Financial Analysis

The Application of Quality Control and Automation in Reducing the Real Cost of the Dyeing Process

By P. S. COLLISHAW, B. GLOVER and R. F. HYDE, Imperial Chemical Industries PLC, Blackley, Manchester, England

Financially analyzing the dyeing process has always been a problem to wet processors. The mere handling of the mass of data required in doing a meaningful analysis offers its own problems. But recently developed computer techniques have simplified the task and made it more practical to evaluate the cost effectiveness of dyeing processes now being used as well as alternate ways of doing the same thing.

Before examining methods for determining dyeing costs, let’s consider the current scenario in the dyeing sector which makes a realistic cost analysis so important. The great disparity in labor costs in the textile producing nations illustrates the handicap that the developed countries have in competing with the developing countries. Recently published figures are given in Table I.

In markets where base costs are high it is vital to utilize labor in the most effective manner. The use of automation and computer control techniques helps meet these needs.

The latest machinery developments are designed to achieve short, simple, automated processing. This applies in all areas of dyeing and printing. Such developments are engineered to give the most efficient use, not only of labor, but in all cost elements of processing; i.e., energy (gas, electricity, oil, etc.), water, chemicals and dyes. When comparing costs, a plant’s capital and fixed costs must be considered.

The rapid growth in sportswear and leisure wear has led to more emphasis on this fashion sector. This has been apparent not only in the cotton and polyester/cotton knitted goods area but also in the woven goods continuous-dyeing sector. The sports and leisure wear area is an excellent added value segment and many dyers have been encouraged to enter this field. It does mean, however, that orders for fashion shades are placed on short notice and their frequently changing nature requires short delivery times. There also is a reluctance by garment makers to maintain high inventories of colored fabrics in this rapidly changing fashion scene.

In addition there is an increasing demand for higher fastness levels from the major retail organizations. This is a result of the growing trend in contrast trims (often white), heavy shades and the fact that sportswear is laundered more frequently than formal wear. This demand in itself could add to the fundamental costs of processing; e.g., in lengthy reduction clearing of dispersive dye processes for polyester/cellulose blends.

Therefore pressure is on such developed markets as the U.S. and Western Europe to introduce quality control and automation to provide means of responding to their own market needs and to increased competition from low cost imports.

Interestingly the use of quality and automation is not confined to developed markets. The same trends are apparent in Taiwan, Korea and Hong Kong where, in anticipation of increasing labor costs, automation is being rapidly introduced.

The developed countries therefore ignore the potential cost benefits from these techniques at their peril.

Quality Control/Automation

The object of quality control and automation is to increase right-first-time production by capital investment in both automation and dyeing equipment. The steps to achieving this are: (1) telescoped dyeing processes where control is by temperature, liquor ratio and time, and a minimum of adds during the process; (2) reproducible processes leading to blind dyeing; (3) investment in hardware; (4) meeting the market needs; and (5) avoiding false economies.

The basic philosophy behind these statements has been described earlier by the author (2). In brief, the dyeing processes should be looked at in their entirety. They should be made as reproducible as possible through the use of appropriate dyes, techniques and procedures. Automation should be introduced at a last stage.

Finally, any cost analysis should include the total dyehouse process over a week or more of production and in awareness of the associated income. It must also be remembered that the most expensive thing the dye does is to dye something wrong. A faulty dyeing not only cannot be sold, but the cost of a shading addition increases the total process cost by 30%, a redyeing by 70-130%. Reasons for this are shown in Fig. 1 where the costs of all components of dyeing a medium shade are compared for two processes—preparation followed by dyeing and a combined scour-dye process. It can be seen that the cost of dye is third in importance. The cost of a shading addition is therefore influenced considerably by costs other than dye. Another observation is that the savings from moving to a scour-dye process from the traditional process in water, energy, chemicals, labor and fixed costs are greater than the total cost of the dye.

