POLLUTION PREVENTION IN THE TEXTILE INDUSTRY

DEVELOPED BY:

U.S. EPA/SEMARNAP
POLLUTION PREVENTION
WORK GROUP

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PURPOSE OF THIS MANUAL

This manual provides an overview of the pollution prevention and recycling options that are available in the textile industry. This report is intended only to assist the user in his or her preliminary research and development of pollution prevention options. Each company is responsible for identifying, evaluating, and implementing pollution prevention options that are appropriate to its specific situation. By compiling and distributing this manual, EPA and SEMARNAP are not recommending the use of any particular processes, raw materials, products, or techniques in any particular industrial setting. Compliance with U.S. and Mexican environmental laws, occupational health and safety laws, and all applicable federal, state, and local laws and regulations is the responsibility of each individual business; however, this is not the focus of this document.

The information in this manual is intended to be a comprehensive overview of the documented information on pollution prevention and recycling practices for the textile industry. However, the collection, organization, and dissemination of pollution prevention information is a relatively new initiative, and an ongoing process. In addition, there are limits to any manual, including this one. Therefore, this summary may not contain every relevant piece of information on pollution prevention and recycling for **textile and apparel manufacturing firms**. EPA encourages all users who discover, in the literature or in the industry, pollution prevention options that are not cited in this report, to share this information with EPA. Please submit any corrections, updates, or comments on this report to the following:

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This manual is an assimilation of existing research and case studies of pollution prevention and recycling options. Because of the voluminous amount of such information, referencing sources in the text as they are used would make the manual cumbersome for the reader. Therefore, the authors of this manual wish to acknowledge the authors of all documents referenced in the bibliography section, which were used to compose the manual.

INTRODUCTION

Production of economically competitive products is the driving force behind any successful business. Production frequently requires the use of various chemicals throughout the manufacturing process. The purchase and storage of these chemicals, their use in the process, and the ultimate disposal of the waste generated by the manufacturing process can present many challenges. Such challenges involve disposal costs, waste management, and worker health and safety. Pollution prevention provides an effective means of minimizing, and even eliminating, such challenges.

The U.S. Environmental Protection Agency (EPA) defines pollution prevention (also referred to as source reduction) as the use of materials, processes, or practices that reduce or eliminate the generation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous and nonhazardous materials, energy, water, and other resources, in addition to practices that protect natural resources through conservation or more efficient use.

Because of the enormous potential for pollution prevention along the U.S.-Mexico border, the Pollution Prevention Work Group was established in February 1992. The lead federal agencies of the Work Group are EPA and Secretaria Del Medio Ambiente Recursos Naturales y Pesca (SEMARNAP). EPA and SEMARNAP began promoting and coordinating the reduction of pollution through a broad range of approaches: technical assistance, training, public and private sector programs in pollution prevention awareness, assessment of pollution prevention options, policy development and institutional support, and technology development and investment activities.

The purpose of this manual is to provide pollution prevention information for the textile industry. This manual is the fourth in a series of industry-specific pollution prevention manuals. "Waste Minimization for the Metal Finishing Industry," "Pollution Prevention for the Wood Finishing Industry," and “Pollution Prevention in the Electronics Industry” were the first three in a series of bilingual pollution prevention manuals prepared jointly by EPA and SEMARNAP. Future manuals will include other industries that are typical in the border area. This manual contains the following sections:

Section I — Goals and Benefits of Pollution Prevention

This section defines the term "pollution prevention," and provides an overview of the goals and benefits of, and the methods of developing, a successful pollution prevention program.

Section II — General Pollution Prevention Options and Common Practices

This section discusses general pollution prevention options and common practices that are applicable industry-wide.

Section III — Pollution Prevention Options in the Textile Industry

This section describes various processes and waste streams associated with the textile industry and pollution prevention options for each process associated with that industry.

Section IV — Case Studies

This section includes specific examples of companies that have used pollution prevention techniques. These case studies describe the benefits, particularly cost savings, that these companies have derived.

Glossary

Bibliography

Appendix Additional Sources of Information

The Appendix lists additional technical documents pertaining to pollution prevention options for the textile industry, and other pertinent information. These documents are currently available only in English.

Attachment A Information on Accessing Pollution Prevention Information Clearinghouses

Attachment B Survey

PLEASE COMPLETE THE SURVEY INCLUDED IN THIS SECTION. Your response provides valuable information for evaluating the usefulness of this manual. Additionally, when your survey has been returned, your name will be placed on a mailing list for updates to the manual and other documents as they become available.

SECTION I

GOALS AND BENEFITS OF POLLUTION PREVENTION

SECTION I
GOALS AND BENEFITS OF POLLUTION PREVENTION

WHAT IS POLLUTION PREVENTION?

Pollution prevention (**P2**) (also known as source reduction) is the act of eliminating the pollutant before it is generated. The purpose is to prevent pollution from being generated rather than determine how to control pollution or manage waste after it has already been generated. P2 is a philosophy that prevents or reduces pollution at the source through cost-effective changes in design and production. It includes practices that reduce the use of hazardous and nonhazardous materials, energy, water, and other resources, in addition to practices that protect natural resources through conservation or use that is more efficient. Such changes (1) offer industry substantial savings in reduced raw materials, pollution control, and liability costs, (2) protect the environment, and (3) reduce risks to worker health and safety.

Moreover, P2 is more than just another way of reducing pollution. P2 is a philosophy. This philosophy continually searches for innovative ways to do things and to overcome the inherent human resistance to change. Such a philosophy does not accept "that is how we have always done it" as a rationale for maintaining a policy or practice.

Source reduction eliminates the pollutant before it is generated. Source reduction strategies include the following:

- Make raw material changes by substituting raw materials that are less hazardous for process chemicals that generate waste.

- Introduce process modifications that increase efficiency and reduce or eliminate the amount of waste generated.

- Promote good operating practices that reduce waste, such as inventory control to eliminate the accumulation of unused or expired chemicals, and preventative maintenance to eliminate leaks and spills.

On-site recycling and reuse is also considered to be a form of P2, because post-processing materials, which would normally be disposed of, are reintroduced into the generating process. This not only extends the life of the waste raw material but minimizes the introduction of additional raw material into the process. A variation of this is to recycle the waste raw material into another useful application, thereby eliminating disposal. Although they may not always be considered P2 in the strictest sense, recycling and reuse strategies are discussed in this manual.

Figure I-1 presents various methods of source reduction and recycle/reuse strategies. Table I-1 summarizes specific examples of source reduction options.

TABLE I-1

EXAMPLES OF SOURCE REDUCTION OPTIONS

Raw material changes

- Purchase raw materials that are free of trace quantities of hazardous impurities.
- Switch to nonmetallic dyes and synthetic sizes.
- In wet processing of fabric, use auxiliary agents that are less hazardous.

Process modifications and new technologies

- Redesign equipment and piping to reduce the volume of material contained, thereby reducing losses during batch or color changes, or when equipment is drained for maintenance or cleaning.
- Change to mechanical finishing of fabrics to avoid using chemicals.
- Use an alternative wet processing technology, such as supercritical carbon dioxide.
- Use ultrafiltration to recover valuable sizing chemicals and dyes.
- Use volume displacement to minimize chemical and water use in dyebaths.
- Use foam processing technologies in fabric dyeing, printing, and final finishing operations.

Improved operating practices

- Properly train equipment operators.
- Screen incoming substrates and chemicals for hazardous impurities.
- Segregate waste streams to avoid cross contaminating hazardous and nonhazardous materials.
- Increase control of operating conditions (including flow rate, temperature, pressure, residence time, and stoichiometry), and change maintenance scheduling or procedures to increase efficiency.
- Optimize purchasing and inventory maintenance methods for input materials. Reevaluate shelf life standards to avoid unnecessary disposal of stable items.
- Prevent leaks, drips, and spills, and use drip pans and splash guards.
- Place equipment in a manner that will minimize spills and losses during transport of parts or materials.
- Reuse or recycle rinse water, process water, and wastewater from wet processing operations.

Note:

The opportunities presented here are P2 options because they prevent pollution from being generated or reduce the pollution that is generated.

OTHER ENVIRONMENTAL MANAGEMENT STRATEGIES

Numerous pollution control or waste management strategies are applied only after wastes have been generated. Therefore, they are not correctly categorized as P2. Table I-2 provides examples of waste management strategies that are not categorized as P2.

Many waste management practices used to date have merely collected pollutants and moved them from one environmental medium to another. Companies should recognize that transferring hazardous wastes to another environmental medium is not P2. For example, solvents can be removed from wastewater by using activated carbon. However, regenerating the activated carbon requires using another solvent or heating, which transfers the contaminants to the air. In some cases, this type of waste management strategy is a valid treatment option. However, the result has often been to shift a pollutant to a medium that is regulated less stringently.

For example, waste treatment prior to disposal reduces the toxicity and/or disposal-site space requirements but does not eliminate all pollutant materials. Frequently, the effect is to transfer pollution from air or water to land. Conventional waste treatments include processes such as volume reduction, dilution, detoxification, incineration, and stabilization.

Off-site recycling, which is another waste management strategy, is vastly preferable to other forms of off-site waste handling, because it helps to preserve raw materials and reduce the amount of material that will require disposal. However, off-site recycling is likely to result in more residual waste that requires disposal than with closed-loop recycling (reuse) performed at the production site. Furthermore, waste transportation and off-site recycling increase the risk of worker exposure and release to the environment.

The waste management hierarchy (Figure I-2) presents P2 options (source reduction and recycling/reuse) and pollution control measures (treatment and disposal), in priority order from top to bottom, from the most environmentally beneficial to the least environmentally beneficial. Section III of this manual contains specific technical information on P2 options for the textile industry.

POLLUTION PREVENTION GOALS

The goal of a P2 program is to improve the quality of the environment by preventing waste from being generated—or reducing the waste that is generated—at the source. Pollution prevention includes any action by a company to reduce the amount of waste generated by a manufacturing process prior to off-site recycling, treatment, or disposal of the waste. To effectively accomplish this, the program must include an ongoing, comprehensive assessment of the operations at a facility.

BENEFITS OF A POLLUTION PREVENTION PROGRAM

Businesses have strong incentives to reduce the toxicity and volume of the waste that they generate. ***As P2 options lower operating costs, production costs will decrease. Therefore, companies with an effective, ongoing P2 program will have a significant competitive advantage.***

TABLE I-2

WASTE MANAGEMENT STRATEGIES THAT ARE NOT POLLUTION PREVENTION

Off-site recycling

- Off-site recycling (for example, solvent recovery at a central distillation facility) can be an excellent waste management strategy. However, because it is not re-introduced into the generating system or used as an alternative material or product, it is not a P2 measure.

Waste treatment

- Waste treatment involves changing the form or composition of a waste stream to reduce the amount of, or eliminate, the pollutants. However, they do not affect the pollutants until after they have already been generated. Examples include wastewater pretreatment, detoxification, filtration, incineration, biodegradation, stabilization, and solidification.

- Waste treatment technologies are generally "end-of-pipe" approaches to pollution. Many waste treatment technologies that have been used have only collected pollutants and moved them from one environmental medium (air, water, or land) to another. For example, activated carbon filters may prevent air pollution, but they can a create a solid waste problem.

Concentration of hazardous constituents to reduce volume

- Volume reduction operations, such as dewatering, are useful waste treatment approaches, but they do not prevent pollution or reduce the amount of pollutants being generated.

The following subsections discuss the benefits that can be gained from a P2 program, as follows:

- Reduce operating costs.
- Protect human health and environmental quality.
- Improve employee morale and participation.
- Enhance the company's image in the community.
- Assist in compliance with environmental laws.

Reduce Operating Costs

An effective P2 program can yield cost savings that will more than offset program development, implementation, and operational costs. Cost reductions may be immediate savings that appear directly on the balance sheet or anticipated savings that are based on avoiding potential future costs. Cost savings are particularly noticeable when the costs resulting from the treatment, storage, or disposal of wastes are allocated to the production unit, product, or service that produces the waste.

Materials costs, or the costs of purchasing materials, can be reduced by adopting production and packaging procedures that consume fewer resources. This approach uses resources more efficiently, and reduces the quantity of waste generated. As wastes are reduced, the percentage of raw materials converted to finished products increases. This results in a proportional decrease in materials costs.

Waste management and disposal costs may be reduced when less waste is produced. Required procedures for proper handling of the waste at the facility—in addition to specific treatment, disposal, and transportation methods—are typically labor-intensive and very costly. These requirements and their associated costs are expected to increase.

Production costs can be reduced through a P2 assessment. When people examine production processes from a P2 perspective, they find opportunities for increasing efficiency that might not, otherwise, have been noticed. Production scheduling, material handling, inventory control, and equipment maintenance are areas in which facilities can work to reduce the production of waste of all types, thereby controlling the costs of production.

Energy and water usage costs will decrease as the facility implements P2 measures in various production lines. In addition, by thoroughly assessing how operations interact, companies can reduce the energy and process water used to operate the entire facility.

Protect Human Health and Environmental Quality

Reducing the release of pollutants to air, land, and water will protect the environment and human health. Releases typically containing harmful pollutants that can be reduced significantly by P2 options include the

following:

- Air emissions, including solvent fumes, fine particulates, and carbon monoxide

- Land disposal, including ash from incineration, waste solvents, and debris

- Water disposal, including wastewater contaminated with solvents and other toxic materials

- Releases from process operations, including leaks and spills

Poor ventilation, mishandling of chemicals, and a lack of proper safety equipment can affect the health and safety of employees. An informative employee training program is an important way to reduce accidents. Reducing the amount of chemical materials and wastes at a facility is also beneficial, because it reduces the amount of space required for storage and the potential for accidental spills. Furthermore, reducing the volume of waste generated minimizes the amount of solid and hazardous waste that requires transport and disposal.

Improve Employee Morale and Participation

Employees are likely to feel better about their company when they believe that management is committed to providing a safe work environment and is acting as a responsible member of the community. By participating in P2 activities, employees have an opportunity to be part of a "team," and interact positively with coworkers and management. Helping to implement and maintain a P2 program will typically increase each employee's sense of commitment to company goals. This positive atmosphere helps a company to retain a competitive work force and to attract high-quality new employees.

Enhance the Company's Image in the Community

The quality of the environment has become an issue of critical importance to society. Your company's policy and practices for controlling waste increasingly influence the attitudes of the local community towards industry.

Community attitudes are more positive toward companies that operate P2 programs and publicize them. If a company creates environmentally compatible products, and avoids excessive use of material and energy resources, the company's image will be enhanced both in the community and with potential customers and consumers.

Assist in Compliance with Environmental Laws

Enforcement of Mexico's environmental laws includes administrative penalties that entitle government inspectors to require temporary or permanent closure of businesses that are not in environmental compliance. By implementing and following a P2 program, a company increases its chances of avoiding violations and associated penalties.

DEVELOPING A POLLUTION PREVENTION PROGRAM

Keys to a Successful Program

The following characteristics are crucial to the success of a P2 program:

- Support from top management
- Champions—personnel who actively promote the program
- Written mission statement backed by company policy
- Defined and measurable goals
- Solicitation of, and follow-up on, employees' suggestions
- Continuous reevaluation as economic conditions and/or the manufacturing processes change

Any effective and enduring program—including P2—must have the ***support of top management.*** Executives and managers set the tone for the P2 program. To build and sustain a successful program, companies need to integrate P2 into their business practices. As production-level employees see a company-wide commitment, they will be more likely to support the program. This is crucial, because they will be the most active personnel in both identifying P2 opportunities and in implementing solutions. The company should write a P2 mission statement to emphasize its commitment to the program.

Next, a company should organize a P2 team that includes ***managers, supervisors, and line workers.*** From the beginning, the team should involve those who are knowledgeable about the processes that generate wastes. Recognize those who contribute, and continually encourage suggestions from all employees. Designate one or more P2 champions from the team. Champions are assigned to overcome resistance to the program and obstacles to change. The champions should be high-profile employees that are respected and trusted by their coworkers. The P2 team should write a plan that details (1) methods of encouraging participation, (2) stipulations for employee training, (3) procedures for conducting process assessments, and (4) criteria for implementing P2 projects. If management is not on the P2 team, the plan should be presented to, and agreed to by, management. This plan will be a starting blueprint for the program, but it should be updated whenever necessary, because a company should continually strive to improve the program.

After the company has established the general organization of the program, the team must ***establish goals for the program.*** The team may want to establish both an ultimate goal and one or more short-term goals—for example, reducing waste by 10 percent annually. Goals can be revised. Build on the successes achieved, and update your company's goals. P2 is a continuous process.

Throughout the process, ***employee suggestions must be actively encouraged and seriously considered.*** Suggestions should be evaluated quickly and, if they meet the designated criteria, put into practice. If you choose not to implement a particular suggestion, explain your reasons to the employee who suggested it. Reinforce the importance of each individual's contributions and their value to the overall company objectives.

The Pollution Prevention Process

The process (Figure I-3) can be divided into the following basic steps:

1. Characterize the production process.

2. Assess waste streams.

3. Identify P2 options.

4. Evaluate the economic and product quality implications of each option.

5. Choose and implement the best options.

6. Measure results.

7. Reevaluate the program.

To complete steps 1 and 2, you must collect information about your facility. Collect as much information as you need, but remember to keep your data collection system as simple as possible. The information gathered will help to focus the efforts during the ensuing phases of the program.

Possible sources of useful information include the following:

- Regulatory information
  - Permits
  - Waste shipment manifests
  - Emission inventories
- Engineering information
  - Process flow diagrams
  - Operating manuals
  - Equipment lists
  - Material balances

- Production data
  - Production schedules
  - Product and raw material inventories
  - Material safety data sheets
  - Raw material use efficiency

- Accounting data
  - Costs of handling and disposal of hazardous and nonhazardous waste
  - Product, energy, and raw material costs
  - Operating and maintenance costs

Under step 3, members of the P2 team and other employees will identify many options. Encourage creative and independent thinking, and use brainstorming sessions. Many other options—and information useful in evaluating options—can be obtained through (1) trade associations, (2) published literature, (3) other companies, (4) government agencies, (5) equipment suppliers, and (6) technical consultants. The Appendix presents some sources of information.

Under step 4, identify and document the benefits and costs associated with each project. Benefits and costs may be economic, technical, or environmental.

After the options have been evaluated, the P2 team can choose the options that meet the company's criteria for technical and economic feasibility (step 5). Some projects may be beneficial for reasons other than P2. For example, some options may improve economic competitiveness or increase employee safety. Options that do not involve a large capital expenditure—such as procedural or housekeeping changes—can be implemented quickly after the appropriate reviews and approvals have been obtained. The other approved projects may be implemented as soon as it is technically and economically possible.

Under step 6, compare your achievements to the goals that were established for the program. How much waste has been reduced? What costs or savings have resulted? How has the product quality been affected?

Under step 7, the P2 program is periodically reevaluated to identify ways to improve and adapt it to changes in industry processes and in the regulatory environment.

Sustaining the Program

Maintaining a successful P2 program cycle after cycle is challenging but can provide large dividends for a company. For example, such a program can achieve the following:

- Lower material and disposal costs incrementally.

- Focus employees on continuous improvement.

- Reinforce a positive view of the company with its employees and within the community.

Following are suggestions for maintaining the momentum of a P2 program:

- Reemphasize the economic benefits to employees and management.
- Publicize success stories, and reward innovation.
- Hold operating units accountable for the full costs of controlling and disposing of any waste that they generate.
- Rotate the members of the P2 team to sustain an inflow of fresh ideas.
- Provide updated training.

SECTION II

GENERAL POLLUTION PREVENTION OPTIONS AND COMMON PRACTICES

SECTION II
GENERAL POLLUTION PREVENTION OPTIONS AND COMMON PRACTICES

IMPACT OF POLLUTION PREVENTION ON COMPANY EXPENSES

This section presents various P2 options that can be applied industry-wide. P2 can improve worker health and safety, and increase the profitability of the business. In the simplest form, a company's finances may be calculated as follows:

Profit = Income - Expenses

P2 can decrease two major expenses: raw material costs and the cost of waste disposal. Reducing the amount of waste generated decreases the waste that requires disposal. Wastes often consist of potential product that has been squandered. For example, a finishing material, such as paint, that ends up on the floor instead of on the product is a purchased raw material that could have been sold as part of a finished product. On the floor, it is merely a waste. Not only is that wasted finishing material never sold as part of a product, but it will cost money to clean up and dispose of; also, regardless of whether your company is in the U.S. or Mexico, the cost of disposal is expected to continue to increase. On the other hand, if your company used equipment that applied paint with less overspray, less paint would be wasted, and the company would need to purchase less paint, thereby decreasing raw material and disposal costs.

DESIGN FOR ENVIRONMENT

Design for Environment (DfE) aims to minimize environmental impacts and use resources efficiently. The aim of DfE is to promote sustainable development. Simply stated, sustainable development consists of meeting the needs of the current population without compromising the ability of future generations to meet their needs. DfE considers the environmental impact of a product throughout its entire life cycle, including raw material acquisition; processing; manufacturing and assembly; product use, service, and repair; retirement; and treatment and disposal. A life-cycle assessment is conducted to gain an understanding of these impacts.

A life-cycle assessment includes three phases of analysis: (1) inventory, (2) impact, and (3) improvement. During the inventory analysis, all energy and raw material requirements, emissions to air and water, solid wastes, and other releases are quantified for the product throughout its entire life cycle. During the impact analysis, the effects of the resource requirements and wastes generated are qualitatively and/or quantitatively assessed. The improvement analysis evaluates the opportunities to reduce the environmental impact on the production, use, and retirement of the product. This assessment naturally leads into product design and DfE. Therefore, environmental considerations should be included as design criteria, as are legal, cultural, performance, and cost criteria.

Design objectives that minimize environmental impact include the following:

- Use recycled or renewable sources of raw material.

- Design a product to be more energy efficient.

- Make a product with a longer useful life.

  - Increase reliability
  - Simplify maintenance
  - Increase durability
  - Design for adaptability
  - Plan for product remanufacture or reuse

- Make a product that is easier to recycle or that, when disposed of, has less environmental impact.

These types of objectives take different forms for different products. For example, in the electronics industry—in which technology changes rapidly—extending the useful life of a product might involve making a computer more easily upgradable or adaptable. However, for the textile industry, an example of extending the useful life of a product would be to make carpeting or a piece of apparel more durable.

HOUSEKEEPING

Housekeeping efforts are often the first attempt that a facility makes to minimize waste. This is to be expected, because such efforts often require relatively low capital commitment and are often perceived as simple common sense solutions. However, these types of changes are often people-based, rather than technology-based, and can be more difficult to maintain over the long term. The best manner in which to implement effective housekeeping changes is to make it easy for employees to do the right thing.

Facilitating segregation of waste streams is a common housekeeping measure that can make the difference between reclamation and disposal. When a waste is mixed with other wastes, it loses much of its reuse potential and value. Rather than allowing wastes to become mixed with other wastes, companies should capture wastes in their concentrated forms, thereby facilitating their reuse. Separation of unit process rinse and wash waters, process wastewaters, and fiber wastes from different machines is especially important in managing waste streams in the **textile industry**. However, many of these process streams may resist recovery options that use standard equipment.

Other housekeeping changes may include spill and leak prevention, contamination control, and equipment maintenance.

INVENTORY CONTROL

Properly controlling raw materials, intermediate products, final products, and wastes is a significant way to minimize pollution. Wastes may consist of either raw materials that are out of date, no longer used, or unnecessary; or final products that are off-specification or damaged. Including wastes in an inventory program can make them more recoverable. Improving inventory control ranges from simple modifications in the procedure of ordering materials to just-in-time (JIT) manufacturing techniques. ***Improved inventory control can reduce material expenses and reduce the waste that is generated, and its associated costs.***

The following changes can improve your inventory management:

- Purchase only the amount of material needed.
- Review materials for hazardous content, and examine alternatives that are less hazardous.
- Track and control the use of materials to reduce excess use.
- Designate specific employees or departments as responsible for the purchase and disposition of supplies and materials.

REDUCE PACKAGING WASTE

Packaging can (1) protect a product during transportation, (2) make handling easier, and (3) provide information about a product. However, packaging is often a significant component of a company's solid waste stream.

Where practical, the easiest way to reduce packaging waste is to ship a product without packaging. However, some packaging is often required. In this case, the following options can minimize its environmental impact:

- Reduce the amount of packaging used.
- Reconfigure the packaging so that products can be transported more efficiently.
- Use reusable packaging.
- Use packaging that is composed of materials that are more biodegradable.
- Use recycled materials in packaging.

The amount of packaging required for each unit of product can be reduced by shipping in bulk and changing the amount of protection that the packaging provides. The packaging may be determined to be excessive and provide more protection than the product needs. Perhaps the product can be modified to require less packaging. A more sturdy product may require less packaging and may better serve the customer.

Wholesale and intermediate products can often be shipped in reusable containers. Tanks, wire baskets, wooden shooks, and plastic boxes are often used as reusable containers. Procedures for collecting and returning, and for storing and handling, reusable containers may prevent them from being discarded.
Finally, the impact of packaging on the environment may be reduced by using materials that are more biodegradable or using packaging that contains a high content of recycled material. Some inks and pigments now available for use in package labeling are less harmful than those traditionally used, but they are just as effective for most applications.

Examples of recycling textile packaging include the following:

- Specify burlap bale wraps or Tyvek bale covers instead of polypropylene, which is not easily recycled.

- Sell used cardboard tubes and cones back to the suppliers.

- Reuse intact cardboard tubes directly, and reuse damaged tubes by salvaging shorter pieces from longer damaged tubes, such as cutting the damaged end from a 60-inch tube for use as a 48-inch tube.

- Incinerate broken pallets to recover their fuel value.

- Recycle pallets as pallets.

ESTABLISH AN ON-SITE RECYCLING PROGRAM

Section III will identify on-site recycling options for each textile process. Although on-site recycling is not source reduction, it can be a relatively easy way to reduce waste and costs simultaneously. On-site recycling reduces a company's overall waste stream. A smaller waste stream can (1) require fewer garbage collections, (2) enable the company to rent a smaller Dumpster™, and (3) reduce the costs of the ultimate destruction or disposal of the waste. Recycled materials may be (1) purchased by a recycler, (2) collected without charge, or (3) collected for a charge. This depends on the materials being recycled and the local market.

Implementing a recycling program involves four basic steps: (1) analyze your company's waste stream, (2) identify recycling opportunities in your area, (3) negotiate a contract with a recycler, and (4) design a recyclables collection program.

First, analyze your company's waste stream. Identify the materials that you may want to separate for recycling, such as solvents, scrap metal, paper, or cardboard.

Second, identify recycling opportunities in your area. To be a candidate for recycling, a material must have a market. That is, someone must be able to use the old materials in new products. Call recyclers to ask the following questions:

- What materials are recycled locally?

- How are materials collected and processed?
- How much is paid or charged for picking up different recyclables?

Third, negotiate a contract with a recycler. Traditionally, recycling markets have had frequent changes in the amount paid per pound of material. It is important to find a reliable company that will weather the market fluctuations. Ideally, a company will accept a wide range of materials so that you will have the option to expand the recycling program.

Fourth, design a recyclables collection program. For a company to obtain maximum value, it must separate a recycled material from the waste stream and, usually, from other recycled materials. For a collection program to be successful, employees must be able to easily participate in it.

- Place recycling containers in convenient locations.

- Clearly label containers.

- Place waste baskets near the recycling containers so that recyclables are not contaminated.

If your company's area does not have a recycler that will accept a specific waste, there are still several options. One alternative is to talk with other companies in your area. Perhaps a nearby company could use your company's waste. If a nearby company has the same waste, you may be able to combine your wastes with its for a sufficient quantity to make it attractive to a recycling company. Another option is to contact a waste exchange. Over 50 waste exchanges are operating in North America. Waste exchanges help companies generating waste to find possible markets for the waste. ***The Resource Exchange Network for Eliminating Waste—located in Austin, Texas—helps companies throughout the southwest United States and northern Mexico ([512] 239-3171).***

In 1994, U.S. textile manufacturers recycled about 65 percent of their wastes, including metals, fiber waste, carding waste, assorted rags, fabric waste, plastic, metal dye drums, and wood pallets—thereby significantly reducing the amount of solid waste that would normally be disposed of in landfills.

SECTION III

POLLUTION PREVENTION
IN THE TEXTILE INDUSTRY

SECTION III
POLLUTION PREVENTION IN THE TEXTILE INDUSTRY

Introduction

The main purpose of this section is to present practical P2 options for the textile industry. Chapter 1 of this section presents a brief overview of the textile industry, textile products, textile processes, and associated waste streams. Chapter 2 discusses P2 options—source reduction (raw material changes, process modifications, and improved operating practices) and recycling/reuse strategies—for individual textile processes. Many of these P2 options can save money for a company, and decrease waste. Section IV, *Case Studies*, provides examples of companies that have developed a P2 program and implemented P2 strategies.

Chapter 1

THE TEXTILE INDUSTRY

Overview of the Textile Industry

In almost every developing nation, textile manufacturing is among the first industries to be established. In 1994, the textile production was a $70 billion industry that employed nearly 670,000 textile workers and over 900,000 apparel workers.

The Maquiladora textile and apparel industry is growing stronger every year, with plants now expanding further south into Mexico, beyond the U.S.-Mexico border. Currently, about 345 maquiladoras, or about 16 percent of all maquiladora industries, are involved in some facet of the textile and apparel industry, including the fabrication of apparel, carpeting, automobile accessories, and household goods.

Markets for textiles are most frequently divided into (1) apparel; (2) domestic—household items, such as towels and bed coverings; and (3) industrial—automotive components, such as tire cord, filters, carpet, and upholstery; and (4) recreational equipment, such as backpacks and parachutes.

