp; grease, mg</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>BOD (5 days 20°C), mg</td>
<td>30</td>
<td>350</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>COD, mg</td>
<td>250</td>
<td>—</td>
<td>—</td>
<td>250</td>
</tr>
<tr>
<td>Sulphides as S, mg</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>5</td>
</tr>
<tr>
<td>Sulphate as SO₄²⁻, mg</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>—</td>
</tr>
<tr>
<td>Chloride (Cl), mg</td>
<td>1000</td>
<td>1000</td>
<td>600</td>
<td>—</td>
</tr>
<tr>
<td>Total residual chlorine, mg</td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Ammonical nitrogen (N), mg</td>
<td>50</td>
<td>50</td>
<td>—</td>
<td>50</td>
</tr>
<tr>
<td>Total N- Kjeldhal, mg</td>
<td>100</td>
<td>—</td>
<td>—</td>
<td>100</td>
</tr>
<tr>
<td>Total chromium, mg</td>
<td>2</td>
<td>2</td>
<td>—</td>
<td>2</td>
</tr>
<tr>
<td>Chromium (VI), mg</td>
<td>0.1</td>
<td>2</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Max. temp., °C</td>
<td>40</td>
<td>45</td>
<td>—</td>
<td>45</td>
</tr>
</tbody>
</table>
pH 7.0
Suspended solids 14,000 ppm
Total solids 70,000 ppm
BOD 30,000 ppm
Permanganate value 6,000 ppm
Grease (wool wax) 30,000 ppm

Unless this impurity is reduced to a level given in Table 1, one cannot discharge the scour liquor to the drain. In order to do so, dilution with water to the extent of 3000 times will be required. This is just not practicable. The other approach is to remove wool wax by breaking the emulsion by acid cracking. This works satisfactorily only if the detergent used for scouring is soap. Unfortunately, synthetic detergents have replaced soap long ago. Further, the acid cracking method has never been economical, as the grease so recovered has limited utility in the industry.

In the nineteenth century, wool combers in Bradford (UK) used to discharge their scour liquor directly into the river. Each day, 50 tons of wool wax used to be drained. The wax accumulation reached such an alarming level that occasionally the wax caught fire and set the river ablaze. In 1899 in UK, pollution norms were made stringent and today they are even more stringent. The situation in India was no different when combing units were set up three decades ago. These units were scattered all over India. Initially, the untreated scour liquor was discharged into the rivers. Some units, e.g. BIC, Kanpur, used acid cracking method to remove wax. Later, a better alternative was adopted which was based on continuous centrifuging of the scour liquor in the first bowl to separate wool wax and recycling the scour liquor after requisite replenishment back into the bowl. This gave some saving on the detergent and soda ash and also reduced the cost of total effluent treatment. The scour liquor after 24 h was finally centrifuged to remove 60% of the wool wax and then discharged for further treatment. The accumulation of wool wax in the first bowl after 20 h was observed to be 28,000 mg/litre as reported by Jaidka et al. in a study made at the combing unit of Raymond Woollen Mills, Thane in 1969.

The recovered wax more than paid for the initial capital investment. The payback period was just three years in 1970. The centrifuges used by the Indian wool combing units were of the Alfa-Laval SVK4 type that separated suspended solids as sludge and wool wax and the scour liquor containing soluble wax and dissolved solids. The separated scour liquor was recycled continuously at Wool Combers of India, W. Bengal, Doon Valley Combers, Dehra Dun and Modella combing unit, Chandigarh. Recycling of scour liquor reduced the inputs of detergent and gave creamy wool wax that had ready market in India in the cosmetic industry. In 1966, India imported 141 tons of wool wax for this industry. The setting up of the combing industry in India thus reduced these imports besides helping reduce pollution.

Some of the units recycled the scour liquor by transferring it from the third bowl to the second and from the second bowl to the first when the liquor from the first bowl was discharged. This counter current flow principle also added to the savings on detergent and builders besides reducing pollution load.

