Waste Minimization in the Dyehouse

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The world has become increasingly aware of environmental issues through discussions on the greenhouse effect, ozone layer depreciation, water pollution and waste disposal. Traditional industries such as textiles have had to change their working culture from the days when natural resources were readily available, and when effluent and disposal of waste were not issues. Environmental concerns are increasingly a focus of management attention.

The driving force for this change has been legislation. At first consideration it is difficult to see any payback from investment in environmental issues other than being a "good citizen." It also is difficult to reconcile a situation where a local producer—either in the U.S. or Europe—is expected to operate to higher environmental standards than an importer into the same country.

ABSTRACT

The dyer has always been faced with choices regarding which dye to use and which application process to choose. In previous years, the cost of the dyeing process and the fastness of the dyeings obtained were prime considerations. Today these basic needs have been supplemented by the need for high productivity in the dyehouse together with an awareness of the environmental impact of the dyeing process used. Waste minimization has become an essential requirement and is increasing in importance, not just for environmental reasons but also in terms of the impact it makes on the total cost of dyeing.

In this work the environmental impact and the effect on waste minimization is compared for several dyeing processes—batch, continuous and semi-continuous—and printing. Costs are compared by process for such factors as energy and water utilization, chemicals and dyes, effluent and shade reproducibility or level of redyes. Alternative approaches are offered to aid in selecting processes that offer both financial and environmental benefits.

KEY TERMS

Commission Dyeing
Cost Analysis
Cotton
Dyeing
Effluent Treatment
Environment
Polyester
Waste Management

The purpose of this study was to demonstrate that by positively embracing a waste minimization culture it is possible to be a good citizen and gain economic advantage at the same time. A different working culture is needed, but to quote a UK colloquial expression, "Where there's muck, there's brass." Translated that means "Where there is waste, there is money to be made." Much has been written on how industrialization has caused changes in global climate and depletion of the earth's resources.

Legislation is increasing with toxic substance control acts, clean air acts, and water and effluent regulations. It can be confidently expected that the severity of all these measures will increase *(1)*. All these factors increase operating costs; for example, effluent treatment costs in the UK have increased in some cases by a factor of 10 when textile effluent is discharged into public sewers.

The challenge facing today's textile finisher is to strike a balance between environmental regulations, business economics and the need for the customer to obtain goods that offer value for money. In other words, maintaining profit margins—or just staying in business—cannot be achieved by simply passing the costs on to the consumer.

Waste Minimization Or Waste Treatment

Waste minimization programs approach the key environmental issues in a pragmatic way. The full concept has been excellently reviewed by Sunde and Pfeiffer *(2)*. It is worth highlighting some of the key points.

Firstly, minimizing waste must be addressed over a period of time, not in a draconian overnight approach. This allows a company to manage its way to becoming more environmentally friendly *and* staying in business.

Secondly, the concept must embrace a company's entire operation and not focus piecemeal issue by issue.

Thirdly, the concept focuses on not creating waste in the first place. It is worth restating, as done in *(2)*, EPA's perspective of waste minimization: "The idea of generating wastes first and dealing with them thereafter is not only very expensive in the overall perspective, but also potentially risky to the future well being of the planet."

Failing to see further than the end of one's overflow pipe will result in only one thing: increasing costs by attempting to cure the symptoms of unsustainable industrial practices.

The purpose of this study was to look at existing dyehouses and consider what approaches could be made as first steps in a waste minimization program. Solutions requiring capital expenditures were excluded from the study, which followed the strategy that a reappraisal and changes in current dyehouse practice can not only have a major impact on waste-minimization but also reduce overall operating costs.

The study concentrated on a commission dyer rather than a dyehouse that is part of a vertical operation. This was done to highlight measures any dyehouse can introduce irrespective of its size or organizational structure.

Sources of Waste

All processing operations have basic costs for the materials and energy they consume; for example, energy required for space heating, office materials, transportation, etc. Consideration of these fixed elements was not included in the study.