Experience To Date

All dyeing procedures using our computer expertise have been modeled into computer simulations which allow input of cus-

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Table I. 1987 Labor Costs for the Textile Processing Industry

<table>
<thead>
<tr>
<th>Country</th>
<th>Labor Cost (U.S. $)</th>
<th>Index (U.S. = 100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>9.24</td>
<td>100</td>
</tr>
<tr>
<td>Canada</td>
<td>9.85</td>
<td>107</td>
</tr>
<tr>
<td>West Germany</td>
<td>12.98</td>
<td>141</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>7.09</td>
<td>77</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>1.93</td>
<td>21</td>
</tr>
<tr>
<td>South Korea</td>
<td>1.77</td>
<td>19</td>
</tr>
<tr>
<td>Turkey</td>
<td>1.28</td>
<td>14</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0.20</td>
<td>2</td>
</tr>
</tbody>
</table>

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ABSTRACT

The authors describe how computer modeling techniques can be used to analyze the dyeing process to determine how various manufacturing techniques impact on quality, productivity and profit. Procedures are described for producing consistent and improved quality, lowering overall costs and establishing greater flexibility in meeting market demands for getting it right the first time.

KEY TERMS

Automation
Computer Analysis
Cost Analysis
Dyeing
Dyeing Costs
Productivity
Quality Control
Quick Response

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Quality Control and Automation

tomer's data.

In the dyeing process each piece of equipment is treated as a separate module and the appropriate costs for each parameter involved are allocated to each process stage. The direct cost information required includes steam (cost/kg), electricity (cost/Kwhr), gas (cost/GJ); water (cost/m³), labor (cost/man/hour), dyes (cost/kg) and chemicals (cost/kg). The fixed costs of the capital investment in each machinery unit are also incorporated in the computation.

Other factors which aid the refinement of the program are the average weight per unit length of fabric, the average length of fabric dyed per shade, the number of hours worked and working days per annum.

With these data the computer program can produce the total cost for various processes. Variation in the different process modules is straightforward, thus enabling a reliable cost analysis to be custom built for different markets and local customer situations.

We have done studies in batch dyeing of piece, yarn and continuous dyeing. Considerable cost savings or productivity increases have been possible in all dye-houses we have looked at by simply changing the techniques being used. This is an important consideration when companies are considering buying new machinery.

Following is a good example of the type analysis possible. An expanding batchwise dye-house was in the process of buying a new $50,000 jet dyeing machine. We were able to show that better use of existing equipment could increase production by 30%. Trials were made and 20% increases were attainable in bulk. The differences between theoretical amounts and levels actually achieved were caused by bottlenecks in the factory—e.g., availability of finishing stenters, etc.

Computer models also can be used to compare the costs of different processes. Previous papers (2,3) have described the benefits from single-bath systems for the polyester/cotton blends using the Select I process and the scour-dye processes. These studies have been extended to include continuous dyeing with several processes (Table II). Comparative costs of dyeing per 1000 meters are shown in Fig. 2. The program also includes the total processing costs comprised of preparation, dyeing and finishing (Fig. 3).

The schematic representations of the four processes in Table II show that the RTN process by ICI, with its shorter processing route, will likely be a more economical process than the more conventional methods used for dyeing polyester/cellulose with disperse/reactive dye combinations. The problem always has been to quantify these economic benefits. The computer cost analysis simulation enables this quantification to be realized.

For example, the cost benefits in changing from a conventional two-stage process to the shorter one-stage RTN process can be assessed before any dyeing trials are carried out. Thus if the RTN process is compared with the commonly used pad-dry-thermofix-reduction clear-dry-batch (Table II), it can be seen that the RTN process offers demonstrable cost savings, almost all of which will be transferred to bottom-line profit.

Based on this comparison the processing cost/1000 meters by the RTN process would be $60 whereas the pad-thermofix/pad-batch process would cost $120. The cost reduction using the RTN process is $0.06 cents/meter.