3 Utilizing Leftover Yarn in Worsted Spinning and Weaving

The inventory of leftover yarn in the worsted spinning and weaving mills usually leads to depletion of profits. The actual data in three worsted mills during the eighties is given in Table 2. The singles yarns were from spinning store room and the doubled yarns were from weaving store room. Most of these worsted yarns were of 100% wool and polyester: wool blend. The annual turnover of the three mills was of the following order:

Mill A: Rs. 60 - 75 crores
Mill B: Rs. 80 - 90 crores
Mill C: Rs. 120 - 150 crores

<table>
<thead>
<tr>
<th>Year</th>
<th>Mill A</th>
<th>Mill B</th>
<th>Mill C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Singles (tons)</td>
<td>Doubled (tons)</td>
<td>Singles (tons)</td>
</tr>
<tr>
<td>1985</td>
<td>24</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>1987</td>
<td>31</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>1989</td>
<td>19</td>
<td>9</td>
<td>20</td>
</tr>
</tbody>
</table>
In a typical Indian worsted mill, about 12-16 types of yarns of different materials/blends, counts and colours are spun at the same time. Usually, different coloured yarns are doubled to produce grandrelle yarns. Unless the lengths of different yarns to be doubled are exact, which is very difficult in practice, some yarns will always remain in single form. Generally, such excess yarns are around 1.7%. Occasionally, some yarns are accumulated due to cancellation of sales order and their quantity is very difficult to predict.

Doubled yarn is accumulated when in a multi-coloured warp, one of the yarns runs out on a warping machine leaving excess yarn on cheeses on the warping creel. Yarns of similar counts are then rewound into cones that are stored. These yarns cannot be used later in similar designs as minor colour variation from lot to lot leads to weft bars or streaks. Also, there will be a number of knots in a rewound cone that may lead to fabric defect. Splicing also does not help in this regard, particularly when grandrelle yarns are involved.

The lot size of singles yarn is usually 2-8 kg (doubling mismatch) or more if the orders are cancelled. The utilisation of leftover yarns partly in the subsequent order is, as mentioned earlier, dangerous as minor shade difference shows out. Secondly, there is no demand for such small lots of singles yarn in the market. The size of the doubled leftover yarn varies from 2 kg to 10 kg. Such yarns have demand from small powerloom units. However, the price they fetch is too low and eventually the stocks keep on piling for want of courage to take a decision. The stocks are carried forward, neglected and disposed off, when they are damaged by moth attack on wool portion, mostly for landfill.

It is mind boggling when one estimates the cost of blocked inventory. At Rs. 2 lakh per ton and accumulation of nearly 40 tons of yarn each year, Rs. 80 lakhs are blocked each year and this continues till the stocks are disposed off. Often, the yarn has to be discarded by shredding or sold at 10-20% of its cost price. This is the situation after taking all the precautions of producing exact lengths of yarn by fixing yarn length measuring counters on winding machines, cross checking the weight of the lot, etc. Hence, another solution had to be found to minimize this loss and control mounting of inventory to an unacceptable level. The steps taken to reduce this inventory were essentially recycling based on technological solutions with the aid of computer applications.

One of the solutions attempted by the mills was to dye the leftover yarns into black shade. The following three problems were noticed:

- The shades were not jet black but had memory of the parent shade. Yellow brown shades had yellowish tone, maroons had a reddish tone and navy had a bluish tone. One could not produce any homogenous looking fabric from it.
- Very heavy shades led to poor fastness properties.
- The cost of redyeing was too high.

