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# Project Summary

# Investigation of Textile Dyebath Reconstitution and Reuse

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**About 80% of textile finishing mills discharge their wastewater to publicly owned treatment works. Most of the wastewater receives little or no pretreatment before discharge. A variety of wastewater recycle/reuse technologies, allowing these mills to reduce the amount of wastewater and pollutants discharged, were described in an earlier (Phase I and II) report.**

**This two-volume (Phase III) report examines in detail one of these recycle technologies, dyebath reconstitution and reuse. This technology is considered promising for several reasons: significant environmental benefits, potential for widespread application, low capital cost, cost savings in textile dyeing, and economic attractiveness.**

**Volume 1 gives results of a detailed investigation of dyebath reconstitution and reuse at a carpet mill. The results of bench-, pilot-, and full-scale testing are presented. Wastewater data documenting the pollutant reductions achieved through dyebath reuse are presented. The economic feasibility of implementing the technology full-scale is addressed.**

**Volume 2 gives detailed procedures and methods for implementing dyebath reconstitution and reuse. It can be used as an operations manual for other mills wishing to investigate this technology.**

***This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

## Introduction

Over 100 x $10^9$ gal. (3.8 x $10^8$ $m^3$) of wastewater is discharged annually in the U.S. from the finishing of textile products. An estimated 80% of textile finishing mills discharge their wastewater to publicly owned treatment works (POTWs). Most of this wastewater receives either no treatment or only primary treatment (e.g., settling, screening, equalization, or neutralization) before being discharged to municipal sewers.

Major textile finishing operations include fiber preparation (desizing, scouring, mercerizing, bleaching), fiber coloring (dyeing, printing), and functional finishing. Wastewater results primarily from preparation and coloring.

Many wastewater recycle/reuse technologies, allowing reuse of these wastewaters, are described in detail in an earlier report. One of these technologies, dyebath reconstitution and reuse, appears to offer significant environmental benefits and substantial cost savings to the industry, and also has the potential for widespread use within the industry. This report investigates dyebath reconstitution and reuse in detail.

## Textile Dyeing

The vast majority of textile products are colored by dyeing. In 1980, about 7.8 x $10^9$ lb (3.5 x $10^9$ kg) of fibers were dyed. For this dyeing, 171 x $10^6$ lb (7.8 x $10^7$ kg) of dyestuffs and 1.28 x $10^9$ lb (5.8 x $10^8$ kg) of additives (auxiliary chemicals) were used. Most auxiliary chemicals do not exhaust during dyeing and are thus discharged with the dyeing wastewater. Dyestuffs, however, generally exhaust to over 90% during dyeing. The often quoted value for average dyestuff exhaustion during dyeing is 95%. Assuming a 95% exhaustion rate for the dyestuffs still leaves about 8.5 x $10^6$ lb (3.9 x $10^6$ kg) of dyestuffs discharged annually in dyeing wastewater.

Dyeing can involve either continuous or batch operations. About half of the textile fibers dyed in the U.S. are batch dyed. Certain products (e.g., knit fabrics, hosiery, and yarn) are almost exclusively dyed using batch processes. Large amounts of carpet and some woven fabrics are also batch dyed. Batch dyeing remains popular due to its flexibility, short-run capability, and ease of control. Batch processes, however, are generally inefficient in their use of water and auxiliary chemicals.

In typical batch dyeing, 1-5 gal. (0.004-0.02 $m^3$) of water is used as dye liquor for each pound (0.45 kg) of fiber dyed. Auxiliary chemicals and dyes are added to this dye liquor. Auxiliary chemicals can include exhaust agents, leveling agents, buffers, pH control chemicals, retarding agents, wetting and dispersing agents, carriers, softeners, lubricants, and penetrants. The total amount of auxiliary chemicals added will vary depending on the fiber and dyestuff types, but will generally range from a few percent of the fiber weight (2 or 3% o.w.f—of weight of fiber) to as much as 50% where high concentrations of exhaust agents are required. Dyestuff quantities are generally a few (less than 4) percent of the fiber weight. After adding auxiliary chemicals and dyes, the dyebath temperature is raised to (and held at) the desired dyeing temperature until dyeing is complete and a level dyeing is achieved. The exhausted dyebath, now containing only a few percent of the original quantity of dyestuff but still most of the auxiliary chemicals, is dropped, and the dyed product is rinsed with fresh water.