A dyehouse consumes energy, water, dyes and chemicals in the dyeing of textile materials whether they are woven, knitted or yarn. The typical processes include preparation, dyeing and finishing. Waste is created in the form of "off spec" materials, and while these may be corrected by shading additions or redyeing, correctional processes require additional energy, water, dyes and chemicals, thus increasing waste rather than minimizing it. In previous publications *(3)* it has been shown that the cost of a shading solution can add up to 30% to the cost of dyeing. Undesirable end products of these processes include atmospheric emissions, aqueous waste and solid waste including

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Table I. The Costing Equation

$$C = R + V + \frac{OtB}{Os} + \frac{StS}{Ss}$$

Where C = Total charge per m^3
R = Reception and conveyancing charge per m^3
V = Preliminary treatment charge per m^3
B = Biological oxidation cost per m^3
S = Treatment and disposal of primarily sludge per m^3
Ot = COD of effluent
Os = Average COD of region
St = Total suspended solids
Ss = Average TSS of region

Actual Costs Used	R = $1.03	Ot = 4000 mg/L
(based on typical UK experience)	V = $0.83	Os = 370 mg/L
	B = $0.99	St = 830 mg/L
	S = $0.61	Ss = 240 mg/L

Total costs = $1.44 per m^3

Table II. Continuous Preparation Costs

Process: Singe-Desize-Scour-Bleach-Mercerize-Stenter (Dry)
3000 m Batch 100% Cotton

	Energy	Water	Chemicals	Effluent	Total
$/100 kg	12.60	2.41	7.36	5.09	27.46
%	45.9	8.8	26.8	18.5	

Table III. Base Case Coloration Costs

Process: Continuous prepare — 500 kg Batch — LR 10:1
Portionwise addition of salt
Wash-off 3 hot rinses

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/100 kg	43.20	26.23	8.23	26.87	8.00	112.53
%	38.4	23.3	7.3	23.9	7.1	

Table IV. Influence of Shading Additions

Base Case:

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/100 kg	43.20	26.23	8.23	26.87	8.00	112.53
%	38.4	23.3	7.3	23.9	7.1	

Base Case + 1 Shading Addition:

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/100 kg	47.52	28.30	8.23	26.87	8.12	119.04
%	39.9	23.8	6.9	22.6	6.8	

Base Case + 2 Shading Additions:

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/100kg	51.84	30.33	8.23	26.87	8.14	125.41
%	41.3	24.2	6.6	21.42	6.5	

Base Case + Strip and Redye:

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/100 kg	86.40	36.45	8.50	86.00	10.98	228.33
%	37.9	16.0	3.7	37.7	4.8	

flocculated products from treating effluents or from air filters.

Previous studies *(4)* have used computer modeling techniques to identify the operating costs of a dyehouse. These included the cost of dyes, chemicals, energy and water as well as labor and other fixed costs. We have now extended this model to include the costs for effluent, assuming discharge to a municipal sewer. The model is capable of looking at the effect of reprocessing off spec material and different operating procedures. At present we do not have a facility to cost airborne waste or solid waste, primarily because no standard costing procedures are available.

To calculate the costs of effluent, we have used the so-called Mogden equation (Table I). This is the standard costing equation in the UK and it is used by all 10 water authorities who cater to indirect discharges (discharges to sewers). These authorities treat the aqueous effluent and then discharge it to rivers, seas and free water courses. Other equations can be substituted in the model.

Using the equation, we have investigated the cost impact of different processes. The amount of unfixed dye and chemicals present in the effluent, unused reaction products and carryovers from previous processes have all been calculated.

Results

Base Case

As a base case, the exhaust dyeing of 500 kg of woven 100% cotton with a fiber reactive dye has been used. To prepare the fabric for dyeing, the following procedure has been used: singe-desize-scour-bleach-mercerize-stenter dry. It has been assumed that 500 kg is equivalent to 3000 meters. The costs for waste—i.e., all those elements which need to be addressed in a waste minimization program—are shown in Table II.

The cost figures are based on the use of typical starch based sizes, and on the assumption that no recycling or reclamation of size is required. This is viewed as being typical of the case for a continuous dyehouse unable to specify the type of size to be used.

For the dyeing process, it was assumed that a jet dyeing machine was used and a 2% reactive dye shade applied. It was further assumed that the fixation level was 70% and that a 10:1 liquor ratio was used. The dye and fabric were entered into the dyeing machine at room temperature and then brought to a dyeing temperature of 80C. Salt (90 g/L) was added portionwise followed by the addition of 20 g/L of soda ash as the alkali. The dyeing was carried out at 80C for 60 minutes.