A decision was therefore taken to dye the leftover singles yarns to darker shade after doubling. The yellow brown, reddish brown, grey and navy/blue shades were segregated each month and dyed using a computer predicted recipe to produce a corresponding dark shade. The dyed yarns of the same shade were then twisted together to produce solid coloured yarns. These yarns were handed over to the designing department to develop stock yarn designs that had sales demand. The redyed yarns were used in the weft. Fresh yarn was used in the warp. Designs in 25-60 metres were produced that had instant demand. The leftover yarns were thus recycled by judicious use of technology. Action was taken each month and two weaving machines were reserved for this purpose. The advantages of this recycling action were as follows:

- The redyeing did not necessitate excessive use of dyes.
- The fastness properties were not seriously affected.
- Small well segregated yarn lots when used in weft produced small lengths of fabric which could be cut into pant lengths. This fetched more than the cost price of the yarn.
- The inventory reduced within a year to less than 4 tons per year.

There were many small lots — too small to bother about. Such yarns were sorted out into wool-rich blend that was teased open into a fibrous form and used as a raw material for manufacturing blankets. The fibrous mass of polyester-rich blend was sold at cost price to the quilt maker who produced pillows and quilts after mixing with other soft waste from the worsted spinning unit. This is the case study of one of the VXL groups of mills in 1987.
The doubled yarns were segregated into small lots and large lots. Large lots of 20 kg and above were handed over to the designer who worked out the minimum additional yarns needed to produce designs from the prevailing range that had demand in the market. This had to be done with the help of computer by linear programming after the data on shades, available and used in individual designs that had ready order, was fed into the computer. The new programme that was developed for this purpose was able to reduce the inventory by 70%. This exercise was carried out in each season. New designs were developed for the smaller lots of doubled yarn to be used as weft only.

The steps mentioned above reduced the inventory to a level of just 3.7 tons which were sold out at a discounted price. The annual savings due to recycling of at least 40 tons each year in this manner was about Rs. 1 crore. This is one example of how modern technology can lead to solutions that were not even thought of a few years ago. Saving of Rs. 1 crore on a turnover of Rs. 76 crores every year shows that how the recycling technology is useful in this context. Indecision, inaction and reluctance to sell the yarns at much below the cost price is the dilemma before most of the worsted mills that leads to piling up of inventory of yarns in the spinning and weaving departments.

4 Utilization of Catch Selvedge in Rapier Weaving Machines

At least 3-4% of the weft yarn including 'catch ends' is unavoidable waste in every rapier type weaving machine such as Dornier. The catch selvedge yarn strip is sold at a throwaway price. The fibres are separated by the garnetter who uses them for stuffing of pillows and quilts. Some use this waste for making fancy composites for floor covering. There is a tendency to use P-V yarn or other cheaper yarns as ends in the catch selvedge. By using 100% wool yarn for 100% wool weft or polyester-wool blended yarn weft, the wool-wool catch selvedge can be teased to recover fibres to feed to the woollen cards to produce blankets which have a market in the northern parts of the country. This is a cost-effective solution and provides for the wool-rich raw material needed for producing blankets. The wool-rich ends to be used for trapping weft yarn as catch selvedge can be from leftover small yarn lots. This is yet another example of recycling waste for another end-use.

5 Recycling of Size from Effluent

It is a common practice in India to use starch-based sizing recipes for sizing cotton warps. The starch solutions have a limited shelf-life since the use of PCP was banned universally. A lot of unused size bath or desized solutions are drained off adding to the BOD values. Though the synthetic sizing formulations based on PVA and acrylic resins can be used as a substitute for starch, they are expensive. However, when one considers the cost of effluent treatment, these synthetic sizing formulations are not so expensive.

Fortunately today, nano-filtration techniques have advanced to such an extent that the synthetic size, whether PVA or acrylic, can be recovered for reuse. This recycling of synthetic size by nano-filtration was tried successfully at ATIRA, Ahmedabad, and is regularly in operation at one of the leading mills in Ahmedabad producing denims. The membranes are easily available and made in Baroda.

The recycling of size is another example of how pollution load can be reduced by reutilization of the waste. When the costs are compared taking into account the cost of effluent treatment to meet pollution norms, recycling is economical even if more expensive synthetic size has to be used.