## Dyebath Reuse

The exhausted dyebath may be used for subsequent dyeings, thus using the auxiliary chemicals for more than one cycle of dyeing. This results in production cost savings and also decreases the volume of wastewater and quantity of pollutants discharged. To reuse the dyebath, a method was needed for analyzing the exhausted dyebath to determine the quantities of dyestuffs remaining and thereby the quantities to add for the next dyeing.

Much of the development of the dyebath analytical techniques and reconstitution methods was performed at the School of Textile Engineering at the Georgia Institute of Technology in the 1970s. The success of this developmental work led to several full-scale demonstrations, also by Georgia Tech.

The work under Phase III of EPA's Textile Wastewater Recycle/Reuse project expands on earlier work on dyebath reconstitution and reuse:

1. It examines the application of dyebath reuse at a mill that is fairly typical of many dyehouses, yet is not a "perfect" candidate for this technology.
   - Dye formulations had to be modified to use a smaller number of dyestuffs before reconstitution became technically feasible.
   - Quality control requirements are strict at this mill, thus posing a stiff test of the ability of dyebath reuse to produce acceptable dyeings.
   - Overflow rinsing is typically used at this mill, thereby affecting not only the dyebath analysis/reconstitution methods, but also the economics of dyebath reuse.
2. It presents a detailed examination of the techniques used not only in full-scale testing but also in the development and testing of the technology at this mill. These techniques can be directly applied by other mills wishing to examine the feasibility of dyebath reuse.
3. It presents the first development of environmental data for this wastewater recycle/reuse technology. Thus, the environmental benefits of dyebath reuse can be quantified for the first time.
4. It updates the equipment used in dyebath analysis to include a modern desktop computer, a commercially available interface for the spectrophotometer/computer, and software written in the BASIC computer language to allow for greater comprehension and adaptability to a variety of desktop computers.

Volume 1 of this report details the results of a study of dyebath reuse implementation at a carpet mill. Volume 2 is a dyebath reuse operations manual, providing information on the technology to mills interested in adopting dyebath reuse.

## Dyebath Reuse Studies

To develop information on full-scale implementation and costs of dyebath reconstitution and reuse, a demonstration of the technology was performed at a carpet mill, Mill C-2 of earlier studies. Mill C-2 performs atmospheric batch dyeing primarily of nylon carpet, discharging about $1 \times 10^6$ gal./day of wastewater to the municipal collection system.

Two popular, large-volume carpet styles were selected for dyeing using dyebath reuse procedures. The dye recipes for these styles had recently been reformulated to utilize a small number of dyestuffs. Many of the different shades now have recipes containing varying amounts of the same three dyestuffs. This is an essential step in implementing dyebath reuse since the residual dyes in the dyebath from the just completed dyeing must be the same ones that are to be used in dyeing the next shade.

The dyebath was analyzed using a visible-light spectrophotometer. Dyestuff absorbance coefficients were determined in the laboratory for each dyestuff. These coefficients are the k-values in the Lambert-Beer equation:

$$A = kC$$

where A = absorbance of the dyestuff, and C = concentration of the dyestuff.

These values were then used to analyze exhausted dyebaths to determine the amounts of dyestuffs that remained at the end of a dyeing. A desktop computer was programmed to perform all the calculations needed to determine how much dye remained in a used dyebath and how much had to be added to perform the next dyeing. In this way, the actual procedures needed to reuse a dyebath could be carried out in only a few minutes by dyehouse personnel.

Twenty-six series of dyeings were performed with dyebath reuse, each series consisting of 5-10 dyeings using the same dyebath.