Consider a continuous dyeing operation by an average size company with an annual production of 60 million meters. Not all of the production will be dedicated to disperse/reactive dyeing. Therefore, assume that 20% of the production is dying polyester/cotton using disperse/reactive dyes by the two-stage method; i.e., 12 million meters/annum. At $0.06/meter cost benefit for the RTN process, a mill could gain $720,000/annum using the process.

It is also possible to calculate weekly production rates (Table III), and compare different dyeing techniques (Fig. 4) to determine which method would be the most economical for dyeing short runs on woven cotton fabrics. This simulation was run on a random lot size from 1000 to 10,000 meters but with an average lot size of 3000 meters.

Cost efficiency improvements are valid only if the resulting end product maintains its ability to meet the market specifications for quality, fastness, etc. Simplifying the processing route and reducing the costs will only bring economic benefit when the new process proves itself suitable for that dyeing plant.

An examination of the actual perfor-

<table>
<thead>
<tr>
<th>Table II. Continuous Dyeing Routes Investigated</th>
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<tbody>
<tr>
<td>RTN One-Stage Process (ICI)</td>
</tr>
<tr>
<td>Pad With Dispersed Dyes + Procion Dyes</td>
</tr>
<tr>
<td>Dry Thermofix at 210C (410F) Wash Off</td>
</tr>
<tr>
<td>Conventional Pad-Steam</td>
</tr>
<tr>
<td>Pad With Disperse Dyes + Reactive Dyes</td>
</tr>
<tr>
<td>Dry Thermofix at 210C (410F) Chemical Pad Steary Wash Off</td>
</tr>
<tr>
<td>Two-Stage Thermofix/Pad-Batch</td>
</tr>
<tr>
<td>Stage I: Pad With Disperse Dye Dry Thermofix at 210C (410F) Reduction Clear Steary Wash Off</td>
</tr>
<tr>
<td>Stage II: Pad With Reactive Dye + Alkali Batch 4 Hours Wash Off</td>
</tr>
<tr>
<td>Two-Stage Double Bake</td>
</tr>
<tr>
<td>Stage I: Pad With Disperse Dye Dry Thermofix at 210C (410F) Reduction Clear Steary Wash</td>
</tr>
<tr>
<td>Stage II: Pad With Reactive Dye, Alkali, Urrea Dry Bake at 150C (302F) Wash</td>
</tr>
</tbody>
</table>

*$n = 2-24$ hours.
mance and technical profile is necessary and this has been done for all the dyeing processes we have studied.

**Bulk Reproducibility**

As stated earlier, the most expensive thing a dyer does is to produce an unsatisfactory dyeing. Unsatisfactory dyeings are usually caused by: (1) using dyes that are sensitive to variations in process conditions; (2) using dyes that have an inherent application weakness—e.g., poor level dyeing performance, poor washoff, low fixation, poor fastness; (3) operator error; (4) operating an inherently nonreproducible process or process step; and (5) lack of control—every dyeing is an adventure.

It is possible to overcome all these problems. For example, the Select II process has become established as a routine operation in major dyehouses in the U.K., U.S. and Germany for knitted piece goods and yarn. This process is a one-bath telescoped process for dyeing polyester/cotton with disperse and reactive dyes. In these dyehouses blind dyeing is the norm and this has been done for all the dyeing processes we have studied.

"The main message is clear. If the right dyes for that procedure must be used.

An area of current research interest is the washing off stage in reactive dyeing. Traditionally the dyebath is dropped and a cold rinsing process is performed prior to a hot washing treatment. We are looking at processes which omit this time and energy consuming cold rinse sequence.

In these methods the dyebath is dropped at the end of dyeing and hot water is immediately introduced. This shortens the process and all of the heat energy in the machinery and fabric is retained. With a cold rinse the equipment and fabric are cooled and heat energy has to be introduced to raise the temperature for the hot wash sequence. Also the rate of diffusion of unfixed dye is higher with a hot rinse than at lower temperatures.