After the dye cycle, the dyebath was dropped and the goods were washed in three hot (70C) rinse baths, soaped at 98C and rinsed twice more at 70C and 20C. Each time the jet was emptied, refilled and reheated to the prescribed temperature. It was assumed in the base case that all dyeings were satisfactory; i.e., that 100% right-first-time levels of production were achieved.

Cost Analysis: Batch Dyeing of Woven Cotton

The cost data derived from the base case are shown in Table III. The total cost for water, energy, dyes, chemicals and effluent treatment was $112.53. Of this amount, effluent treatment alone comprises $8.00, 7.1% of the total cost. This by itself may not seem a high figure, but experience has shown that it will increase year after year as discharge limits become increasingly severe. Note that the cost of treating this aqueous effluent is already virtually the same as the cost of purchasing pure water used in the dyeing process. Using data from Tables II and III, the cost of preparing the fabric prior to dyeing represents 24% of total dyeing costs, providing a graphic example of why preparation costs cannot be ignored in waste minimization studies.

Influence of Right-First-Time

As noted, the base case assumes 100% right-first-time production. This is unlikely, and the need to make shading additions and even the possibility of stripping and redyeing some shades cannot be ignored. The effect of shading additions, stripping and redyeing is shown in Table IV.

Any extra processing increases all elements of the base case. Not achieving right-first-time, or only achieving low levels of right-first-time production, will adversely affect any waste minimization

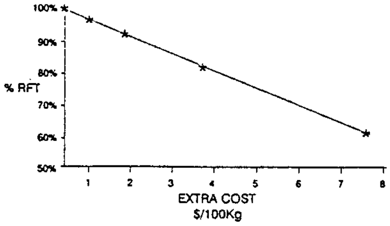

Fig. 1. Influence of reprocessing woven cotton dyed with a 2% reactive at a 10:1 liquor ratio.

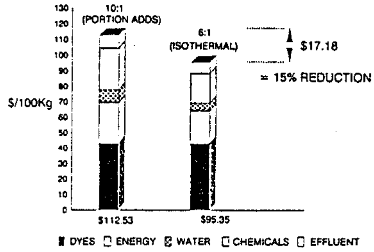

Fig. 2. Effect of liquor ratio.

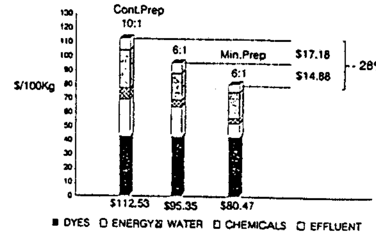

Fig. 3. Effect of liquor ratio and preparation on woven cotton on a 2% reactive dyed shade.

program. In general, the two elements that increase most in reprocessing are the cost of dyes and chemicals. The total costs and their impact on waste minimization are shown in Fig. 1.

It has been assumed in this calculation that any fabric not acceptable after the first process can be made acceptable by some retreatment. In other words, there is no solid textile waste generated. It has been further assumed that for any dyeings not initially correct, 60% of them could be corrected by a single shading addition, 30% by two shading additions; 10% would require a strip and redye. This calculation *excludes* any contribution from fixed costs or labor costs, and any impact on productivity and subsequent dyehouse profitability. From the data used to generate Fig. 1 it was found that for every 10% improvement in right-first-time production there is a corresponding 1.7% decrease in wastage and a reduction of $2 per 100 kg of fabric dyed. Put into perspective, this means that a dyehouse processing some 100 tons of fabric every 24 hours and working 300 days a year would save $57,000.

Other paybacks from right-first-time production—i.e., productiivity, better use of fixed capital and labor and the subsequent improvement in overall profitability—have been described elsewhere *(4)*. Needless to say, they are substantial, with improvements exceeding $500,000 having been achieved in practice *(3)*.

Effect of Liquor Ratio And Dyeing Technique

The base case has assumed a 10:1 liquor-to-goods ratio in a jet dyeing machine. (Newer machines have effective liquor ratios of around 6:1.) By changing the data in the base case, the corresponding costs associated with the lower liquor ratio dyeing have been calculated and are shown in Fig. 2. The isothermal dyeing technique was used in which auxuliaries and all the salt are added to the dyebath which is then raised (7C/min) to 80C at which stage dye is added followed by alkali. Dyeing was carried out for 60 minutes. The washing sequence was identical to the base case.