6 Utilization of Heat and Water in Polyester Dyeing

In dyeing polyester-cellulose blends, the polyester component is dyed at 130-135°C. The liquor is then dropped at that temperature into a sump containing enough water to cool it down before draining. This eliminates oligomers but there is a lot of wastage of heat. By selecting polyester that gives minimum oligomer problem and by incorporating chemicals that minimize the deposition of oligomers, it has been possible to reduce polyester in jet dyeing machines without any special arrangement for high-temperature draining. After cooling the liquor to 95°C, it can be drained into a sump for cooling before it is discharged to the drain. In this approach, there is wastage of water and heat.

In Surat, some process houses have recycled the exhaust dye liquor by first using the pressure inside the jet-dyeing machine to carry it to an overhead tank already containing some cold water. The dyed fabric is then unloaded from the machine, new lot of fabric loaded and the overhead stored hot dye liquor admitted into the machine. Additional dyes are added and dyeing continued at 70°C. Up to four lots starting
from light shades to dark shades can be conveniently processed in this manner. No water softeners or dispersing agents are required in the subsequent lots. The quality of dyeing is comparable to that obtained from fresh bath. The starting temperature of dyebath is high but does not lead to unlevel dyeing. The following dyebath particulars are given:

First bath: X % dye
Y g/l dispersing agent
Z g/l EDTA solution
pH buffer to 6

Subsequent baths: Dye as needed
pH buffer to 5.5

The amount of dye left in the bath after the first dyeing is usually too small to bother about. In the subsequent baths, by careful selection of dyes (Foron RD type), the bath can be exhausted to a substantial extent below 1.5-2% total conc. of dye. A dark shade, e.g. dark olive, dark navy, dark coffee or black, can be applied in the last bath after which the dye bath can be drained. Significant savings on heat and chemicals are thus achieved by recycling of the hot dye liquor.

In UNEP report 6, a case study from Dominion Textiles Inc., Valleyfield, Quebec, mentions how the recycling spent nylon hosiery dyebaths have reduced raw material and disposal costs. It is mentioned that an average of 30 batches can be dyed before discharge. Capital costs for the equipment in 1980 were $28,441. Operating costs for wet processing fell by $0.044/kg, giving a disposal and feedstock saving of $12,240 per annum along with a 19% reduction in dye consumption, 35% in auxiliaries use and 57% on energy costs.

7 Reducing Salt and Recycling it in Reactive Dyeing

The following approaches are available to reduce salt in the exhaust dye liquor:

- Using machinery employing low material-to-liquor ratio (M:L).
- Using dyes that need little salt for exhaustion.
- Inserting reactive group in cellulose so that salt is not necessary.

From a practical point of view, dyes that need small quantities of salt are not easily available at an affordable price. Producing sensitized fabric by introducing reactive cationic groups in the fabric using a process called React-o-Cell, developed at ATIRA7, has not met with commercial success so far and the pad-batch process is suitable mainly for large lots of fabrics. For yarn packages and small lots of fabric, the batch process alone has to be used. Hence, the only practical solution for reducing salt is to use lower liquor ratios. Reduced liquor ratio also means reduced usage of M:L dependent chemicals, reduced usage of water itself, faster operations due to quicker drains and fills, lesser energy consumption and better shade reproduction due to better levelling. It also means lesser quantity of effluent for treatment.

The M:L ratios normally used for reactive dyeing of cellulose8 are as follows:

- Jet dyeing 1:10
- Jigger dyeing 1:50
- Beam dyeing 1:16
- Garment dyeing 1:50
- Paddle dyeing 1:40
- Hank dyeing 1:20
- Yarn package dyeing 1:10

However, even at lower liquor ratios, many batch-dyeing units, e.g. small process houses and yarn package dyeing units, have to discharge their effluent on agricultural land.