The first 15 series (bench-scale dyeings) provided opportunities to become familiar with dyebath reuse concepts and procedures, to test the shade-matching capability of dyebath reuse, and to resolve problems while still on a small scale. Six shades from each of the two carpet styles were selected for dyeing. For each shade, the dyebath was reused until a series of five dyeings was completed. This accounted for the first 12 series. The final three bench-scale series each started with a light shade and gradually progressed to darker shades as the dyebath was reused. The dyed carpet samples from these bench-scale dyeings were analyzed with a Diano/Hardy II spectrophotometer to evaluate the ability of dyebath reuse to produce acceptable shade matches. Results were very good.

Following the success of the bench-scale dyeings, eight additional dyebath reuse series were conducted using a pilot-scale beck(vat). The pilot-scale beck and dyeing procedures more closely resemble full-scale dyeing than bench-scale dyeing. Thus, the pilot-scale dyeing would provide an opportunity to test dyebath reuse under conditions that approximate full-scale dyeing, and resolve any probems. Both single- and multi-shade series were dyed for each carpet style. The shade matching, levelness, and color fastness results (primary measures of product quality) of the dyed samples were very good.

The final three series were full-scale dyeings conducted in a 6,000-gal. (22,700-1) atmospheric beck. The first series had to be aborted after three dyeings due to an unexpected yarn lot change. The remaining two series were multi-shade dyeing series consisting of 6 and 10 dyeings, respectively. The process was monitored carefully to calculate the savings in water, energy, dye, and chemical use due to dyebath reuse. Shades were matched successfully in all dyeings. The carpets produced were of first quality. Both the number of adds and redyes were within the mill's typical frequency for these styles. Thus, the full-scale experiments demonstrated that the ease of obtaining satisfactory dyeings with reconstituted baths was comparable, if not superior, to that of conventional dyeing.

## Environmental Benefits

Wastewater samples were collected during both the pilot- and full-scale dyeings. Results of the full-scale data (below) characterize the potential environmental benefits of dyebath reuse:

| Pollutant | Percent Reduction in Discharge | |
|---|---|---|
| | Series 25 | Series 26 |
| Flow (gal./lb) | 24 | 34 |
| BOD | 13 | 33 |
| COD | 32 | 33 |
| TSS | 47 | 0 |
| TDS | 25 | 43 |
| Phenolics | 0 | 0 |
| Total-P | 28 | 44 |

The concentrations of various pollutants in the dyebath increased as the dyebath was reused. This is suspected to be due to the buildup of yarn finishes that are removed from the carpet during dyeing. Despite these higher concentrations, the net effect of dyebath reuse is to reduce the mass of pollutants actually discharged, as compared to conventional dyeing. The lack of suspended solids reduction in Series 26 is an exception to this observation that cannot be explained. This net reduction is due to the smaller amounts of auxiliary dyeing chemicals needed to perform reuse dyeings.

The larger reductions in wastewater volume and pollutant discharge in Series 26, as compared to Series 25, were due to attempts to reduce the volume of overflow cooling water used in the dye cycle. Less cooling water results in less dilution of the dyebath. Consequently, smaller amounts of auxiliary chemicals are needed to reconstitute the dyebath for reuse. This results in both wateruse/discharge and pollutant discharge reductions. Further optimization in this area will result in even greater environmental benefits.

## Economic Analysis

In general, dyebath reuse has favorable economics due to its relatively low capital cost and significant cost savings. Payback periods of about 1 year are common for this technology.

An economic analysis was conducted for dyebath reuse implementation at Mill C-2. The cost savings due to dyebath reuse were calculated based on data collected during the full-scale tests. The calculated savings averaged $23.85 and $28.60 per dye cycle for the two carpet styles, or about $0.011 to $0.012/lb of carpet. About 65% of these savings are due to reduced auxiliary chemical requirements. Energy savings account for another 20%. Water and sewer use savings account for the remaining 15%. Future optimization of the reuse dyeing procedure, by reducing the amount of overflow cooling water used, could easily increase the per-cycle cost savings to over $30.