Textile facilities range from small family-owned operations that use older traditional manufacturing processes to large integrated mills that operate the most modern textile machinery and equipment. Textile establishments are engaged in receiving and preparing fibers; transforming fibers into yarn, thread, or webbing; converting the yarn into fabric or related products; and dyeing and finishing these materials at various stages of production.

The process of converting raw fibers into apparel and nonapparel textile products is complex, and most textile mills are specialized. In the U.S., a notable exception is the more than 300 integrated mills that combine spinning and weaving in their operations. However, even these large integrated mills do not normally conduct their own finishing operations. This requires a relatively extensive textile finishing industry that comprises over 700 finishing and dyeing mills.

Textile Processes

Because there is such a diverse product and application range of textiles, the type of processing used is highly variable and depends on site-specific manufacturing practices, in addition to the type of fiber used, and the final physical and chemical properties that are desired. Even for a constant product type, no two textile mills use exactly the same methods of production.

Textile manufacturing begins with the production or harvesting of raw fiber. After the raw natural or manufactured fibers have been shipped from the chemical plant or the farm, they pass through the following processing stages: (1) yarn formation, (2) fabric formation, (3) fabric preparation, (4) dyeing, (5) printing (6) final finishing, and (7) product fabrication. Raw fiber is formed into yarn (Process 1), which is spun or woven into fabric, or greige goods (Process 2); the fabric then undergoes various “wet” processing (Processes 3, 4, 5, and 6). Each of the wet processes—fabric preparation, dyeing, printing, and final finishing—is followed by a drying step. Some of the processes may be omitted, and the order of the operations may vary, depending upon the particular end-product that is desired. These processes are discussed in more detail in Chapter 2.

To simplify process descriptions and more effectively organize the associated P2 strategies, this manual will follow a generic sequence of minimum processing steps, as shown on Figure III-1.

The common equipment set-ups used for textile processes shown on Figure III-1 include batch, continuous, and semicontinuous. In batch set-ups, a fixed amount of substrate (cloth or yarn) is placed in the machine, chemical solution is added, and processing proceeds. After the reaction is complete, substrate is removed, and chemical solutions are discharged, or reused if feasible, with any subsequent auxiliary processes (rinsing and washing) occurring in the same vessel. In continuous systems, chemical solution is added to the machine, and fabric is moved through it without interruption. Semicontinuous systems are a combination of batch and continuous set-ups. Because batch systems inherently tend to generate more waste than continuous systems, batch systems are generally used for treating (dyeing) small quantities of a particular type of product, whereas continuous systems are more amenable to processing large yardages of product.

Textile Process Waste Streams

The textile industry is energy-, water-, and chemical-intensive. Within the industry, the majority of energy, water, and chemicals consumed is for wet processing. Most wet processing involves treatment with chemical baths, which often require washing, rinsing, and drying steps between key treatment steps. Consequently, wastewater is generated, having a very diverse range of contaminants that must be treated prior to disposal (Table III-1); energy is consumed to (1) heat and cool chemical baths and washwater, and (2) dry fabrics or yarns.

Because of the quantity and toxicity of generated wastewater, the industry has faced increasing pressure regarding environmental and waste-related concerns.

The industry has significantly reduced the waste generated by (1) making equipment changes, (2) on-site recycling, and (3) implementing nonprocess-related measures, such as housekeeping, in addition to research and development activities that are centered on cleaner technology.

Textile manufacturing is one of the largest producers of wastewater; about 20 gallons of water are required to produce 1 pound of textile, on the average. Textile manufacturing is also a chemically-intensive industry and, therefore, the wastewater from textile processing operations contains processing bath residues from preparation, dyeing, slashing, and various other operations.

Many processes in textile mills produce atmospheric emissions. Air emissions from chemical finishes, dyeing process residues, and assembly/fabrication residues can include formaldehyde and amine. Other air emission sources may include (1) solvent-based cleaning activities (facility cleanup, maintenance, parts

cleaning, and print screen cleaning), (2) wastewater treatment systems (mixed liquor and spent processing
baths with dye carriers and solvent scours), (3) warehouses (formaldehyde emissions from stored fabric), and (4) spills. Pollutants may include mineral oil, knitting oils, fiber finishes, softeners, hydrocarbons, urea, and volatile disperse dye carrier components that are desorbed from the fabric during subsequent heatsetting, drying, and curing.

Chapter 2

POLLUTION PREVENTION OPTIONS FOR THE TEXTILE INDUSTRY

Organization of this Chapter

Section I introduced a waste management hierarchy. The preferable option is source reduction, which consists of decreasing the amount of waste generated at the source, then recycling or reusing the material, followed by treating the waste and, ultimately, disposing of it. Although recycling is not necessarily a method of P2, some aspects of recycling are covered in this section.

Recent developments in the textile industry are providing opportunities for more recycling and reuse of process water and chemicals. Furthermore, interest in media other than water, such as solvents and foams, for chemical application is increasing. Accordingly, the industry is finding that, beyond meeting regulations, the potential economic gain through reduction of treatment costs and wasted resources is significant.

Overall changes in the textile production infrastructure are likely, such as integrating automation into many aspects of production, from dyebath chemical analysis and reuse to garment fabrication. An essential aspect of automation is ***demand-activated manufacturing, or quick response (QR)***. An example is coloring preassembled items to order rather than carrying a large inventory. Increased vertical integration of individual functions is also desired, as closely coupled manufacturing processes tend to maximize energy and water efficiency, chemical recovery, and production rate. In the future, synergistic relationships will be identified between different industries, and facilities will be built in close geographical proximity to strive for complete closed-loop systems. In its efforts to improve operation, the textile industry has reached out into other sectors of the research community. The American Textiles Initiative, which is a cooperative research agreement between the U.S. Department of Energy (national research laboratories) and numerous organizations from the textile industry and academic sectors, has facilitated collaborative research, incorporating P2 and waste minimization technology, in many aspects of textile manufacturing that are important in enhancing the global competiveness of U.S. textiles.

In 1991, the American Textiles Manufacturers Institute launched the Encouraging Environmental Excellence (E3) initiative with the goal of expanding environmental awareness in the textile industry. The E3 initiative challenges participating companies to strengthen environmental efforts and promote environmental stewardship as everyone's responsibility. E3 promotes a proactive attitude regarding the environment with a goal of exceeding government requirements. As a bonus, participating companies are beginning to reap economic benefits through reduced costs and an increased interest in their products from an increasingly environment-conscious public. The program is also attracting the attention of customers. Mail order giant L.L. Bean has expressed an interest in products containing materials manufactured by E3 member companies, and NationsBank has requested a list of E3 companies. E3 is monitored by a seven-member advisory board of academicians and environmentalists to provide an objective view.

In this chapter, each textile process—(1) yarn formation, (2) fabric formation, (3) fabric preparation, (4) dyeing, (5) printing, (6) final finishing, and (7) product fabrication—and its associated waste streams will be discussed briefly, followed by a more detailed discussion of P2 options. P2 options are organized into source reduction and recycle/reuse strategies. Source reduction is further organized into discussions of input material changes, process modifications/new technologies, and improved operating practices.

PROCESS 1—YARN FORMATION

Fiber used in textiles can be (1) harvested from natural sources (for example, wool and cotton), (2) manufactured from regenerative cellulosic materials (for example, rayon and acetate), or (3) be entirely synthetic (for example, polyester and nylon). In yarn production, natural fibers, predominantly cotton and wool, are cleaned, blended, carded and/or combed, drawn, drafted, and then spun into yarn. Man-made cellulosic and synthetic fibers are often shipped as staple, which are ready for spinning, or as continuous filament yarn, which may be used directly or following further shaping or texturizing.

Unlike cotton and man-made fibers, raw wool must be cleaned by wet processes before the fiber can be dry-processed to produce yarn or fabric. The wool is scoured to remove waste impurities—such as natural secretions, dirt, and other residues—and then dried.

Spun yarns are made by loosely gathering natural fibers, man-made fibers, or blends into a rope-like form, drawing them out to increase fiber alignment, and then applying twist. The most common spinning system in use today is ring spinning. In this system, the spinning machine drafts the input form (roving) to the necessary dimensions, inserts twist, and forms the yarn, which is wound on a spinning bobbin. The rate of front roll feed and the spindle speed determine the amount of twist. Spinning provides spun yarns with their natural integrity and strength.

Texturizing increases the apparent volume of continuous filament yarns so that their appearance more closely resembles that of conventional (natural) spun yarns. Numerous processes can be used for yarn texturizing, including torsional crimping, edge crimping, compressions crimping, and air texturizing.

Natural fiber contaminants include (1) natural waxes and oils, (2) metals, (3) agricultural residues, and (4) lubricant residues arising from harvesting and processing. Synthetic fibers can contain impurities, such as finishes, polymer synthesis by-products, and processing additives, which are imparted to the fibers during fiber manufacturing and before they reach the textile manufacturer. Wastes associated with spinning include (1) fiber waste, resulting from cleaning and other operations, and (2) packaging wastes. Additives—such as tints, antistatics, and lubricants—that are applied during spinning, as well as some natural fiber contaminants, may become a waste as they are removed during subsequent wet processing operations.

Source Reduction

PROCESS MODIFICATIONS AND NEW TECHNOLOGIES

Spinning

New spinning equipment focuses on open-end or rotor spinning, which (1) produces four to five times the output of ring spinning, and (2) integrates roving, spinning, and winding into one operation.

Open-end or rotor spinning is significantly different from ring spinning in that the spinning operations are performed directly on drawn sliver, which eliminates roving. In this process, the staple fibers in the form of a sliver are fragmented as they are fed into a small spinning centrifugal mechanism. Within this mechanism, the fibers are oriented and discharged in yarn form, with twisting being added through the rotation of the rotor. This system can process fibers of varying lengths and use waste material that is unsuitable for conventional ring spinning. New open-end spinning frames can produce yarns routinely at 250 to 300 feet per minute (fpm). Open-end spinning consumes less energy than does ring spinning for heavier yarns, because roving is eliminated.

Air-jet spinning has also generated great interest because of the high speeds and quality output of this system. Air-jet yarns have limited applications. The system is particularly suited to synthetic fibers and blends that have a minimum acceptable length and a very high-bending modulus. Air-jet spinning of 100 percent cotton is very difficult but not impossible. Air-jet spinning does not require lapping, combing, and roving. New air-jet spinning equipment promises to deliver output of as high as 600 fpm. Modern equipment has also dramatically reduced the number of steps needed to convert baled fiber into yarn. By increasing process efficiency, less raw material is wasted. Air-jet spinning production costs are consistently higher than rotor production costs. More energy is needed for the air compressor and the higher production speed.

Texturizing

Recently in Great Britain, a new ***steam texturizing system*** was developed (Figure III-2). This system provides a textured yarn with consistent dyeing properties, thereby eliminating a large volume of waste that is generated by current processes. Current technology calls for an entire machine of over 200 positions to operate in the same conditions at each position and produce yarn identically from position to position. Consequently, dyeability of the yarn may vary because the yarn texturizing input is inconsistent. The new system nonisothermally adjusts—in closed loop—the heat flux take-up by the yarn in tension to a specific dyeability. The new technique allows compensation for the effects of yarn tension and shrinkage variation in a supply package during texturizing. This method allows variation of texturizing in a single position. The system has a steam supply for the texturizing heater, which provides a rapidly adjustable heat-flux to the yarn. Variations are controlled by the signal generated by the unit's yarn-speed sensor. When the sensor detects a yarn-speed change, steam conditions are altered to reverse the yarn-speed change while maintaining the requisite degree of texturizing. The system permits a constant level of heat transfer (heat flux) to the yarn, which, in turn, permits short thread lines to be incorporated. The inherent reduction in surging offers the possibility of higher processing speeds than current large machines. The additional

appeal of consistent dyeability means more efficient use of dyestuffs and less waste during the dyeing process.

Air-jet technology is being introduced to the texturizing process. Texturizing with air-jet crimpers is replacing mechanical false-twist texturizing. The new technology can texture yarn at over 3,000 fpm.

IMPROVED OPERATING PRACTICES

Quality Control (QC) for Incoming Fiber

Standard fiber-extractable tests are available for testing incoming fiber for the presence of oils, fats, waxes, metals, enzymes, solvents, and other impurities and residues from prior handling. During processing, these contaminants are released into the water and air as pollutants. Because of the massive amounts of
fiber used in textile manufacturing, even trace amounts of contaminants can accumulate to become large pollutant loads. Studies have shown that elevated metal concentrations in processing wastewater are attributable to incoming fibers that are contaminated with metals. In another case, pentachlorophenol, which is a parasitic organochlorine pesticide applied to sheep, was detected at levels of as high as 100 ppm in consumer products, such as carpets. To avoid using contaminated fibers, it is important to conduct proper raw material prescreening (see Case Study No. 5). This requires a global P2 approach not usually seen in the textile industry. The spinning mill should perform the incoming QC step to eliminate contaminants in the effluent of the finishing mill or in the finished consumer product.

Recycling and Reuse

Zinc Viscose Rayon Manufacturing

Over 50 million pounds of zinc sulfate are used annually in the U.S. in the manufacture of about 1 billion pounds of viscose rayon. Zinc is used as a regeneration retardant in the acid spinning bath. Because it is not consumed in any of the viscose reactions, these 50 million pounds of zinc represent process losses, through dragout by the filaments to the subsequent wash streams, filter backwashing, splashes, leaks, and the washing of equipment. Zinc has traditionally been precipitated from the acid waste streams with lime, but the resultant sludge has been of low zinc assay, contaminated with other compounds and with very poor settling characteristics.

America Enka Company has developed a process for precipitating a dense sludge of high zinc assay, recovering the zinc, and recycling it into the rayon manufacturing plant, with no ill effects on the rayon yarn. The key to recovering the zinc is a two-stage precipitation that occurs under careful pH control, by using sodium hydroxide in contact with a circulating slurry of zinc hydroxide crystals. All of the zinc precipitates in the second step, and most of the impurities (iron, calcium, sulfate) precipitate in the first. Acid and alkaline waste streams are collected in a neutralization tank, in which sufficient lime is added to raise the pH to 6.0. At this point, no zinc hydroxide will precipitate, but a portion of the impurities will form a light precipitate. With a coagulant aid, the remaining mixture is sent to a clarifier, in which a clear overflow containing the dissolved zinc is obtained. The clear overflow is contacted in a reactor with a circulating stream of previously precipitated sludge that contains zinc hydroxide. Subsequently, the pH is raised to 9.5 to 10.0 with sodium hydroxide. The bulk of the zinc precipitates onto the existing crystals in the circulating slurry. At steady state conditions, a withdrawal of the circulating slurry stream is made equivalent to the zinc being added, and this dense sludge is then settled. The settled sludge of 4 to 7 percent zinc assay is converted back to zinc sulfate with sulfuric acid and is then sent back to the spinning bath. The zinc content of the overflow water from the densator-reactor is set by the pH-solubility relationship of zinc in water and results in a zinc content of 0.5 to 1.0 ppm at a pH of 10.

Countercurrent Rinsing and Washing of Wool

Countercurrent rinsing and washing involves the recycling, reuse, and reclamation of wool wastewater. Effluent from the first washing bath is centrifuged to recover suint and to partially recycle wash water. Rather than being discharged to a holding pond, bottom residual water containing mud and heavy grease is subjected to further treatment, which consists of a multiple-effect evaporation to concentrate the grease. Water condensate is reused in washing and rinsing. Grease concentrate is vacuum-dried to produce a combustible residue (oil distillate and bitumen) for the evaporation boiler. Rather than being discharged to the public sewer, rinse water in reused in the washing process. Liquid wastes are completely eliminated with this low-waste technology. By implementing this process, a textile manufacturer in France—having a production capacity of 18,500 metric tons of wool per year—decreased water consumption by nearly 75 percent.

Recycling Fiber Waste

Reworkable fiber waste of 5 percent is typical in spinning operations, and can be reclaimed by reintroducing it back into the opening line through a waste hopper.

PROCESS 2—FABRIC FORMATION

Textile fabrics are formed mainly by weaving or knitting processes. Broadwoven mills consume the largest portion of textile fiber and produce the raw textile material from which most textile products are made. Knit fabrics are used largely in the hosiery and sock markets, for the manufacture of underwear, lingerie, and outerwear, such as knit sport shirts. Yarns are also used directly in the production of floor coverings. Narrow wovens, waddings, nonwovens, and rope and cordage are used mainly in industrial applications.
Before the actual weaving operation, the yarn must be prepared by one or more of the following operations: winding, spooling, warping, and/or slashing. The purpose of these operations is to transfer the yarn from the type of package that resulted from the spinning or texturizing operation onto a type that is suitable for fabric manufacturing. Slashing (1) consolidates the proper number of warp yarns on the warp beam for the fabric construction, (2) coats the yarn with a protective coating, or size—usually starch or polyvinyl alcohol (PVA)—for strengthening, and (3) dries the yarn in preparation for the weaving operation. As part of the fabric preparation step, the desizing operation removes size from the fabric after the weaving operation has been completed.

In preparation for knitting, the yarn is lubricated to increase the speed and ease of the knitting operation. This step may be accomplished in the knitting mill or during yarn formation (spinning or texturizing).

Sizes serve only a transitory need for weaving, resulting in the use and disposal of huge quantities of warp size by the textile manufacturing industry each year. In the U.S., consumption is estimated at about 200 million pounds per year. Size types include (1) natural starch, (2) fully synthetic products, such as PVA, polyvinyl acetate, and polyester, and (3) semisynthetic products, such as modified starches, starch esters, and sodium carboxymethyl cellulose (CMC).

Starch accounts for the majority of all size chemicals used in the U.S. A major problem with starch size is that it cannot be reused or recycled because the starch degrades to various sugars during desizing. Starch size can contribute up to 50 percent of the total biological oxygen demand (BOD) loading from processing of woven fabrics.

A slashing operation must look beyond weaving performance to the desizing operation and the pollution generated by size at that stage. A global attitude concerning size is required for P2, because the size will probably be removed at another location or mill during wet processing of the fabric. Desizing and associated P2 strategies are discussed under Fabric Preparation, which is the next process step.

Source Reduction

INPUT MATERIAL CHANGES

Synthetic Sizes

Two significant gains in pollution reduction result from choosing synthetic sizes that have (1) lower BOD levels, and (2) the ability to be recycled and reused. The combination of moving from starch to a synthetic that can be reused can reduce BOD output by nearly 100 percent. Synthetic sizes are not degraded by the removal process; therefore, synthetics can be recovered for reuse as a sizing agent.

Currently, new sizing chemicals are being developed using a technique called Interpenetrating Polymer Network. Each polymer consists of numerous monomers that must react with each other to form the polymer. This new technique allows molecules, that under normal conditions do not react with each other, to coexist in the same polymer. The result is a hybrid polymer that has the characteristics of both monomers. The ideal size is a polymer that provides high weaving efficiency and dissolves readily in water. Sizes that can be removed in cold water and permanent sizes that can also function as dyesites are also being developed.

PROCESS MODIFICATIONS AND NEW TECHNOLOGIES

High-Pressure Squeezing (Slashing)

Several systems are presently available for new slashers or as a retrofit, including high-pressure squeeze rolls and modified size boxes. The high-pressure system provides higher slashing speeds and better size penetration. The new system is able to remove more moisture from the warp yarns before they pass over the dryer cans, thereby reducing the drying energy requirements. The savings gained in drying energy requirements compensate for the increased electrical energy that is required to produce the higher roll pressures. The main disadvantage is a decrease in size migration to the surface, thereby causing a flattening effect on the yarn.

Shuttleless Looms

Traditional fly-shuttle looms are rapidly being phased out and replaced with modern shuttleless looms. In shuttleless weaving, the filling yarn is inserted by air, water, or a special metal projectile that replaces the conventional shuttle. Compared to conventional shuttle looms, shuttleless looms (1) operate at three times the rate, (2) are quieter, and (3) require less floor space per unit of production. This translates into lower energy usage and more efficient production. Shuttleless looms currently produce about one-half of all woven fabric output. Shuttleless loom technologies include rapier, projectile, water-jet, and air-jet looms.

Needleless Knitting

A 28-cut knitting machine uses about 6,000 needles having an average life span of about 6 months. Needle replacement costs can run as high as $15,000 per year per machine. Conventional knitting machines require lubrication with knitting oils, which must be disposed of upon exhaustion.

Pneumatic knitting without needles is accomplished by yarn-feeding air nozzles and ejector nozzles of a circumferentially perforated cylinder, which open and close intermittently. Synchronized with this action is a yarn-feed system that intermittently feeds yarn to the yarn-supply jets in lengths that correspond to the loop size. Productivity is improved, and yarn breakage is rare.

Solid-on-Solid (SOS) Technologies

In solid-on-solid (SOS) processing, chemicals—such as size, dyestuffs, prints, and finishes—are applied to fabrics without using liquids. This technology uses electrostatic fluidized powder beds to apply the chemicals to textile yarns and fabrics. The slashing process is most amenable to SOS technology. In SOS slashing, a textile staple yarn is passed through a bed of electrically-charged powder, where the particles attach to the fiber surface. A melt stage is then used to form a film, or sheath, of the chemical finish around the fiber. The quality of the SOS slashed yarns is comparable to that of conventionally slashed yarns, and the process has the potential to (1) save about 85 percent of the energy that is currently consumed in the slashing process, and (2) minimize wastewater that is generated.

IMPROVED OPERATING PRACTICES

Proper Selection and Monitoring of Size

Pollution can be reduced significantly by carefully selecting the warp size mixture. Different fiber types, weaving looms, cost requirements, fabric designs, and pollution characteristics are among the factors that must be balanced in selecting a size. The most accurate means of evaluating a size formula involves in-plant testing. Some sized yarn characteristics will give an indication of the overall weavability, including elasticity, elongation, tensile strength, resistance to abrasions, continuity, and consistency. These can be accurately evaluated by testing samples in the plant laboratory, following test procedures developed by organizations such as the Institute of Textile Technology. Another consideration during size selection should be the nature of additives in the size mixture. Surfactants and biocides contribute to BOD, and their use should be examined in light of the facility's overall P2 goals. Additives can also interfere with the recyclability of sizes.

Analytical methods are available for determining the size contents of yarns and fabrics. Size add-on should be the minimal amount required to achieve the desired results in the subsequent weaving operation. Size recipes and add-on levels should be monitored and correlated with production performance. In many cases, size use may be reduced without significantly affecting production operations.

By their nature, many size mixes have essentially no shelf life and cannot be reused if they are allowed to sit in storage. Production planning is essential to eliminate mix dumping. Size requirements should be estimated carefully to avoid mixing of excessive amounts of size. The frequency of style and size mix recipe changes should be minimized to reduce wastes from changeovers. Efforts should be made to use the same size recipe on as many different styles as possible, and then to group the production accordingly.

Auxiliary Chemical Alternatives

In many cases, auxiliary chemicals—such as adhesives, binders, antistatic agents, antisticking agents, biocides, defoamers, surfactants, lubricants, softeners, and tints—are added to overcome or prevent the occurrence of specific problems that may arise during slashing, weaving, or storage. It may be possible to resolve these problems by using the following mechanical or other nonchemical means:

- Air conditioning and humidification systems can be used to prevent static electrical build-up, thereby eliminating or reducing the need for antistatic agents.

- Teflon-coated dry cans and guide rollers are widely used and help reduce fouling, thereby avoiding the need for antisticking agents and toxic machine cleaners.

- Timely movement of goods into wet processing (desizing) operations will eliminate the need for long shelf life and the use of biocides. Cool, dry storage conditions suppress mildew and fungus growth, and further minimize the need for biocides.

- The need for size bath stabilizers, such as surfactants or acetic acid, can be reduced by maintaining proper pH control in predyed yarns, and ensuring that residual alkalinity is minimal in incoming yarns.

- Evaporation barriers on size boxes will eliminate surface skinning, and the associated need for deliquescents, stabilizers, emulsifiers, dispersants, and surfactants.

- Sizing agents should be based on proper polymer molecular weights and concentrations to achieve the proper viscosity, thereby eliminating the need for thinning agents.

- Bar code tracking can be used to eliminate the need for tints to visually identify warp beams.

- Proper yarn counts and fabric construction will ensure that fabric of the desired weight is produced, thereby eliminating the need for weighters.

Organizing production activities in this manner will potentially facilitate the implementation or operation of size recovery systems, reduce BOD and aquatic toxicity in desizing wastewater, and reduce waste from sizing operations.

Raw Material Control

Control over incoming raw materials can be an important overall P2 strategy. Incoming warp sizes (and yarn) should be tested for the presence of toxic contents, notably zinc and biocides. Textile mills should always seek raw size materials of the highest purity. Mill personnel should use established procedures to perform prescreening and shipment checking of size.

Equipment Maintenance

Equipment maintenance and operations audits are critical to ensure proper slashing and to minimize fabric waste and loss of size mix. Avoiding leaks and spills from size boxes, proper foam suppression, and other such considerations are essential not only to P2, but also to proper slasher operation in general. Maintenance of mix kitchen equipment—including mix tanks, stirrers, implements, scales, pumps and piping—is essential. Maintenance, cleaning, and other nonprocess chemicals should be screened for aquatic toxicity.

Recycling and Reuse

Recycle/Reuse of Water-Jet Weaving Wastewater

Wastewater generated during water-jet weaving can be reused within the jet looms. It can also be reused in the desizing or scouring process, provided that fabric impurities and oils have been removed by in-line filters.

Lubricant Recovery

In manufacturing polyester fiber, fiber producers coat the thread with mineral oil or other substances to function as a lubricant. “Blue haze” is a hydrocarbon emission that results when the various oils on the polyester are subjected to the heat of a tenter. During tentering, the fabric is stretched out over a frame in a hot oven so that it dries evenly without shrinking. At four J.P. Stevens textile plants, tenter exhaust pollution was turned into auxiliary heat for the drying process. In-house engineering efforts resulted in the development of the “autocondenser,” which cleans up the exhaust stacks and recovers oil in the process. The autocondenser is a type of packed-column scrubber, which has not been successful on oil mists in the past, because the hydrophobic oil droplets are not inclined to enter the falling water stream. In the autocondenser, the scrubbing fluid is the oil itself. The hot oil gas stream is passed upward through a column packed with ceramic packing. Cold oil distributed over the top of the packing falls by gravity, countercurrent to the gas stream. As the gas is cooled, a mist is formed and is absorbed by the falling oil. Some of the vapor passes into the oil stream without condensing. The oil is heated as the gas stream is cooled. This oil is then cooled in a heat exchanger and returned to the top of the column. The oil is collected and reused to heat the plant and its boilers. In only 5 years, the recovery systems paid for themselves and eliminated an environmental problem.

Fiber Industries uses a different method to remove lubricating oil from its textile operations. Mineral oil is first washed from the fabric by using water and detergents. Commercially available membrane separation equipment is then used to separate the oil and water. The oil is then concentrated, homogenized, and used as a fuel to burn in the plant’s boilers; the water has reuse potential in several wet processing operations.

One American fiber manufacturer recycles its costly proprietary mineral oil by using a reverse osmosis membrane system. Installation of an Osmo™ spiral-wound membrane module increased the concentration of soluble oil rinse waters containing 0.1 percent oil to a level of 20 percent oil. The permeate subsequently contained such a low concentration of oil that it was suitable for recycling in the rinsing process. The concentrated oil fraction is suitable for reuse as a fiber lubricant in the company’s fiber processing operations. According to the manufacturer, the reduction in processing costs, resulting from the oil recovery system, yielded a 6-month payback on the equipment.

Acetate Yarn Recycling

One of the more innovative uses of textile by-products was developed jointly by Satkin Mills of New Bedford, Massachusetts, and the Advanced Technology Center for Business, Textiles & Manufacturing (ATC) at the University of Massachusetts—Dartmouth. Satkin Mills weaves acetate yarn into linings for mens' suits on 130 water-jet weaving machines, which generate about 200,000 pounds of wet yarn waste per year. The water-jet process leaves a tangle of wet yarn, which is too costly to dry and too costly to ship for disposal. Satkin Mills and ATC developed a process to blend the acetate waste with 50 percent polyester and manufacture aquarium filters. This new venture could offer the aquarium filter at one-half the market cost, because it used recycled materials.

PROCESS 3—FABRIC PREPARATION

Fabric preparation, which is reserved for natural fiber-containing fabric, cleans the fabric and increases its absorbency and whiteness, which ensures better dye uniformity and color fastness. Some of the following processes may be omitted, and the order of the processes may vary depending upon the particular end-product that is desired.

In fabric preparation, or fabric pretreatment, contaminants that will interfere with dyeing, printing, and finishing are removed by using a series of cleaning treatments. These preliminary treatments include singeing, desizing, scouring, and bleaching. Additional treatment processes, including heatsetting and mercerizing, are used to make the cloth more stable and chemically reactive, so that subsequent chemical finishes will be more permanent. Desizing, scouring, and bleaching can be carried out in either batch or continuous modes. Singeing and mercerization are always carried out in continuous mode.

Singeing is a dry, continuous process that is used on woven goods. It removes fibers protruding from yarns or fabrics, usually by burning them off. Before the fabric can be properly dyed, the sizing chemicals which are applied to the warp yarns in the slashing process before weaving, must be removed from the fabric.

Desizing involves the removal of sizing agents applied to warp yarns to protect against chafing or breakage during weaving. Natural fibers (cotton) are usually sized with water-insoluble starches, which are broken down into water-soluble sugars by desizing enzymes prior to scouring.

Scouring uses a hot caustic solution (alkali) to remove impurities and handling contaminants that are present in the fiber. These impurities and contaminants may include lubricants, dirt, other natural materials, water-soluble sizes, antistatic agents, and fugitive tints.