In a typical terry-towel processing unit in Gujarat dyeing about 5 tons of yarn with reactive dyes per day, salt up to 2.5 tons is needed. To remove this salt from the effluent, at least 2 tons of commercial lime that will generate 2.5 tons of gypsum every day is needed. This will create insurmountable problems in solid waste disposal. To overcome this problem of massive solid waste disposal, the only practical way is to recycle the salt solution. There are two major hurdles in doing so. They are as follows:

- Considerable quantity of hydrolyzed unfixed reactive dyes must be removed from the exhaust dyebath before the solution can be reused. The hydrolyzed reactive dyes have poor colour fastness and hence are not worth salvaging. However, they have good tinctorial value which interferes with the final shade.
- Levelling may be adversely affected if all the salt is present in the bath (salt at start). Some of the reactive dyes cannot be applied by this technique. Such dyes will have to be identified and omitted. For example, the following dyes are sensitive to

- Some dyes are not significantly affected by the presence of salt at start. They are C.I. Reactive Red 2, C.I. Reactive Red 141, C.I. Reactive Blue 171, and C.I. Reactive Yellow 84.

Removal of colouring matter from the exhaust reactive dye liquor can be done by chemical means in two ways. One is to use cationic or high molecular weight compounds that combine with the dye to produce fine suspension which can be conveniently filtered off. The other is to use dye flocculating agents and collect the solution of salt after filtration. In both the methods, the following lacunae have been noticed:

- Slight excess of cationic agent precipitates reactive dyes which are added when the bath is recycled for fresh dyeing. This affects the depth of dyeing.
- Precipitation of freshly added dyes also occurs when the excess dye flocculating agents are present. This also affects the depth of dyeing.
- It is not practicably feasible to add the precise amount of cationic or dye flocculating agents to the exhaust dyebath.
- When the residual dyes are removed by precipitating them with cationic agents, the tone of the shades obtained after adding fresh dyes is affected; the blue shades turn violet, red shades appear bluer and the yellow shades are dulled.
- Even if the same shade is to be repeated, the depth decreases progressively when the salt solution is recycled.
- Some shades dye unlevel when the salt solution is recycled.
- Flocculation of the dye-cationic agent complex takes sometime and adequate storage facilities are needed for this purpose.

Table 3 highlights the above-mentioned difficulties of depth and tone change when the colourless salt solution is recycled for producing the same shade. The data is from a terry towel unit in Gujarat, where the reactive dyeing of cotton yarn package was carried out. The dyes used were Procion Yellow HE4R, Procion Red HE3B and Procion Blue HERD. They were applied by salt at start method. The exhaust dye liquor was treated with a cationic product 'Catafix CR' that formed a complex with the dye for producing suspension for ultimate precipitation. The salt solution was filtered, replenished and reused.

It is seen from Table 3 that there is a fall in the depth of shade with the number of cycles. This is reflected in 'L' which increases with the number of cycles. Cycle '0' indicates fresh bath whereas cycles 2 and 5 are indicative of two and five recycling of salt solution. Tonal changes are reflected in the hue angle. In case of the medium blue shade, the tone is progressively redder. The chroma 'C' falls as the cycles increase, indicating that the colour value decreases with each cycle. The colour difference also increases with the number of cycles to an unacceptable level. In other words, the approach of using cationic compounds / agents to recover salt solution for reuse is not a practical solution.

Other polymeric agents including alum, ferrous sulphate, ferric chloride and polyelectrolytes were also tried for precipitating dyes but they suffered from the same drawbacks as mentioned above. The tonal changes were, however, minimum. The depth losses were unacceptably high.

The third approach that has been widely used in Europe is nanofiltration of the dye solution. Membranes that last for several months and can filter out dyes and separate salt solution are now manufactured in India. The entire plant costs about Rs. 5 lakh and the membrane can be used to filter 10 megalitres of exhaust dyebath. This would mean that at salt concentration of 50 g/l, the recovery of at least 35 kg of salt over a period of one year is practically feasible at 70% efficiency. At Rs 5 per kg, this would