These figures substantiate claims that the lower liquor ratio machines offer lower direct operating costs. There is an obvious reduction in the cost of water used, and less chemicals are used since they generally are added as a percentage of volume. Energy costs are lower since there is less liquor to either pump or heat. The effluent charge is lower not only because of the lower volume being treated but also due to the lower chemical concentrations. The cost of dyes remains the same since these are added as a percentage of weight of the fabric.

The total cost of dyes, chemicals, energy, water and effluent at a 6:1 liquor ratio are $95.35, a reduction of $17.18 per batch over the base case. This represents a reduction of 15%.

Interim Conclusions

For a given batch dyeing process and given fabric using a common preparation and dyeing procedure, waste minimization can best be achieved—in order of importance—by:

- Operating at the lowest liquor ratio possible
- Minimizing (ideally avoiding) the need to strip and redye
- Avoiding shading additions

Alternative Processes

There are other ways that the same 500 kg of woven cotton could be dyed. Using all the procedures so far described, it would be expected that the material so produced would be identical. If differences could be accepted, or if the fabric was going into outlets and end uses where different standards were used, then other methods could be considered.

Four scenarios have been looked at: using a minimum prepared technique in batchwise dyeing with reactive dyes, continuous dyeing with either vat or reactive dyes and pad batch dyeing. All four scenarios have been restricted at this stage to woven fabric.

The minimum prepare approach is particularly interesting in view of the high

Table V. Comparison of Continuous and Semi-Continuous Processes

Base Case - Exhaust 10:1

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/100 kg	43.20	26.23	8.23	26.87	8.00	112.53
%	38.4	23.3	7.3	23.9	7.1	

Continuous Process: Pad-Dry-Chem Pad-Steam(Vat)

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/100 kg	46.98	28.03	6.01	18.43	7.02	106.47
%	44.1	26.3	5.6	17.3	6.6	

Process: Pad-Dry-Bake (Reactive Dye)

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/100 kg	29.25	29.02	3.65	17.87	6.14	85.93
%	34.0	33.8	4.2	20.8	7.1	

Process: Pad-Batch (Reactive Dye)

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/100kg	31.32	19.48	3.60	13.44	6.12	73.96
%	42.3	26.3	4.9	18.2	8.3	

Table VI. Color in the Effluent from Batchwise Dyeing

Coloration Method	:	Jet
Fabric	:	100% Cotton
Batch size	:	500 kg
Dye class	:	Reactive
Depth of shade	:	2%
Dye fixation	:	70%
Liquor ratio	:	10:1
Number of baths (including preparation)	:	10
Weight of dye applied	:	500 x 0.02 = 10.0 kg
Weight of dye washed off	:	10 x 0.3 = 3.0 kg
Total water usage	:	500 x 10 x 10 = 50,000 liters
Concentration of dye in effluent	:	3.0/50,000 = 60 ppm

cost of preparation. In this procedure the fabric is scoured at 60C on the jet dyeing machine using specially developed agents; i.e., eXceL scour process used with Procion HEXL dyes *(5)*.

This minimum prepare approach has been directly compared to that using continuous prepared fabric, 6:1 liquor ratio and both using the isothermal technique. Results are shown in Fig. 3 where it can be seen that the impact of changing to a minimum prepare is to reduce the total cost per 100 kg of those elements requiring consideration in any waste minimization program by some $14.88 (15.6%) over the standard continuous preparation process. Compared to the base case, this represents a saving of some $32 per kg or around 28%.

In the case of continous and semi-continuous dyeing it was assumed that 500 kg was the equivalent of a 3000 meter batch. In all cases the preparation process was singe-desize-scour-bleach-mercerize. The processes considered for the coloration stage were pad vat dye-dry-chemical pad-steam; pad reactive dye-dry-bake; pad reactive dye-batch.

In all processes a continuous washing procedure was carried out. The coloration and processing conditions were standard for these processes. In the pad batch process no sodium silicate was used. Results are shown in Table V. The difference in dye costs is brought about by the different chemical types used and the different levels of fixation obtained in the processes.

As can be seen, these alternative methods also show savings over the base case. Purely from a waste minimization standpoint, continuous and semi-continuous methods are worth considering.

The example cited assumes that the product obtained from these preparation routes is acceptable to the end user in terms of brightness, fastness, etc., and also is totally economic to the producer in terms of payback of capital investment, labor and other cost considerations.