Bleaching decolorizes colored impurities that are not removed during scouring, and prepares the cloth for further finishing processes, such as dyeing or printing. About 95 percent of bleaching operations use hydrogen peroxide, and the rest use calcium hypochlorite.

Heatsetting is a dry process that is used to (1) stabilize shrinkage—which may occur as a result of exposure to hot water in subsequent processing operations—in fabrics having a high content of man-made fibers, and (2) impart a various textural properties to man-made fibers.

Mercerization is a chemical (alkali) process for cotton and polyester goods that improves the fabric's chemical and physical properties, including dyeability, luster, strength, and smoothness.

Many of the pollutants from preparation result from the removal of previously applied contaminants and upstream processing residues, and can be passed on to subsequent stages if fabric preparation is poor. Characteristic wastes include (1) degraded starch (high BOD), enzymes, and polyvinyl alcohol (PVA) from desizing operations; (2) sodium hydroxide, chelates, fats, oils, pectins, wax, organic material, knitting lubricants, and spin finish from scouring; (3) hydrogen peroxide, sodium silicate, sodium hydroxide, surfactants, chelates, and sodium carbonate from bleaching; and (4) sodium hydroxide from mercerizing.

Source Reduction

INPUT MATERIAL CHANGES

Alternate Desizing Agents

Hydrogen peroxide can reduce BOD caused by degraded starch (size) in the spent desizing bath. Starch is traditionally removed by using amylase enzymes. When the starch is degraded by oxidation by using hydrogen peroxide, the starch is fully degraded to carbon dioxide and water. Hydrogen peroxide is not widely used, because problems can arise from oxidation damage to the cotton. Temperatures, dwell times, and chemical concentrations must be controlled extremely tightly to carry out oxidation desizing successfully; until recently, this has been impractical, because extremely close tolerances were required. However, with microprocessor-controlled chemical feeds and temperature and speed sensors, the necessary degree of control can be accomplished.

Another innovative desizing method uses enzymes originally developed for the home laundry market. Some of these new enzymes degrade the starch size to ethanol instead of anhydroglucose. The ethanol can then be recovered by distillation for use as a solvent or fuel, while considerably reducing the BOD load in the desized effluent.

Alternate Scouring Agents

Surfactants, or nonionic surface active compounds (SAC), such as alkyl phenol (AP) compounds, are not completely degradable in typical waste treatment systems; even if they are degraded, the residues are phenols, which are aquatic toxins. Although degradable and less toxic surfactants, such as linear alcohol ethoxylates (LAE), have extremely high BOD values, they should be favored over nondegradable surfactants.

The Henkel Corporation has developed a new class of SAC—labeled Glucopons™—which are based on alkyl polyglucocides. Mainly suited for scouring because of their excellent detergency characteristics, the Glucopons are (1) completely biodegradable, (2) powerful dispersants at low concentrations, and (3) especially interesting for textile operations that are considering land application of their pretreated effluent. The SACs are alkali stable and good wetting agents, and should prove applicable to combined scour and bleach processes.

Substituting linear alkylbenzene sulfonates for hard-to-treat AP in scouring eliminates waste system pass-through and aquatic toxicity. Hoechst-Celanese Corporation has developed a new line of LAEs, called Hostapur EF™, that mimic the excellent detergency of the APs, but are low-foaming, nontoxic, and biodegradable.

Sandoz Chemicals Corporation has introduced a scouring agent called Sandoclean PCA Liquid™, which has excellent emulsifying and dispersing power. Biodegradable, AP- and solvent-free, and in an aqueous, glycolic solution at a pH of 5.5, this SAC is especially adept at removing mineral oil contamination from knits or wovens. Emulsifying the mineral oil, the SAC is readily removed by hot rinsing. The ecologically friendly Sandoclean PCA is a good detergent for cotton, blends, and especially elastomeric fibers. Its good enzyme compatibility also allows use in all enzymatic desizing operations.

Waterless Mercerization

In another type of mercerizing, the fabric is treated with liquid ammonia. The ammonia is captured as gas, recovered, and reused. The benefits of this system are the reduced alkalinity of the wastewater and reduced chemical consumption. Research is underway for the use of ammonium thiocyanate in the ammonia bath to elevate the boiling point of the liquid ammonia to room temperature, which reduces the need for expensive cooling systems to run the liquid ammonia mercerization process.

PROCESS MODIFICATIONS AND NEW TECHNOLOGIES

Wastewater/Rinse Water Reuse

Continuous preparation processes give many opportunities for wastewater reuse, because the waste stream is continuous and fairly constant in characteristics. Wastewater reuse possibilities during continuous preparation of 100 percent cotton fabric include the following:

- Recycle the J-box or kier drain wastes to the saturator.
- Reuse the wash water from the bleach washer in the caustic washer.
- Reuse the wash water from the caustic washer in the desize washer. The presence of caustic in the desize washer will help to remove the desize chemicals and some of the natural impurities of the cotton.
- Use countercurrent washing (see Case Study No. 1).
- Reuse of non-contact cooling water in the color kitchen for the preparation of dye liquors (see Case Study No. 6).

The rinse water from the scouring operation is adequate for reuse in other processes that do not require extremely high water quality, such as desizing. This is particularly true with scouring wastes from synthetic or cotton/synthetic blend fabrics. Scouring rinses may, in some areas, also be reused for the washing of floors and equipment. Wastewater from cotton scouring contains a large amount of impurities, which may make reuse economically infeasible. However, wastewater from the scouring of synthetic fibers contains fewer impurities than cotton scouring wastes, which makes reuse in the desizing process, where water quality requirements are less stringent, technically feasible.

If size recovery is not practiced, mercerizing or bleaching rinse water can be used in scouring and desizing operations. The caustic or bleach stream will generally degrade many size compounds to an extent that they cannot be recovered. However, for many mills, the benefits of water and energy savings, and the low capital costs, indicate that more widespread application of this technology can be expected.

Figure III-3 illustrates possible water reuse strategies for continuous and batch-type bleaching methods for cotton fabric.

The ***recovery of caustic*** from the mercerization process is a common practice in the textile industry. The mercerizer rinse water is normally (1) recovered for evaporation when its concentration is above 2 to 3 percent, and (2) discharged to waste treatment when its concentration is below this level. The impurities from within the fabric build up in the used caustic solution as the caustic is recycled and eventually require that the waste stream be discharged and fresh caustic be used for mercerization. One alternative to this procedure is to use an ultrafiltration (UF) membrane to filter the caustic rinse water before the solution goes to the evaporator. The clarified and concentrated caustic solution is then ready for reuse many times, and consumption of caustic is decreased significantly. After 4 years of operation for one system, the

payback of invested capital was reported to be within 12 to 18 months and amount to $1.5 million in raw materials savings per year. A good recovery system can recover up to 98 percent of the caustic.

Before wastewater from the mercerizing process enters the evaporator, it is filtered to remove gross solids and lint. Most of the water is evaporated, and a concentrated caustic solution remains. The water vapor is condensed and reused at the mercerizing process or other processes that require hot water. Concentrated caustic is filtered and returned to the mercerizing process or other processes that require the use of caustic. Known installations for caustic recovery use multiple-effect evaporators in which the vapor from one effect is used to heat the following effect, boiling at a lower pressure. This maximizes the energy efficiency of the process.

Figure III-4 illustrates a typical caustic recovery system.

Countercurrent washing is simple, and it is usually not expensive or difficult to implement. Basically, the least contaminated water from the final stage is reused for the next-to-last wash and so on, until the water reaches the first wash stage, where it is then discharged (Figure III-5). This is a useful technique for washing after such processes as continuous dyeing, desizing, scouring, or bleaching (see Case Study No. 1). An important variant in this idea is the "horizontal," or "inclined," washer concept. Because of the inherent countercurrent nature of the water flow within the machine, their efficiencies are much higher. In theory, the operation is excellent and very efficient. However, some of these machines have lost their earlier wide acceptance, and a few manufacturers of washers have gone back to the vertical configuration. The horizontal configuration requires higher standards of mechanical construction to ensure proper alignment of its components; otherwise, the weight of the water pressing down on the fabric can cause it to sag, balloon, or stretch. If properly constructed, horizontal washers can produce a high quality fabric without mechanical problems and give a much better washing efficiency with reduced water use. Although countercurrent washing equipment has low operating costs, and offers pollution and energy savings, it has a relatively high capital cost.

Low bath ratio kier bleaching systems, such as the Scholl AG Bleachstar® ultra low liquor bleach range, reduce wastewater volume. This machine, which is designed for a wide range of knit fabrics, features holding tanks in which scouring and bleaching baths can be stored. These counterflow tank systems facilitate easier bath reuse. Wash water from the previous load is recovered and then fully used in the bleach bath for the current load, which can then be used to scour the next load (see Case Study Nos. 9 and 10). Each bath is used three times, and the ultimate water usage is only about 0.8 gallons of water per pound of cloth, compared to an average of 4.5 to 6.0 gallons.

Size recovery is generally practiced only in vertically integrated mills. Mills that buy woven fabric do not invest in size recovery equipment, because they do not have the benefit of the recovered material. On the other side, synthetic sizes are more expensive than starch-like chemicals. Mills that weave the yarn, but do not desize it after the weaving process, do not buy the more expensive synthetic sizes. This is one example of a situation in which an arrangement between two mills could result in benefits for both parties.

Nonintegrated mills face substantially greater barriers to recycling size, because sizing and desizing operations occur at different firms. Reusing or recycling requires that sizing and desizing mills coordinate activities, in terms of both (1) information transfer (types of size applied and quantities recycled), and (2) physical activities (transport of goods, quality testing, and financial arrangements). The benefits of

recycling will accrue to the desizing facility, which recovers a waste that has economic value, whereas the costs accrue to the sizing operation, which absorbs the higher costs of size reformulation.

Many plants in the U.S. have been recovering PVA size for many years. One size recovery technique, which is based on UF technology (also known as hyperfiltration), was developed jointly by Clemson University, J.P. Stevens Company, Gaston County Dyeing Machine Company, and Union Carbide Corporation (Figures III-6 and III-7). The desize effluent can be separated into two recyclable streams. The concentrate stream contains the size, oils, and waxes that can be reapplied to warp yarns. The permeate stream consists, essentially, of hot water and detergent, that can be returned to the washer. The concentrate includes both PVA and wax and may be reused in the desizing bath either (1) as is, or (2) in blends with virgin size.

Compared to the more common through-flow filtration, in which an ever increasing layer of filtered material builds up on the surface, requiring frequent cleaning or replacement, the Ultrafiltration Loop™ tends to be self-cleaning as subsequent flows reduce the accumulation. About 96 percent of the size in the effluent is recovered by the ultrafilter. The concentration of the final stage is monitored by a refractometer, which prevents the discharge of PVA concentrate until the desired 10 percent level required for slashing is achieved. The equipment costs, including installation, were $1,275,000. When 2.5 million pounds of PVA is used each year and the cost of virgin PVA is $1 per pound (1981 dollars), the payback period is 9 months. Weaving efficiencies with recycled size equal that with virgin size. Other savings not included in this analysis include the following:

- Reduced cooking/slashing expense
- Reduced waste treatment cost
- Value of recycled permeate water and energy

The return on investment will vary with several factors, including system size and warp size used. However, simple returns of less than 1-½ years are common. Gaston County, the distributor, claims that tubes mounted in systems in operation for over 7 years exhibit no signs of wear or loss of filtration efficiency.

Spring Mills is another large textile plant that uses membrane technology to recover PVA. Its Abcor System™ consists of a spiral-wound module that is attached to a perforated central permeate pipe. The module is a sandwich of two membrane layers back-to-back, separated by only a permeate conducting layer. PVA recovery from the waste stream is 96 percent.

Many large textile companies, such as J.P. Stevens, own grey (greige) mills and finishing mills, permitting good cooperation between the two plant types for size recovery. Currently, the smaller independent finishing plants that process a large variety of fabrics supplied by many grey mills are experiencing more difficulty in attempting to recover size. Good cooperation is needed between grey mills and finishing plants to enhance the feasibility of size recovery among smaller facilities. An additional problem facing the small operator is the cost of transporting the recovered size from the desize plant back to the grey mill.

PVA can also be reclaimed by using vacuum extraction. Currently, vacuum extraction is widely used to remove water from the fabric before drying. PVA recovery via vacuum extraction involves either saturating the fabric with water in a desize saturator or spraying the fabric. Afterward, the cloth is passed through a vacuum extractor. The recoverability of the PVA depends on its viscosity and water solubility. The temperature of the water was also an important factor. A recovery of 53 percent of the size from 50/50 polyester/cotton blend at a vacuum of 15 inches of mercury was reported.

There are several technical and business barriers to further recycling, including (1) the practice of mixing PVA with sizes that inhibit recovery, (2) the high expense of shipping recovered PVA concentrate solution, (3) the high capital cost of recovery equipment, and (4) the commingling of goods that contain different sizes. PVA recovery is routinely used in large weaving and finishing plants where the size is either reused in-house or sold. Also, the hot permeate is recycled back to the desizing bath. Lower BOD surcharges, heat recovery, and water reuse produce cost savings. The recovered size may be reusable, and hauling costs are eliminated if the size is sold. The equipment can be paid for within about 1 to 2 years. One very important benefit of size recovery is that 60,000 fewer gallons per day, for each range on which the sizing waste is recycled, will be discharged to the environment. Some blowdown and cleanup waste are still discharged; however, the volume is minimal. The cost of PVA has increased significantly, in addition to the cost of fresh water and waste treatment.

Most of the effluent volumes arising from a textile mill come from washing operations, fabric preparation and dyeing operations. Countercurrent washing equipment can be retrofitted to any multistage continuous washing operation, whether it be for dyeing, printing or, in this case, preparation. Continuous preparation ranges run the fabric through three consecutive stages, which progressively clean the fabric—desizing, scouring, and bleaching. As the fabric progresses through each step, various impurities are removed. Wash water from the final stages contains fewer impurities and can be reused as feed for previous processing stages. In the countercurrent system, water is not disposed of; it is recycled to previous stages. With this method, the least contaminated water from the final wash is reused for the next-to-last wash and so on until the water reaches the first stage, where it is finally discharged. Water flows are generally excessive, so flow optimization should also be practiced.

Gaseous Bleaching

Gaseous reactants for bleaching—including ozone, singlet oxygen, or vapor phase reactions—result in reduced aqueous waste and energy and water consumption. AGA Gas Inc., investigates the use of oxygen in peroxide bleaching. According to this company, the system results in the same whiteness, with a substantial lower concentration of hydrogen peroxide and sodium peroxide. The oxygen works synergistically with the hydrogen peroxide.

Combined Single-Stage Processing

A logical approach to conserving energy and material in preparation is to shorten the sequence of events by combining the desizing, scouring, and bleaching operations into one stage. Such a process would establish conservation through elimination while drastically reducing operating costs. The following

combined preparation processes have recently been investigated:

- Tetrapotassium peroxydiphosphate (KPP) process
- Caustic soda/hydrogen peroxide foam (CP) process
- Sodium disper sulfate (SPS) process
- Actiron ash and Protegal DM™ (AA) process

All of these processes involve a single pad-steam-wash sequence. Of these processes, the SPS and AA processes yielded poorly prepared fabrics. The KPP and CP processes yielded commercial-quality goods. Of these two, the KPP process requires no additional capital investment to implement, and the KPP process is projected to have a 50 percent market penetration and cut energy consumption costs by 80 percent.

In 1985, Juby developed a single-stage process for the preparation of cotton and polyester/cotton blends. The new system includes a singer, an open-width saturator, a J-box, and three Tensitrol washers. The new one-step bleach system has several advantages. The reaction time in the J-box is reduced by one-third, from 75 minutes to 45 minutes at 210°F. The tensile strength losses are significantly decreased. The conventional three-stage bleaching system results in a tensile strength loss of 11 to 14 percent when 88-inch-wide 50/50 polyester/cotton muslin sheeting is bleached. The tensile strength loss is reduced to 4 percent in the open-width one-stage bleaching process. The wastewater production is reduced by 90 gallons per minute at 190°F. The reduced consumption of hot water will also cut the energy requirements. Currently, more efficient washers are available, with a total water use of about 40 gallons per minute. The chemical costs increased, and redesign of the chemical feeders was needed.

Solvent Processing

Solvent processing offers the prospect of substantial energy savings over conventional aqueous processing, mainly because about eight-and-one-half times more energy per pound is required to heat and vaporize water than is required to heat and vaporize typical organic solvents. Further, because nonaqueous solvents have higher vapor pressures, drying rates are appreciably faster. Solvent processing is potentially applicable to most major wet processing operations, such as sizing and desizing, scouring, bleaching, dyeing, and various finishing processes. However, solvent processing has major economic and environmental disadvantages. Direct solvent losses from the process range from 5 to 8 percent, and more than 98 percent of the solvent must be recovered to make the economics of the processes acceptable and to meet air quality requirements. There are installations with carbon adsorption systems for solvent recovery, and the users claim acceptable economics and compliance with air pollution and worker exposure regulations. Solvent processing has already established a firm, but specialized, position in (1) the finishing of synthetic knit fabrics and (2) where superior fabric properties are desired, such as in the application of stain-repellant finish to upholstery and drapery materials. In these cases, aqueous treatment is not always possible, because the fabric is sensitive to water. Solvent scouring (Figure III-8) and finishing of synthetic knit fabrics is widely practiced, because improved quality is obtained by avoiding contact with water.

IMPROVED OPERATING PRACTICES

Heatsetting

Proprietary spin finishes, which contain volatile components, are often applied to synthetic fibers to provide lubrication and other desirable properties. These volatile components are vaporized during heatsetting, which is a dry process that is used to stabilize fabrics having a high content of synthetic polymers.

There are several P2 options that will prevent this. In gas-fired heatsetting frames, up to 50 to 80 percent of the air can be recirculated, resulting in incineration of the volatile contaminants. Improved or more aggressive scouring may remove these finishes from the goods before heatsetting. The contaminants are more easily treated in the wastewater stream.

Testing and Monitoring of Incoming Greige Goods

Incoming synthetic goods or fiber should be monitored for spin finish add-on levels and chemical makeup. The quantitative amount of spin finish in fiber can be easily monitored by extracting the finish from the fiber. Chemical content can be determined by analyzing the extract by infrared or chromatographic methods. Mills should follow up on this analysis by developing a fiber and fabric purchasing specification that is based on the monitoring results.

To reduce the potential for release of metals from incoming textile fibers and fabrics to the wastewater stream during preparation, the mill should test and monitor incoming greige goods as part of its QC program.

PROCESS 4—DYEING

After preparation, color is applied to fabric through dyeing and/or printing. Textiles may be dyed, during any of the four stages of production, by using either batch or continuous techniques. Continuous dyeing is used for long runs of a particular fabric color and tends to be more efficient than batch processes, which are generally the only economical method for small runs with many color changes. Textiles may be dyed
(1) in fiber form (before spinning), (2) as spun yarns, (3) after the finished material has been woven or knit, or, (4) in the case of apparel, in garment form after cutting and sewing. Batch and continuous dyeing processes both consist of dye application, dye fixation with heat and/or auxiliary chemicals, and washing. Dye categories include acid, azoic, basic, direct, disperse, pigment, reactive, solvent, sulfur, and vat dyes. Most woven fabric is continuously dyed with pad/squeeze type equipment; the dye is transferred to the fabric by passing the fabric across rollers that are partially submerged in the dye solution. The moisture content of the fabric is then reduced with squeeze rollers to (1) conserve dyestuff and hot water, and (2) reduce drying time. Batch dyeing of fabric is usually accomplished in atmospheric becks or in pressure-jet dyeing machines.

Dyeing processes generate many pollutants, which may either (1) originate from the dyes, or (2) derive from auxiliary chemicals—such as salts, surfactants, levellers, lubricants, and alkalis—used in the processes. Dyeing contributes most of the metals and, essentially, all of the salt and color in wastewater effluent from textile operations. Dyeing uses many volatile chemicals, which contribute to air emissions. Cleaning solvents used during dyeing equipment maintenance and cleaning constitute an additional source of air and water pollutants.

Certain dyes and/or their metabolized degradation products are mutagens or carcinogens, which increases their environmental liability. Color in effluent from textile dyeing and printing operations is being regulated increasingly. Generally, effluent from most textile dyeing operations has a dark reddish-brown hue that is aesthetically unpleasing when discharged to receiving waters. Although there are many methods of removing color, none works in every case.

Source Reduction

INPUT MATERIAL CHANGES

Alternative Dyes and Auxiliaries

Many dyes and pigments, especially blues and greens, contain metals, such as copper and nickel, as part of the dye molecule. In many situations, these metal-containing dyes can be replaced with dyes that do not contain metals or contain a lower metal content. For example, metal-free vat dyes can be substituted for metal-containing direct or fiber-reactive dyes that are used for dyeing cellulosic materials. Typically, for direct dyes, only 85 to 95 percent of the metals exhaust into the fiber; the rest is left in the dyebath and is dumped. Dyeing conditions should be optimized to maximize exhaustion where metallized dyes are used. All chemicals used should be investigated to allow selection of the most environmentally friendly products (see Case Studies Nos. 2, 5, and 10).

Acid is the major class of dyes used for wool and nylon in the U.S. Many acid dyes contain metals as part of the dye structure. Work is underway to develop ***azo dyes***—which are based on iron—to replace acid dyes—which are based on the more harmful cobalt, nickel, lead, chromium, or zinc ions. These new dyes are not mutagenic and do not introduce metals into dyeing wastewater. Research has already produced substitutes for the cobalt-containing acid dyes Acid Red 182 and Acid Blue 172, and the chromium-containing Acid Black 172; however, commercialization is still years away.

Disperse dyeing of polyester and polyester/cotton blends commonly includes an "afterclearing" step, in which disperse-dyed polyester fabrics are treated with a reducing solution. New ester-type disperse dyes have been introduced; these dyes can be cleared with alkali alone and without using reductive afterclearing agents. These dyes are based on the diesters thiophene and benzodifurone, and they resist thermomigration. Sensitive disperse dyestuffs need buffering in media containing temporary hardness, or the pH tends to drift. Sandoz Chemicals' Sandacid PB™ is an anionic, phosphate-free buffer and dispersant system for disperse polyester dyeing that controls pH more tightly than either monosodium phosphate or acetic acid, thereby increasing reproducibility while decreasing the number of required adds.

Fiber-reactive dyeing of cotton and other cellulosics cannot achieve the high fixation level of other fibers, which—in wool and synthetics—typically range from 90 percent up. During application, some unfixed hydrolyzed reactive dye remains in the fiber to be washed off, which requires substantial amounts of water. An alternative is to limit the amount of washing and then fix the remaining dye. Several new cationic polymeric fixing agents are available; these agents are more efficient with fiber-reactive dyes than the standard agent—formaldehyde.

Hoechst Celanese has developed the Remazol™ fiber reactive dye line for cellulosics, which is based on vinyl sulphone chemistry. Incorporating di- and tri-anchors on the core chromophores can increase the fixation rate to the 95 to 98 percent range. As the number of reactive sites on a single dye molecule increases, so does the probability that one will become attached to a cellulose hydroxyl group rather than become hydrolyzed, which is the common fate of many reactive dye groups in the basic fixation media. Improved fixation reactives, such as those with Remazol™, result in less unreacted and hydrolyzed (degraded) dye in the spent bath and wash water, which improves reuse opportunities. Hoechst Celanese is also developing new dyes that would allow drastic reductions in the concentrations of sodium chloride required to exhaust the colorants before fixation.

To reduce the toxicity (metal content) of spent dye bath and wash water, Ciba-Geigy Company has reduced the metal content in its Cibacron™ reactive dyes. Ciba-Geigy's bifunctional reactive dyes yield color fixation rates of 95 percent, which reduces dye usage, auxiliary salt consumption, and the volume of dyes in wastewater. Yellow F-4G and Blue F-GFN, both of which are free of copper, have been introduced to achieve, in combination, bright green shades on 100 percent cotton fabrics, especially knits that are currently based on copper-containing turquoise and green colorants.

High-temperature reactive dyes, such as Imperial Chemical Industries' (ICI) Procion™, allow for simultaneous application of disperse and reactive dyes, resulting in (1) a reduction in energy use, and (2) the elimination of the caustic bath required after disperse dyeing. These new dyes, which arose from flame retardant research, contain phosphorous acid or phosphoric functional groups that form a covalent bond with the cellulose on reaction. Major characteristics include the following:

- They are unaffected by water in any form.
- They function best under mildly acidic conditions.
- Relatively high temperatures are required for fixation.

ICI's Procion T/Dispersol T™ system is designed for simultaneous dye application to polyester/cotton blends in continuous ranges. This variety of reactive dye shades has many advantages over conventional low-temperature reactive dyes, including the following:

- Shorter application cycle
- Elimination of steaming process, resulting in energy savings
- Elimination of the caustic/hydrosulfite reduction clearing bath loaded after disperse dyeing

New types of ***sulfur dyes*** which have been introduced recently feature lower sulfide content, which lowers sulfide discharges to mill effluent, and reduces hydrogen sulfide odors in the mill and in the waste treatment system. Glucose or even sugars from corn can also be substituted for sulfide-containing reducing agents. In one case, using alternative reducing agents significantly lowered the sulfide concentration in the effluent. Sandoz Chemicals Corporation has developed the Sandozol RDT™ line of sulfur dyes, which offers benefits similar to those of its traditional line, while adding environmental advantages, such as reduced odor, sulfide reduction, lower water requirements, and easier cleanup. Sandozol RDT dyes are manufactured with a minimum of sulfide reducer and require no additional sulfide in processing; they rely instead, on a proprietary reducing agent that was developed especially for Sandozol Reducer RDT™, a new colorant line,.

New ***auxiliary agents***, such as Sandoz Chemicals Corporation's Sandpure RSK™, increase wash efficiency, thereby decreasing water consumption and improving the fastness of the reactive dyes. Sandpure RSK is especially effective with difficult blue and green shades, and is innocuous to the environment. BASF is developing a new and improved leveling agent formulation, which is coded NBSE™ and consists of a combination of selected surfactants. The main attribute is rapid efficient biodegradability.

Acetic acid is used in a variety of textile processes. For example, in disperse dyeing of polyester fabrics, it is used to lower pH. Substituting formic acid for acetic acid can significantly reduce the waste load of the mill. Acetic acid has a BOD equivalent of 0.64 pound/pound, whereas the BOD equivalent of formic acid is only 0.12 pound/pound. Eighty-five percent of the BOD load of a dyeing procedure using acetic acid can come from the acid. Substituting formic acid for acetic acid can also reduce costs because of the lower weight equivalent and higher purity of formic acid. Organic acids, such as acetic acid, can also be substituted for by ammonium sulphate, ammonium chloride, or mineral acids (0 percent BOD) for pH adjustment in disperse dyeing and pigment printing. Although the salt concentration of the effluent would increase in this substitution, ammonium would serve as a nutrient in the biological treatment process. Another substitute for acetic acid is sodium bicarbonate, in conjunction with peroxide or perborate, for the oxidation of vat dyestuffs.

Other chemical substitution strategies in dyeing include the following:

- For dyeing blended varieties in pale shades, use single-class dyestuffs, such as Indigisol and pigments, rather than two-stage dyeing, which uses two different classes of dyes (such as polyester using disperse dyes, cellulosics using vats, and reactives).
- Use all-aqueous phthalogen blue dyeing rather than solvent-based phthalogen blue dyeing, which requires specialty auxiliary products.
- For dyeing Dacron™, use monochlorobenzene rather than other carriers.

PROCESS MODIFICATIONS AND NEW TECHNOLOGIES

Ultra-Low-Liquor-Ratio Dyeing

In dyebaths, chemicals that act on the bath—salt, pH control, acid/alkali, lubricants, and dispersing agents—are normally measured by bath volume, and chemicals that act on the fabric—dyes and softeners—are measured by the weight of goods (fabric). There is now a trend toward reduced bath ratio dyeing, in which energy and chemical use in dyeing is generally a function of the bath volume, not the amount of fabric, thereby saving energy and dyebath chemicals (see Case Studies No. 4 and No. 10).
Ultra-low-liquor-ratio (ULLR) dyeing, which is a form of reduced bath ratio dyeing, has the following advantages:

- Decreased water consumption and associated cost savings
- Decreased consumption of bath chemicals
- Improved dye fixation
- Reduced cycle times because of quicker machine drains and more rapid heating and

cooling

- Decreased energy requirements for heating the dyebath, which results in reduced steam usage, less boiler usage, reduced fuel consumption, and fewer emission losses from combustion

In some fabric dyeing machines, ULLR techniques have lowered bath ratios from 30:1 to 5:1; below the ratio of 5:1, insufficient water is present to keep the pumps "wet." Package dyeing and jet dyeing are commonly used for low-ratio dyeing (Figure III-9). In package dyeing, the yarn remains stationary while the dyebath is being pumped through the machine cylinder. In jet dyeing, a jet of dye solution, foam, or air is pumped through a venturi to transport fabric through a closed tubular system.

Generally, ULLR concepts cannot be retrofitted onto existing dyeing machines, because lower water levels may cause pump cavitation or poor fabric movement through the dye chamber. Companies must purchase specially designed ULLR jet or package machines that feature (1) a kier having a different configuration, size, and shape from that found on a normal jet, and (2) low-volume pumps and piping. The installed cost of a typical ULLR jet with a 30000-pound-per-week capacity is about $1 million (high capital cost).

BASF's Multiplus NB-100™ is an acrylate polymer that is designed to increase liquor pick-up in difficult textile systems, such as low-liquor-ratio coloration of cellulosics, acid dyeing of nylon carpet, and acrylic coloration. The product is stable to acids, alkalis, and electrolytes, and offers increased wet pick-up, better use of dye, increased equipment flexibility, and greater process uniformity. NB-100 also provides excellent lubricity to the dyeing system, which allows ease of loading in jet machines without surfactants, thereby eliminating the need for silicone-based defoamers. Running marks, such as crack marks and crows' feet, are eliminated via added lubricity.