This approach can be extended to package dyeing with a steam injection step introduced after the dyeing stage. The improvement in washing efficiency is shown in Fig. 5. By omitting intermediate cold rinsing in package dyeing the yarn is in the dyebath for a shorter period of time. Since liquor movement is easier at higher temperature, less pump pressure is used. The inclusion of these two factors reduces the potential for yarn damage. This is an increasingly important need as the demand for finer quality fabrics grows.

**Operator Error**

Since people will always make mistakes, a prime role of automation should be to eliminate the possibility of error. Time, temperature, running speed and liquor additions are the main parameters that need to be controlled and modern automation techniques can do this. Backed up by a monitoring computer making the necessary corrections, there is no reason why, with the adequate capital expenditure, any dyeing process should not be controlled fully.

Our thesis is that the simpler and more robust the process the cheaper it will be to automate. For example, in the Select II process less chemical additions are required, therefore less pipework, holding tanks, valves and software are needed (Fig. 6). The main source of error remaining is in the accurate weighing of dyes. Advancements are being made in this area with the development of liquid dyes and the introduction of an automated dispensing system for both liquid and solid dyes. Even with these sophisticated systems and the use of computer recipe prediction, the operator must assume that the dyes are standard from batch to batch and that
solid dyes will dissolve fully when added to the dyebath. These features are described more fully in the next section.

**Quality of Products**

All products with the same Colour Index number are not equal. Products will differ in the amount of effective agent, the degree of standardization and in other physical properties such as solubility.

For the efficient operation of an automated dyehouse, it is essential to use dyes which are accurately standardized for shade and strength. This increases the chance to obtain the right shade, first time, every time and avoid expensive shading additions and redyeings. This means that delivery dates, so important in today's fast moving fashion business, are more easily met, and costs are kept under control.

Let us look at the issue of standardization in greater depth. The variation between different randomly selected samples of Procion Yellow H-E4R are shown in Fig. 7. These differences are considered well within recognized commercial limits of acceptability.

On the other hand when we did the same exercise on a range of randomly selected customer samples of a distributor's product with the same Colour Index number as Procion Yellow H-E4R, results shown in Fig. 8 were obtained. The samples we looked at were all weaker than Procion Yellow H-E4R and significant inconsistency existed between samples. Similar variations were found with other shades.

So what are the messages from these data? First, if a product is varying from batch to batch, then the operator cannot know how much effective agent he is weighing, regardless of his accuracy. In these cases the dyeing process is out of control especially if a mixture shade is being dyed.

The use of computer match prediction makes things more sensitive since the computer makes the assumption that the strength and buildup of each batch of dye are identical. If another supplier's product is used, then the coloristic properties of the dye must be programmed into the computer before accurate shade predictions are possible. If there is a lack of confidence in batch to batch standardization, then each batch must be calibrated before an accurate shade prediction is possible. Otherwise the only thing automation and blind dyeing techniques will do is guarantee the wrong shade. There will be no possibility for the skilled dyer to make shading additions during the process. If this possibility exists one must remember that a shading addition results in a 30% increase in total dyeing cost. Therefore it is a sound investment to purchase quality, well standardized products. Even if they are more expensive initially they can allow major processing cost reductions. To purchase a product a few cents cheaper and incur major dollar extra costs is not a good business practice. After all, if you are spending millions of dollars sponsoring a major Grand Prix racing car, you do not worry about the cost of tires, you worry about their technical performance. And as dyers we are all running multimillion dollar enterprises.

**Market Needs**

The current market need is one of rapid response. Shorter, more productive, more reproducible and right-first-time processes will help meet this need.

One of the factors referred to earlier is the move to higher quality, and in particular, higher fastness demands. It can be assumed that the use of shorter processing techniques with the elimination or reduction of clearing steps could be incompatible with this requirement for higher fastness.

With automation the process should be controlled and should not produce varying fastness results. The key variable then becomes the selection of chemicals and dyes.
It is essential to maintain consistent quality in chemical supplies and to check effective agent content, specific gravity, pH, etc. from batch to batch. Or more sensibly, establish a contract with a supplier who will agree to provide products that meet specification on a vendor schedule.