However, purely from a waste minimization standpoint, it can be seen that the pad batch process appears to offer the best alternative. It is important to understand that this is today's position using the current UK costing equation for discharge to public sewers. In this equation, the cost of color in the effluent plays at present a very small part, affecting only the COD. If the presence of color in the effluent becomes a major issue, then all continuous and semi-continuous processes will need rethinking in terms of unused pad liquor and its disposal or possible recycling. These comparisons are shown in Tables VI and VII.

The calculation shows that the average concentration of dye in effluent from a jet dyeing machine is around 60 ppm. In a pad batch process, or in any continuous coloration process, there is a considerable amount of dye remaining in the pad trough pumps, piping, etc. after the dyeing. Under current practice this is often discharged. The calculation in Table VII shows that color in the effluent can be on the order of 250 ppm. No method is foolproof, and all these figures assume 100% right-first-time production. In padded fabric, a shading addition is not possible. Often the only recourse in correcting the shade is to strip and redye. The added cost of this process compared to a shading addition has to be remembered. Further, it has been assumed that satisfactory dyeings can be obtained without using sodium silicate (which is toxic to fish) as the alkali.

Table VII. Color in the Effluent from Pad Dyeing

Coloration Method	:	Pad batch
Fabric	:	100% Cotton
Run length	:	3000 meters
Run weight	:	500 kg
Dye class	:	Reactive
Depth of shade	:	2% (30 g/L)
Pickup	:	67%
Dye fixation	:	70%
Water usage (including preparation)	:	40 liters/kg fabric
Volume of pad trough	:	40 liters
Volume of piping	:	10 liters
Volume of buffer liquor	:	20 liters

Volume of pad liquor required : 500 × 0.67 = 335 liters

The pad trough must be full at the end of the run to avoid tailing effects due to variable dip times. Thus an extra 40 liters is made up.

Volume of liquor required + pad trough : 167.5 + 40 = 375 liters

As running out of pad liquor could ruin much of the batch it is normal practice to make up extra liquor, or buffer stock, say 20 liters.

Volume of pad liquor buffer : 375 + 20 = 395 liters

The pad trough may be considerable distance from the feed tank so there may also be waste from this source. This will be ignored in this example.

As 395 is an awkward number for calculating the weight of dye required it would be normal practice to round up to 400 or even 500 liters.

Liquor left over at end of run	:	400 – 335	=	65 liters
At 30 g/L dye, weight of dye	:	(65 × 0.3)/1000	=	1.95 kg
At 70% fixation (2% shade) dye washed off	:	10 × 0.3	=	3.0 kg
Total dye in effluent	:	1.95 + 3.0	=	4.95 kg
Total water usage	:	40 × 500	=	20,000
Concentration of dye in effluent	:	4.95/20,000	=	248 ppm

Dyeing Other Textiles

Thus far only woven fabric has been considered. Textiles are dyed in knitted and yarn form too, of course. Thus three scenarios have been considered, again for 100% cotton. Yarn, knitgoods and the woven fabric of the base case are used in these examples.

For yarn and knitgoods, comparisons have been made between knitted and woven fabric dyed at 6:1 liquor ratio using the minimum prepare and isothermal dyeing techniques. All other conditions are the same as in the base case. For yarn, dyed batchwise, a similar minimum prepare scouring process has been used but the dyeing process is one developed for yarn dyeing; namely, the eXceL rapid process. The process is similar to the isothermal technique with salt auxiliaries and dye added initially, the dyebath raised quickly to temperature, alkali added and the dyeing carried out for some 60 minutes *(5)*.

Costs for the various elements are shown in Table VIII. The cost of dyes in all processes is assumed to be equal, but there are major differences between the other cost elements. This results in the clear message that the dyeing of yarn and knitgoods has a lower "environmental cost" than the dyeing of woven fabric even when the minimum prepare route is used. The implications for this are that if waste minimization is extended beyond the module of one dyehouse, there is a clear incentive for more knitted garments be used or that dyeing be done at the yarn stage. Dyed yarns would then be either woven or knitted into the final textile product.

As shown in Table VIII, yarn dyeing can offer savings of some $7.54 per 100 kg compared to woven piece dyeing. This is equivalent to more than a 9% savings over the minimum prepare process, and about a 35% savings over the base case (Table II).