Pad-Batch Dyeing

In pad-batch dyeing, the prepared, dyed fabric—mainly 100 percent cotton and polyester/cotton blends—is impregnated with a cold solution of reactive dye and alkali. The excess liquor is squeezed from the fabric as it leaves through the padding trough. The wet fabric is stored on rolls at ambient temperatures for fixations during a period of 2 to 48 hours. While in batching, the dyestuff reacts with, and penetrates, the fabric, which results in a very even and consistent color. Rolls are covered with a polyethylene film to prevent evaporation of the dye solution. The goods can then be washed, in any of several conventional ways, to remove unfixed dye.

Pad-batch dyeing offers several significant advantages, mainly in waste reduction, simplicity, and speed. The quality of pad-batch dyeing is equal to or better than that of other dyeing systems. Benefits include the following:

- Minimize (eliminated in some cases) use of salt or specialty chemicals, resulting in reduced effluent waste loads and increased savings in chemical and wastewater treatment costs
- More efficient use of dyes, resulting in reduced water and energy consumption
- More consistent dye quality
- High production speed
- High color yields
- Excellent penetration and leveling characteristics
- Rapid fixation, resulting in shade reliability and reproducibility
- Can be used on wovens or knits in many constructions
- Can retrofit available equipment, such as becks, beams, and continuous washing equipment
- Requires a low capital outlay
- Substantial overall cost savings, in dyes, chemicals, labor, and water

Production case histories have shown that pad-batch dyeing of cotton, rayon, and blends conserves energy, water, dyes, chemicals, labor, and floor space. Water consumption for pad-batch dyeing with beam wash-off is typically under 2 gallons per pound of dyed fabric, compared to typically 20 gallons or more on atmospheric becks for the same fiber-reactive dyed shades. Energy consumption is similarly reduced from about 9,000 British thermal units (Btu) per pound of dyed fabric for becks to under 2,000 Btus per pound for pad batch with beam washing. Use of chemicals—including alkali and specialty chemicals—can be reduced by up to 80 percent from use of chemicals associated with atmospheric becks. Fixation ratios for pad-batch dyeing have been reported from 92 to 97 percent, compared with 42 to 80 percent for reactive dyes at a 10:1 exhaust dyeing bath ratio. In terms of reduced labor costs, two workers per shift can dye 200,000 pounds of fabric per 5-day week.

Uniform preparation of the fabric is required to obtain good quality dyeing in cold pad dyeing. The fabric should not contain any traces of natural oils, waxes, or sizing chemicals, because they interfere with dyeing.

Pad batch dyeing requires highly reactive “cold dyeing” fiber-reactive dyes. Examples include the following:

- Atlantic’s Altafix CX™

- Ciba-Geigy's Cibacron F™

- Sandoz Chemicals Corporation's Drimarine K™

- C & K's Intracon C™

- Mobay's Levafix E (A)™

- ICI's Procion MX™

- Hoechst Celanese's Remazol™

- Wright's Sumafix™

Capital costs of pad batch equipment are less than one-third the cost of conventional exhaust dyeing based on becks. Operating costs (excluding dyes) are about 20 percent less, and pad-batch dye chemical costs are about 40 percent less.

Foam Processing Technology

There are several common commercial applications of foam processing, including carpet dyeing, coating operations, foam dyeing, and foam finishing. Textile dyes can be applied through foam media by replacing water with air. The foam process is applicable only to continuous dyeing. Unlike continuous dyeing— in which fabric is immersed in a liquid, and excess dye liquor is squeezed out before fixation and/or drying—the precise amount of foamed dye composition is applied to the fabric. Because absolute uniformity of application is required in continuous dyeing of solid shade, foam application systems are used in the U.S. mainly to apply finishes rather than apply colorants.

Dye penetration and uniformity are problems to be solved. Foam dyeing has been used in limited commercial practices with some textiles, such as nylon carpet, polyester and acrylic nonwovens, and polyester/cotton narrow-width industrial toweling. Flocked and velour-type plush fabrics have been successfully foam-dyed in limited production trials; however, this technology has recently yielded to spray and liquid slot dyeing techniques in carpet production.

Advantages of foam processing are as follows:

- Reduced water and energy consumption

- Reduced chemical waste

- Less time required for drying (less water to evaporate)

Automated Chemical and Dye Dosing Systems

Automated dosing systems can be optimized to deliver the correct amount of a specific chemical at precisely the desired time. This improves the efficiency and reliability of chemical reactions in the dyebath, ensuring results that are more consistent and reproducible. Also, these systems avoid the tendency to overuse environmentally harmful chemicals that may pass through treatment systems unreacted or react to produce undesirable by-products. Dosing systems reduce handling losses and equipment cleanup. Automated dosing systems are commercially available and are being adopted throughout the textile industry (see Case Study No. 1). Some systems that are now being developed can sense dye exhaustion as it occurs and adjust the dosing profile of salt and alkali accordingly.

Fast and accurate dry dispensing systems for powder dyes are available. The systems feature storage compartments, valves, weighing devices, and mechanical parts that are extremely resistant to corrosion and easy to clean. Precision of 0.01 gram on a 10-kilogram delivery is available, and the accuracy is within 1 percent. Hard automated container transport to and from the dispensing area is also included in the system.

The automated color kitchen conducts automatic color mixing and batching, which not only reduces working losses from cleanup and disorderly work practices, but also ensures that the correct amount of mix is prepared every time, thereby reducing discards. Reducing start-up and stop-off waste also makes shorter runs on continuous equipment economically feasible.

Continuous Dye Ranges

Continuous dyeing ranges offer inherent P2 advantages, including the following:

- No exhausted dyebath to discard
- High levels of fixation
- Ability to reuse washwater in countercurrent operation
- Less use of specialty chemicals
- Elimination of salt for dyeing cotton

Disadvantages include the following:

- High lengthwise tension to which knits would be subjected, thereby preventing normal dyeing of knits in continuous processes
- Lot size restrictions
- Discharge of leftover mixes and pad baths at stop-off and color changeovers
- Higher pollution potential of cleaning agents

Several equipment manufacturers have recently introduced features intended to overcome the limitations of continuous dye ranges (Figure III-10), including (1) continuous knit dyeing ranges that feature tensionless knit handling, (2) dye application systems that avoid tubular edge marks, and (3) suitable guidance systems for knits. The ability to run knits by continuous dyeing methods opens up many possibilities, including the use of vat dyes for green shades, thereby eliminating metal-containing reactive dyes, eliminating salt from effluents, and generally increasing flexibility for dye class selection.

Mercerizing to Improve Dye Fixation

Improvements in dye fixation and lower chemical requirements overall can be attained by mercerizing cotton yarn or fabric during the preparation process, thereby decreasing dye uptake and reducing the need for chemical accelerants. Therefore, mercerizing can reduce the amount of dye needed to achieve a specific shade and decrease the amount of color in the wastewater. The tradeoff is that mercerization uses highly concentrated sodium hydroxide (22 percent), which is a pollution concern.

Improved Efficiency in Washing Technology

Washing operations consume a high percentage of the water used in wet textile processing. Continuous dyeing machines can be made more water-efficient through the use of flow restrictors, which control water volume. In addition, countercurrent washing and recycling of clean water are important features of continuous dyeing and printing operations (see Case Study No. 6).

Supercritical Fluid Dyeing

Supercritical fluid (SCF) dyeing is an emerging P2 technology that uses carbon dioxide as the fluid medium for disperse dyeing on synthetics. No water or pollution is associated with the SCF process, and the carbon dioxide evaporates without any applied heat, thereby conserving energy.

Ciba Geigy Limited has teamed with the German Center for Textile Research Northwest e.V. (Krefeld, Germany) and equipment manufacturer Joseph Jaspers GmbH & Co. (Velen, Germany) to develop a range of disperse dyes that can be carried in supercritical carbon dioxide instead of water; this technology promises dye uptake of 100 percent with no wastewater. Pilot plant operations went online in the summer of 1992. Although it is currently limited to polyester, the process appears to be promising for other hard-to-dye fibers, such as aramids and polypropylene.

Vacuum Impregnation and Extraction

In vacuum impregnation, the fabric contacts a perforated cylinder, and air is extracted by the vacuum. Dye solution contacts the fabric before the fabric is returned to atmospheric pressure, thereby promoting penetration of dye into the fabric. This technique is particularly useful for dyeing heavy fabrics, which are difficult to dye uniformly by conventional means. Vacuum impregnation can also be applied to various

finishing processes (see Final Finishing subsection), such as durable-press and flame retardant finishing. Vacuum extraction systems have been applied successfully in pigment dyeing and continuous dyeing with solid shades.

Vacuum extraction by slots or porous rollers will reduce the water content more effectively than conventional methods, thereby reducing the amount of energy required for drying. The key is to economically separate (via a cyclone separator) air and water, and recycle the dye solution.

Indigo Dye Recovery through Ultrafiltration (UF)

Indigo dyes pose a major waste problem for textile manufacturers. Using UF to recover indigo dye can prevent pollution and save a valuable resource—indigo dye has a significant value at $9 per pound. The UF process centers on a pressure membrane that separates the effluent stream into two components (Figure III-11). The isolated component, or concentrate, contains the reusable indigo dye. The second component, or permeate, is nearly pure water with a fraction of solid materials. The UF system uses a cross-flow technique that circulates the effluent across, or parallel to, the membrane surface, thereby creating a self-cleaning action that minimizes accumulation of materials that can reduce filtration efficiency. More than 98 percent of the indigo in wash water can be separated by the filtration process. Figure III-12 shows the processing savings and costs associated with UF of indigo dyes.

Gaston County Dyeing Machine Company manufactures an UF system which uses a porous carbon tube with an inert zirconium membrane. The membrane is usable for the full pH range of 1 to 14 and to temperatures approaching 100^{o}C, and can be designed for either batch or continuous systems.

Since 1981, a Liberty, South Carolina, textile plant has been recovering indigo with minimal problems, and paid for the recovery system in less than 2 years of operation. UF is accomplished by using a vinyl-sulfone membrane system. The Liberty plant modified the dyeing process to prevent contamination of the indigo waste stream, as follows: when sulfur dyes are used, they are applied after the indigo dye has been applied. The multistage recovery system uses a single-feed pump and a bleed valve to automatically establish progressively higher steady state concentrations of dye at each stage, with the final stage achieving the maximum concentration of indigo for reuse. The indigo waste stream should be produced from countercurrent flow wash boxes having an adjusted flow of about 25 gallons per minute; this minimizes the cost of the membrane system. The system is preceded by a vibrating screen that is used to remove lint. After the indigo has been concentrated, it is filtered through a basket strainer and stored in a holding tank.

Cone Mills (Greensboro, North Carolina) and the Dan River Textile Company (Greenville, South Carolina) are two satisfied customers that installed indigo recovery systems. Installation of an indigo recovery system requires redesign of the rinse boxes to a countercurrent rinse system. The redesign reduces the amount of water required in rinsing by 80 percent and results in an adequately concentrated feed for the UF unit.

Improved Operating Practices

Because of the difficulties and expense involved in treating color, the best approach to minimizing color discharges is through P2. Three important areas for preventing and minimizing color discharges are as

follows:

- Maximizing exhaustion from dyebaths
- Maximizing fixation and minimizing wash off
- Optimizing dye handling to eliminate spillage, machine and implement cleanup, and discards

In cellulosic batch dyeing processes, the most important factors are as follows:

- Good cloth preparation
- Low bath ratio
- High-affinity dyes
- Optimization of pH and salt
- Proper time-temperature profile relationships
- Avoidance of auxiliaries that retard or reduce exhaustion
- Minimized use of auxiliaries and surfactants
- Avoidance of adding chemicals to offset undesired side effects (nonchemical alternatives—such as procedural or mechanical remedies, changing dye selection, or changing product—should be used)

In fiber-reactive batch dyeings, the most important factors are as follows:

- Use of two-step dyeings, not all-in-one
- Use of fixatives
- Ensuring maximum fixation by proper sequencing of events

In continuous dyeing, the most important factors are as follows:

- Proper dwell time and temperature in the steamer/thermofixation oven
- Not introducing oxygen in steamers, which can oxidize vat dyes prematurely and lead to excessive washoff
- Preparation of precise amounts of dye solution, because extra amounts will be discarded

Dyebath ratios can sometimes be reduced by using volume displacers that result in lower chemical and water use requirements (Figure III-13).

Many textile chemical suppliers have already implemented container return programs that facilitate return and recycling of many metal, plastic, and cardboard containers from the manufacturing sites to the generating facility. In the long term, an increased reliance on tank car deliveries, facilitated by improved and controlled automatic delivery systems, will minimize the need for small and prolific containers.

Right-First-Time Dyeing

"Right-first-time" dyeing is an effective P2 practice that eliminates (1) reworks, (2) redyes, (3) shade adjustments, (4) top-ups, or (5) adds. These corrective measures (1) can be very chemically-intensive,
(2) have less chance of achieving the desired quality, and (3) represent high reprocessing costs, in terms of additional dyes and chemicals. Studies have shown that the cost of dyeing can increase by as much as 30 percent when dye additions are required. Right-first-time dyeing leads to increased productivity and more efficient use of fixed capital and labor. Improved dyeing machines have features that facilitate right-first-time dyeings, such as accurate process conditions (pressure sensors and chemical feeds). In one case, a 10 percent improvement in right-first-time production generated a 1.7 percent decrease in product waste and a $2 cost reduction per 100 kilograms of fabric dyed.

Recycling and Reuse

Dyebath Reuse

Dyebath reuse is the process by which exhausted hot dyebaths are analyzed for residual colorant concentrations, replenished, and reused to dye additional batches of material. Dyebath reuse provides an alternative that is less than constructing a pretreatment system; also, it reduces effluent volume and pollutant concentrations in the effluent. Dyebath reuse requires a smaller capital outlay than pretreatment systems and offers a return on the investment in the form of dye, chemical, and energy savings. Dyebath reuse principles can also be applied to bleach baths.

Dyebath reuse carries the higher risk of shade variation, because impurities can build up in the dyebath and decrease the reliability of the process. Dyebath reuse can be used reliably on dyes that exhaust quantitatively, such as acid dyes on nylon or basic dyes on acrylic.

Figure III-14 illustrates a typical dyebath reconstitution process.

If properly controlled, dyebaths can be reused for 15 or more cycles (ranging from five to 25). For maximum dyebath reuse benefits, use dye classes that undergo minimal changes during the dyeing process, such as (1) acid dyes for nylon and wool, (2) basic dyes for acrylic and some copolymers, (3) direct dyes for cotton, and (4) disperse dyes for synthetic polymers. Vat, sulfur, and fiber-reactive dyes are very difficult to use. Typical costs for dyebath reuse include capital costs of about $24,000 to $34,000 per dye
machine for lab equipment and machine modifications, and annual operating costs of $1,000 to $2,000 per dye machine. Typical annual savings—in the form of dyes, chemicals, water, sewer, and energy—are about $21,000 per dye machine.

Reconstitution and reuse of dyebaths have also been extended to the dyeing of fabric in jet dyeing machines. Dyeing of Nomex Type 455 (Aramid, Du Pont) plain weave fabrics was selected, because large quantities of costly auxiliaries are required to dye this material. A spectrophotometer was used to monitor for proper dye concentrations. Most auxiliary chemicals used in dyeing are generally nonreactive and are not absorbed by the substrate being dyed. Because they are not consumed or removed during the dyeing cycle, the principal loss results from the retention of liquor in the fabric that is being dyed. Dyebaths were used up to 15 times before being discharged. Color reproducibility, color uniformity, crock fastness, and flammability of samples dyed by the reuse system were comparable to those achieved with conventional dyeing. Dye, chemical, water, and energy requirements were reduced significantly. The capital cost of modifying a typical jet-dyeing machine for reuse dyeing and for required analytical instrumentation was $15,000. Annual savings possible with the reuse system are projected at over $100,000 ($0.25/pound of fabric dyed). Plant personnel can be easily trained to operate the new system.

Dyebath reuse has also been used with nylon pantyhose that were dyed in rotary drum machines. The textile plant constantly dyes 30 batches of hosiery in reuse sequences. Acid dyes and other chemical auxiliaries were used in the dyeing. The plant's scale of operation was about 612,000 pounds of textile products annually. Cost savings were estimated at $0.02/pound of product (Tables III-2 and III-3).

To gain the maximum benefit from dyebath reuse, users must consider that the easiest systems to manage for dyebath reuse are dye classes that undergo minimum changes during the dyeing processes, as follows:

- Acid dyes for nylon and wool
- Basic dyes for acrylic and some copolymers
- Direct dyes for cotton
- Disperse dyes for synthetic polymers

Salt Recycling

The upsurge in the use of cotton in textile products has significantly increased the use of direct, vat, sulfur, and, especially, reactive dyes. These dyeing processes all require large quantities of salt (up to 120 grams per liter) to achieve good exhaustion of the dyebath. As a result, the content of dissolved salt in textile wastewater is increasing. Progress has been made in reducing salt requirements for some newer reactive dyes, but salt concentrations are still much too high. This is a special problem for plants considering some form of land application for textile processing wastewater. Because of the inactive form of the dye that is present in the bath at the end of the cycle, reactive dyebaths are not amenable to reuse.

Several techniques for removing reactive dyes, and recycling the water and dissolved salt, are being considered. Ozonation, chlorination, and electrochemical reduction are currently being investigated. UF may also be promising for removing the dye, and for reusing the water and salt. In this application, a membrane would be required to pass water and dissolved salt, but retain the larger reactive dye molecules. Such membranes are expected to be relatively easy to engineer, and a simple system for brine recycling could be designed. The cost savings derived from recycling the salt would probably provide an economic

TABLE III-2

TYPICAL COST AND SAVINGS FOR DYEBATH REUSE

Dye Machine	Cost/Savings per Machine ($)
Laboratory and support equipment	9,000
Modifications (tanks, pumps, pipes)	15,000 to 25,000
Annual operating costs	1,000 to 2,000
Annual savings, total Dyes and chemicals Water Sewer Energy	21,000 15,000 750 750 4,500

TABLE III-3

SYSTEMS FOR DYEBATH REUSE

Produce	Fiber	Dye Class	Machine
Knit fabric	• Polyester • Cotton • Polyester/cotton	• Disperse • Reactive or direct • Disperse/reactive or direct	• Jet • Beck • Beck
Yarn package	• Polyester • Polyester/cotton • Acrylic	• Disperse • Disperse/reactive or direct • Basic	• Package • Package • Package
Socks	• Nylon/spandex	• Acid	• Paddle
Pantyhose	• Nylon/spandex	• Disperse/acid • Disperse	• Beck • Paddle/drum
Carpet	• Nylon • Polyester	• Disperse/acid • Disperse	• Beck • Beck
Woven fabric	• Aramid/nomex • Cotton • Cotton	• Basic • Direct • Vat/Sulfur	• Jet • Reel • Jig
Skein	• Acrylic	• Basic	• Skein

incentive for installation of a source reduction technology in reactive dyeing.

Membrane Filtration and Water Reuse

Wastewater discharged from the reactive dyeing of cotton and cotton blend fabrics is characterized by high concentrations of potentially toxic nonbiodegradable salts and unacceptable color levels. Studies have demonstrated that economic payback could be achieved by selectively treating the waters with the heaviest concentration of pollutants and using this permeate as process water in subsequent dyeings. One pilot study at the Sara Lee Knit Products Development Laboratory in Winston-Salem, North Carolina, conducted with dye jet wastewater, demonstrated the viability of a system of UF followed by nanofiltration (UF/NF). The ability to reuse the water and salt permeate offers a cost savings in terms of raw material and disposal costs, with minor changes to established dyeing procedures. For a representative dyehouse, the addition of a 12000-gallon-per-minute UF/NF treatment system would offer a cost return of about 1-½ years, based on capital costs of $850,000 and operating costs of $180,000 per year; operating savings would be about $900,000 per year.

<u>Wastewater Reuse</u>

The colored wastewater from the soaping operation can be reused at the backgrey washer, which does not require water of very high quality. Alternatively, it can be used for cleaning floors and equipment in the print and color shop.

The rinse water from the final rinse in a batch dyeing operation is relatively clean and can be used directly for further makeup of subsequent dyebaths. Several woven fabric and carpet mills use rinse water or non-contact cooling water for dyebath makeup (see Case Study No. 6).

<u>Textile Mill Waste Treatment Plant Sludge</u>

Waste treatment plant sludges, or "biosolids," from textile mills are now being used to add nitrogen and soil conditioner to the clay soils of cotton farming operations. Burlington Industries donates nitrogen-rich textile waste sludge from its Knit Fabrics Division finishing plant in Raleigh, North Carolina, to area farmers, thereby avoiding landfilling fees.

PROCESS 5—PRINTING

In printing, color is deposited on the fabric and fixed by using steam, heat, or chemical treatment. Print pastes are formulated to (1) ensure proper flow properties during application (thixography), and (2) adhere to the fabric until they are dried. Commercial printing methods include (1) pigment printing, which comprises about 75 to 85 percent of all printing operations, (2) wet printing, (3) discharge printing, and (4) carpet printing.

Print application consumes less water and produces less BOD than the preparation operations—such as desizing, scouring, and bleaching—that precede it. In pigment printing, the main source of waste is from the cleanup, during which unused printing paste is removed from the screen.

Typical wastes generated during various printing techniques include color residues, AP-based surfactants, solvents, urea, and metals.

Source Reduction

INPUT MATERIAL CHANGES

Oil/Water Emulsions

Oil/water emulsions, which form the basis of printing paste, contribute substantial amounts of fats, oil, and grease to the wastewater stream, and release hydrocarbons to the air during drying and curing. Synthetic polymers are a good alternative to traditional emulsions. Also, an extremely small amount (compared to deodorized kerosene) of synthetic polymer is needed to thicken pastes for printing. Biodegradable vegetable oils can also be used as an alternative to mineral oils which are difficult to treat.

Reducing (Discharging) Agents

During afterwashing of the printed fabric, metals are released to wastewater as a result of using metal-based reducing agents in discharge printing processes for polyester fabric. Commercially available sodium hydrosulfite and other nonmetallic agents provide good alternatives. In addition, the use of ester-based dyes, rather than azo dyes, for overpadding allows for discharging with alkali-based discharge agents, thereby reducing the need for reductive discharge agents.

Surfactants

Surfactants are commonly used in printing processes (1) to adjust the rheology of the paste, (2) to obtain correct print paste penetration properties, (3) as a component of conventional and foam type print pastes, and (4) for afterwashing of printed fabrics. Whenever possible, nonionic surfactants should be selected, because they have low aquatic toxicity and BOD, yet maintain excellent wetting properties. Nonionic surfactants are also biodegradable and reasonable in cost.

Urea Replacement

Chemical substitution with nonnitrogen chemicals has been unsuccessful to date. One possible substitute for urea is dicyanamide, which contains nitrogen but is less polluting than urea. Combining urea with a proprietary printing assistant can reduce urea usage by up to 80 percent.

PROCESS MODIFICATIONS AND NEW TECHNOLOGIES

Transfer Printing

Transfer printing (sublistatic transfer printing) involves placing synthetic fabric (normally polyester) in direct contact with paper that contains disperse dyes (Figure III-15). Under high pressure and heat, the solid dyes vaporize and deposit themselves onto the cloth, replicating the exact pattern on the paper.

Transfer printing shifts the burden of P2 and waste handling from the textile printer to the manufacturer of the transfer paper. This method of printing deposits only the dye on the fabric without requiring the use of additional chemicals. Therefore, no afterwashing is required, and no effluent is generated during the printing process. Other advantages include the ability to perform

QC on paper before printing on fabric occurs, and this method is economical for short runs, and frequent color or pattern changes.

Limitations of transfer printing include the following:

- Limited to volatile dyes
- Most appropriate for synthetic fibers; does not work well with natural fibers
- Limited dye penetration

Ink-Jet Printing

Ink-jet printing is a noncontact process in which drops of color solution are propelled toward a substrate and directed to a desired spot. Ink-jet printing is a new technology that is not yet used extensively in the textile industry. However, it offers numerous P2 benefits, including the following:

- Does not require the use of solvents for thickeners and clears, or for machine cleaning
- Allows for instantaneous pattern and color change while reducing wastes associated with cleanup
- Eliminates photographic screen making, which reduces silver input into wastewater effluent
- Provides direct QC through computer-controlled printing

Flash Aging

Flash aging, or two-stage printing, is a multistep process that involves printing with highly reactive dyes, drying, overpadding with alkali/salt bath, and high-temperature steaming. This method does not use urea, but it uses more alkali. Urea is generally considered more of a problem than alkali.

Prewetting

Prewetting involves using moisture systems to prewet fabric, immediately prior to steaming, to a wet add-on of 30 percent. Prewetting attracts moisture to the fabric during steaming, which is one of the main functions that urea performs. However, these methods are not as effective on rayon as they are on cotton. With proper attention, use of urea can be reduced in rayon printing.

Foam Technology

In foam printing, the rheology of the print paste is controlled by (1) the volume of air that is whipped into the print formulation, and (2) the size of the air bubbles. This virtually eliminates the need for thickeners. Also, commercial trials of foam printing have demonstrated (1) energy savings of 35 percent, and (2) line speed increases of 30 to 35 percent. Currently, the major limitation in foam printing is the short useful life of the print foam. However, foam printing technology is progressing rapidly.

Xerographic Printing

Xerographic printing of fabrics is an emerging technology that uses modified paper xerography techniques, and promises numerous P2 advantages. The process is based on the electrostatic attraction between charged plates and toner powder. The image is transferred only onto the charged areas, creating a positive image. The print is then fixed by thermally melting the toner. A significant advantage of xerography printing is that the print information can be stored optically by computer rather than in rotary screens.

Specific steps in xerographic printing technology include the following:

- Form a negative image on a light-sensitive, photo-conductive surface via light reflection off a printed master sheet. (This process is often accomplished by a computer-aided design that can be digitally scanned or downloaded.)
- Develop the negative image into a positive image by contact with a powder developer system, transferring toner to the still-charged design areas of the drum.
- Melt the toner by contact with a heated roll, and air cool to fix the print.
- Clean the drum, and recycle any untransferred toner to begin a repeat of the print cycle.

Current barriers that researchers face in adapting xerography printing techniques for use in the textile industry center mainly on developing the proper toners to meet textile requirements, such as fastness and aesthetic properties.

P2 advantages include the following:

- Elimination of water in the printing process
- Significant energy reduction
- No effluent
- QC through computer-aided design

- JIT production for consumers, reducing unwanted goods

Computer-Integrated Manufacturing (CIM) Printing

The concepts of computer-aided design (CAD), computer-aided engraving (CAE), and computer-aided coloring (CAC) are improving the way in which designs are conceived, developed, and transferred into rotary screens for textile printing. The design is created directly on a computer display through CAD, and CAE techniques enable the designer to manipulate geometrical forms and make changes within a few minutes. Colors are manipulated through CAC, working with the plant's shade library and dyestuffs, the latter via a computerized color kitchen operation. Ink-jet printers are used to translate the initial display design into a hard copy for customer approval, usually on paper but increasingly on fabric. Computer-driven laser engraving is used to convert the final design into a working rotary screen. Although the design information is stored on disks, rotary screens must still be made, stored, maintained, and replaced. Direct imaging techniques on fabrics, with complete digital storage and translation of information, will eventually replace computer-aided rotary screen printing.

IMPROVED OPERATING PRACTICES

As in dyeing, the key to minimizing color discharges in printing operations is to maximize fixation. Discards and pad dumps from printing operations comprise the main source of color in wastewater. Printing is an inherently messy operation, and housekeeping can play an important role in minimizing color discharges. Handling of paste and cleaning of mixers, homogenizers, screens, and squeegees should be closely controlled. Drums of print paste or empty drums of chemicals should not be washed out into the drain. Residues should be drained into the next drum to be opened. If excess paste remains, it should be reused or added to in making up a future color recipe. Minimize implement cleanup by using "dedicated" dippers for each chemical or installing an automatic chemical dispensing system.

Washing Practices

During afterwashing of prints, water can be conserved by implementing high-extraction separations between print washes. This provides a more efficient washing by increasing the removal of unfixed dye, print paste, and other residual components. Carryover water can also be reduced with high-extraction pad rolls or vacuum extractors for continuous print washers. Countercurrent washing is a method that uses water efficiently if it is properly implemented.

Print Paste Handling

Color kitchens typically generate significant quantities of solid and liquid wastes during mixing, dispensing, and cleaning. These wastes can be eliminated or reduced by adopting operating practices that focus on

preventing pollution. Examples include the following:

- Shorten piping lengths that carry print paste. This reduces residual paste volumes and cleanup.
- Install automated print paste make-up equipment to eliminate spills and reduce the amount

of paste that remains after a run. Automated make-up equipment allows quick, efficient, and accurate recipes; this reduces the need for mixing and storing large batches of paste that may expire or become unusable.

Recycling And Reuse

Silver

The use of silver is eliminated by the development of emerging printing technologies, such as ink-jet printing and computer-aided screening, that directly digitize patterns, because photographic processes are not required. However, photographic techniques that do generate silver-containing effluent are still common in the textile industry. Precious metals recovery firms can successfully recover silver from fixer and developer solutions, which results in effluent that is less toxic and a recovered solution that is potentially of substantial value (see Case Study No. 3).

Inventory of Print Paste

If properly inventoried and managed, excess print paste maintained in storage can be reused when a suitable use is identified. Good inventory tracking allows (1) all new orders for paste to be reviewed against available colors in storage, and (2) compatible orders to be identified. Maximizing the reuse of pastes can significantly reduce the volume of paste discarded as waste.