<table>
<thead>
<tr>
<th>Shade</th>
<th>Cycles</th>
<th>L</th>
<th>a</th>
<th>b</th>
<th>C</th>
<th>h</th>
<th>CIE-DE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crimson Brown</td>
<td>0</td>
<td>45.0</td>
<td>23.8</td>
<td>14.5</td>
<td>27.9</td>
<td>31.4</td>
<td></td>
</tr>
<tr>
<td>Crimson Brown</td>
<td>2</td>
<td>51.5</td>
<td>21.3</td>
<td>11.2</td>
<td>24.1</td>
<td>27.7</td>
<td>7.7</td>
</tr>
<tr>
<td>Crimson Brown</td>
<td>5</td>
<td>56.1</td>
<td>17.6</td>
<td>9.7</td>
<td>20.1</td>
<td>28.9</td>
<td>13.6</td>
</tr>
<tr>
<td>Medium Blue</td>
<td>0</td>
<td>43.1</td>
<td>1.5</td>
<td>-15.2</td>
<td>15.3</td>
<td>275.6</td>
<td>-</td>
</tr>
<tr>
<td>Medium Blue</td>
<td>2</td>
<td>47.7</td>
<td>2.3</td>
<td>-13.4</td>
<td>13.6</td>
<td>279.7</td>
<td>5.0</td>
</tr>
<tr>
<td>Medium Blue</td>
<td>5</td>
<td>52.3</td>
<td>2.9</td>
<td>-12.1</td>
<td>12.4</td>
<td>283.5</td>
<td>9.8</td>
</tr>
</tbody>
</table>
mean a saving of Rs. 17.5 crores per annum for a process house dyeing three tons of cotton each day. The savings far outweigh the expenditure on nanofiltration plant including its operation. Nanofiltration and flocculation techniques were used in 1991 at a mill in Gwalior successfully on a pilot plant scale and 67% salt was recovered for reuse.

Trials were conducted at ATIRA on nanofiltration of exhaust reactive dye liquor and recycling of the salt solution. It was observed that:

- Dye selection is most critical if this approach is to be taken. Dyes which exhaust rapidly in presence of salt give unlevel dyeing. Dyes which exhaust slowly and the exhaustion of which can be controlled by temperature are ideally suited for this purpose,

- The total changes are small so also the loss of depth if nanofiltered salt solution is used for recycling,

- Prefiltration of exhaust dye liquor through sintered glass is useful to reduce the load on nanofilter,

- Under laboratory conditions, 75% salt recovery is possible, and

- Common salt can be used in place of expensive Glauber's salt.

Trials were taken with a very sensitive dye Procion Turquoise HEG. A mixture shade, based on HE type of dyes, was dyed on single column Ugolini yarn package dyeing machine. The exhaust dye liquor was collected, nanofiltered and reused after necessary replenishment. The results are given in Table 4.

Notwithstanding the colour difference recorded in the last column of Table 4, the use of salt solution up to five cycles did not show too high a colour difference to be unacceptable. The outline of commercial plant for nanofiltration is given in Fig.1.

8 Utilising Cut Portions during Garment Manufacturing and from Discarded Garments

In the garment industry, about 10-12% waste is generated that has to be disposed off economically. Avenues such as selling at throwaway prices to doll makers cannot consume the waste generated each day. As the cuttings are too small to make even children's garments, they are usually disposed off for land fill. The age old method is to sort out the garment waste into all-wool, wool-rich blends and others. The all-

<table>
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<th>Shade</th>
<th>Cycles</th>
<th>L</th>
<th>a</th>
<th>b</th>
<th>C</th>
<th>h</th>
<th>CIE-DE</th>
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<tr>
<td>Pr. Turquoise HEG</td>
<td>0</td>
<td>51.4</td>
<td>-30.5</td>
<td>-28.4</td>
<td>41.7</td>
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<td>-28.3</td>
<td>41.7</td>
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<td>0.22</td>
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<td>41.5</td>
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<td>-12.0</td>
<td>-5.9</td>
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<td></td>
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<tr>
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<td>-10.9</td>
<td>-5.7</td>
<td>12.7</td>
<td>207.6</td>
<td>1.12</td>
</tr>
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</table>