The rule for dyes is very simple. Only those products recommended for the process should be used. These have been designed to be the right products for the job.

We have found with the Dispersol and Procion dyes recommended for particular processes it is possible to meet the latest fastness demands even with short cost-effective processes. For example, performance has been excellent to the new high alkali domestic washfastness tests typified by Adidas demands and the Marks and Spencer C4A test.

Other recently introduced tests concentrate on the sensitivity of the dye-fiber bond to a combination of perborate (retained in the fabric after domestic washing) and sunlight—e.g., Marks and Spencer C9A test. In general the Procion dyes, based on the monochlorotriazinyl reactive group, are stable to this test where other fiber reactive species can show degradation.

Under bulk conditions we have been able to show that the modern telescoped processes can be both cheaper in overall process cost and better in terms of fastness providing the correct dye selection is made.

**False Economies**

A number of false economies have already been highlighted, namely: (1) using poorly standardized, cheaper products; (2) using any technique that increases the need for shading additions or redyes and not building this cost in the total cost; (3) spending capital before rationalizing the process; and (4) concentrating on only one aspect of cost and ignoring total costs.

This latter point was discussed in a previous paper (2) when emphasis was placed on the need to look at the total wet processing sequence rather than one aspect of it. During the past year we had an excellent example of how wrong decisions can be made at the corporate level by making what appears to be a logical decision at the local level.

The situation occurred in the U.S. and was associated with attempts to introduce the Select II process. This process requires the use of sodium sulfate as electrolyte instead of the usual and cheaper sodium chloride and the use of specialty dyes. The dyehouse manager responsible for purchasing dyes and chemicals was considering changing from his traditional two-bath method. He was favoring a scheme using the Inverse dyeing process (dyeing the cotton by batch and then dyeing the polyester) where technically possible alongside a much reduced usage scheme using the Inverse dyeing process (dyeing the cotton by batch and then dyeing the polyester) where technically possible alongside a much reduced usage of the traditional two-bath process. The technical details of the processes are shown schematically in Fig. 6.

The Select II process was rejected on the logic that while the manager expected to pay the same price for his dyes, the Select II process increased the chemical costs. The two-bath method cost $78/1000 pounds whereas the Select II cost $90/1000 pounds, representing a 15% increase. Considering these two factors the manager had made the right decision. But when the other production costs were included in the analysis, a different picture emerged. Energy, water, labor and fixed costs were all lower for the Select II

### Table IV. Summary of Productivity Analysis of Average Wet Processing Costs/Productivity

<table>
<thead>
<tr>
<th>Dyeing Method</th>
<th>Productivitya</th>
<th>Energy</th>
<th>Chemicals</th>
<th>Water</th>
<th>Labor/Fixed</th>
<th>Dyes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select II by ICI</td>
<td>14.5</td>
<td>51.85</td>
<td>88.82</td>
<td>19.49</td>
<td>95.37</td>
<td>133.33</td>
<td>388.85</td>
</tr>
<tr>
<td>Existing Traditional</td>
<td>11.1</td>
<td>58.81</td>
<td>78.34</td>
<td>22.87</td>
<td>124.25</td>
<td>133.33</td>
<td>417.52</td>
</tr>
<tr>
<td>Two-Bath</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proposed Inverse +</td>
<td>11.8</td>
<td>55.25</td>
<td>76.79</td>
<td>23.66</td>
<td>117.10</td>
<td>133.33</td>
<td>406.12</td>
</tr>
<tr>
<td>45% Two-Bath</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*aOne week's production/spread of shades on polyester/cotton blend. *Number of boxes/machine. *In dollars.