PROCESS 6—FINAL FINISHING

Most fabrics undergo one or more final finishing processes (involving both chemical and physical processes) to enhance properties such as durability, appearance, or safeness. Finishing processes can generate (1) solid wastes (scrap fabric, fiber dust, paper tubes, and empty chemical drums), (2) liquid wastes (discarded finishing compounds, rinse waters, and wash water from general cleaning), and (3) air pollutants (VOCs from drying and curing). This section discusses reducing or eliminating these pollutants during finishing operations through source reduction or recycling/reuse.

Fabric coating operations based on latex materials and solvents—such as methyl ethyl ketone, acetone, toluene, and xylene—produce (1) various waterproof products, (2) offset printing blankets, (3) landfill liners, and (4) other engineered textile products. In many cases, they are produced by swelling or dissolving natural or synthetic rubber or latex materials in a mixture of solvents, then spreading or spraying the plasticized material onto fabrics, followed by drying or curing.

Source Reduction

INPUT MATERIAL CHANGES

Cross Linkers

Cotton and cotton blend fabrics often require a finishing step with a reactive cellulose cross linker to reduce fabric shrinking and wrinkling. The use of reactive N-methylol cross linkers in the permanent press finishing step often results in formaldehyde being released. Currently, the most commonly used cross linking compound used in the textile industry is dimethylol dihydroxy ethylene urea (DMDHEU). Releases of formaldehyde resulting from the proper use of DMDHEU are minimal, but they still occur.

Commercially available cross linkers that do not contain formaldehyde include butane tetra carboxylic acid and dimethyl dihydroxy ethylene urea. Neither of these agents contains formaldehyde; however, they are considerably more expensive than DMDHEU and are inferior in performance to DMDHEU.

In the absence of cost-effective substitutes for cross linkers containing formaldehyde, DMDHEU products containing the lowest formaldehyde content should be selected for use whenever possible. Also, the cross linking agent should be properly applied under optimum conditions to reduce the potential for release of formaldehyde.

Builders or Handbuilders

Film-forming agents or builders are often applied during the finishing process to increase the body or stiffness of some lightweight fabrics. Reactive formaldehyde-based N-methylol builders can effectively be replaced by nonreactive agents, such as natural and synthetic polymers, that are less harmful to the environment.

Natural polymers include starches, modified starches, alginates, and gums. The use of these polymers can be relatively environmentally safe; however, they have a high BOD. Synthetic polymers, which include PVA and polyacrylates (acrylic and vinyl), are normally good substitutes for the formaldehyde-based agents. Polymeric-based (nonformaldehyde) fixatives are effective on packages and piece goods, and are competitively priced. However, the manufacture of some of the synthetic polymers has been linked to pollutants being generated.

Softeners

Various natural and synthetic softener compounds are commonly used in the finishing process without regard for environmental considerations. Designed application, performance, and environmental impact of softening agents can vary widely between softener types.

Nonsmoking alternatives to mineral oil and paraffin wax softeners include polyethylene glycol and polyethylene oxide. Triglycerides and oligomeric esters are also being developed as nonsmoking alternatives to fiber finishers and yarn lubricants that allow increased production speeds with low friction while withstanding high temperatures.

Reactive silicone-based softeners can provide enhanced long-term performance, because they do not readily wash off fabrics during home laundering. Silicone-enhanced cationic blend formulations, which are available commercially, are less costly than all-silicone softeners and expand finished design properties, such as increased whiteness.

In the finish process for some textile products, the use of chemical additives as softeners can be eliminated by using cellulose enzymes (liquid acid stable cellulase enzyme) to remove surface roughness. Some types of ring spun yarn that are inherently softer can also be substituted to reduce chemical additives.

Mothproofers

The use of chemicals for mothproofing of wool fabric is often an important finishing procedure, especially in the carpet industry. Traditional mothproofing involved the use of permethrin, which is now under strict regulatory control internationally because of its high aquatic toxicity. Although numerous chemical alternatives to permethrin have been developed, few demonstrate equivalent performance while still being environmentally safe.

Chemical mothproofing alternatives that are currently being used with some success include (1) cycloprothrin (good performance with low aquatic toxicity), (2) diphenylurea (low aquatic toxicity, but not as biodegradable), and (3) sulcofuron (poor affinity when used in certain application methods). Alternatives currently under investigation include nitromethylene and permethrin, and pythroid-based insecticides.

PROCESS MODIFICATIONS AND NEW TECHNOLOGIES

Mechanical Finishing

Chemical usage can often be reduced or eliminated by using properly designed mechanical finishing methods to attain the desired end-use properties of the fabric. Although existing mechanical finishing processes are too numerous to discuss completely, two examples include (1) stabilization of cotton and cotton blend fabrics, and (2) CAD applications.

Cotton and cotton blend fabrics can be stabilized for shrinkage control and sewability without using chemical additives. Important elements include the following:

- Design the process to allow for complete relaxation of the fabric.
- Ensure that this complete relaxation of the fabric meets end-use specifications for the consumer product.

Application of CAD programs (available commercially) in designing the finish process can provide for timely and cost-effective selection of the factors (stitch length, machine cut, and yarn specifications) required for producing knit fabric width and yield that are compatible with the relax dimensions of the greige good. Use of CAD programs should focus on keeping the processing step as tensionless and consistent as possible. In designing the finish process, always consider using commercially available knit finishing equipment that is capable of controlling the fabric width and length dimensions.

Finishing knits mechanically at natural width and yield prevents the need for resins that contain formaldehyde, which inhibits waste system operations.

Mechanical shrinking of fabric by using the rubber-belt method is an example of mechanical finishing in place of chemical finishing (Figure III-16).

Low Add-On Finishing

Several types of low add-on finishing machines are commercially available, all of which apply a very low amount of finish solution to the fabric. Examples of commercial low add-on finishing techniques (segregated by application) include the following:

- Saturation/expression application

  - High extraction pad
  - Vacuum systems
  - Air jet pad

- Controlled application

  - Curved blade applicator
  - Wicking systems
  - Unstable foam
  - Stable foam
  - Gas phase
  - Printing
  - Spray

Low add-on finishing conserves energy, reduces chemical usage rates, prevents chemical leaching or transport, and speeds up production. The most effective or optimum finish distribution with the greatest reduction in chemical add-on is obtained by (1) lowering the wet pick-up level to a minimum level that will still provide a completely wet fabric, and (2) maintaining the minimum temperature in the dryer.

Gaston County Dyeing Machine Company has developed the Chemical Foam System® (CFS), which uses a parabolic applicator system to provide more consistent dwell times for foam in the applicator and a more uniform distribution through the delivery slot across the width of the substrate (Figure III-17). This results in improved end-to-end liquor and chemical uniformity. These foam application units can apply a wide variety of chemicals, binders, dyes, and finishes. Because absolute uniformity of application is required in continuous dyeing of solid shade, foam systems are used in the U.S. mainly to apply finishes rather than colorants. From an environmental viewpoint, CFS offers two possible approaches to eliminating effluent from the chemical application process. One is to take the proper strength of generated foam, when in stand-by or at initial start-up, to pass it through a foam separator unit. The unit removes air from the foam

and returns the chemical concentrate for regeneration. The second means of accomplishing zero discharge is to capture all flush water from the units and collect it in a remote tank, which can be reused pending evaluation.

Advantages are as follows:

- High chemical concentrations in the liquor
- Minimum thickener needs
- Fast rates of wetting and penetration into substrate
- System speeds of 30 to 300 meters per minute
- Reduced consumption of water and energy
- Reduced chemical waste
- Less time required for drying (less water to evaporate)

CFS is ideal for uniformly applying low add-on, expensive chemical finishes to lightweight nonwoven fabrics, such as fluoropolymers, silicones, and wetting agents.

West Point Foundry and Machinery Company developed the Curved Blade Applicator®(CBA) system, which uses a unique film transfer system instead of the foam collapse route. A roller is contacted with a trough of liquor containing the desired application chemicals and selected surfactants that will yield the desired film properties on the roller and on subsequent contact with the fabric. A thin film of liquor is applied to the roll as it contacts the liquid surface. The roll then rotates to a point at which it contacts the moving fabric under fixed pressure. Acting as a curved blade, it brings the film to the interface. Upon contact with the fabric, the film immediately collapses, and the fluid penetrates into the substrate. Two-sided application of finishes—water repellent on one side and softener on the other—is made possible by the unit's low wet pick-up, which uses a double-blade modification of the CBA system. The main concern is generating and maintaining the desired viscosity range for various finish formulations.

The low wet pick-up system that has gained wide acceptance in the large-volume, commodity textile markets is the vacuum extraction and concentrate reisolation system from EVAC Corporation (U.S. representative: Zima Corporation). EVAC systems allow the manufacturer to fully impregnate the textile with liquor, while providing the mechanism to capture and reuse liquor extracted from the system. Full impregnation avoids problems with applicator systems, such as foam- or film-based units, by supplying enough liquor to the substrate to achieve uniform through-structure penetration. The EVAC vacuum system removes the bulk of the entrained liquor, and a unique centrifugal force-based separation unit isolates fine microdroplets of liquor from the air stream; most of the recovered liquor is reused. The only effluent from the system is the chemically-bound water of the substrate, which is emitted as steam from oven stacks.

Wet-on-Wet Finishing

The normal practice is to apply finishes to dry fabric. The drying step can be eliminated by using a wet-on-wet process, in which the substrate comes directly from a previous wet process, and is treated to ensure a very low and even moisture content, thereby eliminating a costly drying step (Figure III-18). Finish can be applied at a higher wet pick-up (amount of solution retained by the substrate). During the process, the finish mix tends to be diluted by the water in the incoming substrate. A control system to sense and adjust the chemical feed to the finish mix saturator is often required.

Fabric Coating

Mills should explore the possibility of using water-based—rather than solvent-based—emulsions for fabric coatings. In many applications, this is a technically feasible substitution. New forms of materials, such as fiber-reinforced composites, may be a suitable replacement for coated fabrics in some applications.

Powder-coating technology offers a pollution-lowering substitute to waterless systems that some use solvent-based coatings. Three applications that have been researched are gravure rollers, powder scatter, and paste-point (Figure III-19).

Recycling and Reuse

Discharge of mothproofing agents from wool carpet manufacturing is one area of wool finishing that is being regulated to reduce aquatic toxicity. One possible method for reducing pollution from mothproofing operation is microemulsion spray and centrifugal extraction to remove excess mothproofing treatment solution from wool substrate, followed by recycling of the pesticide solution (Figure III-20). Using this process can reduce discharges of permethrin to as low as 1.7 grams per ton of wool treated, as compared to 8 grams per ton for conventional hank treatments in dyebaths. The concentrated residue removed from the centrifuge is returned to the process, thereby reducing the amount that is ultimately released to the environment.

PROCESS 7—PRODUCT FABRICATION

Finished cloth or fabric is fabricated into a wide variety of apparel, household, and industrial products. Textile mills produce some of the simpler products, such as bags, sheets, towels, pillowcases, blankets, and draperies. However, goods to be made into apparel or the more complex housewares are usually sold to the cutting trades for fabrication.

Numerous factors affect the amount of waste generated in cutting, sewing, and product fabrication operations. Such factors include pattern layout efficiency and the level of expertise of cutting and sewing operators. The level of waste is also affected by design and planning decisions, information flow, and communication. The amount of waste generated by product fabrication operations varies with the type of goods being produced. On average, open-width knits appear to generate the least waste (13 to 16 percent)

followed by denim manufacturing (16 to 24 percent) and knit tubular (25 to 27 percent). In general, fabric utilization efficiency in cutting and sewing ranges from about 72 to 94 percent. In the U.S., about 800 million yards of denim are produced. The efficiency for cutting denim is typically 84 percent or less. Therefore, cutting waste therefore represents about 16 percent of denim production.

Carpet mills use mostly synthetic fibers, such as nylon, acrylic, and polyester, but some wool and cotton is also processed. Operations at a carpet mill may include some or all of the following processes: bleaching, scouring, carbonizing, dyeing, printing resin treatment, waterproofing, flameproofing, soil repellency, and backing with foamed and unfoamed latex or jute. Carpet backing without other carpet manufacturing may be included in the dry processing mill category. Some carpet is backed with latex in a separate plant; other carpet mills perform latexing in the same plant in which the finishing is performed. The yarn is tufted into a woven or synthetic nonwoven polypropylene or jute primary backing in a dry operation. The tufted carpet is then either printed or dyed. After dyeing, the carpet is dried in a tunnel dryer. The carpet is then ready for application of adhesive and secondary backing.

Carpets and rugs are produced from either dyed or undyed yarns, and may receive a secondary backing of either foam and/or woven material. Processes include heatsetting, tufting (process of attaching carpet yarn to a primary backing material), dyeing, drying, printing (rotary screen/ink-jet replacing flat screen), finishing, and secondary backing (applied with latex).

Industrial fabric scrap, or “edge trim,” consists of cut selvage ends, roll-ends, reject lots, set-up yardage, and other waste materials generated during the manufacture of coated and laminated fabrics. Reprocessing of edge trim is difficult, because industrial fabric end-products are often conjoined hybrid structures. Coatings are designed to adhere inseparably to their substrates; lamination adhesives are selected for their long-term bonding properties. Coatings and laminate films are selected to pair with their substrates through complementary physical properties. This pairing demands that the same polymer is not used for both substrate and top layer, as in vinyl-laminated polyester. In 1993, the industrial fabric industry generated over 6,000 tons of edge trim. This translates into an estimated $250,000 in annual disposal costs. The indirect costs are much greater. Manufacturing that generates this amount of waste during primary processing is inefficient and uncompetitive in today’s global marketplace.

Source Reduction

PROCESS MODIFICATIONS AND NEW TECHNOLOGIES

Recycling Edge Trim

Several techniques may be applicable in recycling edge trim waste, including the following:

- Cryogenic fracture
- Powdering (solid-state shearing)
- Pyrolysis
- Hydrolysis and alcoholysis
- Catalysis
- Biodegradation
- Thermal processing
- Infrared surface heating
- Gamma irradiation

Cryogenic fracture uses liquid nitrogen or other cold-temperature materials to reduce polymers to a temperature below their glass transition temperatures, which makes the coatings or films brittle, and easily broken and separated. Research has shown that additional energy input is required, in the form of mechanical or ultrasonic vibration, to complete the fracturization. However, unacceptable levels of residual textile fibers are left behind in the reclaimed vinyl, and "gum up" the processing machinery, and making the reclaimed vinyl unsuitable for most applications. Redesigning the coatings and laminates might lead to ready cryogenic separation without the undesirable residual contamination.

Powdering, or solid-state shear extrusion, of edge trim by low-temperature grinding at high pressures may be a workable method of reducing these composite fabrics for additional processing. The key element is the use of high pressure combined with low temperatures.

A North Carolina industrial fabric manufacturer has implemented a pilot study to use a new ***cryogenic freezing and grinding process***—a combination of the two aforementioned processes—that would enable it to recycle polyvinyl chloride (PVC)-coated fabric trim waste into reusable plastic resin powder. This would reduce the quantity of virgin resin and filler purchased, and eliminate the costs of disposing of the PVC trim in landfills (see Case Study No. 11). The CRYO-GRIND® Liquid Nitrogen (LIN) Grinding System was developed by Air Products of Pennsylvania.

Pyrolysis is the thermal decomposition of organic material in an oxygen-deficient environment. Products-To-Oil, Inc., has developed a thermal organic reactor to produce fuels and chemicals from various organic feedstocks, such as waste automobile tires. The reactor uses molten lead in a sealed chamber to reduce the organic material to its organic residues, without harmful emissions resulting from incomplete combustion. A conveyor and filter system separates and removes the residue, allowing a continuous feed process. Edge trim materials, which are thinner and contain more digestible energy than tires, are expected to be readily processible in these reactors. Versions of the pyrolytic kiln are operating nationwide for commercial tire disposal and electric co-generation.

Hydrolysis and alcoholysis are chemical processes that are used to reduce polymers to their constituent monomers.

Catalysis involves the use of additive or accelerating agents that are not used up during the chemical reaction.

Biological organisms can, and have been tailored to, break down specific synthetic chemicals, such as the oil-eating microbes (bioremediation).

Thermal processing involves applying heat to melt the polymers into their constituent parts. Unfortunately, this method is not very effective for materials having specific melting point properties, such as polyester and vinyl. However, selective heating through microwaves can be used to impregnate one of the polymers or the lamination adhesive with a heat-absorbing powder to speed the separation process.

Infrared surface heating of the fabric surfaces to loosen coatings or adhesives may prove effective if integrated into the production process, in which layers would be separated immediately after they were trimmed from the roll.

Gamma irradiation might induce favorable changes in the structure of some coated and laminated fabrics, such as increasing crosslinking in certain polymers. Exposure to the nonionizing radiation would not cause the fabric to become radioactive.

IMPROVED OPERATING PRACTICES

Pattern Marker Efficiency

Pattern marker efficiency is critical in reducing the amount of cutting room waste, but it depends strongly on garment design factors, such as shape and seam location, size assortment required by retail sales, fabric width, and other technical considerations. Cutting practices that minimize waste in view of these factors are well known, and material utilization departments are skilled at optimizing cutting efficiency. Waste minimization in this area is a highly developed science, and many operations use sophisticated computer algorithms and other techniques. Improvements can be made through design modifications or better planning, such as coordination of fabric suppliers and retailers.

Carpet Manufacturing

P2 opportunities that have been implemented in carpet manufacturing include the following:

- Reducing size of tufting dyeheader samples (yarn QC check) from 1 yard to 8 inches, a savings of 80 percent
- Reducing "runout," during tufting yarn changeovers, to a minimum distance, resulting in an average savings of about 25 inches of carpet
- Converting from lap to butt seams in carpets, which can reduce seam waste by 50 percent
- Improving worker training and attention to cutting (straighter cuts reduce trimming waste prior to seaming), and width control in tufting and printing
- Minimizing excessively large samples for testing, as for flammability

Recycling and Reuse

Seam trimmings, selvage pieces, and cut-outs can be collected and segregated in an organized manner to facilitate recycle and reuse. If properly handled, these waste materials can often be sold as raw materials for textile-related production activities. Suggestions for reducing labor costs while increasing resale value include (1) using traversing wind-ups to form neat rolls of trimmings with standard dimensions, and
(2) segregating cut-outs and selvage by fabric type.

Latex Recovery in Carpet Manufacturing

Latex is an expensive material that is used in carpet manufacturing. The latex-laden stream is too dilute to reuse and is discarded, causing a color and BOD problem. Recovering latex by UF is a standard operation for many carpet manufacturers. Benefits of latex recovery include lower total use of latex and BOD reduction. Additionally, the permeate is an excellent process for cleaning water, because it is loaded with surfactant.

Reuse of Cutting Room Fibers

At present, denim cutting waste is recycled into end-uses, such as paper making. The value of this fiber in such cases is not as high as its value in denim manufacturing. Manufacturing procedures must be developed to reclaim fiber from denim cutting waste and reuse it, thereby reducing the cost of the raw fiber and dyeing requirements, which would also reduce the pollution associated with dyeing, because the indigo denim color would already exist in the reclaimed fiber.

Recycling of Polyester from Fabric Waste

The Department of Textile Technology at Anna University in Madras, India, conducted research to recycle polyester from polyester/cotton blended fabric waste (tailoring bits). The fabric waste is boiled with soda and soap to remove the impurities and is then carbonized with 70 percent sulfuric acid to remove the cotton component. The polyester fibers are mechanically separated from the wastes by using a licker-in type opener, or shirley analyzer. Recovered fibers are characterized and hand-spun into yarns, which are used as weft and woven with 100 percent cotton warp on a handloom. Fabrics can be used as furnishings material. Nonwovens prepared with these fibers can be used as floor coverings, table mats, filter pads, backing, and packing material.

Work is also progressing to recover polyester by chemical and thermal dissolution techniques. Prior to polyester recovery, the cotton component is acetylated and recovered in the powder form. The resulting polyester powder can be used to produce engineering plastics and monofilaments.

Recycling of Carpet and Floor Coverings

BASF has established a program in which carpets made of postdyed and predyed BASF nylon are backstamped at the mill. At the end of the useful life of the carpet, the end-user may return the carpet to a BASF collection point, after which BASF will recycle the fiber for other products.

Collins and Aikman converts discarded vinyl-backed floor coverings into weather-resistant picnic tables and park benches. The floor covering is chopped into granules, and reprocessed under heat and pressure, to create durable, water-resistant materials that can be molded into furniture.

Recycling Automobile Seatbelts

Akzo Faser of Germany manufactures polymers and uses them to make specialized yarns for industrial applications. In 1993, the German government issued a directive requiring plastic materials used in automobiles to be recycled at a rate of 20 percent by 1996, and 50 percent by 2000. Included in the plastics category were seatbelts manufactured of spun-dyed black yarn; the yarn type was Diolen® Polyester 177/178T/56. Akzo initiated a seatbelt recycling program. Stoppers, tags, and seams removed from the seatbelts to eliminate any materials other than polyester. Glass fiber, in the form of injection-molding granules, was fabricated from regranulated raw material, or used seatbelts. The glass fiber was spun into high-tenacity filament yarns dyed with carbon black, and refabricated into seatbelt webbing. The quality of the reprocessed yarn was comparable to original yarn made of virgin raw material.

Recycling and Reuse of Apparel

Postconsumer recycling of discarded blue jeans or other denim products could be combined with technology to reuse cutting room denim waste. U.S. denim producers and apparel manufacturers dispose of an estimated 70 million pounds of denim scrap in landfills each year.

Attempting to reprocess fibers consisting of 100 percent garnetted denim poses significant quality barriers. However, the International Textile Center at Texas Tech University investigated adding quantities of low-grade Pima cotton as a “sweetener,” or carrier fiber, to produce a blend level that would foster the processing of reclaimed fiber into acceptable denim fabrics. Using Pima cotton as a carrier enabled rotor spinning of the garnetted, recycled cotton fabric. A blend consisting of 70 percent reclaimed fiber and 30 percent Pima cotton experienced the greatest success during processing. Quality characteristics of the recycled denim fell within the Levi Strauss acceptable ranges.

Martin Color-Fi has developed a process that grinds, melts, and extrudes polyethylene terephthalate (PET) from plastic bottles to produce fiber for use in carpets, rugs, home furnishings, apparel, and automotive and industrial fabrics. Because the polymer used in beverage bottles is of a higher grade than that found in virgin polyester fiber, NatureTex™, which is Martin’s trademarked 100 percent recycled PET, features attributes that other fibers have been unable to match.

Burlington manufactures Reused Denim™ made of 50 percent denim scraps and Tencel denim, which is manufactured by using a nonchemical solvent spinning process in which the dissolving agent is recycled, thereby eliminating all environmentally harmful effluent. Burlington also introduced Bottle Blue Denim™, which contains a recycled fiber called EcoSpun™, which Wellman, Inc., manufactures from recycled PET bottles.

Lee Apparel and Swift Textiles have initiated a cooperative effort with plastic recyclers. Their new line of Soda Pop Denim™ consists of 80 percent cotton and 20 percent PET from recycled plastic soft drink bottles. Each pair of jeans contains the equivalent of two large soda pop bottles. Soda Pop Denim can be used for both apparel and nonapparel products.

Other efforts include transforming worn-out garments into wiping rags. Old clothing is the most readily reused and/or recycled residentially generated textile category. State and/or local mandates to recycle a percentage of this waste stream are providing the impetus to add new materials to existing collection programs.

Current waste characterization studies do not distinguish between recyclable, or marketable, and nonrecyclable textiles. During 1990, textiles comprised about 5.3 percent of the discarded municipal solid waste in the U.S. About one-third of the total textiles disposed are recyclable. Marketable textiles include old clothing, bedding materials, towels, furniture cushions, carets, nylon, shower curtains, and oily rags from garages. Historically, most textiles collected in the U.S. are reused in their original form for their intended function. Used clothing is generally collected, sorted, wholesaled by the pound or piece, and retailed to the general public mainly in developing countries. Ripped or stained items may be sold for rugmaking, auto insulation, wiping rags, or blanketmaking.

In Germany, a recycling company collects selected textiles and shoes nationally. Many of these items are thrown away, not because they are worn out, but because they are no longer fashionable or they no longer fit. Materials are exported for sale to countries in the developing world, and a small proportion is given to relief organizations for emergency situations. Alternative uses for unwearable clothing and shoes include incineration and the manufacture of insulation board from granulated shoes.

SECTION IV

CASE STUDIES

SECTION IV
CASE STUDIES

CASE STUDY NO. 1—Dyeing and Finishing

Industry: **Bloomsburg Mills, Inc. (SIC 2269)**
Pollution Prevention Application: **Chemical Substitution, Equipment Upgrade, Recycling**

Background

At its Monroe, North Carolina, facility, Bloomsburg Mills, Inc. (Bloomsburg), scours, dyes, and finishes about 22 million yards of fabric each year. The basic flow of material through the plant begins with the scouring of incoming greige and yarn-dyed fabrics. The scoured fabric is then jet-dyed at high temperature and pressure. The application of a chemical or mechanical finish is the last process before the fabric is shipped to cutting and sewing facilities.

Bloomsburg has actively pursued and implemented waste reduction and recycling programs throughout all production processes. These programs were implemented in response to increased landfill fees and regulatory requirements and as part of the membership requirements of the American Textile Manufacturer Institute's Encouraging Environmental Excellence Program.

Waste Reduction Activities

- Most of the greige or yarn-dyed goods arrive at the plant in polyethylene plastic bags. Bloomsburg purchased a baler to compact this material for shipping to a recycler.

- Bloomsburg cuts the length of rolled paper tubes used to handle greige goods during the set-making process to reduce the width of the final product, and then uses the tubes to ship the finished goods to cutting and sewing operations.

- Racks and containers are located at the work stations so that operators can sort plastic bags and paper tubes as the waste is generated; this sorting eliminates the need for a resorting step later in the waste management process.

- Many of the chemicals used in the scouring and dyeing operations arrived in fiber drums that were shipped to the landfill. Currently, chemicals used in large quantities are brought to the plant in reusable tote tanks, which are returned to the vendor after consumption. Chemicals used in smaller quantities are supplied in reusable plastic drums.

- Tetrachloroethylene, biphenyl, and trichlorobenzene are constituents of the dye carrier chemicals that are used to promote level dyeing. Tetrachloroethylene and biphenyl usage exceeded reporting requirements listed under the Superfund Amendments and Reauthorization Act (SARA) Title III, Section 313. In an effort to reduce regulatory burdens, Bloomsburg has discussed the elimination of these chemicals with supply vendors, who substituted a dye carrier containing methyl naphthalene and Rule 66 solvents (Rule 66 solvents are designated as nonphotochemically-reactive and, therefore, are exempt from most reporting requirements). This dye carrier subsequently reduced the release of the hazardous air pollutants. Also, the company substituted a solvent containing isopropanol and heptane as a suitable spot-washing alternative for 1,1,1-trichloroethane, another hazardous air pollutant. No loss of quality was noted with either of the substitutions.

- All cloth seam cuts and small waste rags are baled and shipped for recycling.

- Aluminum cans are collected and donated to local Boy Scout troops.

- Process heat and water is conserved throughout the facility. During the scouring process, water is conserved by using a countercurrent washing procedure on the scouring range. The cleaner wash water enters the exit wash unit and counterflows back toward the dirtier units. Countercurrent washing provides a more efficient, cleaner wash and requires less water. During the dyeing process, cooling water is used to cool the jet dyeing machines. After passing through heat exchangers, the heated water is used in initial baths and washing in other stages of the process, thereby reducing consumption of heating fuel. Instrumentation and process controls for the dyeing process were upgraded from manual to computer control. The controlled time of the wash after dyeing has significantly reduced consumption of heating fuel and usage of water.

Waste Reduction Results

The dye carrier substitution reduced emissions of tetrachloroethylene, a hazardous air pollutant, by 91 percent—from 64,713 pounds in 1988 to 5,932 pounds in 1993.

The computerized automation system on the dyeing process has reduced water consumption by 28 percent and fuel consumption by 15.9 percent.

As a result of the reuse and recycling programs, solid waste disposal from the plant fell 85 percent, from 3,744 cubic yards in 1993 to 560 cubic yards in 1994. By receiving and storing process chemicals in reusable totes and plastic drums, the company eliminated the disposal of 50 drums to the landfill each week. The following table presents a breakdown of the quantity of material diverted from the landfill and the cost savings realized from eliminated disposal costs and resale of the collected material.

Costs

No information is available concerning costs.

Annual Savings

Annual savings realized by Bloomsburg, through the implementation of its waste reduction and recycling programs, are as follows:

Item	Waste Diverted From Landfills (tons)	Landfill Savings ($)	Sales Revenue From Recycling ($)
Paperboard	40.6	1,218	954
Rags	36.4 (52 bales)	1,092	0
Plastics	20 (32 bales)	600	800
Aluminum	0.8	24	0
Fiber drums	21.2	636	0
Paper tubes	30	900	33,000
TOTAL	149	4,470	34,754

By diverting 149 tons of waste from the landfill, and after subtracting the cost of strapping, the company realized $38,881 in disposal costs savings and recycling revenue. This figure does not include savings from reduced consumption of water and fuel oil.

CASE STUDY NO. 2—Textile Manufacturing

Industry: **Cleveland Mills Company (SIC 2261)**
Pollution Prevention Application: **Recycling, Chemical Substitution, Equipment Upgrades**

Background

Cleveland Mills Company (Cleveland) manufactures knit fabric for apparel end-use—mainly jersey and mesh knits. About 330,000 pounds of material are knitted, dyed, finished, and shipped from the facility each week. Cleveland's waste reduction program has significantly reduced wastewater releases, air emissions, and solid and hazardous waste streams.