Fig. 1—Schematic diagram of plant for recycling salt solution

1—Dyeing machine, 2—Side tank for collecting nanofiltered salt solution, 3—Centrifugal pump, 4—Two-way valves, 5—Filter press, 6—Nanofiltration unit, 7—Sump for collecting dyebath to be drained, 8—Stirrer for mixing, 9—Centrifuge for separating dye sludge and dye liquor, 10—Heat exchanger, A—Decolourised salt solution for recycling, B—Discarded dye liquor after multiple recycling and rinsing, C—Dye concentrate separated during nanofiltration, D—Dye sludge for incineration, and E—Discarded effluent containing salt]
wool and wool-rich blends are garnetted and mixed with more wool and converted into blankets and cheap woollen spun items. The rest of the cuttings are shredded mixed with thermosetting resins to produce composites that have wide use in several industries as a reinforcing material. For example, Borgers Pvt. Ltd, Germany, consumes cotton cut portions from jeans to the extent of 1.5 kilotons per year for making composites.

Recycling is well known in case of used garments. The rich or the upper class pass on their used garments to the poor and poor to beggars / scavengers and so on at least in India. The problem is aggravated as polyester-rich garments do not wear out for a very long time. The rich developed countries pass on the discarded garments to Churches and NGOs for charity and these garments are passed on to the poor countries or even sold at 700 OM per ton. The recycling pattern of used garments is as follows:

- Reusable: 55%
- As mops: 25%
- Shredding for reuse of fibres: 10%
- Waste (Land filling): 10%

There are several second hand shops in Europe selling used garments by weight. The price they fetch in Germany is reported to be around 8,000 DM per ton. The unusable garments are picked up by several set ups who recycle it into composites for manufacturing fibre reinforced parts. For example, Borgers Pvt. Ltd, established in Berlin in 1990, is committed to recycling and has 16 sites in Europe. Its turnover is 580m DM per year, employs 2600 workers and produces 75% of the recycled fibres as composites and carpets or other floor coverings used by well-known automobiles, e.g. Audi, BMW, Ford, Volvo and Daimler Benze.

Woollen industry has been consuming wool-rich garments for at least a couple of centuries. The garments are sorted and plastic buttons, zips and non-fibrous material are removed by hand and then the entire garment is opened and broken up into fibrous mass on garnetting machines. These fibres are then dyed, carbonized and converted into woollen spun yarns from which blankets are made. India imports several tons of shoddy, i.e. discarded used garments, from the Western countries for this purpose as pure new raw wool is too expensive. This is perhaps the oldest recycling known to the textile industry.

9 Recycling Water from Chemical Processing

There are several ways of conserving water as per the state-of-the-art technology. This is done by using machinery employing low M:L and by different techniques, e.g. pad-batch and pad-steam. However, spectacular results have been obtained by recycling water. Several mills in Italy recycle water by using counter current principle for washing in the cotton processing and woollen industry. It is common to store spent dyebath that cannot be recycled for rinsing freshly dyed lots or for quenching hot ash from boilers or for washing screen printing blankets. Besides water conservation, it simplifies effluent treatment. Binny Textile Mills, Madras, has been using recycled water for various end uses for a long time. Their efforts have led to reduction in BOD values to a substantial extent.

10 Conclusion

The scope of reducing pollution by recycling various wastes from the textile industry has been discussed. The most relevant item for the textile industry in India is recycling of salt solution after reactive dyeing of cellulose. It has been shown that recycling often pays for the initial capital investment. If the benefits from the recovered products such as wool wax from raw wool scour liquor, and salt from spent reactive dyebaths are taken into account, recycling waste is a profitable option. Recycling can be described as obtaining wealth from waste. This is a strategy now adopted widely in Europe and followed, to some extent, in India. It is expected that continuation of recycling trend would help attain standards required for effluents according to various national and international norms.

References

7 Thakore K A, cited in ATIRA Communications on Textiles, 30(4) (1996) 120.
9 Sule A D, Unpublished data.