Pad Batch of Knitgoods

In considering woven fabric, it was clearly found that pad batch application methods had the major impact on waste minimization. When the comparison was done on knitgoods, a different picture emerged. The comparison has been done for a 500 kg batch but with techniques used to ensure that the quality of the final fabric is the same. For the batchwise dyeing of cotton knitgoods, the minimum scour isothermal process has been used at a 6:1 liquor ratio.

Table VIII. Dyeing Textiles in Different Physical Forms (500 kg)

	Dyes	Energy	Water	Chemicals	Effluent	Total	Difference
Woven $/100 kg Base Case at 6:1 minimum prepare	43.20	9.22	3.83	18.68	5.54	80.47	–
Knitgoods $/100 kg at 6:1 minimum prepare	43.20	9.31	3.83	18.68	2.61	77.63	-$2.84 (-3.5%)
Yarn $/100 kg at 5:1 minimum prepare	43.20	8.08	3.65	15.57	2.43	72.93	-$7.54 (-9.4%)

Table IX. Comparison of Pad Batch Dyeing and Exhaust Dyeing of Cotton Knitgoods

Knitgoods: 100% Cotton
Exhaust Process: Minimum Prepare 500 kg Batch LR 6:1
Isothermal
Wash-off 3 Hot Rinses

	Dyes	Energy	Water	Chemicals	Lab+Fix	Effluent	Total
$/100 kg	43.20	9.31	3.83	18.68	25.42	2.61	77.63

Continuous Process: Pad Batch Prepare 500 kg Batch
Pad Batch Dye
Beam Wash

	Dyes	Energy	Water	Chemicals	Lab+Fix	Effluent	Total
$/100 kg	48.40	6.71	6.84	12.89	58.41	5.94	80.78

For pad batch dyeing, the procedure used was pad batch prepare, pad batch dye, beam washing. The fabric was slit before dyeing to avoid edge marks. Comparisons are shown in Table IX.

In knitgoods, the pad batch process is not the best option in terms of waste minimization. The difference in the cost of dyes is due to lower fixation being achieved in the pad batch process. Excess pad liquor is needed to ensure against running out of color during the padding process.

General Conclusions For Dyeing Cotton

It can be seen in Table X that changes are likely to have a positive effect on any waste minimization program. All the procedures and techniques described are well within the capabilities of most dyehouses without the need for investing in capital equipment. They are, therefore, practical solutions. The extreme cases show that the most negative thing that can be done in terms of waste minimization is to strip and redye. Therefore a right-first-time and total quality management regime is essential. Interestingly, the most positive thing that can be done is to dye in yarn form rather than in piece.

Table X. Summary of Results on Cotton

$/100 Kg (% Improvement in Waste Minimization) vs. Base Case

Right First Impact	Dyeing Process	Woven	Knitgoods	Yarn
Strip and Redye	Batch 10:1	$228.33 [+203%]		
+ 2 shade adds	Cont. prepare	$125.41 [+ 11%]		
+ 1 shade add.		$119.04 [+5.8%]		
100% rft	Base Case	$112.53		
	Batch 6:1 Cont. prepare	$ 95.35 [-15.3%]		
	Batch 6:1 Min. prepare	$ 80.47 [-28.5%]	$77.63 [-31.0%]	$72.93 [-35.2%] (LR 5:1)
	Pad batch	$ 73.96 [-34.3%]	$80.78 [-28.2%]	
	Continuous (Vat) chem	$106.47 [-5.4%]		
	Pad-steam Continuous (Reactive) pad-bake	$ 85.93 [-23.6%]		

Textile Printing

An analysis for printed material was made for a 3000 meter batch (assumed equivalent to 500 kg) of cotton printed with reactive dyes to an assumed 80% coverage by the all-in method. In this method dye and alkali are printed together and the fabric steamed after drying. Urea is required in the print paste to achieve fixation, and a thickening agent is used to maintain print definition. The fabric preparation sequence is singe-desize-scour-bleach-mercerize. Table XI gives a breakdown of costs.

Table XI. Costs in Printing

	Dyes	Energy	Water	Chemicals	Effluent	Total
$/1000 m	37.15	20.95	5.60	32.83	9.81	106.34
%	34.9	19.7	5.3	30.87	9.2	

Two points are interesting to note. The costs for printing, assuming right-first-time, are less than the base case. This is due to lower costs of dyes (because the fabric is not 100% covered), a lower energy requirement and lower water usage. The cost of chemicals is much higher than the base case due to thickening agents, and these in turn increase the cost of effluent treatment.