Waste Reduction Activities

- Cleveland's solid waste reduction program centers around an on-site recycling center. Materials recycled include corrugated cardboard, cardboard tubes and cones, paper, plastics, and wooden pallets. The plastic recyclable material consists of cones, tubes, bagging, strapping, and bale wraps. Yarn manufacturing waste, yarn mill card waste, knitting rags, and finishing rags are collected and baled; they are then sold to a textile waste recycler. Office paper and scrap metal are also collected for recycling.

- Cleveland has converted to bulk or tote chemical storage systems. All drums, and the fiber, plastic, and metal containers are returned to the suppliers. Purchasing its own bulk storage and tote stations has enabled the company to purchase chemicals at volume prices, reduce the number of containers sent to the landfill, and prevent numerous minor spills. Also, the wooden pallets arriving at the facility are either returned to suppliers, reused to ship goods to customers, or recycled.

- Salt brine replaced sodium sulfate in the dyeing operation. By installing a brine water mixing and distribution system, the company prevented 17,000 pounds of previously unrecyclable sodium sulfate bags from entering the waste stream.

- Cleveland has also reduced the concentration of pollutants in the wastewater. After high-pollutant-loading chemicals were targeted for optimization and substitution through a chemical evaluation program, the company subsequently reduced pollutant loading to the treatment plant.

- By upgrading the wastewater treatment system, the facility significantly reduced loadings of biological oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) to the First Broad River. The upgrade involved improved flow control throughout the entire system, which resulted in increased detention time in the contact chamber. The longer detention time, in turn, improved the sludge handling and dewatering systems. The company also installed an outlet diffuser to facilitate additional pollutant breakdown and reduce the possibility of toxicity problems in the river.

- Cleveland substantially reduced formaldehyde air emissions from the manufacturing process by using low-shade resins that contain a lower percentage of the chemical; quality and performance levels were not compromised by the substitution.

- Air emissions from the facility were further improved by replacing the coal-fired boilers with cleaner natural gas-fired boilers.

Waste Reduction Results

Mainly by diverting waste materials to recycling markets, Cleveland reduced the quantity of solid waste sent to the landfill by 50 percent, or 600,000 pounds, between 1991 and 1994. By 1994, Cleveland was recycling 79 percent of its solid waste stream.

By optimizing and substituting pollutant chemicals, and upgrading the wastewater treatment system, the company reduced BOD, COD, and TSS by 50, 24, and 60 percent, respectively.

Cleveland projects that formaldehyde emissions to the air will drop by 84 percent, from 3,600 to 580 pounds per year, as a result of the switch to low-shade change resins in the production process. In addition to reducing air emissions, with the installation of the natural gas-fired boilers, each year the company will eliminate 220,000 pounds of fly ash that was generated by the coal-fired boilers.

Costs

No information concerning costs was available.

Annual Savings

No information concerning annual savings was available.

CASE STUDY NO. 3—Screen Printing

Industry: **T.S. Designs, Inc. (SIC 2399)**
Pollution Prevention Application: **Water Conservation, Chemical Substitution, Recycling**

Background

T.S. Designs (TSD) is a textile screen printing facility that employs 70 people. The company processes about 4.5 million T-shirts, sweatshirts, socks, and piece goods each year on seven automatic screen printing presses. In addition to conducting the actual screen printing process, TSD prepares all of its screens. Screen preparation involves computerized production of the artwork, preparation of color separation, and production of the film positives at the company's on-site photographic darkroom. The polyester screen is covered with emulsion. For the actual screens, film positives are placed on top of the polyester screen and exposed to light. After the screens have been used for printing, they are cleaned and reclaimed.

A few years ago, TSD became concerned with the adverse impact that the company and the entire screen printing industry may have on the environment. The company undertook several programs in an effort to diminish the environmental impact of its operations.

Waste Reduction Activities

- After a screen printing production run, the screens are rinsed in a reclamation tank to remove any emulsion from the screen mesh. Haze and stains are then removed in a tank that contains a concentrated alkaline cleaning solution. Degreasing, the final cleaning process, is accomplished with detergent and water. Previously, chemicals were only used once before being washed down the drain.

  The screens were reclaimed with Autostrip Powder™, a strong oxidizing solution, which was wiped onto the screens with a sponge and then removed with a power washer. Water and chemicals both went down the drain after being used only once, even though the chemicals were not exhausted. To reduce chemical consumption, the company installed a 43-gallon reclamation tank to continually filter and circulate the cleaning solution past the screen suspended in the reclamation tank. This new method effectively removed the emulsion, and the reclaiming solution can now be used continuously for about 1 month. These modifications resulted in both a large reduction in the quantity of reclaimer used and, as a less concentrated solution was required, use of a less hazardous cleaner (CPS Liquid Stencil Remover™).

  For the stain and haze removal process, screens were rinsed in ICC 757 Ghost/Haze Remover™ prior to degreasing. This chemical contained hazardous components and was flammable. With the installation of another holding tank, a less hazardous and flammable solution, which comprises equal parts of water and Easi-Solv 201™, can be used. This modification has extended solution lifetime such that it is added only to compensate for evaporation and spillage.

  With the installation of a holding tank, all water previously used in the degreasing process, which went down the drain, is now supplemented with city water if needed, and is saved, and recycled for use in the reclamation cleaning process.

- The company formerly used platen adhesives to affix garments to print platens. These adhesives are generally solvent-based and release significant quantities of volatile organic compounds (VOCs) to the atmosphere. Until 1992, TSD used about 4,800 cans of solvent-based aerosol platen adhesive each year. The company plans to eliminate the use of these solvents in 1995 by substituting a water-based adhesive. The water-based adhesive system involves purchasing the solution in bulk quantities and applying it to the platens with an automated spray apparatus. Aside from eliminating a source of VOCs, purchase of adhesive in bulk is markedly cheaper than in individual cans.

- In the past, used fixer and silver thiosulfate generated in the company darkroom was poured down the drain. By installing a simple ion-exchange silver recovery unit, the company now receives some of the profits from reclamation of the silver metal. In the first year of operation, about 67 troy ounces of unrefined silver were recovered. Therefore, potentially toxic silver was kept out of the sewer system, and the company realized an additional source of revenue.

Waste Reduction Results

Since the holding tanks for water and cleaning chemical reuse were implemented, water usage at TSD has fallen by about 650 gallons per week, and consumption of reclaiming solution has dropped 75 percent. The haze remover chemicals have never been replaced except to compensate for losses from splashing, runoff, or evaporation.

Costs

See summary table under Annual Savings.

Annual Savings

Capital and annual costs, in addition to annual savings, estimated by TSD are as follows:

Equipment	Capital Cost ($)	Item	Previous Annual Cost ($)	Current Annual Cost ($)	Annual Savings ($)
Water-based platen adhesives	20,000	Solvent-based adhesive	12,096	1,089	
		Water-based adhesive	0	1,650	
		Total	12,096	2,739	9,357
Holding tanks for cleaning chemical and water reuse	5,000	Screen reclaimer	3,528	624	
		Haze remover	1,248	56	
		Water/sewer fees	2,197	1,990	
		Total	6,973	2,670	4,303
Silver recovery system	1,315	Recovered silver	0	(173)	173
TOTAL	26,315		19,069	5,236	13,833

Other Activities

Aside from implementing P2 programs at its facility, TSD is extremely active in promoting environmental stewardship in the local industrial community. Mr. Eric Henry, the company president, founded Environmentally Responsible Businesses of Alamance County, a nonprofit group that currently boasts a membership of 40 companies.

CASE STUDY NO. 4—Knitting, Dyeing, and Finishing

Industry: **Westpoint Stevens (SIC 2258)**
Pollution Prevention Application: **Chemical Substitution, Equipment Upgrades, Recycling**

Background

Alamac Knits is the Apparel Fabric Division of Westpoint Stevens. Its Lumberton, North Carolina, facility employs about 1,000 people, and 1994 production totaled 38,255,000 pounds of knit fabrics for the clothing market. The knit fabrics production process involves knitting, dyeing, and finishing operations.

Waste Reduction Activities

In accordance with the company's proactive environmental policy, Westpoint Stevens implemented a range of P2 programs at the Lumberton facility.

- The company was classed as a major emissions source under Title V of the Clean Air Act. To reduce the regulatory burden associated with this classification, the company contacted chemical vendors to obtain alternate chemicals that emit fewer hazardous air pollutants. These negotiations reduced the quantity of the finishing chemicals emitted from the plant. Emissions were further reduced when No. 6 fuel oil was replaced with cleaner natural gas as boiler fuel.

- Jet-dyeing machinery was upgraded to low-liquor-ratio machines with shorter cycles. This modification reduced usage of chemicals, water, and energy.

- Extensive recycling operations are conducted at the plant for plastic cones, plastic, cardboard cones, wooden pallets, cotton wipes, and scrap cloth.

- Eleven bulk storage tanks were installed onsite to store process chemicals. Through negotiations with vendors, wooden pallets and 55-gallon shipping drums are now returned to the suppliers. This policy alleviates the need to maintain a storage location for these items onsite and conserves landfill space.

- Cardboard spinning tubes were unrecyclable, because heavy glues are used to manufacture them. These tubes were replaced with recyclable polyvinyl chloride (PVC) cones, which not only last five times longer but can be recycled when they wear out.

Westpoint Stevens has adopted a chemical approval process, wherein any new chemical must be approved by a committee before it is used in the plant. Chemicals are evaluated for functional use, financial feasibility, employee safety, and environmental and waste treatment impact. The approval process has enabled the company to (1) choose alternative chemicals without toxic ingredients that may harm the Lumber River, (2) find dyestuffs that offer lower concentrations of heavy metal, and (3) avoid using chemicals that are considered dangerous for storage and employee handling.

Waste Reduction Results

- Chemical substitutions and the conversion to natural gas for boiler fuel resulted in the company's reclassification as a minor source under Title V.

- Upgrades of dye machinery decreased consumption of dye chemicals by 60 to 70 percent.

- From 1991 to 1994, total pounds of solid waste landfilled fell by 39 percent, from 882 tons to 540 tons. A similar improvement was evident in the percentage of solid waste recycled—2,280 tons of material were recycled in 1994, which was an increase from 55 to 75 percent of all solid waste generated.

Costs

No information concerning costs was available.

Annual Savings

The company has not calculated the savings from the new equipment and chemical substitution, but the savings from increased recycling efforts from 1991 through 1993 were $7,692. In 1994 alone, the company collected over $160,000 in revenue from recycling efforts.

CASE STUDY NO. 5—Nylon Hosiery Manufacturing

Industry: **Americal Corporation (SIC 2342)**
Pollution Prevention Application: **Chemical Substitution, Process Modification**

Background

Americal Corporation (Americal) produces nylon hosiery that is dyed during production. The wastewater discharged from the dyeing process to the publicly-owned treatment works (POTW) in Henderson, North Carolina, results in high levels of BOD, COD, and ammonia (NH_3-N). As requirements by the State of North Carolina, concerning the levels of pollutants entering the city's waste treatment system, became more stringent, Americal responded with efforts to develop methods of reducing levels of the pollutants.

Waste Reduction Activities

A survey of the dyeing plant revealed several areas in which changes could be made:

- Oil and grease discharges were reduced through improved accuracy in monitoring and testing the oil levels in the nylon yarns.
- In the dyeing process, acid dyes, disperse dyes, and softening chemicals are used. To help reduce the levels of pollutants, Americal investigated four dye manufacturers and five auxiliary chemical manufacturers and determined which products had the least amount of BOD, COD, and NH_3-N. These products were implemented in the dyeing process.
- Americal also experimented with temperature regulation schemes. In testing for optimum temperatures, Americal discovered that, at 180°F with a 15-minute extension period, the dye exhausted more completely. More importantly, this temperature allowed for a reduction in chemical use, which, in turn, resulted in lower BOD, COD, and NH_3-N bath levels.
- To pretreat its waste water, Americal converted a cement tank into an aerated equalization basin that allowed for reduction in pollutant levels of effluent.

Waste Reduction Results

Following is a comparison of average effluent levels (milligrams per liter [mg/L]) recorded before and after the grant study:

Parameter	Before Study (mg/L)	Current Tests (City of Henderson) (mg/L)
BOD	1,120	460
COD	3,200	1,850
NH_3-N	45	1

Costs

No information concerning costs was available.

Annual Savings

Because of these reductions, Americal has saved about $35,000 annually on waste treatment surcharges levied by the City of Henderson.

Other Activities

Since the grant, Americal has installed new low-liquor-ratio dyeing equipment that requires fewer chemicals and less water.

CASE STUDY NO. 6—Acrylic Yarn Production

Industry: **Amital Spinning Corporation (SIC 2281)**
Pollution Prevention Application: **Water Conservation and Reuse, Solid Waste Reduction, Energy Conservation**

Background

Amital Spinning Corporation (Amital) produces packaged, custom-dyed, high-bulk acrylic yarn for the textile industry. To achieve significant energy and cost savings, Amital has combined a process water reuse system with a solid waste recycling system.

Waste Reduction Activities

- To reuse and conserve process water, Amital collected noncontact cooling water to use in the color kitchen for the preparation of dye liquors. Using this water allows the dye liquors to be prepared at high temperatures, thereby reducing steam requirements during dyeing. Process water is recovered, and the expended chemicals are replenished. These changes reduce water and energy consumption and costs. Other savings include reductions in (1) the quantity of batch chemicals, and (2) the time required for heating, by 8 to 10 minutes per cycle.

- Amital also increased its profitability by implementing a solid wastewater recycling and reuse program for various cardboard, metal, plastic, and acrylic fiber components. Waste products are recycled back to the same process or sold through an outside market. Disposal costs for these recyclables are, therefore, avoided. A baler was installed to facilitate program operation. Of 1.1 million pounds of solid waste generated in 1992, the company recycled about 933,000 pounds.

Waste Reduction Results

From 1988 to 1992, Amital reduced the amount of wastewater generated per pound of yarn from 19.34 gallons to 3.19 gallons. Average daily wastewater volume was reduced from 320,000 gallons to 112,000 gallons, and production increased from 12 to more than 25 batches of yarn per day. Through the recycling program, the solid waste stream destined for disposal was reduced by 933,000 pounds per year, or an annual solid waste reduction of about 80 percent.

Costs

No information concerning costs was available.

Annual Savings

In 1992, Amital’s savings totaled about $800,000, from (1) avoiding solid waste disposal costs, (2) reducing water use ($185,000), and (3) reducing energy use ($500,000). Amital is also saving about $45 per batch in chemicals. The company netted about $100,000 revenue through its solid waste recycling and reuse program.

CASE STUDY NO. 7—Spun Cotton Yarn Manufacturing

Industry: **Harriet & Henderson Yarns, Inc. (SIC 2342)**
Pollution Prevention Application: **Recycling and Reuse**

Background

Harriet & Henderson Yarns, Inc. (HHY), manufactures spun cotton yarn at (1) four plants in Henderson, North Carolina, (2) two plants in Clarkton, North Carolina, and (3) one plant in Summerville, Georgia. Part of the manufacturing process involves cleaning the raw cotton to remove bits of crushed cotton stalks and seeds, dust, and short cotton fibers. All of this cleaning by-product was formerly baled and sent to the local landfill. The four Henderson plants generate 80 bales (44,000 pounds) of the cleaning by-product per week. Landfilling the material costs about $10.00 per bale in Vance County.

Waste Reduction Activities

HHY sought alternative ways to use or manage the material to avoid landfilling. By modifying the cleaning operations so that more of the short fibers could be recovered, HHY is currently selling about 5,300 pounds per week (10 bales) to textile by-product brokers at 1.5 cents per pound. After modifications have been completed at all plants, HHY expects to sell 16,000 pounds per week.

Agents with the Vance County Cooperative Extension Office advised that the material has potential uses in agriculture, including the following: (1) as a soil amendment and nutrient source for crops, (2) as a soil stabilizer for erosion control, and (3) as a feed source for livestock. To research and test these applications, HHY received a Challenge Grant from NCDEHNR’s Pollution Prevention Program to evaluate these potential uses. HHY matched the grant with its own funds.

The by-product can feasibly be used as a soil amendment to supplement commercial fertilizer or as a soil stabilizer to replace wheat straw and asphalt, but it must first be milled to permit even distribution for either of these applications.

The most promising of the alternative uses was as a feed source for livestock. Cotton by-products—such as cottonseed hulls and cottonseed meal—are already widely used as livestock feed ingredients. Feeding studies by animal nutrition specialists at North Carolina State University revealed that the cleaning by-product is comparable to low-quality hay.

Hay of this quality has a value of about 1.5 cents per pound, but the HHY policy is to provide the by-product to interested livestock producers at no charge. HHY currently distributes an average of 20 680-pound bales per week, and there is a waiting list of farmers requesting this free feed. After further modifications, the company expects to be able to supply 50 bales per week.

The success at HHY has been advertised among Cooperative Extension personnel across the state, and other cotton processors have begun to evaluate the potential to use their cleaning by-products for cattle feed.

Waste Reduction Results

HHY eliminates about 80 bales (44,000 pounds) of the cleaning by-product per week by selling it to textile by-product brokers.

Costs

No information concerning costs was available.

Annual Savings

Annual savings in landfilling costs are estimated at $41,600.

Annual revenue generated by the sale of short fibers to textile by-product brokers is estimated at $12,480.

CASE STUDY NO. 8—Textile Processing

Industry: **Neuville Industries, Inc. (SIC 2252)**
Pollution Prevention Application: **Solid Waste Reduction, Recycling**

Background

The cotton and blended hosiery manufacturing process at Neuville Industries, Inc. (Neuville), consists of knitting, dyeing, and boarding the hosiery products. Using fabrics and chemicals, that are used in this process and in fabric processing, produces large solid waste streams that comprise cardboard, plastic, paper cones, and polybags for packaging.

Waste Reduction Activities

Neuville established a recycling committee to evaluate, organize, and implement solid waste reduction techniques to reduce the cost burden of solid waste disposal. The committee—which comprised the facility safety inspector and members of the housekeeping, accounting, knitting and seaming, and training staffs—first established a recycling program in 1990. To spark immediate awareness of the need for recycling and facilitate employee involvement, the committee organized an employee suggestion program. Following is a summary of the programs implemented to recycle office, purchasing, and processing wastes.

- Office and Break Room Waste
  - A "bag it" program, in cooperation with Garbage Disposal Systems (GDS), to handle paper and aluminum can waste, including color-coded waste cans to ensure effective separation of different paper grades
- Purchasing Waste
  - Cardboard recycling program, in cooperation with GDS
  - Plastic cone recycling program in cooperation with GDS
  - Selling paper cones
  - Reuse of most shipping pallets in plant
- Processing Waste
  - Donation of hosiery toe clippings to interested parties

The recycling committee is seeking other recycling programs for additional waste streams such as polybags from packaging, knitting oils, and some plastic cones that GDS will not accept. The program implemented an employee benefit program to funnel savings back to the employees and facilitate ongoing employee involvement. The committee meets biannually.

Waste Reduction Results

From 1990 to 1992, Neuville reduced its solid waste disposal from 266 cubic yards per week to 180 cubic yards per week.

Costs

No information concerning costs was available.

Annual Savings

In 1992, Neuville's reductions in solid waste avoided costs of $12,738 for disposal charges. Also, in 1992, Neuville received $2,389 for recyclable materials. Neuville's total 1992 savings was $15,127.

CASE STUDY NO. 9—Textile Manufacturing

Industry: **Riddle Fabrics, Inc. (SIC 2250)**
Pollution Prevention Application: **Process Modification, Chemical Reuse**

Background

Riddle Fabrics, Inc. (RFI), uses a bleaching process in the manufacture of cotton label tape for the garment industry. Because the bleaching bath is frequently dumped, and chemicals are used in other systems, the level of BOD exceeds compliance limits. RFI invited representatives of the State of North Carolina Pollution Prevention Program (PPP) to survey the plant's operation and provide information on waste reduction opportunities.

After the site visit, PPP prepared a report in which it outlined several options for process modifications and housekeeping methods that could help reduce the pollutant levels.

- By using the same vat for bleaching and rinsing, RFI was able to reuse the rinse bath for bleaching purposes but needed to discharge the bleach bath frequently. Following PPP's suggestion, RFI installed a holding bin for the bleach bath, which is contained in the bin during the rinsing stage and is pumped back into the vat before the rinse bath is removed. Through titration, the bleach bath concentration is analyzed and reconstituted as needed. This process modification has reduced BOD levels to within compliance limits, and water usage has also decreased.

Waste Reduction Results

RFI has reduced its BOD levels from 842 mg/L to 400 mg/L. Water usage has decreased by 5,000 gallons per year.

Costs

No information concerning costs was available.

Annual Savings

The plant has realized $1,650 in annual savings from reductions in chemical and water usage and wastewater treatment surcharges. RFI also benefits from avoiding permit fines.

CASE STUDY NO. 10—Textile Manufacturing

Industry: **Ti-Caro, Inc. (SIC 2331)**
Pollution Prevention Application: **Process Modification, Chemical Substitution**

Background

Ti-Caro, Inc. (TCI), is a textile manufacturing company that produces dyed and finished fabrics. Pollutant levels (320 mg/L) in the effluent discharged exceeded compliance limits (300 mg/L) set by the City of Newton. To reduce these levels, the company studied several areas of process modification.

Waste Reduction Activities

Through this research, TCI found that, by pretreating the wastewater in an aeration tank outside the plant and using sulfuric acid to neutralize the liquid, it could reduce the pollutant levels, but it could not reduce them enough to comply with limits. TCI implemented several source reductions options to further reduce the pollutants.

- TCI now requires environmental impact statements on all knitting oils, softeners, winding emulsions, dyes, and other chemicals before putting them into production.
- Fabrics are bleached by a pad batch process that reduces quantities of chemicals and water.
- All exhaust dyeing systems are run with reduced liquor ratios of 10:1.
- Peroxide added to any reduction bath is tested for total kill before the bath is dumped.

Further research showed that, during the dyeing process, TCI used 17 to 27 gallons of water less per pound of cloth than other similar manufacturers, for the following reasons:

- Double-loading of machines
- Running of low-liquor dyeing equipment
- Combining of processes (scour and dye in the same bath)
- Minimizing of prebleaching of shades when possible

Because TCI uses so little water, its BOD concentration was higher than other similar mills, although the total BOD loading was lower. The low volume of water used contributes significantly to the high levels of BOD in the waste stream. For this reason, the City of Newton granted an increase of the limit for BOD to 340 mg/L.

Waste Reduction Results

Through this research, TCI has reduced chemical use and the pollutant levels in the wastewater effluent.

Costs

No information concerning costs was available.

Annual Savings

The process modifications and chemical substitutions have saved money for TCI . However, the increase in compliance limits, which resulted from current water saving practices, accounted for most of the savings.

CASE STUDY NO. 11—PVC-Coated Fabric Finishing

Industry: **Athol Corporation**
Pollution Prevention Application: **Recycling**

Background

Athol Corporation (Athol) produces a waste by-product stream, consisting of PVC-coated fabric, that results from the trimming process of several PVC-coated fabric finished products. In 1994, 115,000 pounds of this trim waste were directly disposed of in the Granville County Landfill, occupying valuable landfill space at a total disposal cost of $1,610 for Athol.

If the trim waste could be recovered, and the total product could be recycled, landfill disposal would no longer be necessary. This would also reduce the overall demand for virgin PVC resin and calcium carbonate filler. Conserving valuable landfill space and reducing the demand for PVC resin and filler, while simultaneously meeting stringent product quality goals in a cost-effective manner, makes this project appealing both environmentally and financially. Additionally, if successful, this process could be used in other commercial applications in the plastic and textile industries, wherever pulverized plastic products can be reintroduced into the manufacturing process.

Waste Reduction Activities

To implement this recycling program, Athol evaluated treatment options, with the help of a firm specializing in powder processing and bulk material handling engineering. Considering the characteristics of the trim waste stream and the overall recycling goals, Athol chose a cryogenic freezing and grinding process that would reduce the PVC trim waste from its original state into a powder form of no greater than 45 microns in diameter. This powder could then be introduced into the production lines as a replacement for virgin PVC resin and filler.

- The CRYO-Grind system consists of a liquid nitrogen (LIN), flow-controlled storage and injection cooling system that cryogenically cools the trim material to -320°F as it is conveyed from the trim hopper feed to the hammer impact mill for grinding. This cooling embrittles the trim material and eliminates the material's resistance to grinding. The hammer impact mill, which is also cryogenically cooled, is constructed of all stainless steel. The hammer mill action reduces the embrittled trim to fine particles by impacting the material against a fine mesh screen until the particle size of the material is smaller than the pore size of the mesh. Depending on the production need for virgin PVC, particles would then be conveyed to bulk storage for recycling or used immediately.

Steps required to implement the trim waste recycling project include the following:

1. Pilot-scale testing with various trim waste types at the Hosokow Micron Powder Systems Laboratory in Summit, New Jersey

   - To determine the LIN coolant requirements to treating trim wastes

   - To determine the behavior of the trim waste during cryogenic treatment and grinding
   - To determine whether adequate reduction of particle size is possible during grinding

2. Specification of equipment and modification of the plant to prepare for installation

3. Installation of the LIN CRYO-GRIND system and full-scale testing

4. Implementation of plant-wide trim recycling program

It is expected that the trim waste stream will lend itself to this recycling program and be suitable for reuse. The reduction of a key waste stream, the avoidance of landfill disposal, and savings realized from reduced PVC resin and filler demand make the potential for this program worthwhile and offset the cost of equipment and implementation.

Costs

The following table summarizes estimated costs, by project step:

Project Step	Costs ($)
Pilot-Scale Testing:	
Laboratory testing, rental of Micron Powder equipment	750
Travel and expenses for three Athol observers	1,800
Shipping of treated materials to Athol for further testing	1,000
Total	3,550
Installation of LIN CRYO-GRIND System and Full Scale Test:	
Equipment purchase	100,000
Installation costs	25,000
Testing materials	N/A
LIN coolant cost (estimated per month, allowing 1 month for testing)	750
Total	125,750
Implementation of Plant-Wide Trim Recycling Program:	
LIN coolant cost (estimated per month)	750
Miscellaneous support costs	750
Total	1,500
TOTAL **130,800**	

CASE STUDY NO. 12—Textile Processing and Washing

Industry: **Waste Minimization Assessment Center Study**
Pollution Prevention Application: **Reuse, Water Conservation, Process Modification**

Background

The U.S. Environmental Protection Agency (EPA) has funded a pilot project to assist small and medium-size manufacturers who want to minimize the waste that they generate but who lack the expertise to do so. To assist these manufacturers, EPA established Waste Minimization Assessment Centers (WMAC) at selected universities, and adapted procedures from the EPA *Waste Minimization Opportunity Assessment Manual* (EPA/625/7-88/003, July 1988). That document has been superseded by the *Facility Pollution Prevention Guide* (EPA/600/R-92/088, May 1992).

The WMAC team at the University of Tennessee performed an assessment at a plant that prewashes denim jeans prior to retail sale. This plant prewashes predyed denim jeans for wear modification prior to retail sale. This plant processes over 7 million pairs of jeans annually. Predyed jeans are received from other facilities and washed. An abrasive material is used in some of the wash loads. Some of the jeans are processed in tumblers to give the jeans a faded appearance. After processing, the jeans are dried, inspected, mended, pressed, packaged, and shipped. The assessment team's report, which detailed the team's findings and recommendations, indicated that (1) the waste generated in the greatest quantity is wastewater from the washers and tumblers, and (2) the greatest cost savings could be realized by installing an on-site wastewater treatment plant.

Waste Reduction Activities

Existing or recommended P2 opportunities for this plant are as follows:

- Containers in which the jeans are received are disassembled and shipped back to the supplier for reuse.
- Pumice of an acceptable size is reused.

- Install an on-site wastewater treatment plant to treat spent water from the washing and tumbling operations. Reuse treated water. If this opportunity is implemented, a nonhazardous sludge will be generated.
- During the next washing cycle, reuse rinse waters used in the washing operations.
- To recover additional pumice stones for reuse, install a screen over the Dumpster that is used to collect pumice from the hydrosieve and the shaker screen.
- Install plastic shrouds to reduce pumice lost in the space between the housings and drums in the tumblers.
- To reduce sewer charges, meter the wastewater leaving the plant. Currently, the plant's sewer charges are based on the amount of water purchased rather than the amount of water sewered. During washing, the jeans absorb a significant amount of water, which is subsequently removed during drying. There are also other water losses from spills and steam pressing.

Waste Reduction Results

Installing the on-site wastewater treatment plant would provide an estimated annual waste reduction of 513,250,000 pounds of wastewater from washers, and 50,760 pounds from tumblers. This equates to a 95 percent reduction of these waste streams.

Reusing rinse waters would provide an estimated annual waste reduction of 284,856,000 pounds (or 53 percent) of wastewater from the washers.

Installing a screen over the Dumpster and plastic shrouds in the tumblers to collect pumice and lint would reduce each of these waste streams by 40 percent annually.

Costs

The following table summarizes the estimated costs of implementing each opportunity presented by the waste reduction program:

Pollution Prevention Opportunity	Implementation Costs ($)
On-site wastewater treatment plant	1,570,000
Reuse of rinse waters	23,260
Installation of screens	3,300
Installation of plastic shrouds	3,000
Metering of wastewater	5,140

Annual Savings

The following table summarizes the estimated annual savings derived from implementing each opportunity presented by the waste reduction program:

Pollution Prevention Opportunities	Annual Savings ($)
On-site wastewater treatment plant	350,000
Reuse of rinse waters	95,480
Installation of screens	23,690
Installation of plastic shrouds	18,690
Metering of wastewater	7,125

In most cases, the economic savings of the minimization opportunities result from the reduced need for raw material and from reduced present and future costs associated with hazardous waste treatment and disposal. Other savings, which this study could not quantify, include a wide variety of possible future costs related to changing emissions standards, liability, and employee health. Also, the savings given for each opportunity reflect the savings achievable when implementing each waste minimization opportunity independently and do not reflect duplication of savings that may result when the opportunities are implemented in a package.