### Table V. Influence on Total Costs/Productivity

<table>
<thead>
<tr>
<th></th>
<th>vs Existing Two Bath</th>
<th>vs Proposed Inverse + Two Bath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Savings from Select II</td>
<td>7%</td>
<td>31%</td>
</tr>
<tr>
<td>Productivity Increase from Select II</td>
<td>4</td>
<td>23</td>
</tr>
</tbody>
</table>
process (Table IV) and higher production rates were achieved.

After one week of production, the Select II process showed slight reductions in cost but major improvements in productivity (Table V). Since the manager had considered only chemical costs, he nearly lost the opportunity to improve profits by 20-30%.

Conclusion

In the past, dyehouse operations were designed by assuming they would be labor intensive. This attitude demanded processes that had high safety margins built in and intermediate checks or clearing processes. For example, dyeing times allowed for slow loading, poor temperature control and the built-in assumption that a natural break taken by the operator could extend the dyeing time by 10-20 minutes longer than recommended. Quality checks were the norm between processes: i.e., (1) between preparation and dyeing; (2) shade checks between the dyeing process and before dropping the machine; and (3) with polyester/cotton where the polyester dyeing was first checked (shade and maybe fastness) before dyeing the cotton.

With automation coupled with the latest machinery developments, it is now possible both to fine tune this process to the optimum, and to telescope or even omit steps that were considered essential in the traditional approaches.

It is predicted that by 1990, 75% of dyehouse color kitchens and continuous and batchwise dyeing production in the developed markets will be automated (4). Any existing process can be automated, but in our view the key steps in obtaining maximum benefit from the major capital investments associated with automation are:

- Redefine processes then telescope and fine tune them to the optimum for the equipment in use;
- Introduce processes and products that are consistently reproducible and eliminate the need for redyes and shading additions;  
- Keep a holistic view to finance—total processing cost per unit time, income derived, capital and cash implications; and
- Avoid false economies that save a cent and increase total cost by dollars.

By following this procedure we are confident that the introduction of automation will increase productivity, lower costs, generate consistent quality production, provide the ability to respond quickly to market changes and improve overall profitability.

References

(1) Werner International Statistics, Textile Asia, August 1987, p204.
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New England Regional Conference
Meets May 4-6 at Hyannis, Mass.

The 26th New England Regional Technical Conference will be held May 4-6 at the Hyannis Tara Hotel in Hyannis, Mass. The conference will open with an Early Bird Reception on Thursday evening, May 4. Four technical sessions are scheduled for Friday, and a “Meet the Speakers” question and answer reception will be offered Saturday morning. Other events Saturday include golf and tennis tournaments, a cocktail party and a banquet.

Ten speakers will take part in the Friday technical sessions. Session 1, moderated by Marty H. Silvia of Hamblet & Hayes Co., Salem, Mass., will feature the following speakers:

- Reactive Dyes: The Choice Is Yours, Martin B. Bochner of Atlantic Industries, Nutley, N. J.
- Dyeing Rayon and Rayon Blends, Richard W. Chalk, Ciba-Geigy Corp., Greensboro, N. C.
- Important Aspects of Dyeing with Vat and Reactive Dyes, Roberta M. Tremain, BASF Corp., Charlotte, N. C.

Session 2 will be moderated by Marcia M. Weeden of Pioneer Finishing Corp., Fall River, Mass. Speakers include:

- Development and Optimization of Diagnostic Test for Dyeability Variations of Rayon, Karen E. Kyllo, University of Rhode Island, Kingston.

Session 3 will be moderated by Karen Kyllo. Speakers include:


Phillip C. Hilton of Hamblet & Hayes Co., Salem, Mass., is chairman of the conference technical program.

The “Meet the Speakers” reception Saturday morning will consist of a continental breakfast and informal discussion with conference guest speakers.

New England Regional Technical Conferences are jointly sponsored by AATCC's Northern New England, Rhode Island and Western New England Sections. All AATCC members—not just those in the New England Region—are invited to attend. Inquiries and requests for registration forms should be sent to Conference Co-Chairman Michael Dycio, 268 Blackberry Hill, Wakefield, R. I. 02879; telephone 401/789-5708.

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