The second point to note is that in printing there is no scope for shade additions, stripping or redyeing. Any fabric wrongly printed can normally be sold only as seconds. A wrong print contributes not only to increased usage of the elements already described but also creates solid waste—i.e., the damaged fabric. The costs for dyes, energy, water, chemicals and effluent is directly proportional to the level of second quality produced; therefore a 5% level of incorrectly printed fabric results in a 5% increase in total cost.

Polyester/Cotton

The analysis was further extended to cover batch dyeing of both woven and knitted polyester/cotton fabrics. In all cases a liquor ratio of 8:1 was used since it is typical for this blend. The principle objective of this analysis was to compare the impact on waste minimization of the two well known application methods. These were the dyeing of the polyester with disperse dyes using conventional high tem-

Table XII. Polyester/Cotton

		Dyes	Energy	Water	Chemicals	Effluent	Total
Woven:	Cont. Prepare 2 bath process	43.20	26.15	9.95	32.56	7.90	119.76
	Cont. Prepare Select II	43.20	24.64	6.97	24.70	7.69	107.20
Knitgoods:	Full Scour Bleach 2 Bath process	43.20	22.68	8.73	41.87	5.44	121.92
	Min. Prepare Select II	43.20	12.56	5.27	23.09	3.55	87.67

Table XIII. Polyester/Cotton Benefit from Telescoped Technique

		Total Cost $/100 kg	Cost Savings
Woven	2 Bath	$119.87	
	Select II	$107.20	$12.56 [10.5%]
Knitgoods	2 Bath	$121.92	
	Select II	$ 87.67	$34.25 [28.1%]

perature dyeing techniques, reduction clearing to clean the cotton and to remove unfixed disperse dyes followed by dyeing the cotton component with reactive dyes. The reactive dye system used was a hot one (80C). This system was compared to one in which the cotton and the polyester were dyed simultaneously with selected disperse and reactive dyes. In this system the fabric is dyed under slightly acid conditions following normal polyester dyeing procedures. The temperature is then lowered to 80C at which point alkali is added to fix the reactive dye. The processing specifics are not within the scope of this paper but have been described elsewhere *(6)*. The combined process used in the calculation was ICI's Select II Process.

For the woven fabric, a continuous preparation sequence was used: singe-desize-scour-bleach-mercerize-stenter-heat set. For the knitted fabrics, one of two preparation techniques was used: either a full scour bleach on the machine or a minimum prepare technique which is an integral part of the Select II procedure. The results are shown in Tables XII and XIII. As can be seen, major benefits can be gained from going from a two-batch process to a telescoped procedure.

Conclusions

Using computer modeling, it has been determined that there are major positive steps that can be made toward waste minimization in conventional dyeing techniques. Reductions in the combined costs of dyes, chemicals, energy, water and effluent treatment in the order of 30% or more are possible. These can all be achieved without major capital expenditure simply by readdressing current practices and procedures.

The main areas from which maximum waste minimization can be achieved are:

- Batchwise dyeing at the lowest possible liquor ratio
- Telescoping procedures and processes using well known techniques
- Eliminating the need for stripping and redyeing by maintaining a high level of right-first-time production
- Using care in selecting the coloration procedure to be used while at the same time ensuring that customer needs are met; woven fabrics, continuous and pad batch applications can offer significant advantages
- Considering which stage in processing is best for dyeing; i.e., yarn dyeing can offer clear advantages over piece dyeing

These observations are valid today but they could change as rules and regulations become more stringent. Even as they do, however, the trends outlined here will remain applicable.

No consideration has been made regarding consent levels and issues not currently covered by effluent treatment. These tend to be very localized and are best done plant to plant. But clearly they must be considered. Even with 97% fixation of reactive dyes (highly unlikely), color could be in the effluent. Levels of less than 5 ppm are being asked for in the UK.

A dyehouse manager has to consider two important issues: profitability and long term financial outlook, and how these can be impacted by waste minimization and environmental requirements. These objectives need not be conflicting. By simple changes in existing procedures, it is possible to reduce waste and maintain profitability. The study has shown that such changes can be made today in a commission dyehouse using existing equipment. The payback is instant.

No one can predict the future or foresee how much more stringent environmental regulations will become, but by following the scheme outlined here we can earn while we learn. We can be good citizens without sacrificing profitability.

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