CASE STUDY NO. 13—Preparation, Printing, and Finishing

Industry: **Preparation, Printing, and Finishing Plant (SIC 2291)**
Pollution Prevention Application: **Reuse, Chemical Substitution, Equipment Upgrade**

Background

The company under study employs 230 people. It is engaged in the preparation, continuous rotary screen printing, and finishing of textile. The company mainly supplies its product to the home fashions industry.

Waste Reduction Activities

- Eliminate concentrated pigment discharge from printing operations to the sewer through a "waste work-off" color matching system.

  The company's printing facility applies aqueous-based pigment emulsions onto its prepared fabric with five rotary screen print machines. The print machines can produce patterns with up to 24 different colors and yield about 6 million yards of printed fabric monthly. During a run of an individual print pattern through the machine, an employee—known as a "printer"—requests that the color shop prepare additional pigment. The printer bases the need for more color on the machine's consumption of each color per yard of fabric previously run (liters of pigment per yard of fabric). About 150 drums of pigment concentrate is used per day, with five drums of waste pigment concentrate sent to the sewer daily.

  Excess pigment remaining at the end of a pattern's run was originally washed to the sewer in a barrel washer. With the aid of the State of Rhode Island Department of Environmental Management (DEM) Pollution Prevention Program, the company purchased a spectrophotometer, equipped with a personal computer, and "Waste Work-Off" software to reduce this waste stream at the source. Operators now run waste pigment samples through the spectrophotometer, which yields shade change formulas for matching the pigments to other patterns not yet printed. This has resulted in the reuse of all five barrels of waste color produced daily.

- Use ultrafiltration (UF) to remove aqueous-based pigments and reuse 300,000 gallons of rinse water daily.

  Rinse waters totaling 300,000 gallons per day are generated by (1) the conveyor sprays of five print machines, (2) three barrel washers, and (3) miscellaneous equipment rinsing with high-pressure hoses. Pigments used in the print operation are rinsed off the equipment, and the resulting colored water flows into two collection sumps. Previously, the two sumps gravity-discharged into the sewer. The company contacted DEM's Pollution Prevention Program to explore water conservation and recycling techniques.

  Upon completion of several pilot studies, the company purchased and installed a 450000-gallon-per-day UF system to remove the suspended pigment solids from its rinse water and to reuse the permeate water at the machines. The Membrex UF system is fitted with 50000-molecular-weight cutoff membranes. The pigment solids and debris that the membranes reject and concentrate are flocculated and filter-pressed for nonhazardous disposal.

- Eliminate the use of naphtha solvent through chemical substitution with an alkaline aqueous-based cleaner.

  The company was interested in finding a suitable nonhazardous replacement for its naphtha solvent. The company contacted DEM's Pollution Prevention Program for vendor and product information.

  Several aqueous cleaners were tested for compatibility with the company's print machine conveyor belts (galvanized rubber) and the metallic screens used to apply pigment onto fabric. In 1993, the company switched from using RI Screen Cleaner (100 percent naphtha) to using Diversey's Jettacin (d-limonene) cleaner. Spent d-limonene cleaner is sent to the company's UF system, where the permeate is used for rinses in the screen printing operation. (UF costs are not included in this payback analysis, because the UF system is part of a much larger project, and the flow from the spent d-limonene cleaner is considered insignificant.)

- Use countercurrent rinsing to conserve water used in textile preparation.

The company's textile preparation facility produces peroxide-bleached, washed, and dried fabric for subsequent printing and finishing at its sister facilities. The facility employs about 80 people. Management contacted DEM's Pollution Prevention Program for assistance in determining water conservation techniques that the facility could implement. The average daily water use at the preparation plant exceeded 250,000 gallons per day. The Pollution Prevention staff recommended countercurrent rinsing methods for the open-width and rope washers at the facility. The company tested its product's quality on a pilot scale with countercurrent rinsing, and determined that the fabric's quality was not affected.

Peroxide-bleached fabric is fed through two rope washers while city water flows opposite the fabric. The discharge water from the second rope washer is pumped into the first, yielding countercurrent rinsing. Fresh water consumption in this process has decreased by 10,000 gallons per day.

The open-width washer consists of seven basins, three of which contain a solution of soap and water. The last four basins contain only rinse water. Fabric is fed into the first of the three soap basins, and fresh water is fed into the last of the three basins. The water from the second and third basins flows over into the first basin. The first basin—which contains soap, water, and fabric contaminants—overflows to the sewer. The fabric is then fed from the third basin into the first of four rinse basins. Fresh water is fed into the last of the four basins, overflowing to the first basin and then to the sewer. Fresh water consumption in this process has decreased by 25,000 gallons per day.

Waste Reduction Results

By implementing the color reuse program (waste work-off software), the company has eliminated a five-drum-per-day discharge of pigment concentrate to the local sewer. The company has found that, by using computer and spectrophotometer technology, it can reformulate leftover pigments to match the colors needed in upcoming patterns. This reshading procedure has not only eliminated the concentrated pigment discharge and the rinse waters associated with it, but it has also reduced the pigment feedstock requirements by five drums per day.

The company has invested the capital to recycle its rinse water. Although no immediate payback will be seen, the company is confident that operating costs for the UF system will be absorbed by the significant savings in water and sewer costs, and the avoided costs of POTW surcharges and fines. The elimination of a colored waste stream of this magnitude has helped the local POTW with excess influent problems.

The elimination of naphtha-based cleaner (two drums per year) has reduced the company's environmental liability and increased worker safety. The company has realized that, by replacing the hazardous solvent naphtha with an aqueous cleaner, it was also able to reduce cleaning costs by over 75 percent.

The company is saving over $20,000 per year by implementing countercurrent rinsing techniques. The company has reduced its demand from the city water works by nearly 9 million gallons per year and has reduced its impact on the local sewer system by the same amount.

Costs

Company costs of implementing its P2 program are as follows:

Pollution Prevention Opportunity	Item	Cost ($)
Color reuse by using “Waste Work-Off” software	ACS spectrophotometer, PC, and software	40,000
	Labor (annual)	9,000
UF for recycling of rinse water	Membrex UF System (450,000 gallon-per-day capacity) and associated construction	1,300,000
	Membrane replacement (annual)	50,000
	Labor (annual)	30,000
	Electricity (annual)	75,000
	Bag filters (annual)	4,800
	Flocculation chemicals (annual)	20,000
Replacement of naphtha solvent	Labor (annual)	192
Water conservation through countercurrent rinsing	Pumps, plumbing, and level switches	3,500
	Electricity (annual)	1,000

Annual Savings

Through color reuse, the company has recovered five drums of pigment concentrate daily worth an estimated $125,000 annually.

Installation of the Membrex UF system, to enable the company to recycle rinse water, has saved an estimated $225,000 annually in water and sewer charges.

Jettacin d-limonene cleaner (used at the required concentration) costs $1.81 per gallon, and the naphtha screen cleaner costs $15.00 per gallon. Feedstock levels have remained the same; therefore, the company is saving $13.18 per gallon with the aqueous cleaner.

Implementation of countercurrent rinsing provides the company with annual savings of $21,875.

GLOSSARY

Acetate: A manufactured fiber made from cellulose

Acetic Acid: A weak acid used in wool, nylon, and polyester dyeing, which can be replaced normally by ammonium sulphate

Acid Dye: Type of dye that is commonly used to color wool and nylon, but may be used on other fibers

Acrylic: Manufactured fiber, made in either filament or staple form, in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85 percent by weight acrylonitrile units

Azoic or Azo: Type of dye used, but not commonly, to color cotton, rayon, polyester, and cotton/polyester blends

Backcoating: Applying latex to the back of a carpet to anchor the tufts, usually followed immediately by the addition of a secondary backing material, such as woven jute or nonwoven polypropylene

Backing: (1) Any system of yarn that interlaces on the back of a textile material; (2) a knit or woven fabric or plastic foam bonded to a face fabric; (3) a knit or woven fabric bonded to a vinyl or other plastic sheet material

Basic Dye: (also known as a cationic dye) A dye used to color synthetic fiber or cotton/polyester blends

Beck: A vessel for dyeing fabric in rope form, consisting mainly of a tank and a reel to advance the fabric

Bleaching: Any of several processes used to remove the natural and artificial impurities in fabrics to obtain clear whites for finished fabric or in preparation for dyeing and finishing

Blend: Combination of two or more types of fibers and/or colors in one yarn

Blowdown: Periodic or continuous draw-off of a mixture from a system to prevent the build-up of contaminants

BOD (Biochemical Oxygen Demand): Amount of oxygen required for degradation of a chemical substance in a standard test, usually expressed in parts per million

Broadcloth: Lustrous woolen fabric that is highly napped and then pressed flat, so that the weave is not visible

Btu (British thermal unit): Amount of heat required to increase the temperature of 1 pound of water by 1°F

Bulked Continuous Filament (BCF) Yarns: Yarns used in carpet trade, made mostly of nylon but occasionally polypropylene

GLOSSARY

Carbonizing: Phenomenon in which the carbonaceous material decomposes, leaving a residue of essentially black carbon, such as soot

Carding: Process in the manufacture of spun yarns whereby the staple is opened, cleaned, aligned, and formed into a continuous, untwisted strand called a sliver

Carpet Backing: A material attached to the back of a carpet, which is usually made of woven jute or formed (nonwoven) man-made fibers; primary backing, through which the carpet tufts are inserted, is always required for tufted carpets; secondary backing is normally added at the latex backcoating stage; carpet backings are an important end use for formed fabrics

Carrier: A water-insoluble organic compound that accelerates the absorption of dyes by a fiber; disperse dyes used with polyester most commonly use carriers

Caustic Soda: A strong alkali that is used, for example, in mercerizing, usually consisting of 50 percent sodium hydroxide in water

Cellulose: A plant material that forms a major component of cotton and rayon; also used as the basis of acetate fiber

Chromophores: A molecular group that is capable of selective light absorption resulting in coloration

CMC (Carboxymethyl Cellulose): Synthetic size used in the manufacture of cotton fabric

Coated Fabric: A fabric to which a substance—such as lacquer, plastic, resin, rubber, or varnish—has been applied, in firmly-adhering layers, to provide specific properties, such as water impermeability

Color Index: List of chemical formulas and properties of dyestuffs, available through the American Association of Textile Chemists and Colorists (AATCC)

Combing: Processing cotton or wool stock, through a series of needles (or combs), to remove short fibers and foreign matter (after carding)

Desizing: Removal of size material from greige (grey) goods to prepare for bleaching and dyeing

Desuinting: Removal of natural impurities and dirt from wool fiber

Developers: Chemicals used in the dyeing process, in which color is developed by reacting on cotton

Direct Dye: Anionic water-soluble dye that is used mainly for dyeing full-shade ranges onto cotton and rayon

GLOSSARY

Disperse Dye: Water-insoluble dye that is used to color several synthetic fibers; applied as a fine dispersion by using a carrier

Drawing: Straightening and paralleling the fibers after combing or carding

Dry Cleaning: Cleaning of dyed yarn or fabric with a solvent rather than scouring it in water solution

Drying Cylinders: Any of several heated revolving cylinders used to dry fabric or yarn; drying cylinders are arranged either vertically or horizontally in sets, with the number varying, depending on the material to be dried; drying cylinders are often internally heated with steam and Teflon™-coated to prevent sticking

Dyestuff: The chemical component of dyes that imparts the color to a fabric; usually a complex, organic compound

Fastness: Resistance to the fading that normally results from exposure to light or water

Fiber-Reactive Dye: A type of dye that is used to color cotton, nylon, and polyester/cotton blend; this dye gives bright shades and good all-round color fastness, and is easy to apply

Filament: A fiber of indefinite or extreme length, such as is found naturally in silk; man-made fibers are extruded into filaments, which are converted into filament yarn, staple, or tow

Filling: In a woven fabric, the yarn running from selvage to selvage at right angles to the warp; each crosswire length is called a pick; in the weaving process, the filling yarn is carried by the shuttle or other type of yarn carrier

Finish: (1) A substance, or mixture of substances, which is added to textile materials to impart desired properties; (2) a process, physical or chemical, applied to textile materials to produce a desired effect;
(3) a property—such as smoothness, drape, luster, water repellency, flame retardancy, or crease resistance—which is

produced by the finish described in either of the first two definitions; (4) the state of a textile material as it leaves a process

Finishing: All of the processes through which the fabric passes after bleaching, dyeing, or printing, in preparation for the market or use; finishing includes such operations as heatsetting, napping, embossing, pressing, calendering, and the application of chemicals that change the character of the fabric; the term finishing is also sometimes used to refer collectively to all processing operations, including bleaching, dyeing, and printing

Fixation or Fixing: The process of setting a dye after the dyeing or printing operation, usually by steaming, other heat treatment, or fixing agents

GLOSSARY

Fly: The short, waste fibers that are released into the air in textile processing operations, such as picking, carding, spinning, and weaving

Formed Fabric: An assembly of textile fibers that are held together by mechanically interlocking in a random web or mat, by fusing the fibers, or by bonding with a cementing medium, such as starch, glue, casein, rubber latex, or one of the cellulose derivatives or synthetic resins; formed fabrics are used for expandable items, such as hospital sheets, napkins, diapers, and wiping cloths, as the base material for the coated fabrics, and in a variety of other applications

Framing: Dyeing or impregnating fabric with a resin or starch, and drying at the correct width

Gravure Roller: Engraved roller that is used to imprint relief images

Greige: Fabrics, just off the loom or knitting machine, in unbleached, undyed state prior to finishing; also referred to as “gray” or “grey” goods

Hand: The qualities of a fabric—such as softness, firmness, elasticity, fitness, and resilience—that are perceived by touch

Hank: Continuous strand of yarn, or cord in the form of a collapsed coil; an intermediate state between sliver and yarn

Heatsetting: The process of imparting dimensional stability and other desirable properties, such as wrinkle resistance, to man-made fibers and fabrics, by means of either moist or dry heat

Hydrophobic: Lacking affinity for absorbing water, or lacking the ability to absorb water

J-Box: A J-shaped device that is often used in continuous bleaching; the cloth is held in a J-shaped arrangement for the required time at a designated temperature

Jet-Dyeing Machine: A tubular machine that uses water jets to circulate fabric in a dye bath

Jig: A dyeing machine in which the fabric, in open-width form, is transferred repeatedly from one roller to another, passing each time through a batch of relatively small volume; jigs are used for scouring, dyeing, bleaching, and finishing

Jute: A woody fiber that is used for sacking, burlap, and twine, or as a backing material for tufted carpets.

Kier: A piece of equipment in which cotton is boiled with dilute caustic soda to remove impurities, or a pressure vessel that is used for dyeing yarn and fabric.

GLOSSARY

Knitting: A method of constructing fabric by interlocking a series of loops of one or more yarns; the two major classes of knitting are warp knitting and weft knitting

Lap: A continuous, considerably compressed sheet of fiber tufts, which is rolled under pressure into a cylindrical package, which usually weighs 40 to 50 pounds

Latex: A milky rubber raw material that is used as a backing for carpets

Levelling Agent: Dyebath additive that promotes uniform distribution or absorption of dye color in a fabric

Long Staple: A long fiber; in reference to cotton, a long staple is a fiber that is not less than 1-_ inches long; in reference to wool, a long staple is a fiber that is 3 to 4 inches long and is suitable for combing

Loom: A machine for weaving fabric by interlocking a series of vertical, parallel threads (the warp) with a series of horizontal, parallel threads (the filling or weft); the warp yarns from a beam pass through the heddles and reed; the filling is shot through the "shed" of warp threads by means of a shuttle or other device, and it is settled into place by the reed and lay; the woven fabric is then wound on a cloth beam.

Loop Pile: Carpet construction in which the tufts are formed into loops from the supply yarn.

Lubricant: An oil or emulsion finish that is applied to fibers to prevent damage during textile processing or to knitting yarns to make them more pliable.

Man-Made Fiber: A class name for various genera of fibers (including filaments) produced from fiber-forming substances, including (1) polymers synthesized from chemical compounds, such as acrylic, nylon, polyurethane, and polyvinyl fibers; (2) modified or transformed natural polymers, such as acetates and rayons; or (3) mineral, such as glass; the term "man-made" is usually used to designate all chemically produced fibers to distinguish them from the truly natural fibers, such as cotton, wool, silk, and flax

Mercerization: A treatment for cotton yarn or fabric to increase its luster and affinity for dyes; the material is immersed under tension in a cold sodium hydroxide (caustic soda) solution in warp, skein form, or in the piece, and is later neutralized in acid; the process causes a permanent swelling of the fiber and, therefore, increases its luster

Metallized Dye: Two acid dyes (anionic, water-soluble) joined together to make a larger molecule that has greater light and wet fastness; it is used mainly for dyeing nylon and wool where high fastness is required

GLOSSARY

Naphthol Dye: An azo dye whose color is formed by coupling with naphthol; used chiefly on cotton

Napping: A finishing process that raises the surface fibers of a fabric by means of passing them over rapidly revolving cylinders that are covered with metal points or teasel burrs; outing, flannel, and wool broadcloth derive their down appearance from this finishing process; napping is also used for certain knit goods, blankets, and other fabrics having raised surfaces

Narrow Fabric: Any nonelastic woven fabric, 12 inches wide or less, having a selvage on either side, except for ribbon or seam binding

Natural Fiber: A class name for the various genera of fibers (including filaments) of animal, mineral, or vegetable origin; examples include (1) silk and wool, (2) asbestos, and (3) cotton, flax, jute, and ramie

Nonwoven: A material that is made of fibers in a web or mat, with the fibers generally held together by a bonding agent

Nylon: Generic name for a manufactured fiber in which the fiber-forming substance is any long-chain synthetic polyamide having recurring amide groups as an integral part of the polymer chain

Opening: (1) A preliminary operation, in the processing of staple fiber, that removes the heavier impurities; and (2) an operation, in the processing of tow, that substantially increases the bulk of the tow by separating the filaments and deregistering the crimp

Package Dyeing: The dyeing of yarns in the form of a package of various kinds and sizes; packages wound onto perforated tubes or springs are placed on perforated spindles in a closed vat, and the dye bath is circulated in and out of the package

Padding: Application of a liquor or paste to textiles either by passing the material through a bath and, subsequently, through squeeze rollers, or by passing it between squeeze rollers, the bottom one of which carries the liquor or paste (a **pad** or **padder**)

Paddle Dyeing Machine: A machine that is used for dyeing garments, hosiery, and other small pieces that are packaged loosely in mesh bags; the unit consists of an open tank and revolving paddles that circulate the bags in the dyebath

Permanent Finish: Fabric treatments, of various kinds, designed to improve glaze, hand, or performance of fabrics; these finishes are durable during laundering

PET (Polyethylene terephthalate): Polyester

Picking: (1) A process that continues the opening and cleaning of staple and forms a continuous fiber sheet (or lap), which is delivered to the card; and (2) the operation of passing the filling through the warp shed during weaving

Pile: (1) A fabric effect that is formed by introducing tufts, loops, or other erect yarns on all or part of the fabric surface; types of pile are warp, filling, and knotted pile, or loops that are produced by weaving an extra set of yarns over wires that are then drawn out of the fabric. Plain wires leave uncut loops: wires with a razor-like blade produce a cut pile surface. Pile fabric may also be made by producing a double-cloth structure woven face to face, with an extra set of yarn being interlaced with each cloth alternately. The two fabrics are cut apart by a traversing knife, thereby producing two fabrics with a cut pile surface. Pile should not be confused with nap. Corduroys are another type of pile fabric, where long filling floats on the surface are slit, causing the pile to stand erect. (2) In carpets, pile refers to the face yarn, as opposed to the backing or support yarn. Pile carpets are produced by either tufting or weaving.

Plying: Twisting together two or more single yarns or ply yarns to form, respectively, ply yarn or cord

Polyester: A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer that is composed of at least 85 percent by weight of an ester of dihydric alcohol and terephthalic acid

Printing: A process for producing a pattern on yarns, warp, fabric, or carpet by any of numerous printing methods; the color or other treating material, usually in the form of a paste, is deposited onto the fabric, which is then usually treated with steam, heat, or chemicals for fixation

Print Paste: The mixture of gum or thickener, dye, and appropriate chemicals used in printing fabrics; viscosity varies with the types of printing equipment, the type of cloth, the degree of penetration desired, and other factors

PVA (Polyvinyl Alcohol): Synthetic size that is used in the sizing process in manufacturing cotton fabric

Raw Fiber: A textile fiber in its natural state, such as silk “in the gum” and cotton as it comes from the bale

Rayon: A generic name for man-made fibers, monofilaments, and continuous filaments, that are made from regenerated cellulose; fibers produced by both viscose and cupra-ammonium processes are classified as rayon

Reactive Dyes: Dyes that react chemically with the fiber

Reed: A narrow, movable frame that is fitted with wooden or metal strips that separate the warp threads

Resin: A chemical finish that is used to impart a property desired in a fabric, such as water repellency

Retardants: Chemicals that are typically applied to fabrics or fibers to retard burning or other unwanted conditions

Rheology: Study of the deformation and flow characteristics of printing pastes

GLOSSARY

Rope Soaper: A piece of equipment that is used for scouring fabric to remove impurities, such as processing oils and excess dye

Roving: (1) In spun yarn production, an intermediate state between the sliver and the yarn; roving is a condensed sliver that has been drafted, twisted, doubled, and redoubled. The product of the first roving operation is sometimes called slubbing; (2) the operation that produces roving (see [1])

Saturator: A box that is used to impregnate fabric with chemicals in a continuous range

Scouring: Removal of foreign components from textiles; normal scouring materials are alkalis (such as soda ash) or trisodium phosphate, frequently used in the presence of a surfactant; textile materials are sometimes scoured by using a solvent

Selvage: The narrow edge of the woven fabric that runs parallel to the warp; to prevent it from raveling, the manufacturer makes it with stronger yarns in a tighter construction than the body of the fabric; a fast selvage encloses all or part of the picks, and a selvage is not fast when the filling threads are cut at the fabric edge after every pick

Shuttle: A boat-shaped device, usually made of wood with a metal tip, that carries the filling yarns through the shed in the weaving process; it is the most common weft-insertion device. The shuttle holds a quill, on which the filling yarn is wound

Singeing: Passing the cloth across an open gas flame at a high speed to burn off the loose surface fibers

Sizing: Applying starch, PVA, or CMC to warp yarns to minimize aberration during weaving

Skein: A continuous strand of yarn or cord in the form of a collapsed coil; it may be of any specified length and is usually obtained by winding a definite number of turns on a reel under prescribed conditions

Slashing: (1) Placing beams from the warper into a creel, running them through a size solution, and drying them on a series of drying cans; (2) a process of sizing warp yarns on a slasher; also, see "Sizing."

Sliver: A continuous strand of loosely assembled fibers without twist. The sliver is delivered by the card, the comber, or the drawing frame. The production of sliver is the first textile operation step that brings staple fiber into a form that can be drawn (or reduced in bulk) and eventually twisted into a spun yarn

Solvent Processing: An assembly of unit operations in which a solvent, such as perchloroethylene, is used, instead of water, to transfer chemical to and from the fabric; this process is not commonly used in the U.S.

GLOSSARY

Spinning: A process by which a large strand of fibers is drawn out to a small strand and converted into a yarn; after the strand has been drawn (or drafted), twist is inserted, and the resulting yarn is wound into a bobbin

Staple: Natural fibers of cut lengths from filaments; the staple length of natural fibers varies from less than 1 inch—as with some cotton fibers—to several feet—for some hard fibers, such as linen; man-made staple fibers are cut to a definite length, from 8 inches to about 1-½ inches (occasionally down to 1 inch), so that they can be processed on cotton, woolen, or worsted yarn spinning systems; the term staple (fiber) is used in the textiles industry to distinguish natural or cut-length man-made fibers from filament

Starch: Highly biodegradable, organic polymer that is used as a size

Suint: Dried sheep perspiration

Sulfur Dyes: A class of dyes that dissolve in aqueous sodium, forming a product having a marked affinity for cotton: the dyes are regenerated by air oxidation

Surfactant: A surface-active substance, such as a detergent

Tentering: Running open-width fabric through a tenter frame, which holds it at the desired width; fabric is dried and wound onto a roll

Textured: Bulked yarns that have greater volume and surface interest than conventional yarn of the same fiber

Thread: (1) A slender, strong strand or cord, especially one designed for sewing or other needlework; most threads are made by plying and twisting yarns; a wide variety of thread types are in use today, such as spun cotton and spun polyester, core-spun cotton with a polyester filament core, polyester or nylon filaments (often bonded), and monofilament threads; (2) a general term for yarns used in weaving and knitting, as in "thread count" and "wrap threads"

Tonne: A metric ton, equivalent to 1,000 kilograms or 1.102 U.S. short tons

Tow: A large strand of continuous man-made fiber filaments, without definite twist, collected in loose, rope-like form, usually held together by crimp

Tubular Fabric: A fabric woven or knit in a tubular form with no seams, such as seamless pillowcases, most knit underwear fabrics, and seamless hosiery

Tufted Yarn: Very coarse yarns, usually plied, designed for the tufting trade; most tufting yarns are made from nylon, acrylic, or polyester fiber

GLOSSARY

Vat Dye: A type of insoluble dye that is applied from a liquor that contains alkali and a powerful reducing agent, generally hydrosulphite; the dye then becomes soluble and completely permeates the cotton fiber; it is then oxidized and again becomes insoluble

Warp: Set of lengthwise yarns in a loom through which the crosswise filling yarns (weft) are interlaced; the warp yarns are sometimes called "ends"

Warping: The operation of winding the warp yarn onto a beam in preparation for weaving or warp knitting; it is also called "beaming"

Warp-Knit Fabric: A fabric that is knit with the yarns running lengthwise, such as tricot, milanese, and raschel

Weaving: The method or process of interlacing two yarns of similar materials so that they cross each other at right angles to produce a woven fabric; the warp yarns, or ends, run lengthwise in the fabric, and filling threads (weft), or picks, run from side to side; weaving may be performed on a power or hand loom, or by several hand methods

Weft: See "Warp"

Winding: Transfering a yarn or thread from one type of package to another (such as from cakes to cones)

Worsted: A wool fabric that uses finer grades of wool with finer yarns and higher weaving construction than a woollen fabric

Woven Fabric: A fabric that is composed of two sets of yarns, warp and filling, formed by weaving, which is the interlacing of these sets of yarns to form a fabric; there may be two or more warps and fillings (wefts) in fabric, depending on the complexity of the pattern; the manner in which the two sets of yarns are interlaced determines the weave; by using various combinations of the three basic weaves (plain, twill, and satin), it is possible to produce an almost limited variety of fabrics; other effects may be obtained by varying the type of yarns—filament or spun, fiber types, and twist levels

Yarn: A combination of fibers or filaments, either manufactured or natural, that is twisted or laid together so as to form a continuous strand, which can be used in weaving or knitting, or can be made into a textile material

Yarn Count: A relative measure of the fineness of yarns; the yarn number is inversely proportional to the linear density

BIBLIOGRAPHY

Achwal, W.B. 1990. "Environmental Aspects of Textile Chemical Processing, Parts 1 and 2." *Colourage*. September. Page 40.

Athol Corporation. 1995. "Grant Proposal: Polyvinyl Chloride Waste Trim Recycling." North Carolina Department of Environment, Health, and Natural Resources (NCDEHNR), Office of Waste Reduction, Pollution Prevention Program. April 21.

Benninger AG. 1990. "Benninger AG: Synthetic Sizing Recovery Plants." *Textile World*. Volume 140, Number 4. April. Pages 97-98.

Brandon, Craig A., and M. Samfield. 1978. "Application of High-Temperature Hyperfiltration to Unit Textile Processes for Direct Recycle." *Desalination*. Volume 24. Pages 97-112.

Brenner, E.T., and M. Scholl. 1993. "Saving Water and Energy in Bleaching Tubular Knits." *American Dyestuff Reporter*. March. Page 76.

Brown, Donald A. 1995. "Evaluation of Membrane Filtration for the Treatment and Reuse of Reactive Dyeing Wastewater."

Buckley, C. A., and others. 1982. "The Performance of an Ultrafiltration Pilot-Plant for the Closed Loop Recycling of Textile Desizing Effluents." *Water Science Technology*. Volume 14. Pages 705-713.

Campe, Jesse G., Jr. 1990. "Gaston County: Foam Application System." *Textile World*. Volume 140, Number 4. April. Pages 100-102.

Castle, M. 1992. "A Novel Approach to Practical Problems." *Journal of the Society of Dyers and Colourists*. July/August. Page 306.

Clemson University (Clemson), School of Textiles. 1995. "Filtration Techniques Used by the Textile Industry for Recovery of Dyes, Chemicals, and Energy." U.S. Environmental Protection Agency (EPA). EPA 760-002-A-000.

Clemson and U.S. EPA. (no date). "Renovation of Textile Dyeing and Finishing by Hyperfiltration for Pollution Abatement by Resource and Energy Recovery through Complete Recycle."

Clemson and U.S. EPA. (no date). "Complete Recycle of Composite Textile Dyeing and Finishing Wastewater Renovated by Hyperfiltration."

Cook, Fred L. 1989. "'Run Me a Xerox Copy of That Pillowcase, Please.'" *Textile World*. Volume 139, Number 8. August. Pages 72-74.