Operating costs for dyebath reuse are relatively low. Yearly operating costs of $5,000 were estimated for Mill C-2, based on 2,400 reuse dyeings per year. This results in operating costs of about $2 per cycle.

Capital costs for equipping two dyebecks at Mill C-2 for dyebath reuse were estimated to be $70,500. This cost includes a pump, an elevated 6,000-gal. (22,700-1) storage tank, piping, valves, controls, and analytical equipment including a spectrophotometer and a computer.

With an allowance of $10,000 for developmental costs, the net payback period is calculated to be 1.5 years:

| | |
|---|---|
| Capital Cost | $70,500 |
| Development Cost | 10,000 |
| Total Capital | $80,500 |
| Yearly Savings | $60,000 (based on $25/cycle) |
| Yearly O&M Costs | 5,000 |
| Net Savings | $55,000 |

$$\text{Payback Period} = \frac{80{,}500}{55{,}000} = 1.5 \text{ years}$$

## Outlook for Use in Industry

As noted earlier, batch dyeing accounts for half of the total amount of textile dyeing. Due to the higher water and chemical usage of batch dyeing, well over half of the wastewater volume and pollutant loading from dyeing results from batch dyeing.

In certain industry sectors, dyeing is performed almost exclusively by batch operations: mills in these sectors can be regarded as potential users of dyebath reuse technology. These sectors include knit fabric, hosiery, and yarn finishing. A large amount of carpet dyeing is still performed in batch operations, although there is a trend toward producing more continuous-dyed/printed carpeting. Most large woven-fabric finishing mills employ continuous dyeing, though some smaller mills still have significant batch dyeing operations. Overall, many mills can potentially adopt this recycle technology.

Dyebath reuse has been tested or demonstrated with a wide variety of products and textile fibers, including nylon hosiery and carpet; polyester fabric, carpet, and yarn; acrylic yarn; and cotton fabric. Dyestuff classes that have been tested or demonstrated include acid, basic, direct, disperse, and reactive.

At many mills, not all production will be amenable to dyeing by dyebath reuse. However, even the conversion of a few machines to this recycle technology will have substantial cost and environmental benefits. A mill that is ideally suited to employ dyebath reuse technology will generally dedicate only half of its dye machines to reuse dyeing, to ensure maintenance of flexibility in production.

The major obstacle to further use of this technology appears to be the lack of detailed information on evaluating and implementing the technology. Volume 2 is an operations manual that should fill this gap.

## Operations Manual

The operations manual (Volume 2) first introduces the reader to the concepts and procedures of dyebath reuse. It then presents a procedure that allows the reader to determine if dyebath reuse is applicable to his dyehouse. A preliminary economic analysis can also be conducted.

The next topic is the development of an evaluation program. Suggestions are given on the content and scope of tests necessary to evaluate the feasibility of dyebath reuse.

Subsequent sections of the manual introduce the concept of light absorbance and how it is used to analyze dyebaths for their dyestuff content. The procedures for analyzing and reconstituting dyebaths for additional dyeings are then presented.

Specifications for equipment and supplies are provided.

The use of desktop computers to perform the calculations for dyebath reuse is discussed. Equipment is listed, and a dyebath reuse computer program written in BASIC is provided.

The final sections of the manual discuss laboratory and full-scale dyebath reuse experiments. Troubleshooting guides are provided. Options and suggestions for full-scale design and implementation of dyebath reuse are given.

The manual provides enough information and guidance to assist textile mill operators who are interested in evaluating or implementing this technology.

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*The complete report consists of two volumes, entitled "Investigation of Textile Dyebath Reconstitution and Reuse:"*

*"Volume 1. Technical Report," (Order No. PB 84-206 465; Cost: $16.00)*

*"Volume 2. Operational Manual," (Order No. PB 84-206 473; Cost: $16.00)*

*The above reports will be available only from: (cost subject to change)*

*National Technical Information Service*
*5285 Port Royal Road*
*Springfield, VA 22161*
*Telephone: 703-487-4650*

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