Cook, Fred L. 1990a. "Fabric Process Beholden to Energy, Environment." *Textile World*. Volume 139, Number 11. November. Pages 49-54.

Cook, Fred L. 1990b. "Quick Response (QR), Environmental Pressure Will Drive Dyeing, Printing." *Textile World*. Volume 140, Number 12. December. Pages 83-85.

Cook, Fred L. 1991a. "Sulfur Dyes: Old Standard Learns Some New Tricks." *Textile World*. Volume 141, Number 3. March. Pages 68-69.

Cook, Fred L. 1991b. "Environmentally Friendly: More Than a Slogan for Dyes." *Textile World*. Volume 141, Number 5. May. Pages 84-89.

BIBLIOGRAPHY

Cook, Fred L. 1993a. "AATC Plugs Advances in Wet Processing at Atlanta Meet." *Textile World*. Volume 143, Number 1. January. Pages 55-58.

Cook, Fred L.. 1993b. "Prep, Finishing Chemicals Turn Green, Nature Friendly." *Textile World*. Volume 143, Number 5. May. Pages 37-45.

Cook, Fred L. 1994. "Less Is More in Applying Chemicals to Textiles." *Textile World*. Volume 144, Number 3. March. Pages 59-65.

Cook, Fred L. 1995a. "Textile Printing Enters the Technological Revolution." *Textile World*. Volume 145, Number 3. March. Pages 73-79.

Cook, Fred L. 1995b. "Specialty Chemicals Turn Green as Pressure Increases." *Textile World*. Volume 145, Number 11. November. Pages 59-61.

Cooper, P. 1989. "Are Textiles Finishing the Environment?" *International Wool Secretariat Development Center Monograph.* International Wool Secretariat, West Yorkshire, England.

Cooper, Sidney G. 1978. "The Textile Industry: Environmental Control and Energy Conservation." *Pollution Technology Review No. 42. Energy Technology Review No. 28.* Noyes Data Corporation.

Cunningham, A. 1993. "Ultra-Low Liquor Ratios Key to Reducing Water and Chemicals in Exhaust Dyeing." *Australasian Textiles*. January/February. Page 39.

Drews, Michael J., and others. 1994. "Evaluation of the Utilization of Supercritical Fluid Technology for Analytical, Process, and Environmental Applications in Textiles." *Textile Chemist and Colourist*. Volume 26, Number 6. June. Pages 31-32.

Easton, J.R., and J.R. Provost. 1993. "Pollution Control and the Textile Printer." *International Dyer*. September. Page 21.

Elliot, Edward J. 1995a. "Recycling: Saving Money and the Environment." *Textile World*. Volume 145, Number 2. February. Pages 72-74.

Elliot, Edward J. 1995b. "Textiles' Role in the Environment." *Textile World*. Volume 145, Number 9. September. Pages 221-222.

Energetics, Inc. 1988. "The U.S. Textile Industry: An Energy Perspective." Pacific Northwest Laboratory, U.S. Department of Energy (DOE). DOE/RL/01830-T56. January.

Freeman, Harry M. 1995. "Pollution Prevention in the Textile Industries." *Industrial Pollution Prevention Handbook*. Chapter 50. Pages 829-845.

Fulmer, T.D. 1992. "Cutting Costs and Pollution: Save Energy and Fight Pollution at the Same Time." *America's Textiles International*. March. Page 38.

Fulmer, T.D. 1993. "Textile Printing and Its Future." *America's Textiles International*. October.

Georgia Institute of Technology (Georgia Tech) and Battelle Pacific Northwest Laboratories. 1982. "Energy Conservation in the Textile Industry, Ten Case Histories." U.S. DOE, Office of Industrial Programs. DE82 018831.

Glover, B., and L. Hill. 1993. "Waste Minimization in the Dyehouse." *Textile Chemist and Colourist*. June. Page 15.

BIBLIOGRAPHY

Grizzle, Tom. (no date). "Ultrafiltration Applications in the Textile Industry." In *Making Pollution Prevention Pay, Ecology with Economy as Policy*. Edited by Donald Huisingh and Vicki Bailey. Pergamon Press. Pages 33-40.

Groff, K.A. 1992. "Textile Waste." *Water Environmental Research*. Volume 64, Number 4. Page 425.

Haas, J. 1993. "Mothproofing Still Possible Within Environmental Laws." *Australasian Textiles*. January/February. Page 43.

Hendrickx, Ilse, and Gregory D. Boardman. 1995. "Pollution Prevention Studies in the Textile Wet Processing Industry." Virginia Department of Environmental Quality, Office of Pollution Prevention. May.

Henriksen, Vald. 1994. "Henriksen: Development of the Air Jet." *Textile World*. Volume 144, Number 4. April. Pages 78-79.

Horstmann, G. 1993. "Fiber Reactive Dyes and Options to Reduce Electrolyte Consumption." *Proceedings, COTTECH Conference*. Raleigh, North Carolina. November 11-12.

Houser, N., and others. 1994. "Pollution Prevention and U.S. Textiles." *America's Textiles International*. March. Page 28.

Hydro Systems, Inc., and J.P. Stevens & Co., Inc. 1987. "Evaluation of a Teflon-Based Ultraviolet Light System on the Disinfection of Water in a Textile Air Washer." NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. August 1.

Indian Institute of Technology. 1994. *The Textile Industry and the Environment*. Technical Report No. 16. United Nations Environment Programme, Industry and Environment.

Jablonowski, Ed, and John Carlton. 1995. "Textile Recycling." *Waste Age*. January. Pages 83-89.

Kemmer, Frank N. 1988. "The Textile Industry." *The NALCO Water Handbook*. Chapter 33. Second Edition. McGraw-Hill Book Company.

Krummheuer, Wolf R., and Michael Scobel. 1993. "Recycling and Disposal of Industrial Fabrics." *Journal of Coated Fabrics*. Volume 23. October. Pages 105-123.

Leaver, A.T., and others. 1992. "Recent Advances in Disperse Dye Development and Applications." *Textile Chemist and Colourist*. Volume 24, Number 1. Page 18.

Lennox-Kerr, Peter. 1995. "British Develop Innovative Steam Texturizing System." *Textile World*. Volume 145, Number 8. August. Pages 82-83.

Looper, R. Daniel. 1976. "Energy and Ecology: The Potential Cost of Pollution Control." *Textile Industries*. July. Pages 69-71.

McCurry, John W. 1993. "Encouraging Environmental Excellence." *Textile World*. Volume 143, Number 11. November. Pages 56-58.

McCurry, John W. 1994. "Massachusetts Weaver's Waste Filters into New Product Line." *Textile World*. Volume 144, Number 8. August. Page 32.

Malone, N.H. 1990. "Eastman Chemical Company's Leadership Role in Waste Management." *International Fiber Journal*. June. Page 30.

BIBLIOGRAPHY

Morrissey, James A. 1995. "Textiles' Encore Performance: Growing Number of U.S. Firms Parlay Recycled Materials into Popular Products." *Textile World*. Volume 145, Number 9. September. Pages 214-220.

Moser, L. 1989. "Case Studies for Textile Printing." *Proceedings, Pollution Source Reduction in Textile Wet Processing*. Raleigh, North Carolina. May 23-24.

Norman, P.I., and R. Seddon. 1991a. "Pollution Control in the Textile Industry: The Chemical Auxiliary Manufacturer's Role, Part 1." *Journal of the Society of Dyers and Colourists*. April. Page 150.

Norman, P.I., and R. Seddon. 1991b. "Pollution Control in the Textile Industry: The Chemical Auxiliary Manufacturer's Role, Part 2." *Journal of the Society of Dyers and Colourists*. May/June. Page 215.

North Carolina Department of Environment, Health, and Natural Resources (NCDEHNR), Office of Waste Reduction, Pollution Prevention Program. (no date). "Case Studies for Textile Printing."

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. (no date). "Case Study: Application of Counter-Current Rinsing and Washing in Woollen Industry." Page 1297.

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. (no date). "Case Study: Dye Baths Are Reused in the Textile Industry." Adams-Millis Company. Page 1217.

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. (no date). "Case Study: Recovery of Toluene from Printing Press Cleanup in a Textile Industry." Rexham Corporation. Page 1289.

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. (no date). "Case Study: Use of a Heat Exchange System to Reduce Waste Effluent Temperatures and Energy Costs." Hampshire Hosiery (Ellen Knitting Mills).

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. 1985a. "Pollution Prevention Tips: Water Conservation for Textile Mills."

NCDEHNR, Office Waste Reduction, Pollution Prevention Program. 1985b. "Pollution Prevention Tips: Dyebath and Bleach Bath Reconstitution for Textile Mills."

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. 1986. "Case Study: Management of BOD and pH from Textile Processes at Carolina Mills, Plant No. 4." Newton, North Carolina. May.

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. 1989. "Pollution Source Reduction in Textile Wet Processing." May.

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. 1993. "Pollution Prevention Case Studies." September.

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. 1994. "Pollution Prevention Case Studies." December.

NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. 1995. "Update to Pollution Prevention Case Studies." December.

North Carolina State University (NCSU). 1988. *A Workbook for Pollution Prevention by Source Reduction in Textile Wet Processing*. NCDEHNR, Office of Waste Reduction, Pollution Prevention Program. October.

NCSU, School of Textiles. 1972. "Water Pollution Reduction through Recovery of Desizing Wastes." U.S. EPA. Water Pollution Control Research Series 12060 EOE 01/72. January.

BIBLIOGRAPHY

Norton, Sir James Farmer. 1994. "Norton: Single-Stage Preparation with Advanced Impregnation." *Textile World*. Volume 144, Number 4. April. Pages 84-87.

Palmer, J. 1983. "Waste Management: How to Turn Carpet Waste into Bottom Line Profits." *Carpet and Rug Industry*. October. Page 8.

Patel, H. 1993. "Synthetic Softener Developments and the Environment." *Australasian Textiles*. January/February. Page 48.

Pollution Probe Foundation. (no date). "Textiles." In *Profit from Pollution Prevention, A Guide to Industrial Waste Reduction and Recycling*. Pages 281-309.

Powell, D. 1992. "New Foam Technology Makes Pollution Prevention Pay." *Australasian Textiles*. November/December.

Provost, J.R. 1992. "Effluent Improvement by Source Reduction of Chemicals Used in Textile Printing." *Textile Horizons*. May/June. Page 260.

Rao, J. Venkata. 1988. "Recycling of Polyester from Fabric Waste." *Industrial Engineering Journal*. Volume 68. January. Pages 36-38.

Ravnitzky, Michael. 1994. "Tackling the Edge-Trim Problem." *Industrial Fabric Products Review*. September. Pages 76-80.

Reichard, Robert S. 1994. "A Better Year is Cooking for 1994." *Textile World*. Volume 144, Number 11. November. Pages 54-58.

Richardson, G.A. 1990. "Are Textiles Finishing the Environment: A Case Study." *Proceedings, Textile Institute Finishing Group Conference*. Manchester, England. May 8.

Rozelle, Walter N. 1994a. "Filtration Gains in Applications for Textile Firms." *Textile World*. Volume 144, Number 1. January. Pages 67-68.

Rozelle, Walter N. 1994b. "NTC Is Making Quantum Leaps in Research Projects." *Textile World*. Volume 144, Number 5. May. Pages 46-47.

Rozelle, Walter N. 1994c. "Environmental Concerns of Warp Sizing." *Textile World*. Volume 144, Number 11. November. Pages 50-57.

Shaw, T. 1989. "Environmental Issues in Wool Processing." *International Wool Secretariat Development Center Monograph*. International Wool Secretariat. West Yorkshire, England.

Shaw, T., and D. Allanach. 1989. "Mothproofing and the Environment." *International Wool Secretariat Development Center Monograph*. International Wool Secretariat. West Yorkshire, England.

Shelley, Suzanne, and others. 1993. "Dyeing to Conform." *Chemical Engineering*. March. Pages 69-71.

Smith, Brent. 1985. "Determining Optimum Wet Pickup and Low Add-On Finishing." *American Dyestuff Reporter*. May. Page 13.

Smith, Brent. 1987. "Troubleshooting in Textile Wet Processing—An Overview." *American Dyestuff Reporter*. February. Page 28.

Smith, Brent. 1989. "Source Reduction by New Equipment." *Proceedings, Pollution Resource Reduction in Textile Wet Processing*. Raleigh, North Carolina. May 23-24.

BIBLIOGRAPHY

Smith, Brent. 1992a. "Source Reduction: Alternative to Costly Waste Treatment." *America's Textiles International*. March.

Smith, Brent. 1992b. "Reducing Pollution in Warp Sizing and Desizing." *Textile Chemist and Colourist*. June. Page 30. Smith, Brent. 1994. "Future Pollution Prevention Opportunities and Needs in the Textile Industry." In *Pollution Prevention Needs and Opportunities*. Center for Hazardous Materials Research. May.

Smith, Brent, and V. Bristow. 1994. "Indoor Air Quality and Textiles: An Emerging Issue." *American Dyestuff Reporter*. January. Page 37.

Smith, Brent, and E. Simonson. 1987. "Ink Jet Printing for Textiles." *Textile Chemist and Colourist*. August. Page 23.

Smith, William C. 1995. "Zero Discharge: More than a Wish." *Textile World*. Volume 145, Number 2. February. Page 65.

Sokolowska-Gadja, J., and others. 1995. "Synthetic Dyes Based on Environmental Considerations. Part I: Iron Complexes for Protein and Polyamide Fibers." *Textile Research Journal*.

Source Reduction Research Partnership, Metropolitan Water District of Southern California and Environmental Defense Fund. 1990. "Textiles Manufacture: Source Reduction of Chlorinated Solvents." June.

Sverdrup & Parcel and Associates, Inc. (Sverdrup). 1984a. "Wastewater Recycle and Reuse for Indirect Discharge Textile Finishing Mills, Volume 1, Technical Report." U.S. EPA. EPA-600/2-84-070a. March.

Sverdrup. 1984b. "Wastewater Recycle and Reuse Potential for Indirect Discharge Textile Finishing Mills, Volume 2, Six Mill Engineering Reports." U.S. EPA. EPA-600/2-84-070b. March.

Tincher, Wayne C. 1993. "Mills Will Face New Effluent Challenges." *Textile World*. Volume 143, Number 5. May. Pages 60-62.

Tincher, Wayne C., and others. 1981. "Reusing Dyebaths in Jet Dyeing." *Textile Chemist and Colourist*. Volume 13, Number 12. December. Pages 14-17.

Tyndall, R.M. 1994. "Relaxed Knit Fabric Finishing and Compacting (Tubular and Open-Width)." *American Dyestuff Reporter*. April. Page 28.

United Nations Economic and Social Council, Economic Commission for Europe. 1985. "The 'Kemafil' Process for Manufacturing Filling and Sealing Ropes out of Cut-Off Margins Resulting from the Manufacture of Textile and Synthetic Face Materials." May 6. ENV/WP.2/5/Add.120.

United Nations Environment Programme (UNEP), Industry and Environment. 1993a. "Case Study: Chrome Recovery and Recycling in the Leather Industry." *Cleaner Production Worldwide*. Pages 6-7.

UNEP, Industry and Environment. 1993b. “Case Study: Minimised Environmental Effects in Cotton Production.” *Cleaner Production Worldwide*. Pages 18-19.

UNEP, Industry and Environment. 1993c. “Case Study: Reduction of Sulphide in Effluent from Sulphur Black Dyeing.” *Cleaner Production Worldwide*. Pages 18-19.

U.S. EPA. 1974. “Recycling Zinc in Viscose Rayon Plants by Two-Stage Precipitation.” EPA Technology Transfer Capsule Report 12090 ESG.

BIBLIOGRAPHY

U.S. EPA, Office of Research and Development, Center for Environmental Research. 1994 (draft). “Pollution Prevention Best Management Practices for the Textile Industry.”

University of North Carolina at Chapel Hill, Kenan-Flagler Business School, Center for Emerging Markets. 1993. *Textile Technology Sourcebook: A Guide to U.S. Suppliers of Technologies to Reduce Pollution and Save Energy in the Textile Industry*. July.

University of Tennessee, Department of Engineering Science And Mechanics. 1994. “Environmental Research Brief: Waste Minimization Assessment for a Manufacturer of Prewashed Jeans.” U.S. EPA. EPA/600/S-94/006. September.

Wagner, S. 1993. “Improvements in Products and Processing to Diminish Environmental Impact.” *Proceedings, COTTECH Conference*. Raleigh, North Carolina. November 11-12.

Williams, David B. 1993. “Techniques for Pollution Prevention in Textile Wet Processing Operations.” *Proceedings of the Conference for Executives and Managers on Environmental Issues Affecting the Textile Industry*. Charlotte, North Carolina. June 14-15. Pages 75-83.

Woerner, Douglas L., and Nancy E. Wheeler. 1993. “How Mills Can Save Money While Treating Wastewater.” *Textile World*. Volume 143, Number 5. May. Page 65.

(author unknown). 1995a. “Washington Outlook: Textiles Companies Show Progress in Reducing Waste.” *Textile World*. Volume 145, Number 8. August. Page 18.

(author unknown). 1995b. “Is Reprocessing Denim Fabrics a Viable Choice?” *Textile World*. Volume 145, Number 8. August. Pages 48-50.

(author unknown). 1996. “Textile Reclamation in Germany.” *Journal of the World Resource Foundation: Warmer Bulletin*. Number 48. February. Page 13.

APPENDIX

ADDITIONAL SOURCES OF INFORMATION

APPENDIX
ADDITIONAL SOURCES OF INFORMATION

The following are additional documents on P2 that you may find useful. Unfortunately, they are available only in English. Copies of documents with an U.S. Environmental Protection Agency (EPA) document number may be obtained from the EPA Center for Environmental Research Information (CERI) or the Pollution Prevention Information Clearinghouse (PPIC). Some documents are available, without charge, from PPIC. For a current list of these documents, please contact PPIC.

EPA CERI Publications Unit 26 West Martin Luther King Drive Cincinnati, OH 45268 (513) 569-7562	PPIC 401 M Street Mail Code PM221A Washington, DC 20460 (202) 260-1023	PIES Technical Support Office SAIC 7600-A Leesburg Pike Falls Church, VA 22043 (703) 821-4800

GENERAL INFORMATION

American Institute for Pollution Prevention. 1993. "A Primer for Financial Analysis of Pollution Prevention Projects." EPA/600/R-93/059. April.

Higgins, Thomas. 1989. *Hazardous Waste Minimization Handbook*. Lewis Publications, Inc. Chelsen, Michigan.

Toxics Use Reduction Institute. (no date). "Massachusetts Toxics Use Reduction Program, Curriculum for Toxics Use Reduction Planners." University of Massachusetts. Lowell, Massachusetts.

United Nations Environment Programme, Industry and Environment. 1993. "Cleaner Production Worldwide." March.

U.S. Environmental Protection Agency (EPA). 1989. *Pollution Prevention Benefits Manual, Volumes I and II, Phase II.* Office of Policy Planning and Evaluation, and Office of Solid Waste. October.

U.S. EPA. 1992a. "Facility Pollution Prevention Guide." Risk Reduction Engineering Laboratory, Office of Research and Development. Ohio. May.

U.S. EPA. 1992b. "Industrial Pollution Prevention: A Critical Review." *Journal of the Air and Waste Management Association*. Vol. 42, No. 5. May. Pages 617-655.

U.S. EPA. 1994. "Abstracts of Pollution Prevention Case Study Sources." EPA/742/B-94/001. January.

RECYCLING

Blackman, Ted. 1991. "Recycling: Not Just for Papers and Bottles Anymore." October. Pages 19-20.

COMPUTER SOFTWARE

U.S. EPA. 1991. "Strategic Waste Minimization Initiative (SWAMI) Version 2.0." May.

U.S. EPA. 1992. "User's Guide: SWAMI Version 2.0, A Software Tool to Aid in Process Analysis for Pollution Prevention." January. EPA/625/11-91/004.

ATTACHMENT A

INFORMATION ON ACCESSING POLLUTION PREVENTION INFORMATION CLEARINGHOUSES

ATTACHMENT A
INFORMATION ON ACCESSING POLLUTION PREVENTION INFORMATION CLEARINGHOUSES

Envirosense Database
U.S. EPA
Bulletin Board: (703) 908-2092
Help Line: (703) 908-2007

Pollution Prevention Information Clearinghouse (PPIC)
U.S. EPA
401 M. Street, SW (3404)
Washington, DC 20460
(202) 260-1023

United Nations Environment Programme (UNEP)
Industry and Environment
39-43, Quai Andre-Citroen
75739 Paris Cedex 15 - France
Telephone: 33 (1) 44 37 14 50

American Institute for Pollution Prevention
Cincinnati, OH
(513) 556-3693

Manufacturing Extension Partnership (MEP)
U.S. Department of Commerce
National Institute of Standards and Technology (NIST)
(301) 975-5020

National Roundtable of State Pollution Prevention Programs
(202) 543-P2P2 (7272)

Association of State and Territorial Solid Waste Management Officials (ASTSWMO)
Washington, DC
(202) 6224-5828

California Department of Toxic Substances Control
Sacramento, CA
(916) 324-1807

Center for Environmental Research Information
Cincinnati, OH

(513) 569-7562

Center for Hazardous Materials Research
Pittsburgh, PA
(412) 826-5321

Environment Canada
Ottawa, Ontario
(613) 241-5692

Gulf Coast Hazardous Substance Research Center
Beaumont, TX

(409) 880-8897

Illinois Hazardous Waste Research and Information Center (HWRIC)
Champaign, IL
(217) 333-8940

National Pollution Prevention Center for Higher Education
Ann Arbor, MI
(313) 764-1412

Northeast Waste Management Officials Association (NEWMOA)
Boston, MA
(617) 367-8558

Pacific Northwest Pollution Prevention Research Center
Seattle, WA
(206) 223-1151

Pollution Prevention Education and Research Center
Los Angeles, CA
(310) 206-2098

Solid Waste Association of North America
Silver Spring, MD
(301) 585-2898

Toxics Use Reduction Institute (TURI)
Lowell, MA
(508) 934-3275

Waste Reduction Resource Center for the Southeast (WRRC)
Raleigh, NC
(800) 476-8686

Waste Reduction Institute for Training and Applications Research, Inc. (WRITAR)

Minneapolis, MN
(612) 379-5995

DIRECTIONS FOR HOW TO CONNECT AND REGISTER ON THE ENVIROSENSE BBS VIA MODEM

This document (which can be viewed in the BULLETINS section of Envirosense' BBS or downloaded from the UTILITIES directory of the Envirosense (ES) Communications Network. It does not provide any details concerning the World Wide Web (WWW) platform of Envirosense.

Envirosense (703/908-2092) TELEPHONE/ADDRESS INFORMATION:

HOTLINES:
BBS: 703/908-2007
WWW: 703/526-6956

CO-MANAGERS:

BBS Platform: Louis Paley, 202/260-4640
WWW Platform: Myles Morse, 202/260-3161

WWW/INTERNET ADDRESS
http://wastenot.inel.gov/envirosense/

I. THE ENVIROSENSE NETWORK:

The Envirosense Communications Network is a free, public, interagency-supported system operated by EPA's Office of Enforcement and Compliance Assurance and the Office of Research and Development. The Network allows regulators, the regulated community, technologists, and the general public to share information regarding: pollution prevention and innovative technology; environmental enforcement and compliance assistance; laws, executive orders, regulations, and policies; points of contact for services and equipment; case studies; technical databases; and other related topics. The Network welcomes receipt of environmental messages, information and data from any public or private person or organization.

II. SUMMARY INSTRUCTIONS - CONNECTING AND REGISTERING:

- Connect to ES via a modem, using communications software set to conventional BBS settings, by calling:

  (703) 908-2092

- Hit the RETURN/ENTER ("RETURN" is used hereafter to represent this key regardless of what your keyboard name is or where it is located) key twice (2) if you want to get the default values for the screen;

- On successive screens, type your first name and hit RETURN; type your last name and hit RETURN; and type your password (if you have NOT registered yet, make one up and make a note of it) and hit RETURN; and

- Register (first time only) and immediately receive access to the BBS for 120 minutes per day;

  - Type responses to the Registration questions. and hit RETURN to begin using Envirosense.

NOTE: When working within Envirosense, one may generally abort scrolling by typing "N"; and one may generally return to a menu screen by hitting RETURN, either once or twice as needed in a particular situation.

III. DETAILED INSTRUCTIONS - CONNECTING AND REGISTERING:

A. Modem Settings

Connecting to the Envirosense BBS is done using a modem and communications software. The modem can be either an internal or external model connected directly to your PC. The communications software (e.g., CrossTalk[1], ProComm, QModem, etc.) is what allows you to access and control your modem. Your software needs to be set to the values noted below:

- Telephone Number - 703-908-2092
- Baud rate - up to 14,400 BPS is supported (always select the highest speed which YOUR modem will support);
- Terminal Emulation - BBS, ANSI, VT-100, VT-102 (TTY for Macintoshes), etc.;
- Data Bits - 8 (Eight);
- Stop Bits - 1 (One);
- Parity - None;
- Transfer Protocols - ZModem, YModem, XModem, HS/Lin, BiModem, ASCII (text files only). Zmodem is very efficient. You must select the same protocol that BOTH your communications software and the BBS support so that they can "talk the same language"; and
- Error Correction/Data Compression Protocols - v.32, v.42 - and other older, hardware-dependent protocols are supported.

Refer to your communications software manual on how to set and save the communication parameters noted above (these will generally be the default).

B. **Registration Procedure** (first time only)

After you tell your software to dial in, a connection should be established and you should see the opening screen for the Envirosense BBS.

- Accept the default settings by hitting "RETURN" twice;
- Type in your first name, hit RETURN; type in last name, and hit RETURN;
- ES checks to see if you are already registered; if you are not registered, type "C" to register and hit RETURN;
- Respond to each of the questions regarding name and address information and hit RETURN repeatedly until you are sent to the "list of Bulletins;"
- Read the bulletins, and exit to ES' "System Menu";
- Set the desired "file transfer protocol" (matching it to whatever you set on your PC) by typing "S (et) File Transfer Protocol" at the System Menu and hit RETURN;
- Type "V(iew) Current Settings" to confirm your answers and settings and hit RETURN;
- Type "C(hange) Settings if any need to be changed; and
- Type "Q" to exit back to the System Menu

C. **Initial ES Use**

- ENJOY USING Envirosense by taking the following steps:

  - Conduct file (document) searches ("S");
  - Look at directories and file ("F");
  - Look at new files ("N");
  - Upload files ("U");
  - Download files ("D");
  - Read or leave messages ("M")
  - Read bulletins ("B"); or
  - Go through the door ("O") to access one of several databases.

Additional help is available on-line by typing "H" at almost any BBS area (e.q., type "S", then "H" in response to the "Text to scan for" question). Also read the help bulletins (in BULLETINS) or download the files from the Utilities directory (#160). These bulletins explain how to connect and register, find and view, convert to text, compress, and uncompress, download .TXT and .ZIP[2] files, and upload files. The titles of the files are: "CONREGWP.TXT," "FINDVIEW.TXT," "CONVCOMP.TXT" "DNLDTXWP.TXT," "DNLDZPWP.TXT," and "UPLOADWP.TXT."

1 The mention of any software products by name is not an official endorsement but used for illustrative purposes only.

2 The PK commands for the files PKZIP.EXE and PKUNZIP.EXE work very similarly to DOS' copy command. You must be at the DOS prompt in order to use them. To view details on how to use either command, simply type the command PKZIP or PKUNZIP at the DOS prompt and hit RETURN. The files will automatically go into help mode and give you a brief explanation of how they work. If a user needs more direction, there is full explanation included in the PKZ204G.EXE file. Type PKZ204G.EXE file at the DOS prompt to expand the file and read the instruction files. Refer specifically to the help file called HINTS.TXT.

ATTACHMENT B

SURVEY

MAILING LIST FOR FUTURE PUBLICATIONS

Name: ______________________ Organization: ______________________

Position: ______________________ Address: ______________________

Phone: ______________________ ______

Fax: ______________________ ______

SURVEY:

DID YOU FIND THIS MANUAL USEFUL?

Please help us by answering the following questions:

A. PROFILE OF YOUR ORGANIZATION

( ) Trade Association ( ) Business ( ) Government Office

( ) Other ____

What product or service does your business/organization provide? ______________________
____

How old is your business/organization? ___ years

How many employees work in your business/organization? ____

B. TRAINING NEEDS

U.S. EPA and SEMARNAP plan to add sections to this manual or develop new manuals for other industries in the border area. Which industries should be addressed next? ____
____

What type of training would you attend?

( ) Technical Workshops ( ) General Training ( ) None ( ) Other ____________

U.S. EPA and SEMARNAP are considering holding training sessions on "pollution prevention."

What information would be useful to you in this area?

____
____
____

C. USEFULNESS OF MANUAL

Did you find the format of this manual useful? ( ) Yes ( ) No

Did you find its content useful? ( ) Yes ( ) No

How would you improve it? ______________________________

What other information should be included? ______________________________

——————— ***(fold here)*** ———————

Who else should receive this manual?

Name: ____________________ ____________________

Address: ____________________ ____________________

____

____

D. ADDITIONAL COMMENTS

Please provide any additional comments on this manual and its usefulness.

____

____

____

Please fold on the dotted line and mail. If you have any questions regarding this publication or would like additional information, you may contact ***U.S. EPA (214) 665-2258***, or ***SEMARNAP (52)5 553-9928***.

——————— ***(fold here)*** ———————

Place
Stamp
Here

ROBERT D. LAWRENCE (6EN-XP)
POLLUTION PREVENTION COORDINATOR
U.S. EPA REGION 6
1445 ROSS AVENUE
DALLAS TX 75202

(Place tape here)